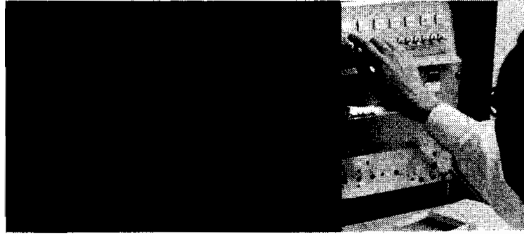
HEWLETT hp PACKARD

A Pocket Guide to Hewlett-Packard Computers



A Pocket Guide to Hewlett-Packard Computers

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PREFACE

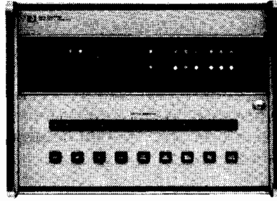
This manual combines in one convenient publication comprehensive hardware specifications for Hewlett-Packard 2100 Series Computers and programmer's reference manuals for the principal software systems. Software manuals included are FORTRAN, BASIC, Assembler, Basic Control System and Program Library. System designers and programmers will find this book a handy, permanent reference. Potential users will find the technical descriptions valuable for evaluating Hewlett-Packard computers and supporting software. Since Hewlett-Packard hardware and software specifications are subject to change, the information in this manual is intended to be used strictly as a guide and does not necessarily represent current policies and products supported by Hewlett-Packard.

Further information on Hewlett-Packard computer products is available from your local Hewlett-Packard field office; one of more than 130 Sales and Service Offices throughout the world.

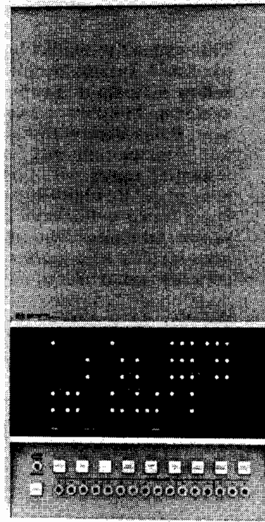
Or write Hewlett-Packard, 1501 Page Mill Road, Palo Alto, California 94304; Europe, 1217 Meyrin-Geneva, Switzerland.

Here is a family of computers with the power to solve problems for engineers and scientists — at a cost that makes them uniquely practical.

2114



2116



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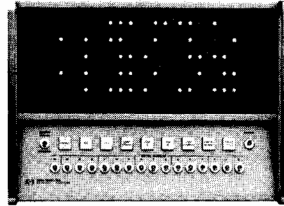


.... Backed up by software which is compatible to all three computers.

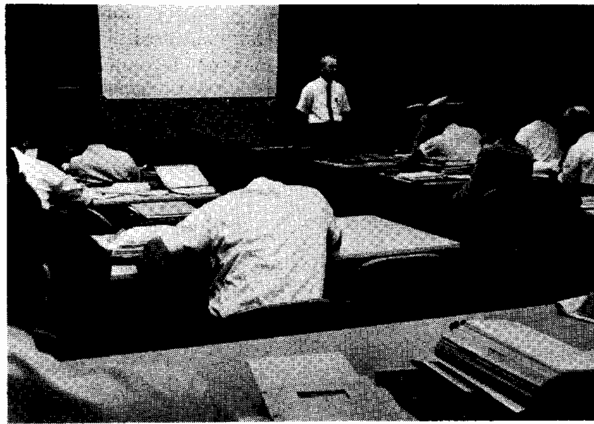
Hewlett-Packard computers combine performance and economy with small size. Achieved by simplicity of design — in package, in hardware, in software. A package that's easy to set up, with peripherals interfaced through plug-in cards. All modular for easy expansion. Straight forward machine organization and consoles that are easy to use. Integrated circuit construction that means long life, no quick obsolescence. A full-range of proven software packages — compatible between all models. All designed for busy engineers and scientists who want tomorrow's answers today.

FEATURES

- Low cost
- Proven software
- 16-bit word size
- 1.6μS memory cycle time
- Large 1024-word page size
- Powerful instruction set of 70 basic instructions
- Peripherals interfaced simply with plug-in cards
- Multilevel priority interrupt for device servicing
- Two accumulators, both addressable to simplify programming
- Extended Arithmetic capability available as plug-in option
- Magnetic core storage expandable to 32,768 words
- Protected loader
- Multiplexed I/O available
- Power Fail option preserves status, restarts automatically
- Optional high-speed Direct Memory Access
- Modular I/O drivers — for device independent programming
- Two-pass ASA Basic FORTRAN — extended
- Modular Debug package — for on-line program debugging
- ALGOL and BASIC language compilers

LOW COST COMPUTERS WITH HIGH-PRICED PERFORMANCE

IN-DEPTH TRAINING IN PROGRAMMING AND MAINTENANCE

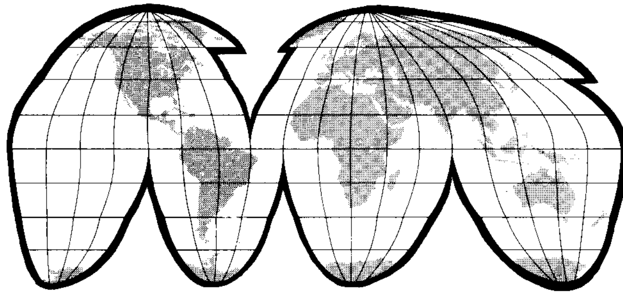


USER (PROGRAMMING) TRAINING

Hewlett-Packard provides a free user-programmer course for customers at the factory in Cupertino, California. Training materials are also provided at no charge. The complete User Training Course assumes no knowledge of computer programming or electronic systems operation. It covers instruction on programming languages and operating system. At least two full days are devoted to hands-on experience.

MAINTENANCE TRAINING

Regularly scheduled Maintenance Training courses for customers are also available at the factory in Cupertino, California. The course assumes familiarity with digital logic circuits and covers the following subjects in depth: computer organization, computer instructions, logic operation and timing, I/O interfaces, and fault diagnosis. A full-time staff of professional instructors insures complete coverage of each subject using proven methods of presentation.



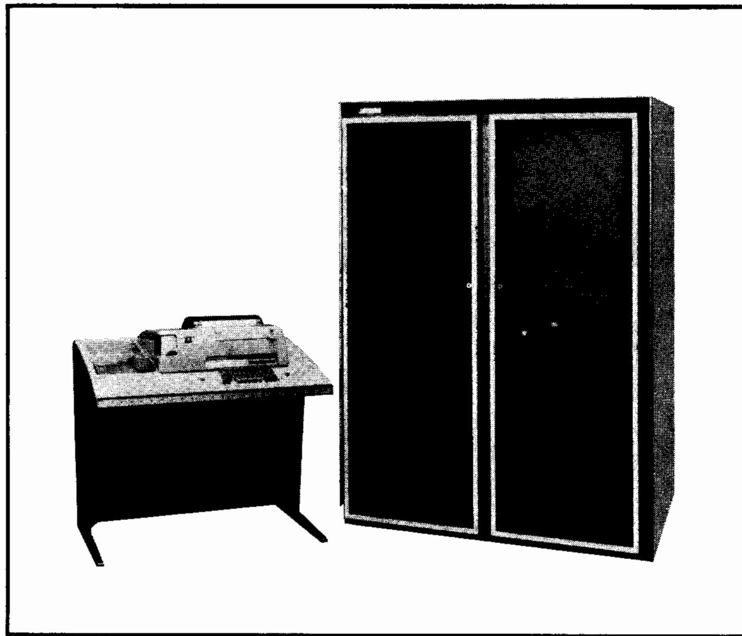
WORLD-WIDE REPAIR AND PARTS SERVICE

Service and parts assistance are available from Hewlett-Packard field offices throughout the United States, Canada and Europe. Local office facilities are backed up by Regional Service Centers. Major parts warehouses are located in Mountain View, California and Paramus, New Jersey. Parts orders are filled promptly; Hewlett-Packard uses a computer-controlled parts ordering and processing system which ensures that over 90% of orders for replacement parts are shipped the same day they are received.

WARRANTY

All Hewlett-Packard products are warranted against defects in materials and workmanship. This warranty applies for one year from date of delivery, or in the case of certain major components listed in the operating manual, for the specified period. We will repair or replace products which prove to be defective during the warranty period provided they are returned to Hewlett-Packard. No other warranty is expressed or implied. We are not liable for consequential damages.

Service contracts or customer assistance agreements are available for HP products that require maintenance and repair on-site.



Illustrative of HP 2116 Computer power is its use in HP Series 2000 Time Sharing Systems. Here, up to 32 users may communicate with the computer simultaneously, in conversational BASIC language.

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Specifications and Basic Operation Manual

Assembler Reference Manual

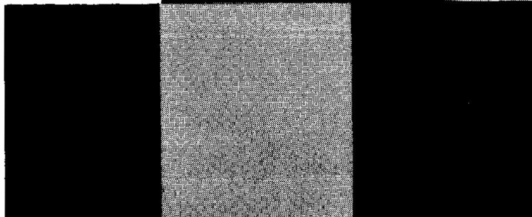
Basic Control System Reference Manual

FORTRAN Reference Manual

Program Library Reference Manual

BASIC Language Reference Manual

Specifications and Basic Operation Manual



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INTRODUCTION 1

The Hewlett-Packard Models 2116, 2115, and 2114 Computers are small, general purpose computers which are particularly suited, in computational power and input/output flexibility, to educational, scientific, and industrial measurement applications. See Figure 1.1. The logical design and software follow conventional standards of computer usage and notation so that each HP computer may be used as a free-standing device or in systems, such as process control, media conversion, data reduction, communications systems, or time-sharing systems. The three computers vary in size and in memory and input/output capacity, but all use identical software and interface components. The capabilities of the three Hewlett-Packard computers are compared in Table 1.1.

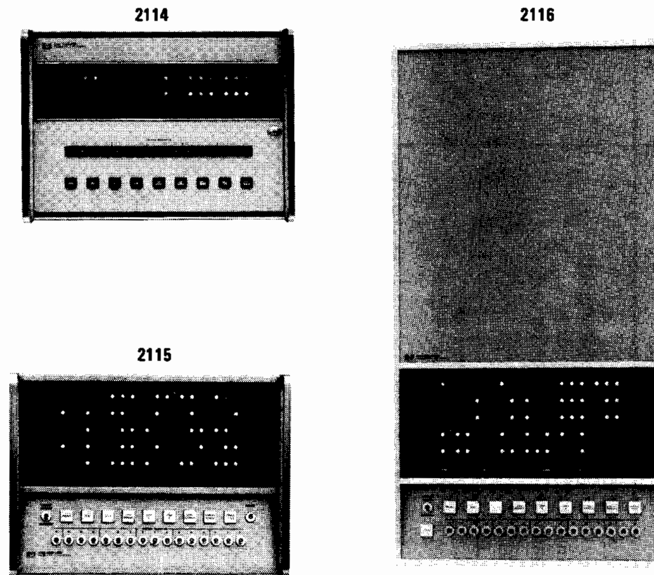


Figure 1.1. Hewlett-Packard Computers

Table 1.1. Comparison of Features for Hewlett-Packard Digital Computers

FEATURE	2116B	2115A	2114B
MEMORY SIZE			
Basic Configuration (16-bit words)	8,192	4,096	4,096
Maximum Available Memory	32,768	8,192	8,192
Expandable in Mainframe to:	16,384	8,192	8,192
WORD SIZE			
Data Bits	16	16	16
Memory Parity with Interrupt	Optional	Optional	Optional
Memory Protection (Area Protect)	Optional	No	No
MEMORY CYCLE (usec)	1.6	2.0	2.0
INSTRUCTION EXECUTION SPEED (usec)			
Store Word	3.2	4.0	4.0
Add (full word)	3.2	4.0	4.0
Multiply (subroutine max. time)	150	187	187
Divide (subroutine max. time)	310	387	387
Multiply (hardware) EAU Option	19.2	24.0	-
Divide (hardware) EAU Option	20.8	26.0	-
Number of Instructions	70	70	70
MULTILEVEL INDIRECT ADDRESSING	Yes	Yes	Yes
HIGH SPEED BUFFERED I/O CHANNELS			
Maximum number available (DMA Option)	2 (Assignable)	2 (Assignable)	1 (Assignable)
Maximum word transfer rate (per second)	263,000	210,000	500,000
Cycles required to set-up block transfer	13	13	13
Cycles stolen (from main program) per word transferred	1	1	1

PRIORITY INTERRUPTS			
External interrupts in basic unit	16	8	7
Maximum number of external interrupts	48	40	56
Program enable/disable of individual interrupts	Yes	Yes	Yes
ENVIRONMENTAL TEMPERATURE, HUMIDITY	0°-55°C RH 95% at 40°C	10°-40°C RH 80% at 40°C	10°-40°C RH 80% at 40°C
CIRCUITRY	Integrated Circuits (CTL)	Integrated Circuits (CTL)	Integrated Circuits (CTL-TTL)
POWER FAILURE PROTECTION	Yes	Yes	Yes
Automatic Re-start	Optional	Optional	Optional
PARTY LINE	Yes	Yes	Yes
MULTIPLEXED I/O	No	No	Yes
COMPILER			
FORTRAN (Extended ASA Basic FORTRAN)	Yes	Yes	Yes
ALGOL (A subset of ALGOL 60)	Yes	Yes (8K memory)	Yes (8K memory)
BASIC	Yes	Yes (8K memory)	Yes (8K memory)
ASSEMBLER	Yes	Yes	Yes
REAL TIME EXECUTIVE SOFTWARE SYSTEM	Yes	No	No
TIME SHARED BASIC SYSTEM	Yes	No	No
DISC OPERATING SYSTEM	Yes	No	Yes

1.1 INTERFACING

Interfacing an HP computer with a peripheral device consists of inserting one or two standard microcircuit cards in easily accessible input/output slots in the computer and connecting the device cable. Each HP computer provides a unique channel identification and service priority interrupt for every input/output channel used. Priority levels of the peripheral equipment connected to the computer can be altered simply by changing the positions of the interface cards in the I/O slots. Each computer operates with virtually all Hewlett-Packard measurement instruments providing a digital data output.

a. Digital voltmeters and associated signal converters, for measuring dc and ac voltages, currents, and resistances. With suitable transducers, physical quantities such as pressures, loads, temperatures, and fluid flows can be measured with an HP computer.

b. Electronic counters, for frequency or period measurements from a few cycles per second into the microwave region.

c. Scaler timers for nuclear radiation measurements.

d. Quartz thermometers for high-resolution temperature measurements in chemical analysis and oceanography.

Analog input scanners are available for multiplexing signals into these measuring instruments. Digital scanners are also available for applications where it is desirable to multiplex the data outputs of these instruments before entry into the computer. Table 2.6 in Chapter 2 provides further detail on input/output options.

Off-the-shelf interface cards enable the customer to operate a wide variety of devices of his own choosing with any HP computer. These include 8 or 16-Bit Duplex Register cards, Microcircuit Interface card, a Relay Output card, a D-to-A Converter card, Party Line Input/Output to enable computer users to interface many devices of their own choosing, and Multiplexed Input/Output for connection of up to 56 devices to the 2114 Computer.

1.2 INPUT/OUTPUT DEVICES

Instructions or data may be entered on punched tape through a teleprinter, high-speed photoelectric tape reader or card reader. Data output devices include the teleprinter, which provides typewritten and punched tape records, a high-speed tape punch, magnetic tape units (for IBM-compatible, 7- and 9-channel recording) and line printers. Fixed-head disc or removable disc storage units are

available for on-line mass storage requirements. Data can be entered on-line from Hewlett-Packard data sources and computed in real time, or recorded on punched tape or magnetic tape for subsequent computer processing. For example, each computer accepts data from punched tapes and magnetic tapes recorded by HP data acquisition systems. Data-Set interfaces are also available which enable information to be transmitted over the telephone system, into or out of the HP computer.

1.3 SYSTEM DOCUMENTATION

Full documentation is provided with each computer or computer system shipped to a customer and consists of four volumes as follows:

a. Volume One: Specifications and Basic Operation Manual. This volume describes the full capabilities of the basic computer for which it is supplied (2116, 2115, or 2114, as applicable), including standard hardware options, standard software, and fundamental computer operation. This manual is intended both as a reference for users who are familiar with computer terminology and as a source of detailed definitions, so the material will be meaningful to a wide range of readers.

b. Volume Two: Installation and Maintenance Manual. This volume gives installation and maintenance information for the basic processor only. Its contents include installation instructions, maintenance and troubleshooting information, logic and schematic diagrams, and a parts list.

c. Volume Three: Input/Output System Operation Manual. This volume describes the input/output structure and the standard Input/Output Options numbers, which form the basis for all HP computer systems. Procedures are given for connecting, operating, and programming the input/output devices for which Hewlett-Packard designs interface cards. The information in these sections condenses operating procedures from the manuals of the individual instruments, and adds material relating specifically to operation with the applicable HP computer. Maintenance information in these sections covers only the interface circuits, and not the peripheral itself. Complete Operating and Service Manuals for the peripheral device are furnished when the device is included in a particular system.

d. Volume Four: Programmer's Reference Manuals and Manual of Diagnostics. This volume consists of one or more manuals containing documentation for each item of software supplied

with the computer. Standard software programs, software especially originated for an individual user, and diagnostics are fully described as to specifications and usage. A "Software System Installation Record" at the front of Volume Four lists all software furnished with the original shipment, and provides an index to the supporting documents in Volume Four. Space is provided for noting changes and additions, so that an up-to-date record can be maintained by the user. Manuals normally included in Volume Four are listed below. (This pocket manual includes the first five of the listed reference manuals.)

1) Assembler
2) BASIC Language
3) Basic Control System
4) FORTRAN
5) Program Library
6) Standard Software Systems Operating Manual
7) Symbolic Editor
8) ALGOL
9) Manual of Diagnostics

In addition to the four volumes shipped with each computer, a manual titled "An Introduction to Hewlett-Packard Computers" is also available. This manual is designed to provide a general introduction to digital computers, how small computers operate, and the concepts of programming.

COMPUTER SPECIFICATIONS AND DESCRIPTION 2

This chapter provides specifications for the HP 2116B, 2115A, and 2114B Computers and describes them in terms of memory, working registers, programming instructions, input/output options, and software provided. All specifications apply to the basic computer unit only, unless specifically denoted as an Option specification. All information applies to all computers unless specified otherwise.

2.1 OPTIONS

Options for the HP computers are of two general types:

a. Processor Options. These options extend the memory and computation capabilities of the basic unit, and are identified by accessory numbers.

b. Input/Output Options. These options add input and/or output facilities to the basic HP computer. The input/output option consists of a peripheral device and an interface kit which provides the circuitry, cabling, and software to enable the computer to operate with a specific peripheral device or series of devices. General-purpose Interface Kits are also available from Hewlett-Packard which permit a wide-variety of devices to be interfaced to the computer by the user.

2.2 PHYSICAL SPECIFICATIONS

2.2.1 POWER REQUIREMENTS

a. 2116B Line Voltage: 115 Vac (15A) or 230 Vac (7.5A), changeable by internal jumpers. Voltage tolerance is ±10%.

2115A Line Voltage: 115 Vac (11A) or 230 Vac (5.5A), changeable by internal jumpers. Voltage tolerance is ±10%.

2114B Line Voltage: 115 Vac ±10% (7A). 230 Vac (3.5A) operation requires an external transformer.

b. Line frequency 50 to 60 Hz, ±10%.

c. Main unit power consumption with internal supply loaded to capacity by plug-in options:

2116B: 1600 watts maximum.
1000 watts minimum (with Teleprinter Option).
2115A: 1200 watts maximum.
700 watts minimum (with Teleprinter Option).
2114B: 800 watts maximum.
500 watts minimum (with Teleprinter Option).

d. Power cable: Standard 3-prong connector (two power, one grounding).

2.2.2 ENVIRONMENTAL LIMITS

a. Temperature:

2116B: 0° to 55°C (32° to 131°F)
2115A/2114B: 10° to 40°C (50° to 104°F)
2114B with wide temp. option 0° to 50°C (32° to 122°F)

b. Relative Humidity:

2116B: to 95% at 40°C
2115A/2114B: to 80% at 40°C
2114B with wide temp. option: to 80% at 50°C

2.2.3 VENTILATION

a. 2116B: Intake on sides and back at bottom, exhaust at top.

Air Flow: 600 cubic feet per minute.

Heat Dissipation: 5500 BTU/hour, maximum.

b. 2115A and 2114B: Intake at rear, exhaust on sides.

Air Flow: 400 cubic feet per minute.

2115A Heat Dissipation: 3500 BTU/hour, maximum.

2114B Heat Dissipation: 2200 BTU/hour, maximum.

2.2.4 PHYSICAL DIMENSIONS (See Figure 2.1)

a. Width: 16-3/4 inches, adapters are furnished for mounting in a standard 19-inch rack.

b. Panel Height:

2116: 31-1/2 inches
2114/2115: 12 inches
2115 Power Supply: 10-1/4 inches

c. Depth:

2116: 19-3/8 inches
2114/2115: 24-3/8 inches

d. Recommended cable clearance at rear: 5 inches minimum.

e. Recommended air exhaust clearance:

2116: at top, 3 inches minimum.
2114/2115: at sides, 2 inches minimum.

f. Weight:

2116: Net weight, 230 lb. (104 kg)
Shipping weight, 330 lb. (150 kg)
2115: Net weight, 65 lb. (29, 5 kg)
Shipping weight, 99 lb. (44, 9 kg)
2161A Power Supply: Net weight, 95 lb. (43 kg)
Shipping weight, 138 lb. (62, 6 kg)
2114: New weight, 102 lb. (46.3 kg)
Shipping weight, 132 lb. (59, 9 kg)

2.2.5 SERVICE ACCESS

a. 2116 Computer:

1. Panel hinged at left edge (see dimensional illustration, Figure 2.1). Permits front access to input/output connectors, test switches, plug-in circuit boards, and panel wiring.

2. Main chassis slides forward out of cabinet and swings to right. Permits front access to back plane wiring, power supply, fuses, and 115/230V jumpers.

Note

Unstable mounting racks must not be used to mount the HP 2116, due to weight shift forward when chassis is withdrawn for service. Table-top usage or Hewlett-Packard system cabinets are recommended.

b. 2115 and 2114 Computers:

1. Top panel slides back and up, permitting top access to input/output connectors, test switches, plug-in circuit boards, and wiring.

2. Bottom panel is removable for access to backplane wiring.

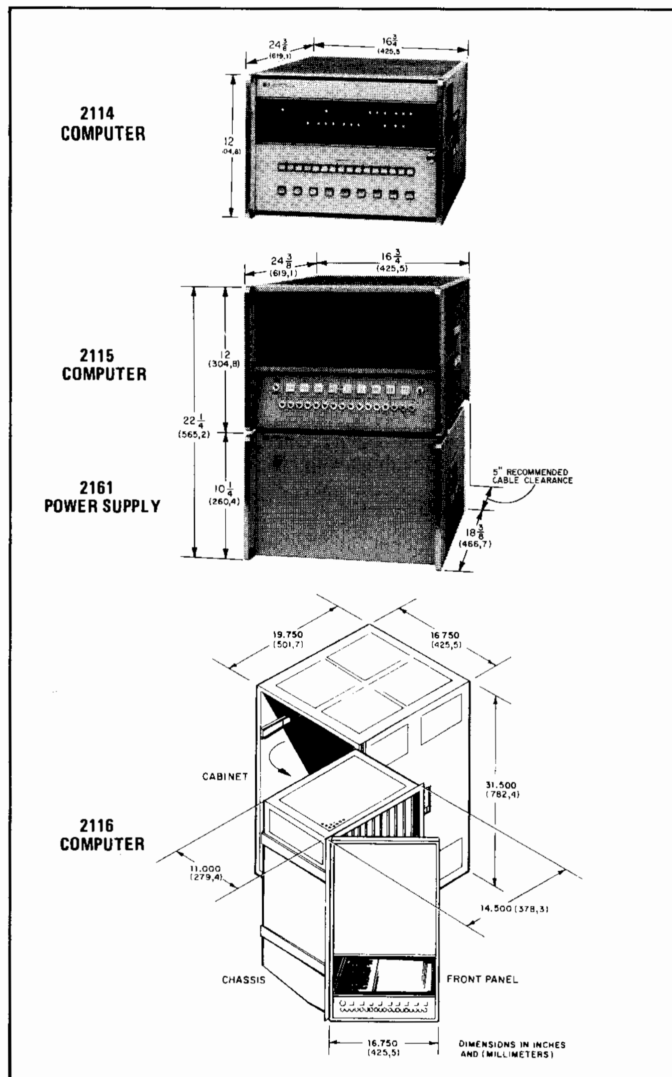


Figure 2.1. Dimensions of Computers

2.2.6 EXTENDER MODULES

The HP 2150B Input/Output Extender provides 32 extra input/output channels for the 2116 and 2115 Computers. It also allows the addition of 16,384 words of memory to the 2116 Computer, permitting an overall 2116 memory capability of 32,768 words.

The 2151B Extender provides plug-in Input/Output expansion for HP 2114/2115/2116 Computers. It adds 16 I/O channels to 2116/2115 Computers or when added to a 2114 Computer provides a total of 24 I/O channels (main frame plus extender).

Either extender may be ordered as an option. Each of the extenders is easily installed as a plug-in option with self-contained power supply.

2.3 COMPUTER TIMING

An internal 10-megahertz timing generator automatically generates read/write memory cycles every 1.6 microseconds in the 2116 Computer and every 2.0 microseconds in the 2115 and 2114 Computers. See Figure 2.2. Each HP computer has four machine phases (Fetch, Indirect, Execute, Interrupt), of which the first three include a memory cycle. Phases do not occur in a fixed sequence, but rather are determined by conditions which occur during operation. The computer can go directly from one of the first three phases to certain others in the manner indicated in Figure 2.2, and an external device can cause the computer to go into the Interrupt phase on completion of any current phase. The Fetch phase may be thought of as the "normal" or "home" condition; the processing of each instruction begins with a Fetch phase. Each phase of 2116 Computer operation takes 1.6 microseconds with one exception: the Execute phase of the ISZ instruction (Increment, and Skip if Zero) takes 2.0 microseconds. These times are 2.0 and 2.5 microseconds, respectively, for the 2114 and 2115 Computers.

FETCH PHASE. The contents of the currently-addressed memory cell is read into the T-Register during the Read portion of the memory cycle, and written back into the memory cell during the Write portion of the memory cycle. The information left in the T-Register is taken as an instruction when read during the Fetch phase. If the instruction includes an "indirect address bit", the computer sets the Indirect phase condition, and if the instruction does not have an indirect address bit but does include a memory reference (two-phase instruction), the computer sets the Execute phase condition. Otherwise the current instruction is fully executed at the end of the Fetch phase, and the computer remains in the Fetch state for the next memory cycle. An exception to these conditions is the JMP (jump) instruction, which is a Memory Reference instruction

but does not require an Execute phase; the computer executes the instruction at the end of the Fetch phase or the Indirect phase, and then sets the Fetch phase again for the next memory cycle.

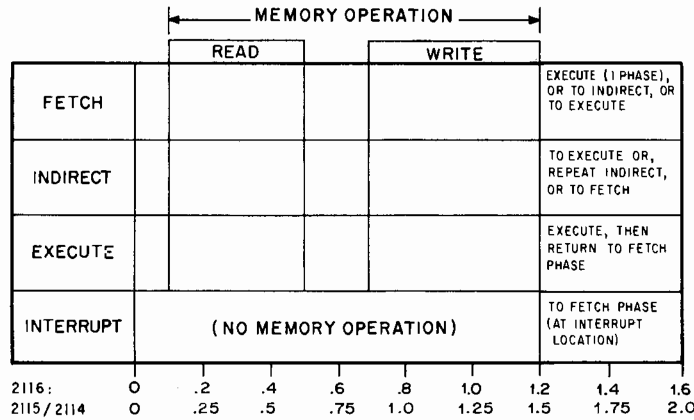


Figure 2.2. Computer Timing

INDIRECT PHASE. The contents of the memory cell referenced during the Fetch phase is read into the T-Register and the entire 16-bit word (15 bits of address, plus a new Direct/Indirect bit) is taken as a new memory reference for the same instruction. The use of 15 bits for an address permits addressing of up to 32, 768 words. If the Direct/Indirect bit again specifies indirect addressing, the computer remains in the Indirect state and reads another 16-bit address word out of memory as a continuation of multiple-step indirect addressing. If the Direct/Indirect bit specifies direct addressing, the computer sets the Execute phase or, in the case of a Jump Indirect, the Fetch phase.

EXECUTE PHASE. The 16-bit data word in the memory cell referenced during a Fetch phase or an Indirect phase is read into the T-Register and is operated on by the current instruction (retained from the Fetch phase) at the end of the Execute phase. At the end of this phase, the computer sets the Fetch phase again to read the next instruction.

INTERRUPT PHASE. An input/output device requesting service at any time during one of the phases is acknowledged at the end of that phase, unless the interrupt is inhibited for any reason by the program being run. The computer then goes into the Interrupt phase,

which does not have a memory cycle. During this phase the P-Register is decremented, so that no instruction in the main program will be skipped or executed twice. At the end of this phase, the interrupt address of the interrupting device is transferred into the M-Register and the Fetch phase is set, to read the instruction contained in the interrupt address location. The Interrupt phase cannot occur again until at least this instruction is completed.

2.4 MEMORY

2.4.1 TYPE

Hewlett-Packard computer memories consist of ferrite-core storage modules. The 2116 Computer memory module is capable of storing 8192 words; the 2115 and 2114 module is capable of storing 4096 words. A word consists of 16 bits, plus a 17th bit when Memory Parity is included in the computer. The 2116 permits the use of up to three additional modules to expand the storage capacity to 32,768 words. The 2115 and 2114 permit expansion to 8192 words.

2.4.2 LAYOUT

Each memory module is logically divided into pages of 1024 words each. A page is defined as the largest block of memory which can be addressed by the memory address bits of a Memory Reference instruction (excluding the Zero/Current page bit; see Figure 2.4). In HP computers, Memory Reference instructions have 10 bits to specify a memory address, and thus the page size is 1024 locations (2000 in octal notation). Octal addresses of the pages of the basic modules are therefore:

8192-word module or two 4096-word modules (8 pages)	4096-word module (4 pages)	00000 to 01777
		02000 to 03777
		04000 to 05777
		06000 to 07777
		10000 to 11777
		12000 to 13777
		14000 to 15777
		16000 to 17777

2.4.3 ADDRESSING

ZERO/CURRENT PAGE. For direct addressing purposes, generally only two pages are of interest: page Zero (the base page, consisting of locations 00000 through 01777), and the Current page (the page in which the instruction itself is located). All Memory Ref-

erence instructions include a bit (Bit 10) reserved to specify one or the other of these two pages. To address locations in any other page, indirect addressing is used. Page references for direct addressing of Memory Reference instructions are specified by Bit 10 as follows:

0 = Page Zero (Z)

1 = Current Page (C)

DIRECT/INDIRECT. All Memory Reference instructions use Bit 15 to specify direct or indirect addressing. Direct addressing combines the instruction code and the effective address into one word, permitting a Memory Reference instruction to be executed in two machine phases (Fetch and Execute). Indirect addressing uses the address part of the instruction word to access another word in memory which is taken as a new memory reference for the same instruction. This new address word is a full 16 bits long, 15 bits of address plus another Direct/Indirect bit. The 15-bit length of the address permits access to any location in any module. If Bit 15 again specified indirect addressing, still another address is obtained; this multiple-step indirect addressing may be done to any number of levels. The first address obtained in the Indirect phase which does not specify another indirect level becomes the effective address for the instruction. Instructions with indirect addresses are therefore executed in a minimum of three machine phases (Fetch, Indirect, Execute). Direct or indirect addressing is specified by Bit 15 as follows:

0 = Direct

1 = Indirect

RESERVED LOCATIONS. The first 64 memory locations of the base page (octal addresses 00000 through 00077) are reserved as listed below. The first two addresses are flip-flop registers (A and B accumulators) and not core storage locations. Locations 5 through 77 are reserved in the sense that interrupt wiring is present for the priority order given. As long as the locations do not have actual interrupt assignments (as determined by the input/output devices included in the user's system), these locations may be used for normal program purposes.

00000	A Register
00001	B Register
00002 00003	For exit sequence if A and B contents are used as executable words.

00004	Interrupt location, highest priority. Reserved for Power Fail interrupt.
00005	Reserved for Memory Protect (2116) and Memory Parity interrupt (2114/ 2115/2116).
00006 00007	Reserved for DMA interrupt
00010 thru 00077	Interrupt locations in decreasing order of priority.

2.4.4 LOADER PROTECTION

The last 64 locations of memory are reserved for the Basic Binary Loader. The Basic Binary Loader is a manually-entered program to permit reading and storing of binary information from punched paper tape, as read by an HP 2748A Punched Tape Reader or an HP 2752A/2754B Teleprinter. Absolute addresses are required in the loaded data. On the 2115 and 2116 Computers, the front panel LOADER switch in the PROTECTED position disables the Basic Binary Loader locations so that they can neither be used nor altered in any way. For entering the Basic Binary Loader manually into the computer and for actual loading of tapes, this switch must be set to ENABLED. The LOADER switch is effective for the last 64 locations of memory, regardless of memory size. Plug-in options which expand memory relocate the protected area automatically to the 64 highest numbered locations. On the 2114 Computer, the same Basic Binary Loader locations are automatically protected during normal operation. For entering the Basic Binary Loader manually, the LOADER ENABLE switch, located behind the hinged, front panel, must be in the ON position.

2.5 WORKING REGISTERS

The HP 2116, 2115, and 2114 Computers have seven working registers. Five of these are 16-bit flip-flop registers, and two are 1-bit flip-flop registers. All seven registers are displayed on the front panel of 2115 and 2116 Computers. The 2114 Computer displays two 16-bit registers (Memory Data and Memory Address) and two 1-bit registers (Extend and Overflow). However, the contents of the 2114 A, B, and P registers can be displayed using these registers. The computer registers displayed are shown in Figure 2.3.

T-REGISTER (MEMORY DATA). All data transferred into or out of memory is routed through the 16-bit T-Register ("Transfer Reg-

ister"). The T-Register display therefore indicates exactly what information went into or out of a memory cell during the preceding memory cycle.

P-REGISTER (PROGRAM COUNTER). On completion of each instruction the P-Register indicates the address of the next instruction to be fetched out of memory. The P-Register automatically increments by one (or two, when executing a skip instruction) after the execution of each instruction. A jump instruction (JMP or JSB) can set the P-Register to any core location number. (On the 2114, the P-Register will not increment if the HALT and LOAD MEMORY or HALT and DISPLAY MEMORY switches are touched simultaneously.)

M-REGISTER (MEMORY ADDRESS). The M-Register holds the address of the memory cell being read or written into. The M-Register indication will differ from the P-Register indication when multi-phase instructions are being processed, since the M-Register will be changed by memory references in the instruction (which may be several in the case of indirect addressing) or by an interrupt, whereas the P-Register remains constant until completion of the instruction.

A-REGISTER (ACCUMULATOR). The A-Register is an accumulator, holding the results of arithmetic and logical operations performed by programmed instructions. This register may be addressed by any Memory Reference instruction as location 00000, thus permitting inter-register operations such as "add B to A", "compare B with A", etc., using a single-word instruction.

B-REGISTER (ACCUMULATOR). The B-Register is a second accumulator, which can hold the results of arithmetic and logical operations completely independent of the A-Register. The B-Register may be addressed by any Memory Reference instruction as location 00001 for inter-register operations with A.

EXTEND. The Extend bit is a one-bit (E) register, and is used to link the A and B Registers by rotate instructions, or to indicate a carry from Bit 15 of the A or B Registers by an add instruction (ADA, ADB) or increment instruction (INA or INB, but not ISZ) which references these registers. This is of significance primarily for multiple-precision arithmetic. The Extend bit is not complemented by a carry if already set. It may be cleared, complemented, or tested by program instruction. The Extend bit is set when the EXTEND panel light is on ("1") and clear when off ("0").

OVERFLOW. The Overflow bit is a one-bit register which indicates, if on, that an add instruction (ADA, ADB) or an increment

instruction (INA or INB, but not ISZ) referencing the A or B registers has caused one of these accumulators to exceed the maximum positive or negative number which can be contained (+32767 or -32768, decimal). This condition is implied by a carry (or lack of carry) from Bit 14 to Bit 15. By program instructions, the Overflow bit may be cleared, set, or tested. The OVERFLOW panel light remains on until the bit is cleared by an instruction, and is not complemented if a second overflow occurs before being cleared. It will not be set by shift or rotate instructions.

2.6 COMPUTER CONTROLS

Panel controls for the HP 2114, 2115, and 2116 Computers are shown in Figure 2.3. The controls of the 2115 and 2116 are nearly identical; the only difference being the tape and location of the POWER switch. The 2115 has a toggle-type ON/OFF switch on the right side of its front panel; the 2116 has a pushbutton ON/OFF switch on the left side of its front panel. Both have toggle switches for the Switch Register and all other control switches are pushbutton-type. The 2114 Computer contains only proximity-type sense switches on its front panel. Each switch requires only a touch for activation. The functions of the various switches are explained in the following paragraphs and apply to all computers unless otherwise specified.

SWITCH REGISTER. Each HP computer has a row of 16 switches on its front panel to enable manual entry of data into the computer. The 2115 and 2116 Computer switches are toggle-type; the up position is a "one", the down position is a "zero". The 2114 Computer switches are proximity-type sense switches which illuminate for a "one" and remain dark for a "zero". (On the 2114, the CLEAR REGISTER switch resets all switches of the Switch Register to "zero".) The setting of the Switch Register may be entered in the computer in the following ways:

a. By program, may be loaded into the A or B Register using LIA or LIB instructions with the Switch Register's Select Code (01).

b. By program, may be merged (inclusive "or") into the A or B Register using MIA or MIB respectively.

c. Manually, using LOAD ADDRESS switch, may be loaded into the P and M Registers (simultaneously), thus directing the computer to a specific memory cell.

d. Manually, using LOAD MEMORY switch, may be entered into the memory cell specified by the M-Register (MEMORY ADDRESS), thus permitting the user to change the contents of any memory cell.

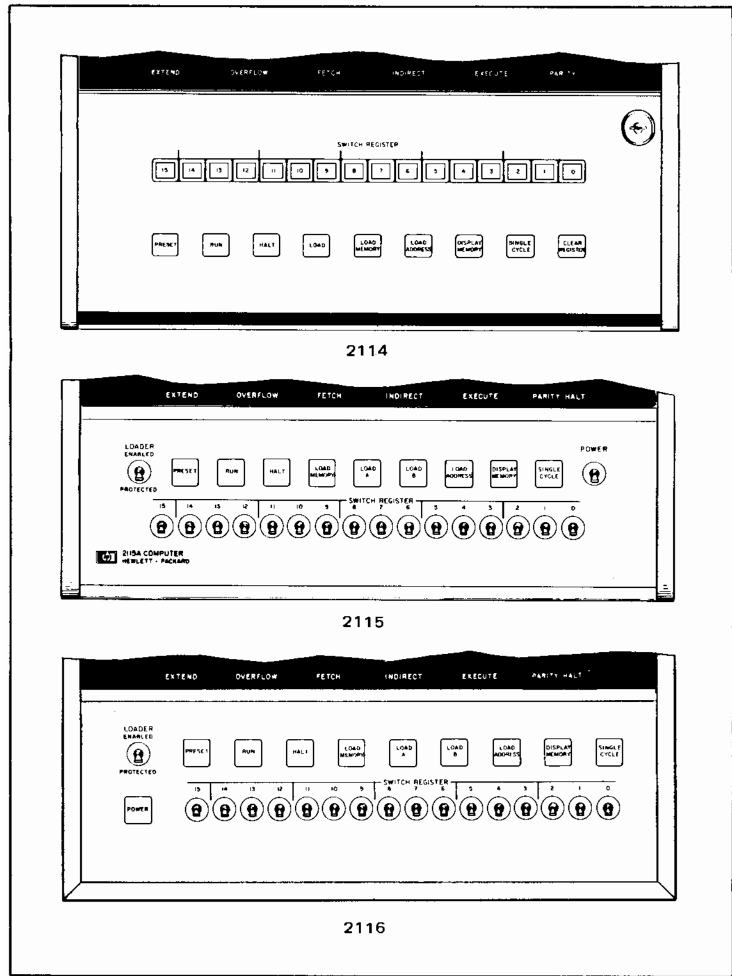


Figure 2.3. Computer Panel Controls

e. Manually, on a 2115 or 2116 Computer, using LOAD A or LOAD B switches, may be loaded into the A or B Registers.

Note

On the 2114 Computer only, the contents of the A or B Register may be output to the Switch Register and displayed by a programmed output instruction (OTA/B: Select Code 01). To display the A and B Register contents manually, press the CLEAR REGISTER switch, the LOAD ADDRESS switch, and then the DISPLAY MEMORY switch. The contents of the A-Register will be displayed in the MEMORY DATA register. The contents of the B-Register will be displayed in the MEMORY DATA register when the DISPLAY MEMORY switch is pressed again.

POWER. Regulated power to each of the HP computers automatically goes off the case of abnormal changes in internal power suppiles. Contents of memory are not affected by switching power off and on; contents of working registers, however, are lost when power goes off (contents are random following turn on). The 2116 Computer POWER switch is a push-on/push-off switch which lights when regulated power is on. The 2114 and 2115 Computers have ON/OFF power switches; located on the right side of the 2115 front panel, and behind the front panel on the computer chassis of the 2114 (accessible only by using a key).

LOADER (2115 and 2116)/LOAD (2114). These switches are associated with the last 64 locations of memory; ofr example, octal addresses 07700 through 07777 in 4K computers, or 17700 through 17777 in 8K computers. These locations are normally occupied by the Basic Binary Loader.

a. With the LOADER toggle switch of the 2115/2116 Computer in the ENABLED position, the last 64 locations of memory can be read of loaded; in the PROTECTED position, these locations are disabled.

b. The LOAD proximity-type switch on the 2114 is interlocked, electrically, with the PRESET switch. To load any absolute binary program using the last 64 locations of memory, these switches must be touched simultaneously.

PRESET. This switch presets the computer to the Fetch phase, to turn off the interrupt system and all input/output Control bits, and to set all input/output Flag bits. The switch resets the PARITY

HALT indication on the front panel of the 2116 and 2115 Computers, and the PARITY indication on the front of the 2114. Also it clears the power fail interrupt circuits. An internal preset pulse accomplishing the same functions is generated each time power is switched on or off.

RUN. This switch starts operation at the current state of the computer. The switch lights when a program is running, and goes off when HALT is pressed, when a HLT instruction is executed, or when an abnormal change occurs in the internal power supplies. When the RUN light is on, all front-panel control switches except HALT, POWER, and LOADER (2116/2115) are disabled, as well as the CLEAR REGISTER switch on the 2114.

HALT. This switch stops computer operation at the end of the current phase. When the computer is halted, the HALT switch lights, and all front-panel control switches are enabled. (On the 2114, the P Register will not increment if the HALT and LOAD MEMORY or HALT and DISPLAY MEMORY switches are touched simultaneously.)

LOAD MEMORY. This switch stores the contents of the Switch Register into the memory location specified by the address in the M-Register. The P and M Registers are automatically incremented after operation of the LOAD MEMORY switch, to simplify storing data into consecutive memory locations (exception for 2114: see HALT switch description). The stored data remains displayed in the T-Register (MEMORY DATA), and the Fetch phase is set at the end of the load operation.

LOAD A (2115/2116 only). This switch transfers the contents of the Switch register into the A-Register. The computer's phase status is not altered.

LOAD B (2115/2116 only). This switch transfers the contents of the Switch Register into the B-Register. The computer's phase status is not altered.

LOAD ADDRESS. This switch transfers the contents of the Switch Register into both the P and M Registers, thus directing the computer to the desired address. The Fetch phase is set at the end of the load operation.

DISPLAY MEMORY. This switch causes the display, in the T-Register (MEMORY DATA), of the contents of the location specified by the address in the M-Register. The P and M Registers are automatically incremented after operation of the DISPLAY MEMORY switch, so that consecutive memory locations may be dis-

played by repeated operation of this switch. The P and M Registers are therefore one step ahead of the T-Register display. The Fetch phase is set after incrementing of the P and M Registers. (Exception for 2114: see HALT switch description.)

SINGLE CYCLE. This switch executes one machine phase each time it is pressed.

CLEAR REGISTER (2114 only). This switch resets the Switch Register to "zero".

LOADER ENABLE ON/NORMAL (2114 only). This switch is located on the inside of the front panel. The NORMAL position protects the contents of the last 64 locations in memory normally occupied by the Basic Binary Loader. In the ON position, the Loader is enabled to allow words in Loader area to be changed, the new Loader loaded in, etc.

LAMP TEST TEST/NORMAL (2114 only). This switch is located on the inside of the front panel. It permits testing of all indicator lights in the front panel.

CONSOLE LOCK LOCK/NORMAL (2114 only). This switch is located on the inside of the front panel. In the LOCK position, the front panel switches are disabled to permit continuous computer operation without accidental interruption or tampering. Wire jumpers on the switch printed-circuit card can be removed to permit the Switch Register switches or the bottom row of control switches to be disabled individually if desired. With the switch in the NORMAL position, all front panel switches are enabled.

Diagnostic Switches. Each HP computer has three switches on the inside of its front panel to aid the computer technician in diagnosing malfunctions in the basic unit. Switch nomenclature defines the functions performed by each switch: looping of a machine phase, looping of a single instruction, and turning memory on or off.

2.7 INSTRUCTIONS

2.7.1 NUMBER

The HP computers have 70 basic one-word instructions, all executable in 1.6 or 3.2 microseconds in the 2116 and 2.0 or 4.0 microseconds in the 2114 and 2115, except for the ISZ instruction. The ISZ instruction is executable in 3.6 microseconds in the 2116 and in 4.5 microseconds in the 2114 and 2115. These instructions are grouped in three types and are summarized in Table 2.1.

Table 2.1. Computer Instructions

TYPE	MNEMONIC	DESCRIPTION	2116B μSEC	2115A/2114A μSEC
Memory Reference (14 total)	AND	"And" (M) to A; result in A	3.2	4.0
	XOR	"Exclusive or" (M) to A; result in A	3.2	4.0
	IOR	"Inclusive or" (M) to A; result in A	3.2	4.0
	JSB	Jump to subroutine, save P	3.2	4.0
	JMP	Jump, unconditionally	1.6	2.0
	ISZ	Increment (M); skip if result zero	3.6	4.5
	ADA/B	Add (M) to A or B; result in A or B	3.2	4.0
	CPA/B	Compare (M) with A or B; skip if unequal	3.2	4.0
	LDA/B	Load (M) into A or B	3.2	4.0
	STA/B	Store A or B into M; A/B unchanged	3.2	4.0
Register Reference (43 total)		SHIFT-ROTATE GROUP	1.6	2.0
	NOP	No operation		
	CLE	Clear E (Extend)		
	SLA/B	Skip if least siguificant bit of A/B is zero		
	A/BLS	A/B arithmetic left shift one bit		
	A/BRS	A/B arithmetic right shift oue bit		
	RA/BL	Rotate A/B left one bit		
	RA/BR	Rotate A/B right one bit		
	A/BLR	A/B left shift one bit, sign cleared		
	ERA/B	Rotate E right oue bit with A or B		
	ELA/B	Rotate E left one bit with A or B		
	A/BLF	Rotate A or B left four bits		
		ALTER-SKIP GROUP	1.6	2.0
	CLA/B	Clear A or B		
	CMA/B	Complement A/B (ones complement)		
	CCA/B	Clear-complement A/B (set to -1)		
	CLE	Clear E (Extend)		
	CME	Complement E		
	CCE	Clear-complement E (set E)		
	SEZ	Skip if E is zero		
	SSA/B	Skip if sign of A/B is zero (positive)		
	SLA/B	Skip if least significant bit of A/B is zero		
	INA/B	Incremeut A/B by one		
	SZA/B	Skip if A/B is zero		
	RSS	Reverse skip sense		
		OVERFLOW	1.6	2.0
	STO	Set overflow bit		
	CLO	Clear overflow bit		
	SOC	Skip if overflow bit clear		
	SOS	Skip if overflow bit set		
Input/ Output (13 total)	HLT	Halt program	1.6	2.0
	STF	Set flag bit of selected I/O channel		
	CLF	Clear flag of selected I/O channel		
	SFC	Skip if flag clear		
	SFS	Skip if flag set		
	MIA/B	Merge ("or") I/O channel into A/B		
	LIA/B	Load I/O channel into A/B		
	OTA/B	Output A/B to I/O channel		
	STC	Set control bit of selected channel		
	CLC	Clear control bit of selected channel		

1. (M) = Contents of Memory Location M
2. Overflow instructions are coded under I/O group

Each of the instructions shown in Table 2.1 are further explained in the following paragraphs. Register Reference instructions can be combined to form additional one-word "microinstructions", executable in a single phase.

2.7.2 FORMATS

The three types of basic instructions are grouped according to the bit format of the instruction word. These types are: Memory Reference, Register Reference, and Input/Output instructions. A comparison of the three formats is given in Figure 2.4, and detailed binary coding is included with the instruction descriptions following.

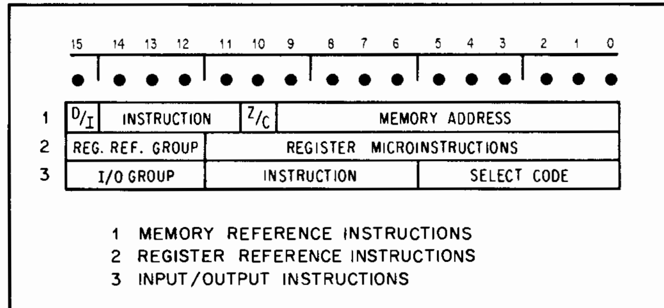


Figure 2.4. Basic Instruction Formats

The first type comprises the Memory Reference instructions, using 10 bits (0 through 9) for a memory address, Bit 10 to specify Zero or Current page, and Bit 15 for direct or indirect addressing. This leaves four bits (14, 13, 12, 11) to encode the 14 instruction commands in this group.

The other two types use four bits (15, 14, 13, 12) to distinguish the Register Reference and the Input/Output instructions. The Register Reference type uses Bits 11 through 0 to combine up to eight "microinstructions" (i. e., instructions formed by only 1, 2, or 3 bits), with the resulting multiple instruction operating on the A, B, or E Registers as a single-word instruction. The Input/Output type uses Bits 11 through 6 for a variety of input/output instructions, and Bits 5 through 0 to make the instruction apply directly to one of 64 possible input/output devices or functions.

The following paragraphs describe in detail each of the instructions in the three type groups. Functions of bits appearing in the form A/B, D/I, D/E, Z/C, or H/C throughout these Specifications are

invariably obtained by coding a 0 or 1 respectively (0/1). Thus, for example, A is specified by a zero-bit, and B by a one-bit. The following defines the abbreviations used:

A/B	A Register/B Register
D/I	Direct/Indirect
D/E	Disable/Enable
Z/C	Zero page/Current page
H/C	Hold Flag/Clear Flag

2.7.3 MEMORY REFERENCE INSTRUCTIONS

The 14 Memory Reference instructions execute some operation involving memory locations, such as transferring information in or out of a memory cell or checking the memory cell contents. The cell referenced (i. e., the absolute address) is determined by a combination of the ten memory address bits in the instruction word (0 through 9) and five bits (10 through 14) assumed from the current indication of the P-Register. This means that Memory Reference instructions can directly address any word in the current page; additionally, if the instruction is given in some location other than the base page (page Zero), Bit 10 of the instruction word doubles the addressing range to 2048 words by allowing selection of either page Zero or Current page(i. e., Bits 10 through 14 of the address in the M-Register can be reset to zero, instead of assuming the current indication of the P-Register). This feature provides a convenient linkage between all pages of memory, since page Zero can be reached directly from any other page.

Note that since the A and B Registers can be addressed, any Memory Reference instruction can apply to either of these registers as well as to memory cells. For example, ADA 0001 means add the contents of the B-Register (its address being 0001) to the A-Register; specify page Zero for these operations, since the A and B Register addresses are on page Zero.

Figure 2.5 gives instruction codes and mnemonics for all 14 Memory Reference instructions. All Memory Reference instructions take a minimum of two machine phases (one to read the instruction word, and one to read the referenced memory cell), except for JMP, which is a one-phase instruction. Logic truth tables, relating to the first three instructions described below, are given in Table 2.2. Note that logic operations are performed on a bit-for-bit basis (i. e., no carries).

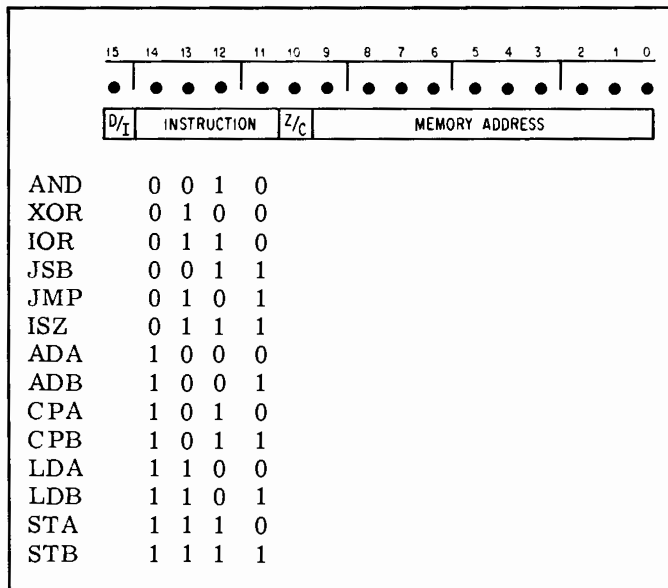


Figure 2.5. Memory Reference Instructions

Table 2.2. Logic Truth Table

	AND	XOR	IOR
A Contents	0 0 1 1	0 0 1 1	0 0 1 1
Memory	0 1 0 1	0 1 0 1	0 1 0 1
Result (in A)	0 0 0 1	0 1 1 0	0 1 1 1
1 = True, 0 = False			

AND. "And" to A. The contents of the addressed location are logically "anded" to the contents of the A-Register. The contents of the memory cell are left unaltered.

XOR. "Exclusive or" to A. The contents of the addressed location are combined with the contents of the A-Register as an "exclusive or" logic operation. The contents of the memory cell are left unaltered.

IOR. "Inclusive or" to A. The contents of the addressed location are combined with the contents of the A-Register as an "inclusive or" logic operation. The contents of the memory cell are left unaltered.

JSB. Jump to Subroutine. This instruction, executed in location P, causes computer control to jump unconditionally to the memory location (X) specified in the address portion of the JSB instruction word. The contents of the P-Register plus one (return address) is stored in location X, and the next instruction to be executed will be that contained in the next location (X + 1). A return to the main program sequence at P + 1 may be effected by a jump indirect through location X.

JMP. Jump. This instruction transfers control to the contents of the addressed location. That is, JMP causes the P and M Registers to be set according to the memory address portion of the instruction word, thus addressing memory cell X, so that the next instruction will be read from location X.

ISZ. Increment, and Skip if Zero. An ISZ instruction adds one to the contents of the addressed memory location. If the result of this operation is zero, the next instruction is skipped, i. e., the P and M Registers are advanced by two instead of one. Otherwise, the program proceeds normally to the next instruction in sequence. The incremented value is written back into the memory cell in either case. An ISZ instruction referencing locations zero or one (A or B Registers) cannot cause setting of the Extend or Overflow bits (unlike INA and INB).

ADA. Add to A. The contents of the addressed memory location are added to the contents of the A-Register, and the sum remains in the A-Register. The result of the addition may set the Extend or Overflow bits. The contents of the memory cell are unaltered.

ADB. Add to B. The contents of the addressed memory location are added to the contents of the B-Register, and the sum remains in the B-Register. Extend or Overflow bits may be set, as for ADA. The contents of the memory cell are unaltered.

CPA. Compare to A, skip if unequal. The contents of the addressed location are compared with the contents of the A-Register. If the two 16-bit words are different, the next instruction is skipped; i.e., the P and M Registers are advanced by two instead of one. If the words are identical, the program proceeds normally to the next instruction in sequence. The contents of neither the A-Register nor the memory cells are altered.

CPB. Compare to B, and skip if unequal. Same as CPA, except comparison is made with the B-Register.

LDA. Load into A. The A-Register is cleared and loaded with the contents of the addressed location. The contents of the memory cell are unaltered.

LDB. Load into B. The B-Register is cleared and loaded with the contents of the addressed location. The contents of the memory cell are unaltered.

STA. Store A. The contents of the A-Register are stored in the addressed location. The previous contents of the memory cell are lost; the A-Register is unaltered.

STB. Store B. The contents of the B-Register are stored in the addressed location. The previous contents of the memory cell are lost; the B-Register is unaltered.

2.7.4 REGISTER REFERENCE INSTRUCTIONS

The Register Reference instructions, in general, manipulate bits in the A, B, and E Registers. There is no reference to memory; thus these instructions are executed in only one machine phase. This type includes 39 basic instructions (plus four Overflow instructions, which are coded under the I/O Group instructions). Register Reference instructions are combinable to form a one-word multiple instruction that can operate in various ways on the contents of the A, B, or E Registers. These "microinstructions" are divided into two sub-groups, the Shift-Rotate Group (SRG) and the Alter-Skip Group (ASG). Three instructions (SLA, SLB, and CLE) appear in both groups and, being combinable in these different contexts, are counted twice in the total of basic instructions. Microinstructions may be combined under the following general rules:

a. Instructions from the two groups cannot be mixed.

b. References to both A and B Registers cannot be mixed.

c. Only one microinstruction can be chosen from each column of the Selection Tables in Figures 2.6 and 2.7.

d. Use zeros to exclude unwanted microinstruction bits.

e. The sequence of execution is left to right in the Selection Tables (column 1, then column 2, etc.).

f. If two (or more) skip functions are combined, the skip will occur if either or both conditions are met. One exception exists: see RSS under the Alter-Skip Group.

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	TYPE 2				A/B	0	D/E	COL. 1			2	D/E	3	COL. 4		
NOP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CLE	0	0	0	0		0					1					
SLA	0	0	0	0	0	0							1			
SLB	0	0	0	0	1	0							1			
ALS	0	0	0	0	0	0	1	0	0	0		X		X	X	X
BLS	0	0	0	0	1	0	1	0	0	0		X		X	X	X
ARS	0	0	0	0	0	0	1	0	0	1		X		X	X	X
BRS	0	0	0	0	1	0	1	0	0	1		X		X	X	X
RAL	0	0	0	0	0	0	1	0	1	0		X		X	X	X
RBL	0	0	0	0	1	0	1	0	1	0		X		X	X	X
RAR	0	0	0	0	0	0	1	0	1	1		X		X	X	X
RBR	0	0	0	0	1	0	1	0	1	1		X		X	X	X
ALR	0	0	0	0	0	0	1	1	0	0		X		X	X	X
BLR	0	0	0	0	1	0	1	1	0	0		X		X	X	X
ERA	0	0	0	0	0	0	1	1	0	1		X		X	X	X
ERB	0	0	0	0	1	0	1	1	0	1		X		X	X	X
ELA	0	0	0	0	0	0	1	1	1	0		X		X	X	X
ELB	0	0	0	0	1	0	1	1	1	0		X		X	X	X
ALF	0	0	0	0	0	0	1	1	1	1		X		X	X	X
BLF	0	0	0	0	1	0	1	1	1	1		X		X	X	X

SELECTION TABLE

1	2	3	4
ALS ARS RAL			ALS ARS RAL

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	TYPE 2				A/B	1	COL. 1		COL. 3		2	4	5	6	7	8
CLA	0	0	0	0	0	1	0	1								
CLB	0	0	0	0	1	1	0	1								
CMA	0	0	0	0	0	1	1	0								
CMB	0	0	0	0	1	1	1	0								
CCA	0	0	0	0	0	1	1	1								
CCB	0	0	0	0	1	1	1	1								
SEZ	0	0	0	0		1					1					
CLE	0	0	0	0		1			0	1						
CME	0	0	0	0		1			1	0						
CCE	0	0	0	0		1			1	1						
SSA	0	0	0	0	0	1						1				
SSB	0	0	0	0	1	1						1				
SLA	0	0	0	0	0	1							1			
SLB	0	0	0	0	1	1							1			
INA	0	0	0	0	0	1								1		
INB	0	0	0	0	1	1								1		
SZA	0	0	0	0	0	1									1	
SZB	0	0	0	0	1	1									1	
RSS	0	0	0	0		1										1

SELECTION TABLE

1	2	3	4	5	6	7	8
CLA CMA CCA	SEZ	CLE CME CCE	SSA	SLA	INA	SZA	RSS

RAR ALR ERA ELA ALF	CLE	SLA	RAR ALR ERA ELA ALF
BLS BRS RBL RBR BLR ERB ELB BLF	CLE	SLB	BLS BRS RBL RBR BLR ERB ELB BLF

COMBINING GUIDE

1. Choose up to 4 instructions, one from each column of the Selection Table.
2. Use a one-bit for Bit 9 to Enable column 1 instructions, and a one-bit for Bit 4 to Enable column 4 instructions. Figure above shows column 1 enabled (executed first) with duplicate column 4 pattern (executed last) indicated by X's.
3. Use a one-bit for Bit 5 to select column 2 (CLE), or a zero-bit to exclude CLE.
4. Use a one-bit for Bit 3 to select column 3 (SLA/B), or a zero-bit to exclude SLA/B.

Figure 2.6. Shift-Rotate Instructions

CLB CMB CCB	SEZ	CLE CME CCE	SSB	SLB	INB	SZB	RSS

COMBINING GUIDE

1. Choose up to 8 instructions, one from each column of the Selection Table.
2. Use the specified two-bit combinations of Bits 9 and 8, plus A/B Bit 11, to encode column 1 instructions.
3. Use the specified two-bit combinations of Bits 7 and 6 to encode column 3 instructions.
4. Use a one-bit in Bits 5, 4, 3, 2, 1, plus A/B Bit 11, to encode column 2, 4, 5, 6, 7 instructions respectively.
5. Use a one-bit for Bit 0 to encode column 8.

Figure 2.7. Alter-Skip Instructions

Register Reference Instructions are recognized by the computer when the four most significant bits of the instruction word are zeros; the general format for this type of instruction (the dots representing variable microinstruction bits) is therefore:

0 000 . . . .

SHIFT-ROTATE GROUP. The SRG instructions are specified by a zero for Bit 10 (compare Figures 2.6 and 2.7). Figure 2.6 gives both the bit format and the Selection Table for using these instructions. Definitions for the mnemonics used are listed below. Note that the Extend bit is not affected by shifts or rotates unless specifically stated. All of the shift and rotate instructions can be executed either first or last in a combined instruction, or both times. This permits sequencing of CLE and SLA/B either before or after shifts and rotates.

NOP — No Operation. Memory cycle only.

CLE — Clear E-Register.

SLA — Skip next instruction if Least Significant bit of A-Register is zero (i.e., skip if an even number is in A).

SLB — Skip next instruction if Least significant bit of B-Register is zero (i.e., skip if an even number is in B).

ALS — A-Register Left Shift one place, arithmetically (15 bits only). A zero replaces vacated Bit 0; bit shifted out of Bit 14 is lost; Bit 15 (sign bit) is not affected.

BLS — B-Register Left Shift one place, arithmetically (15 bits only). A zero replaces vacated Bit 0; bit shifted out of Bit 14 is lost; Bit 15 (sign bit) is not affected.

ARS — A-Register Right Shift one place, arithmetically. Bit shifted out of Bit 0 is lost; copy of sign bit (Bit 15) shifted into Bit 14; Bit 15 is not affected.

BRS — B-Register Right Shift one place, arithmetically. Bit shifted out of Bit 0 is lost; copy of sign bit (Bit 15) shifted into Bit 14; Bit 15 is not affected.

RAL — Rotate A-Register Left one place, all 16 bits. Bit 15 is rotated around to Bit 0.

RBL — Rotate B-Register Left one place, all 16 bits. Bit 15 is rotated around to Bit 0.

RAR — Rotate A-Register Right one place, all 16 bits. Bit 0 is rotated around to Bit 15.

RBR — Rotate B-Register Right one place, all 16 bits. Bit 0 is rotated around to Bit 15.

ALR A-Register Left shift one place, same as ALS, but clear sign bit after shift.

BLR B-Register Left shift one place, same as BLS, but clear sign bit after shift.

ERA Rotate E-Register Right with A-Register, one place (17 bits). Bit 0 is rotated into Extend Register; Extend content is rotated into Bit 15.

ERB Rotate E-Register Right with B-Register, one place (17 bits). Bit 0 is rotated into Extend Register; Extend content is rotated into Bit 15.

ELA Rotate E-Register Left with A-Register, one place (17 bits). Bit 15 is rotated into Extend Register; Extend content is rotated into Bit 0.

ELB Rotate E-Register Left with B-Register, one place (17 bits). Bit 15 is rotated into Extend Register; Extend content is rotated into Bit 0.

ALF Rotate A-Register Left Four places, all 16 bits. Bits 15, 14, 13, 12 are rotated around to Bits 3, 2, 1, 0 respectively. Equivalent to four successive RAL instructions.

BLF Rotate B-Register Left Four places, all 16 bits. Bits 15, 14, 13, 12 are rotated around to Bits 3, 2, 1, 0 respectively. Equivalent to four successive RBL instructions.

ALTER-SKIP GROUP. The ASG instructions are specified by a one in Bit 10. Figure 2.7 gives both the bit format and the Selection Table for using these instructions. Definitions for the mnemonics used are as follows:

CLA Clear A-Register.

CLB Clear B-Register.

CMA Complement A-Register. One's complement, reversing the state of all 16 bits.

CMB Complement B-Register. Reverses state of all 16 bits.

CCA Clear, then Complement A-Register. Puts 16 ones in the A-Register; this is the two's complement form of -1.

CCB Clear, then Complement B-Register. Puts 16 ones in the B-Register; this is the two's complement form of -1.

CLE Clear E-Register.

CME Complement E-Register. Reverses state of the Extend bit.

CCE Clear, then Complement E-Register. Sets the Extend bit.

SEZ Skip the next instruction if E-Register is zero.

SSA Skip next instruction if Sign bit (Bit 15) of A-Register is zero; i.e., skip if the content of A is positive.

SSB Skip next instruction if Sign bit (Bit 15) of B-Register is zero; i.e., skip if the content of B is positive.

SLA Skip next instruction if Least significant bit of A-Register is zero (i.e., skip if an even number is in A).

SLB Skip next instruction if Least significant bit of B-Register is zero (i.e., skip if an even number is in B).

INA Increment A-Register by one. Can cause setting of Extend or Overflow bits.

INB Increment B-Register by one. Can cause setting of Extend or Overflow bits.

SZA Skip next instruction if A-Register is Zero (16 zeros).

SZB Skip next instruction if B-Register is Zero (16 zeros).

RSS Reverse Skip Sense. Skip occurs for any of the preceding skip instructions, if present, when the non-zero condition is met. RSS without a skip instruction in the word causes an unconditional skip. If a word with RSS also includes both SSA/B and SLA/B, both bits (Bit 15 and Bit 0) must be one for skip to occur; in all other cases the skip occurs if either or both conditions are met.

2.7.5 INPUT/OUTPUT INSTRUCTIONS

The HP computers have 17 basic Input/Output instructions, which provide the following general capabilities. (Note: Overflow instructions are associated with register reference operations and are therefore listed under Register Reference instructions in Table 2.1; however, they are coded under the I/O Group.)

a. Fix the state of the Flag, Control, and Overflow bits.

b. Test the state of the Flag and Overflow bits (i. e., skip if set or clear, as specified).

c. Enter data from a specific device into the A or B Registers.

d. Output data to a specific device from the A or B Registers.

e. Halt the program.

Input/Output instructions are recognized by the computer when the four most significant bits of the instruction word are 1000 and Bit 10 is a one. The codes and mnemonics for all 17 instructions are given in Figure 2.8 (the MAC instruction is not counted as a basic instruction). All Input/Output instructions are executed in one phase.

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	TYPE 3				A/B	*	H/C	INSTRUCTION			SELECT CODE					
MAC	1	0	0	0		0										
HLT	1	0	0	0		1		0	0	0						
STF	1	0	0	0		1	0	0	0	1						
CLF	1	0	0	0		1	1	0	0	1						
SFC	1	0	0	0		1	0	0	1	0						
SFS	1	0	0	0		1	0	0	1	1						
MIA	1	0	0	0	0	1		1	0	0						
MIB	1	0	0	0	1	1		1	0	0						
LIA	1	0	0	0	0	1		1	0	1						
LIB	1	0	0	0	1	1		1	0	1						
OTA	1	0	0	0	0	1		1	1	0						
OTB	1	0	0	0	1	1		1	1	0						
STC	1	0	0	0	0	1		1	1	1						
CLC	1	0	0	0	1	1		1	1	1						
STO	1	0	0	0		1	0	0	0	1	0	0	0	0	0	1
CLO	1	0	0	0		1	1	0	0	1	0	0	0	0	0	1
SOC	1	0	0	0		1		0	1	0	0	0	0	0	0	1
SOS	1	0	0	0		1		0	1	1	0	0	0	0	0	1

*Identifies Macroinstructions (0) or standard Input/Output instructions (1).

Figure 2.8. Input/Output Instructions

Note that Bit 11, where relevant, specifies A or B Register; otherwise it may be one or zero without affecting the instruction, although the Assembler will assign zeros (as shown). Bit 9, where not specified, offers the choice of Holding (0) or Clearing (1) the device Flag after execution of the instruction. (Exception: the H/C bit associated with the last two instructions in this list Holds or Clears the Overflow bit instead of the Flag bit.) Bits 8, 7, and 6 identify the instruction; some of the instructions, however, require additional specific bits for the complete code. Bits 5 through 0 form Select Codes to make the instruction apply to one of up to 64 input/output devices or functions.

The MAC instruction listed in Figure 2.8 is available to provide up to 2048 entries to macroinstruction subroutines. Since it is used only by special options and special software, MAC is not counted as one of the 70 basic machine instructions. The basic HP computer will treat MAC as a No-Operation (NOP) instruction.

HLT. Halt. Stops the computer, and Holds or Clears the flag (according to Bit 9) of any desired input/output device (Bits 5 through 0). The HLT instruction has the same effects as the HALT pushbutton: the HALT switch lights, all front-panel control switches are enabled, and no interrupts may occur. The HLT instruction will be displayed in the T-Register, and the P-Register (on 2115A/2116B Computers) will normally indicate the HALT location plus one.

STF. Set Flag. Sets the input/output Flag of the selected device, thus causing an interrupt during the next machine phase if the interrupt system is enabled, and the corresponding Control bit is set. The interrupt system itself is enabled by an STF instruction with a Select Code of 6 zeros (octal 00).

CLF. Clear Flag of selected device. Resets the Flag, thus permitting the device to present another Flag when ready again. A CLF with a Select Code of 6 zeros (octal 00) disables the entire interrupt system; this does not affect the status of individual input/output Flags.

SFC. Skip if Flag Clear. Causes the computer to skip the next instruction if the Flag bit of the selected device is zero (i.e., the device is not ready).

SFS. Skip if Flag Set. The next instruction is skipped if the Flag bit of the selected device is one (i.e., the device is ready).

MIA. Merge Input into A. The contents of the Input/Output Buffer associated with the selected device are merged ("inclusive or") into the A-Register.

MIB. Merge Input into B. The contents of the Input/Output Buffer associated with the selected device are merged ("inclusive or") into the B-Register.

LIA. Load Input into A. The contents of the Input/Output Buffer associated with the selected device are loaded into the A-Register. Previous contents of the A-Register are lost.

LIB. Load Input into B. The contents of the Input/Output Buffer associated with the selected device are loaded into the B-Register. Previous contents of the B-Register are lost.

OTA. Output from A. The contents of the A-Register are loaded into the Input/Output Buffer associated with the selected device. If the Buffer is less than 16 bits in length, the least significant bits of the A-Register normally are loaded. (Some exceptions exist, depending on the type of output device.) A-Register contents are not altered.

OTB. Output from B. The contents of the B-Register are loaded into the Input/Output Buffer associated with the selected device.

STC. Set Control bit of the selected device. This commands or prepares the device to perform its input or output function, and enables its Flag bit to interrupt the program being run (provided the program is not disabling the interrupt system).

CLC. Clear Control bit of the selected device. This prevents the device from interrupting. A CLC instruction with a Select Code of 00 (octal) clears all Control bits, effectively turning off all input/output devices. CLF 00 may be combined with this to additionally turn off the interrupt system.

STO. Set Overflow. The Overflow bit remains set until cleared by one of the following three instructions.

CLO. Clear Overflow. Resets the Overflow register.

SOS. Skip if Overflow Set. If the Overflow register is set, the next instruction of the program is skipped. Use of the H/C bit will Hold or Clear the Overflow bit following execution of this instruction (whether the skip is taken or not).

SOC. Skip if Overflow Clear. If the Overflow register is clear, the next instruction of the program is skipped. Use of the H/C bit will Hold or Clear the Overflow bit following execution of this instruction.

Table 2.3 consolidates all of the instructions contained in Figures 2.5 through 2.8 for a quick, easy reference to all computer instructions. To use the table, simply find the mnemonic for the instruction and then read all coding bits on the same line as the mnemonic. Those bit locations specifying A/B, Z/C, etc. must be programmed to contain a 0 or 1, respectively, as applicable to the instruction to be performed. Also, all mnemonics for instructions involving the A or B Register contain an asterisk in place of the appropriate A or B letter. Each of these instructions use a 0 or 1 in bit position 11 (depending on whether the A or B Register is used) as well as those bits specified on the same line as the mnemonic. The instructions in the Shift-Rotate Group (except CLE and SL*) require a "one" in bit positions 4 and/or 9 to be executed. A "one" in bit position 4 enables an instruction defined by bits 0, 1, and 2; bit position 9 enables an instruction defined by bits 6, 7, and 8. If both bit positions 4 and 9 contain a "one", the instruction defined by bits 6, 7, and 8 is executed first.

2.8 DATA FORMATS

Data is represented in two's complement form internally in the HP computer. The basic format for arithmetic operations on numerical data is defined in Figure 2.9. The data is assumed to be an integer (binary point to the right of Bit 0), and is positive if the sign bit is zero, or negative if one. The largest possible positive number (in octal) is +77777, or (in decimal) +32767; the largest possible negative number is -100000 (octal) or -32768 (decimal). Other possible formats, including packed data words, double-length fixed point, and floating point representations, are defined in standard software packages.

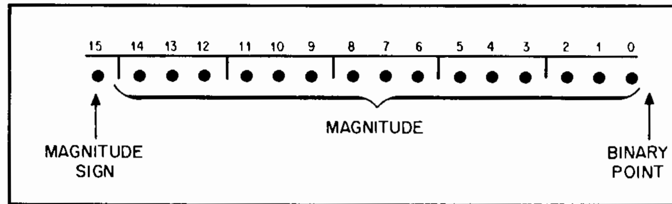


Figure 2.9. Basic Data Format

2.9 INPUT/OUTPUT SPECIFICATIONS

2.9.1 INPUT/OUTPUT SYSTEM DESIGN

GENERAL. Information is transferred into the computer from an external device, or out of the computer to an external device, by

way of its input/output capability, termed the input/output system. A transfer of information is initiated by a signal from a device indicating that it is ready for input or output. The transfer occurs by the process of interrupting a running program (which could be either a problem-solving program, or a program specifically designed to transfer data). The interrupt directs the computer to a location in memory uniquely associated with the interrupting device. This location in turn directs the computer to a program routine (a "service routine", which must previously have been stored in memory), and this routine will contain instructions which effect the actual transfer of information. Since interrupts can occur at almost any time, including during the service routine of an earlier interrupt, a priority network is present in the computer to establish the sequence in which interrupts are serviced. As shown in Figure 2.10, the input/output system capability is physically divided so that part of the capability (including the priority network and the identical hardwiring for optional plug-in card slots) is an integral part of the HP computer main unit. The remaining part is provided by Input/Output Options, which will include the plug-in interface cards and cables for specific devices, and the appropriate software drivers and diagnostic programs. The interface cards may be plugged into any of the identical input/output slots, depending on the desired priority rating. Each combination of interface card and device, when plugged into the computer, constitutes an input/output channel.

NUMBER OF CHANNELS. The coding structure of input/output instructions (Figure 2.8) allows 6 bits for a Select Code, making it possible to specify a total of 64 channels and functions (2^6). Of this total, four Select Codes are assigned to non-interrupting functions (Interrupt System Enable/Disable, Switch Register/Overflow, and initialization of two Direct Memory Access channels). Of the 60 remaining channels and functions with interrupt capability, four interrupt assignments are reserved for internal processor functions: Power Fail, Memory Protect (2116 only)/Memory Parity, and the interrupt assignments for Direct Memory Access. Thus, 56 possible channels remain for input/output devices. Table 2.4 indicates the number of these remaining 56 channels accommodated by the basic unit of each computer and those accommodated by the extender modules used with each computer.

Table 2.3. Consolidated Coding Table

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MEMORY REFERENCE INSTRUCTIONS															
D/I	AND		001	0	Z/C	← Memory Address →									
D/I	XOR		010	0	Z/C										
D/I	IOR		011	0	Z/C										
D/I	JSB		001	1	Z/C										
D/I	JMP		010	1	Z/C										
D/I	ISZ		011	1	Z/C										
D/I	AD*		100	A/B	Z/C										
D/I	CP*		101	A/B	Z/C										
D/I	LD*		110	A/B	Z/C										
D/I	ST*		111	A/B	Z/C										
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SHIFT-ROTATE GROUP INSTRUCTIONS															
0	SRG		000	A/B	0	D/E	*LS		000	†CLE	D/E	‡SL*	*LS		000
				A/B	0	D/E	*RS		001		D/E		*RS		001
				A/B	0	D/E	R*L		010		D/E		R*L		010
				A/B	0	D/E	R*R		011		D/E		R*R		011
				A/B	0	D/E	*LR		100		D/E		*LR		100
				A/B	0	D/E	ER*		101		D/E		ER*		101
				A/B	0	D/E	EL*		110		D/E		EL*		110
				A/B	0	D/E	*LF		111		D/E		*LF		111
				NOP	000				000		000				000
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ALTER-SKIP GROUP INSTRUCTIONS															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	ASG	000		A/B	1	CL*	01	CLE	01	SEZ	SS*	SL*	IN*	SZ*	RSS
				A/B	1	CM*	10	CME	10						
				A/B	1	CC*	11	CCE	11						
MAC AND INPUT/OUTPUT INSTRUCTIONS															
1	MAC	000		A/B	0										
1	IOG	000		A/B	1	H/C	HLT	000		← Select Code →					
					1	0	STF	001							
					1	1	CLF	001							
					1	0	SFC	010							
					1	0	SFS	011							
				A/B	1	H/C	MI*	100							
				A/B	1	H/C	LI*	101							
				A/B	1	H/C	OT*	110							
				0	1	H/C	STC	111							
				1	1	H/C	CLC	111							
					1	0	STO	001			000			001	
					1	1	CLO	001			000			001	
					1	H/C	SOC	010			000			001	
					1	H/C	SOS	011			000			001	

Notes:
1) * = A or B. Use with bit 11 as Ø (A-Register) or 1 (B-Register).
2) D/I, A/B, Z/C, D/E, H/C coded: 0/1.
3) † CLE: Only this bit is required.
4) ‡ SL*: Only this bit and bit 11 (A/B as applicable) are required.

Table 2.4. Computer I/O Channels

Computer	Basic Unit	2150B Extender	2151A Extender	Total w/ 2150B	Total w/ 2151A
2116B	16	32	16	48	32
2115A	8	32	16	40	24
2114B	7	--	17	--	24*

*56 channels are possible using Multiplexed I/O option.

INTERFACE COMPONENTS. Each plug-in interface card normally includes the following components, shown in Figure 2.11.

a. An Input/Output Buffer consisting of up to 16 flip-flops for temporary storage of data to be transferred in or out, so that it is not necessary to tie up a working register during the relatively long transfer periods. The actual number of Buffer bits, from 1 to 16, will depend on the device for which the interface is intended. Data is transferred to the Buffer from the A or B Registers by OTA or OTB instructions, and is brought in to the A or B Registers from the Buffer by LIA, LIB, MIA, or MIB instructions. If the Buffer is less than 16 bits in length, data is transferred to or from the least significant bits of the A or B Registers.

b. An input/output Flag flip-flop, which will be set by a signal from the external device when the device has completed an operation. The Flag may also be set, if desired, by program instruction (STF). Once set, the Flag remains set until reset by a clear instruction (CLF or H/C bit). Provided it is itself not inhibited by the set Flag of a higher priority device, or otherwise disabled (see step "c"), the Flag, when set, inhibits all interrupts for devices having lower priority. It will cause an interrupt after the current machine phase. Successive interrupts for one device may occur on receipt of a number of Flag signals without executing a Clear Flag instruction, thus making it possible to inhibit lower priority devices indefinitely until a desired number of high-priority transfers have been completed. The Flag can be set and cleared even if its interrupt capability is inhibited or disabled, and may be tested by SFS or SFC instructions.

c. A Control flip-flop to command or enable the external device to perform its input or output operation. In addition, the Control bit controls the interrupt capability for that particular device; i.e., unless the Control flip-flop is set, a received Flag cannot cause an interrupt, nor can it inhibit the interrupt capability of any other device in the priority string. Thus the Control bit, when set, effectively "turns on" the individual input/output channel.

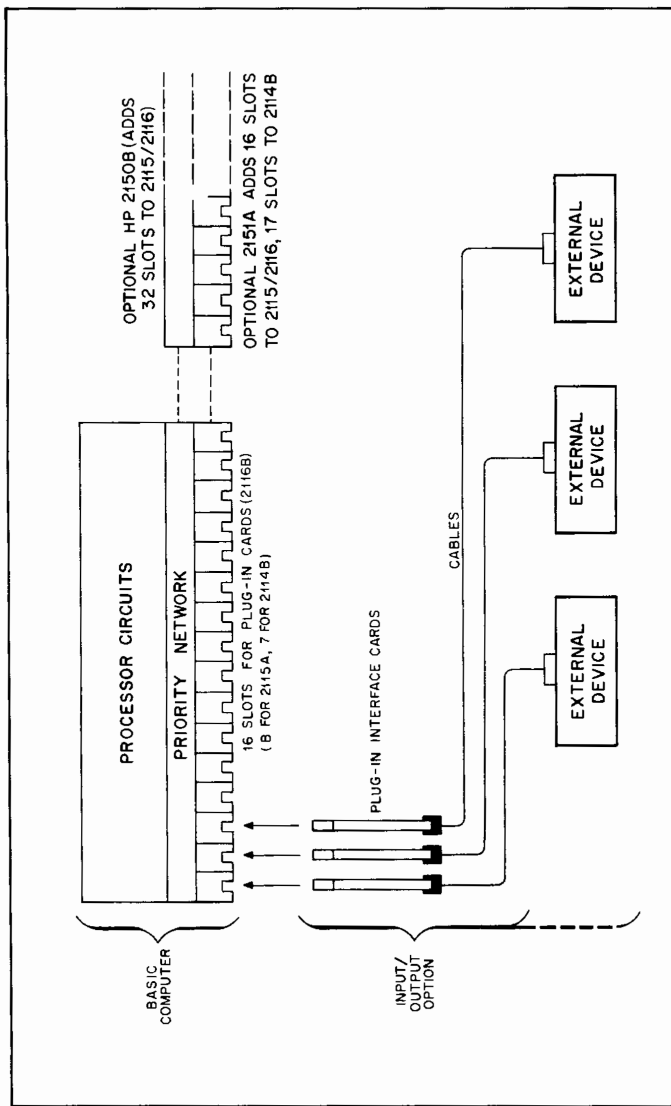


Figure 2.10. Input/Output Design Arrangement

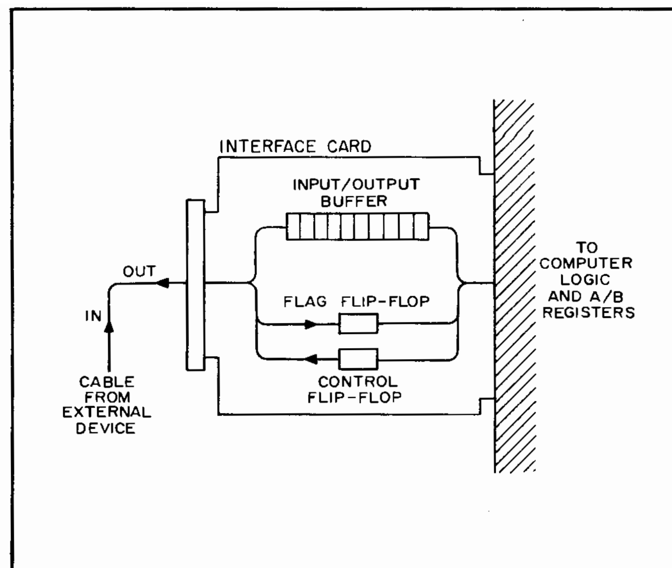


Figure 2.11. Components of Typical Input/Output Interface Card

PARTY LINE INPUT/OUTPUT. This option permits the interfacing of customer designed and standard devices to the 2116, 2115 or 2114 Computer using only those input/output lines normally assigned to a single peripheral device. The input/output lines from the computer are bussed to all devices on the party line so the devices appear as a single device to the computer. (See Figure 2.12.) Since all lines are identically available to all devices, each device must have its own controller (furnished by the customer). The controller must decode device address and command information, send status information to the computer, and maintain overall control of the device to which it is connected. Two Microcircuit Interface cards are required to implement party line I/O. The cards are identical and each card contains two 16-bit "or-tied" registers as well as standard control and interrupt circuits common to all HP input/output interface cards. The receivers and drivers on each card are microcircuit, rather than discrete components for ease of interfacing. The cards provide an Encode (take action) signal to the party line devices, the facilities to recognize a Flag (action completed) signal from a party line device, and 16 lines for input/output data. The party line interface cards plug into any two adjacent computer I/O slots; the remaining slots can be used to interface

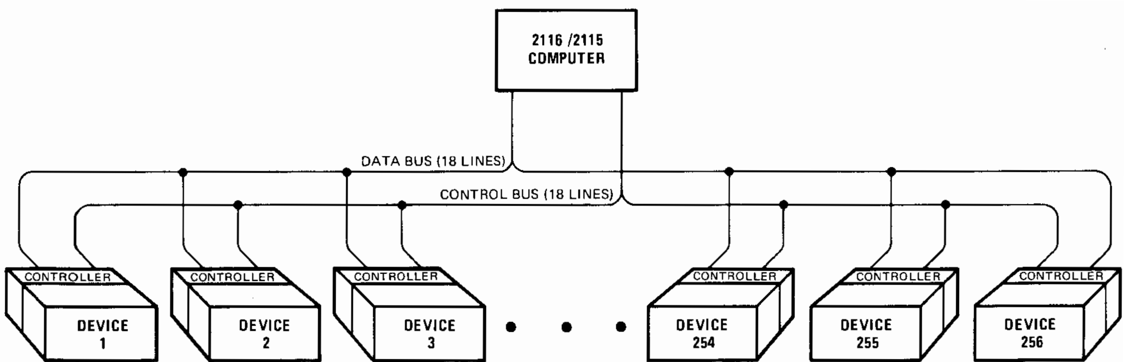


Figure 2.12. Party Line Block Diagram

standard peripheral devices. The slot positions establish the priority of the party line in relation to the other devices connected to the computer. Data transfer rates of 40 kHz are possible under a non-interrupt mode, while rates are limited to 10 to 12 kHz under interrupt control.

2114 MULTIPLEXED INPUT/OUTPUT. This option permits the connection of up to 56 devices to the 2114 Computer. A special interface card, the Multiplexer Data card, plugs into a computer I/O slot and operates in conjunction with an optional I/O Control card (which replaces the standard I/O Control card) to provide 56 signal lines (see Figure 2.13). These signal lines handle addressing, provide the control signals, receive interrupt signals, and input/output up to 16 bits of data. All decoding of device addresses and I/O instructions is performed by the computer. The I/O device requests service of the computer by sending its binary coded address to the computer on six interrupt request lines. Interrupt requests are relayed to specific memory locations through the existing computer interrupt system for processing. Interfaces between the external devices and the computer are customer furnished but interfacing is simplified since all necessary signals are supplied by the computer.

SELECT CODE ASSIGNMENTS. As mentioned previously, Bits 5 through 0 of the Input/Output instructions form a Select Code to specify one of 64 possible input/output devices or functions. Of the 64 Select Codes, some are reserved for specific uses while others are available for assignment to any optional input/output device. Table 2.5 lists these assignments, and gives the corresponding interrupt location (i.e., the location containing the instruction to be executed when interrupt occurs). The first five (octal Codes 00 through 04) are reserved for non-interrupting functions.

2.9.2 INTERRUPT STRUCTURE

OPERATION. On computer command (Set Control instruction STC), one or more external devices begin their read or record operations, putting data into (input) or taking data from (output) the Input/Output Buffer on each individual interface card. During this time, the computer may continue running a program, or may be programmed into a waiting loop to wait for a specific device. On completion of the read or record operations, each device returns an "operation completed" signal (Flag) to the computer. The Flags are passed through a priority network which allows only one device to be servided regardless of the number of Flags simultaneously present. The Flag with the highest priority causes an interrupt at the end of the current machine phase, switching the computer into the Interrupt phase, except under any of the following circumstances.

a. Interrupt System disabled or device interrupt disabled.

b. Computer in HALT mode. SINGLE CYCLE pushbutton cannot step the computer into the Interrupt phase.

c. JMP Indirect or JSB Indirect not fully executed. These instructions inhibit all interrupts until the instruction (plus one phase of the succeeding instruction) is completed.

d. Instruction in an interrupt location not fully executed, even if of lower priority. Any interrupt inhibits the entire interrupt system until one instruction (plus one phase of the succeeding instruction) has been completed. (In the case of a multi-level indirect instruction, the interrupt system will be re-enabled after two Indirect phases; JMP Indirect and JSB Indirect are exceptions and will be fully executed.)

e. Direct Memory Access Option in process of transferring data. Exception: power failure control can interrupt a DMA transfer.

f. The current instruction is one which may affect the priorities of input/output devices (STC, CLC, STF, CLF). The interrupt in this case must wait until the end of the succeeding machine phase.

When interrupt occurs, the computer puts the Select Code number of the interrupting device into the M-Register (with extra zeros to specify page Zero), thus causing the next instruction to be read from the memory location having the same number as the Select Code. This location in memory is referred to as the "interrupt location", and is reserved for that particular device. Example: a device specified by a Select Code of 10 will interrupt to (i.e., cause execution of the contents of) memory location 00010. The instruction in the interrupt location will usually be a jump (JSB) to an input or output subroutine.

To prevent external devices from running when computer power is first turned on, turn-on of the POWER switch automatically clears all Control bits, resets the Interrupt System Enable flip-flop (disabling the interrupt system), and sets all device Flags. Pressing the PRESET pushbutton accomplishes the same function when the computer is on (but not when running, since the control switches are disabled). Therefore, before any device can operate with the computer, it is necessary for the program to set the Interrupt System Enable flip-flop and, depending on the type of device, clear the individual Flag bit and/or set the individual Control bit.

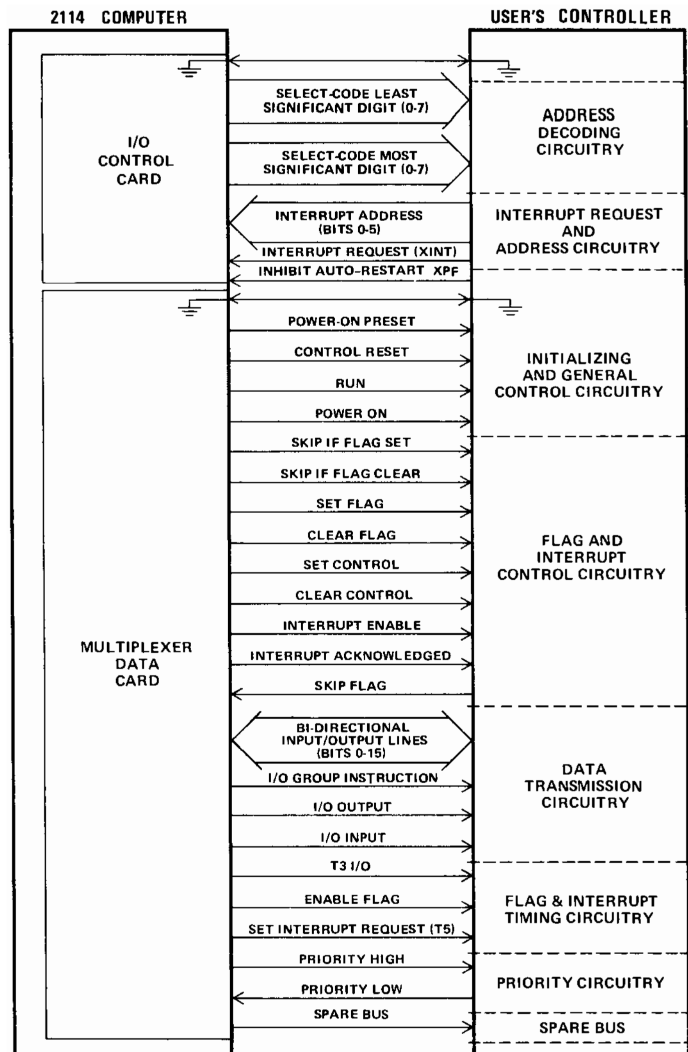


Figure 2.13. Multiplexed I/O Signal Lines

Table 2.5. Select Code Assignments

SELECT CODE (OCTAL)	INTERRUPT LOCATION	ASSIGNMENT
00	None	STF ∅ turns Interrupt System on CLF ∅ turns Interrupt System off
01	None	Switch Register: LIA/B, MIA/B OTA/B (2114A only) Overflow Register: STO, CLO, SOC, SOS
02	None	Initialize DMA Channel 1 (Select Code 6): 2116, 2115, 2114B
03	None	Initialize DMA Channel 2 (Select Code 7): 2116, 2115
04	00004	Power Fail Interrupt Interrupt Source Identification (LIA/B 4 = Select Code of last interrupting device)
05	00005	Memory Protect Interrupt (2116 only) Parity Error Interrupt (LIA/B 5 = address of offending location. If bit 15 = "1", parity error interrupt. If bit 15 = "0", memory protect interrupt.)
06	00006	DMA Channel 1 Completion Interrupt: 2116, 2115, 2114B
07	00007	DMA Channel 2 Completion Interrupt: 2116, 2115
10 thru 77	00010 thru 00077	I/O Device, highest priority thru I/O Device, lowest priority

INPUT INTERRUPT. The typical operation sequence for an input interrupt involves the following steps.

a. A STC instruction, usually accompanied by CLF, sends a command (equivalent to "read", "encode", or "reset" in HP digital measuring equipment) to the external device.

b. The device reads its input, then puts the data into the Input/Output Buffer on the interface card.

c. Simultaneously, the device supplies a Flag signal (equivalent to "record" or "print" commands in HP digital measuring equipment) to the computer.

d. The Flag is converted to an interrupt request by the device interface card.

e. The resulting interrupt causes a service subroutine for that device to begin, temporarily suspending operation of the main program.

f. The service subroutine enters data from the Buffer into the A or B Register, then returns control to the main program.

OUTPUT INTERRUPT. The typical operation sequence for an output interrupt involves the following steps.

a. An OTA or OTB instruction puts data from the A or B Register into the Input/Output Buffer on the interface card.

b. A STC instruction sends a command (equivalent to "record" or "print" commands in HP digital recording equipment) to the external device.

c. The device accepts (records) the data currently in the Buffer.

d. After the data has been accepted, the device returns a Flag signal (equivalent to the end of a "holdoff" or "inhibit" signal in HP digital recording equipment) to the computer.

e. The Flag is converted to an interrupt request by the device interface card.

f. The interrupt causes a service subroutine for that device to begin.

g. The service subroutine loads new data into the Buffer, repeating the sequence.

PRIORITY. The priority network gives highest interrupt priority to Select Code 04, reserved for power failure control interrupt, and decreasing priority to Select Codes in order from 05 through 77. The transfer of data by Direct Memory Access (which transfers data directly to and from memory by inserting a special memory cycle, rather than by interrupt to a service subroutine) effectively has priority between Select Codes 06 and 07, since DMA can inhibit all interrupts except power failure control. DMA Channel 1 has priority over DMA Channel 2 of the 2116/2115 two-channel DMA.

A set Flag inhibits all Flags below it on the priority string, and once this Flag is cleared, the next lower can then interrupt. A service subroutine for any device can be interrupted by a higher priority device; then, after the higher Flag is cleared, the subroutine may continue. In this way, it is possible for several service subroutines to be in a state of interruption at one time; each will be permitted to continue when the higher priority Flag is cleared. All service subroutines normally end with a Jump-Indirect (JMP, I) instruction to return the computer to the point of interrupt.

TRANSFER RATE. Up to 60,000 transfers per second, limited by length of service subroutine, are possible with the 2116. Up to 47,000 transfers per second are possible with the 2114 and 2115.

2.10 PROCESSOR OPTIONS

The following Options (except power fail with auto-restart for 2114 Computer) are capable of being installed in the field. They consist of one or more plug-in cards, and in the case of Option 004, an additional memory module as well. Other processor Options are available, as either standard or custom modifications; consult the applicable HP Computer Technical Data sheet or a Hewlett-Packard field office.

8K MEMORY. Option 004 (2114 and 2115 only). Comprises a set of memory addressing cards and an 8192-word memory module. The module replaces the 4096-word memory module in the computer mainframe.

16K MEMORY. Option 005 (2116 only). Adds 8192-word memory to the 8192-word memory in the basic computer.

POWER FAIL INTERRUPT WITH AUTOMATIC RESTART. (Optional on 2114/2115/2116) Upon losing primary computer power, control is automatically shifted to a power failure subroutine which saves the contents of memory and all computer registers. Restoring power returns control to the user's program.

MEMORY PARITY CHECK. Permits parity checking within memory. Odd parity is used. This option consists of one plug-in card. A parity error may either cause the computer to halt or interrupt to address 05.

MEMORY PROTECT (2116 only) Protects a selected block of memory from 1 to 32,768 words against alteration by memory reference instructions. Gives a program in memory exclusive control of the I/O section of the computer.

EXTENDED ARITHMETIC. (2115 and 2116 only) Permits Integer Multiply, Integer Divide, Double Load, Double Store, Long Shifts, and Long Rotations to be performed by hardware instead of program subroutines.

DIRECT MEMORY ACCESS. Allows data to be transferred directly to and from computer memory rather than through the computer's arithmetic and control logic.

2.11 INPUT/OUTPUT OPTIONS

Input/output options for HP computers, identified by Interface Kit accessory numbers, consist of a combination of plug-in cards, interconnecting cables, and appropriate software. Table 2.6 summarizes some of the available standard input/output options, and the following paragraphs briefly describe the capabilities added by these options.

Most Input/Output Options require only one card. This card by itself has no definite Select Code assignment or interrupt priority. Plugging the card into any of the general purpose input/output slots of the computer, each of which has a Select Code assignment, automatically gives the external device an interrupt priority, according to the Select Code of the slot.

As shown in Figure 2.14, each of the input/output slots in the computer actually has two Select Codes available, although usually only one is used by the interface cards. If a slot between interface cards is unused, a Priority Jumper card must be inserted in the empty slot to maintain interrupt priority continuity. There can be no gaps in the priority string; continuity is required from Select Code position 10 up to the last used Select Code.

To use more interface cards than the computer can accommodate in its Input/Output slots requires an extender module. The HP 2151A Extender can be used with the 2114, 2115 or 2116 Computer and allows the user to double or triple the I/O channels in the computer. (Six I/O slots in the 2114B plus 18 in the 2151A gives a total of 24 I/O slots; eight I/O slots in the 2115 plus 16 in the 2151B gives a total of 24 I/O slots; 16 slots in the 2116 plus 16 in the 2151B gives a total of 32.)

TELEPRINTER INPUT/OUTPUT. The simplest configuration of an HP computer system is provided by a combination of a computer and an HP 2752A Teleprinter (modified Teletype ASR-33) and accessory Interface Kit 12531B. The Teleprinter combines a typewriter, punched tape reader and tape punch. Data and instructions

may be entered from punched tape or the keyboard. Output information is recorded on the typewriter, and may be recorded simultaneously on punched tape. The Teleprinter operates at 10 characters/second for both data entry and data recording. Where heavy use of the Teleprinter is anticipated, exceeding 5 hours per day 30 hours per week, a heavy duty HP 2754A Teleprinter (modi- d Teletype ASR-35) is recommended. This device uses the same erface. The HP 2752A and HP 2754A Teleprinters perform the same functions and operate at the same speed.

HIGH-SPEED PUNCHED TAPE INPUT. For rapid entry of punched tape programs and data into an HP computer, a 500 character per second HP 2748A Punched Tape Reader, with its Interface Kit 12597A-002 is available. The reader is equipped with a container for the tape to be read.

HIGH-SPEED PUNCHED TAPE OUTPUT. Computer data output can be recorded (asynchronously) on punched tape at 120 characters per second with an HP2753A Tape Punch and Interface Kit 12597-003 Includes a tape spooler, which accepts 1000 feet of tape.

7-CHANNEL MAGNETIC TAPE INPUT/OUTPUT. Interface Kit 12538B enables the computer to record on and read from 1/2 inch. 7-channel, NRZI, IBM-compatible magnetic tape with HP H26-2020A and HP H26-2020B Magnetic Tape Units. The HP H26-2020A Magnetic Tape Unit reads and records at 200 bpi density. Tape speed is 30 ips, providing a data transfer rate of 6000 characters/ second. With the dual-density model HP H26-2020B, the Tape Unit operates at either 200 or 556 bpi density, switch-selectable. Tape speed is also 30 ips, providing a data transfer rate of 16,700 characters per second when set to operate at 556 bpi.

9-CHANNEL MAGNETIC TAPE INPUT/OUTPUT. Interface Kit 12559A enables the 2115 or 2116 Computer equipped with DMA to record on and read from 1/2-inch, 9-channel, NRZI, IBM-compatible magnetic tape with the HP H01-3030G Magnetic Tape Unit. This reads and records at 800 bpi density. Tape speed is 75 ips, providing a data-transfer rate of 60,000 characters per second.

DISC MEMORY. The 2770A or 2771A Disc Memory and Interface Kit 12606B provide a high capacity, random-access memory extension for HP Computers equipped with DMA. The 2770A disc memory has a storage density of 184,320 or (optional) 368,640 16-bit words, with an average access time of 17.4 ms. Data can be transferred at 160,000 16-bit words per second. The 2771A disc memory has a storage density of 368,640 or (optional) 737,280 16-bit words with the same access time and transfer rate as the 2770A.

Table 2.6 Input/Output Options

I/O OPTION	CAPABILITY	INTERFACE KIT	PERIPHERAL
TELEPRINTER INPUT/OUTPUT	Typewriter and paper tape output, keyboard and paper tape input, at 10 characters/second. ASCII code; friction-feed platen.	12531B	HP 2752A Teleprinter (modified Teletype ASR-33)
HEAVY-DUTY TELEPRINTER INPUT/OUTPUT	Similar to option above, except heavy-duty teleprinter with pin-feed platen. Recommended where use exceeds 5 hrs/day or 30 hrs/week.	12531B	HP 2754B Teleprinter (modified Teletype ASR-35)
HIGH-SPEED PUNCHED TAPE INPUT	Paper tape input at 500 characters/sec.	12597A-002	HP 2748A Punched Tape Reader
OPTICAL MARK READER	Reads punched and marked cards. 200 cards/min; automatic feed.	12602B	HP 2761A-07 Optical Mark Reader (parallel output)
HIGH-SPEED PUNCHED CARD READER	Reads 12-bit parallel columns, 80 columns/card at 1000 cards/min.	12558B	HP 2779B Card Reader
HIGH-SPEED PUNCHED TAPE OUTPUT	Punched tape output at 120 characters/sec.	12597A-003	HP 2753A Tape Punch
PAPER TAPE WINDER	Hand-held electric winder for rerolling paper tape.	---	HP 12575A Tape Winder
DUAL DENSITY MAGNETIC TAPE INPUT/OUTPUT	Computer records on, and reads from, IBM-compatible 1/2 inch 7-channel NRZI tape. Bit density 200 and 556 bpi, switch selectable. Speed 30 ips.	12538B*	HP (H27) 2020B Magnetic Tape Unit
9-CHANNEL MAGNETIC TAPE INPUT/OUTPUT	Computer records on, and reads from, IBM-compatible 1/2 inch 9-channel tape. Bit density 800 bpi. Speed 75 ips. Requires DMA 12578A.	12559A*	HP (H01) 3030G Magnetic Tape Unit
DISC MEMORY (184K WORDS; EXPANDABLE)	A. Provides storege for 184,320 16-bit words in 64 word sectors, 90 sectors/track. Transfer rate: 160K words/sec. Access time: 17.4 ms average. B. Expandable to 368K words using Installation Kit 12837A. Kit cost: $8,000.	12606B*	HP 2770A Disc Memory with HP 2772A Disc Memory Supply
DISC MEMORY (368K WORDS; NON-EXPANDABLE)	Similar to A above but stores 368,640 words. This unit is not expandable.	12606B*	HP 2770A-01 Disc Memory with HP 2772A Disc Memory Power Supply
DISC MEMORY (368K WORDS; EXPANDABLE	Similar to A above but stores 368,640 words. Expandable to 737,280 words using Installation Kit 12838A. Kit cost: $12,000.	12606B*	HP 2771A Disc Memory with HP 2772A Disc Memory Power Supply
DISC MEMORY (737K WORDS; NON-EXPANDABLE)	Similar to A above but stores 737,280 words. This unit is not expandable	12606B*	HP 2771A-01 Disc Memory with HP 2772A Disc Memory Power Supply
CARTRIDGE DISC MEMORY (1247K WORDS)	A. Provides storage for 1,247,232 16-bit words in 128 word sectors, 12 sectors/track. One fixed disc and one removable disc served by the same moving head. Access time (including head setting): Track-to-track 30 ms; avg. random move 70 ms, max—85 ms; avg. rotation delay 20 ms.	12577A*	HP 2870A Moving Head Disc with HP 2871A Disc Controller, HP 2881 Power Supply, HP 2882A Cabinet
	B. Additional Moving Head Disc Drive Installed in same cabinet with A above to expand total storage capacity to 2,494,464 words.	---	HP 2870A-001 Moving Head Disc Drive
	C. Additional Disc Drives (up to 4 drives can be handled by one controller and interface. However, 3rd and 4th drives require a second cabinet and Power Supply).	---	HP 2870A-001 Moving Head Disc Drive HP 2881 Power Supply HP 2882A Cabinet

*Uses 2 I/O slots

• Following I/O Options do not include the peripheral.

I/O OPTION	CAPABILITY	INTERFACE KIT	PERIPHERAL
POWER SUPPLY EXTENDER	Supplements internal I/O power supply.	---	HP 2160 Power Supply Extender
TIME BASE GENERATOR	Generates real time intervals in decade steps from 100 μs to 1000 sec (derived from crystal oscillator). Used as source of timed interrupts for softwere clock.	12539A	None required
DIGITAL VOLTMETER DATA INPUT (HP 2401C)	System accepts bcd (8421) data output from HP 2401C Integrating Digital Voltmeter.	12604B-001	HP 2401C Integrating Digital Voltmeter (with mod. M21)
DIGITAL VOLTMETER DATA INPUT (HP 3440A)	System accepts bcd (8421) data output from HP 3440A Digital Voltmeter.	12604B-004	HP 3440A Digital Voltmeter (with 8421 output)
COUNTER/THERMOMETER DATA INPUT (8 DIGITS)	System accepts bcd (8421) data output from 8-digit electronic counter and the quartz thermometer.	12604B-002	HP 5245L Electronic Counter (with option D2). HP 2801A Quartz Thermometer (with mod. M6)
DIGITAL VOLTMETER PROGRAM OUTPUT (HP 2401C)	Enables System to select function, range, etc., of HP 2401C Integrating Digital Voltmeter.	12533A	HP 2401C Integrating Digital Voltmeter (with mods. M21, 146)
CROSSBAR SCANNER PROGRAM OUTPUT (HP 2911)	Enables System to select channel, settling delay, for HP 2911 Guarded Crossbar Scanner.	12535A	HP 2911A Guarded Crossbar Switch and 2911B (M33) Scanner Control
DIGITAL PLOTTER INTERFACE	Provides interface for digital plotter.	12560A	Cal Comp 563 or 565
8-BIT GENERAL PURPOSE DUPLEX REGISTER	Dual 8-bit flip-flop register. Permits bidirectional transfer of information between computer and external devices. (Interface kit includes 48-pin mating connector.)	12597A	Determined by user
16-BIT GENERAL PURPOSE DUPLEX REGISTER	Dual 16-bit flip-flop register. Permits bidirectional transfer of information between System and external devices. (Accessory kit includes 48-pin mating connector.)	12554A	Determined by user
RELAY OUTPUT REGISTER	Provides 16 form A contacts for operating external devices. (Accessory kit includes 48-pin mating connector.)	12551B	Determined by user
D-A CONVERTER	Provides two D-A conversion channels, 8 bits/channel.	12555A	Determined by user
MICROCIRCUIT INTERFACE	Dual 16-bit flip-flop register. Permits bidirectional deta transfer between computer and external device at DTL/TTL voltage levels. (Interface kit includes cable and mating connector.)	12566A	Determined by user
MULTIPLEXED I/O	Permits up to 56 devices to be multiplexed into one I/O channel.	12595A	Determined by user
DATA SET INTERFACES	A. Provides interface to asynchronous data-phone communicators.	12587A	Determined by user
	B. Performs automatic dialing for data-phone communications.	12589A	Bell System 801 Automatic calling unit
	C. Provides interface for synchronous send and receive data transmission.	12618A*	Determined by user
	D. Provides interface for synchronous data reception only.	12621A	Determined by user
	E. Provides interface for synchronous data transmission only.	12622A	Determined by user

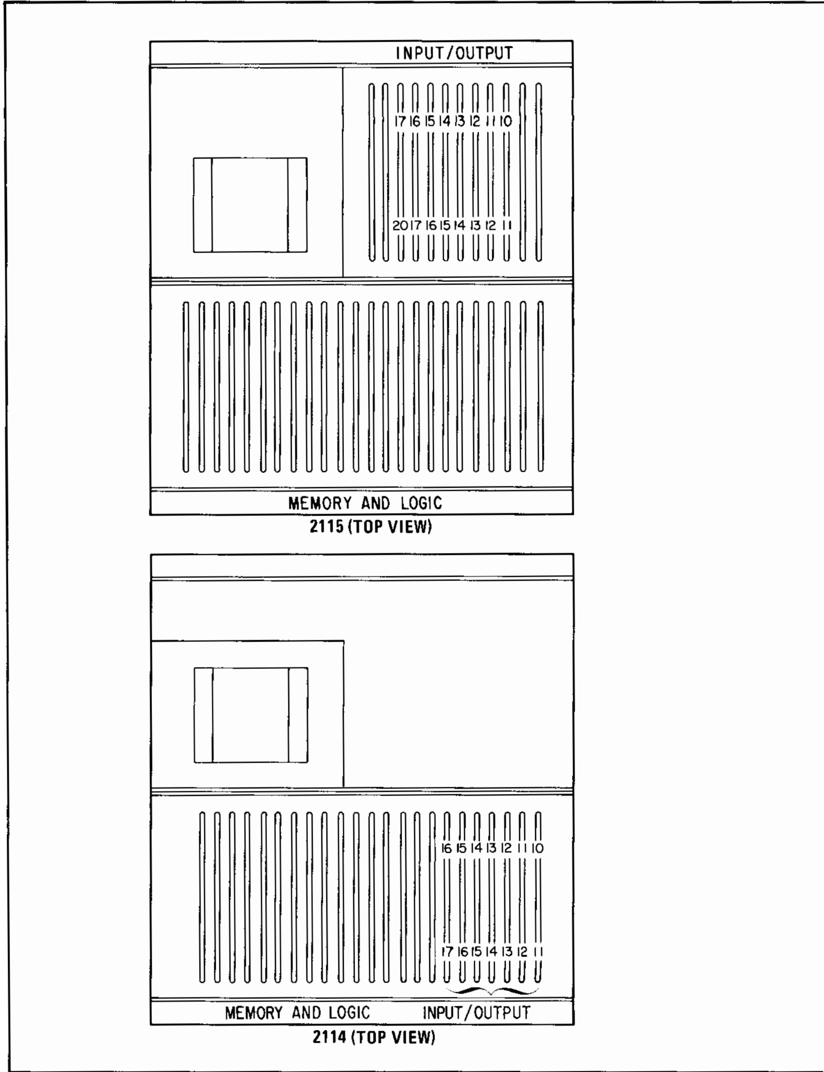
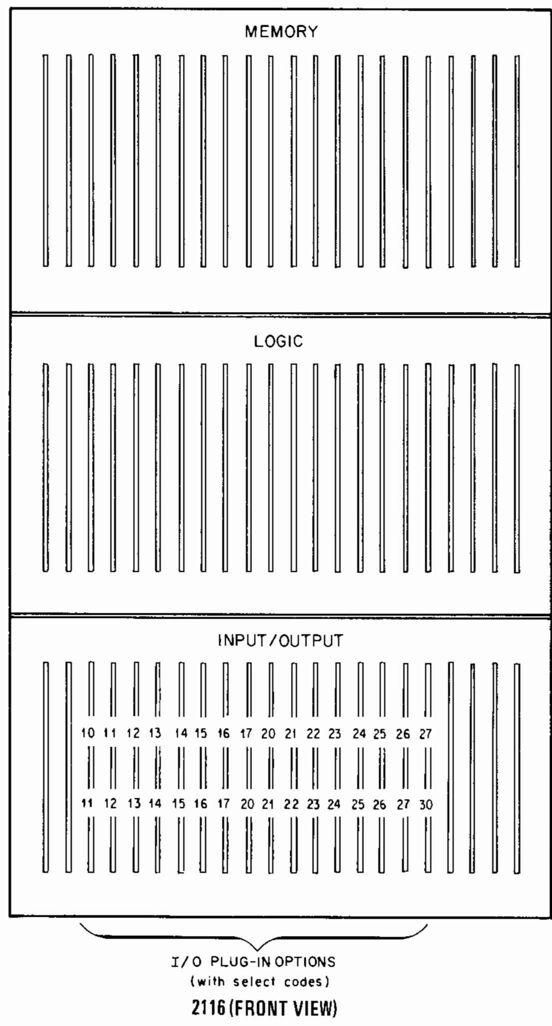


Figure 2.14.



Input/Output Option Locations

DATA SOURCE INTERFACES. A data source interface card, with special cables, is available to permit HP computers to operate with virtually all Hewlett-Packard instruments providing a digital data output in binary or binary-coded decimal, positive or negative-true form. This encompasses a very broad variety of instruments, principal examples being digital voltmeters, electronic counters, nuclear scalers, and quartz thermometers. The same interface card, which accepts 32 bits (8 BCD digits), is used with all these instruments (one card for each instrument) but different interconnecting cables are involved. For simplicity in assembling a system, the interface card, interface kit 12604B, coupled with the appropriate cable is listed with different option numbers for the various data sources it interfaces. Since these instruments require no modification to interface their data output with the HP computer, they can be ordered directly from the Hewlett-Packard catalog.

DIGITAL VOLTMETER PROGRAMMERS. In measurement systems, when using digital voltmeters as data inputs to the HP computer, the computer may select voltmeter functions such as mode (dc/ac volts, ohms), range, and resolution (sample period). Interface Kit 12533A comprises the interface card for this purpose, together with the interconnecting cable for the HP 2401C Integrating Digital Voltmeter. Interface Kit 12534A furnishes the same card, but a different cable, for the HP 3460A Digital Voltmeter. Interface Kit 12567A permits function programming of the 2402A Integrating Digital Voltmeter when it is used in conjunction with the 2911 Guarded Crossbar Scanner. No additional interface circuitry is required when these voltmeters are used with their accessory signal amplifiers and signal converters. The Digital Voltmeter Programmer interface card provides 20 output lines, each capable of switching 200 ma from an external 35-volt negative supply.

CROSSBAR SCANNER PROGRAMMER. For multiple-channel analog measurements with the HP computer, a scanner is necessary to inter-connect the signal input channels with one or more analog-to-digital converters, as required. Any one signal path is enabled at a time on command from the computer, which selects the input channel to be measured and diverts it to the appropriate A-D converter. It also initiates a "measurement delay" before sampling (encoding) commences, if such is necessary for converter settling. The interface card and cable for programming an HP 2911 Guarded Crossbar Scanner are provided under Interface Kit 12535A.

TIME BASE GENERATOR. The Time Base Generator, Interface Kit 12539A, provides the computer with a train of program interrupts at real time intervals. It consists of a crystal oscillator and decade frequency dividers, contained on one I/O card. The inter-

val between interrupts is computer-selectable in decade steps from 100 microseconds to 1000 seconds (approximately 16 minutes). Time-of-day, if required, is obtained from this real time reference by software. Accuracy is better than 1/2 second per 24-hour day, under typical operating conditions, (aging rate $< 2/10^6$ per week; temperature effect $< 2/10^5$, +15° to 35°C).

GENERAL PURPOSE INTERFACE KITS. Several off-the-shelf interface kits are available to permit interfacing the computer to the user's unique device. These interface cards cover a wide range of applicability and include Input/Output characteristics suitable for microcircuits, transistors, or relays. The lower section of Table 2.6 includes several general-purpose interface kits available from Hewlett-Packard as of this printing. Economies in design and manufacture can frequently be effected by using these standard interfaces. Software subroutines are not furnished with general purpose interface cards, unless otherwise specified.

DATA-SET INTERFACES. Information can be transferred in or out of the computer over the telephone system either synchronously or asynchronously using the appropriate Data Set Interface Kit. Each kit consists of one or two data-set interface cards and interconnecting cable to operate with a Bell System or equivalent data modem. For fully automatic dialing capability, the data set interface is used in conjunction with Automatic Calling Unit Interface 12589A.

Any of the above Input/Output Options can be added or deleted, and service priorities changed, on a plug-in basis. No wiring changes to the computer are involved. Input/output software also is modular, and a software configurator is furnished which allows the user to change his software operating system to handle different hardware configurations with minimal programming effort.

2.12 SOFTWARE

2.12.1 GENERAL

Hewlett-Packard computers are supported by a full range of software, normally furnished in the form of punched paper tape. As standard accessories, the following software packages are supplied with all HP computers, unless additions or deletions are otherwise specified. A majority are operable with the minimum computer system configuration; i.e., 4K memory (BASIC and ALGOL require 8K memory) and Teleprinter input/output. The following software is normally furnished as a part of every computer system:

Basic Control System modules

Symbolic Editor

Assembler

FORTRAN Compiler

Program Library

System Input/Output Drivers

Hardware Diagnostics

ALGOL Compiler (8K only)

BASIC Interpreter (8K only)

Each of the software packages listed above consists in most cases of a number of individual tapes. The number of tapes furnished depends on the Options purchased with a system; Driver tapes are normally furnished as accessories to interface Options when purchased, either with the initial order or with field installation.

A description of standard software for HP computers is published in the HP Program Catalog, available from Hewlett-Packard Sales Offices.

In addition to these standard tapes, two configured tapes, incorporating actual system device assignments, are furnished with the initial shipment, one for the System Input/Output Drivers and one for the Basic Control System. The System Input/Output (SIO) Drivers primarily provide input/output capability for the Assembler, Symbolic Editor, and FORTRAN compiler, but may also be used as desired in user's programs. The Basic Control System, on the other hand, is primarily intended to provide a complete software input/output system for user's programs. These two tapes are unique to each system, and do not have HP Accessory Numbers and are not listed in the Software Catalog. Subsequent reconfiguring of System Input/Output and the Basic Control System, if desired, is easily accomplished by the user, with the aid of supplied software (System Input/Output Dump, and Prepare Control System).

TAPE IDENTIFICATION. Each software tape is separately identifiable by description and HP Accessory Number, usually labeled on both the tape container and the tape itself. The letter at the end of the number identifies a particular version of the tape (e.g., B supersedes A). A detailed list of the software packed with the system is given in the Software Installation Record, supplied with the system documentation at the time of computer delivery. When ordering new or duplicate tapes (or documentation), the latest applicable version will automatically be furnished. Software is ordered through Hewlett-Packard Field Sales Offices.

2.12.2 HARDWARE DIAGNOSTICS

To assist the user in hardware troubleshooting, a Manual of Diagnostics is furnished with all HP computers. The programs in the

Manual of Diagnostics are used in addition to the maintenance information given in the HP Installation and Maintenance Manual (Volume Two) provided with the computer. Each package consists of the diagnostic tapes, and use instructions. The maintenance documentation gives procedures to determine that the hardware system is capable of accepting and using the Hardware Diagnostic programs. Then the supplied software may be loaded and run according to set procedures. Programs supplied are:

a. Instruction Tests. These tests check out all instruction codes in groups, halting the computer when an instruction fails to perform its function. The first test program checks out a few basic instructions (Alter-Skip), so that those instructions can be used by the next test program (Memory Reference), which in turn enables checking out the final group (Shift-Rotate).

b. Memory Address Tests. These tests verify the accessibility of all memory addresses for which the computer is configured (e.g., 4K, 8K, etc.). A Low-Core Test and a High-Core Test are supplied as separate test programs, so that the program may be loaded at the end of memory to check all core locations below the test block, or it may be loaded at the bottom of memory to check all higher locations. Each Test checks the addressing logic of a selectable section of memory, and halts when an error is detected. The display on the computer front panel is used to identify the error.

c. Memory Checkerboard Tests. These tests provide a "worst-case" data storage test which is unique to the memory module design of the applicable HP computer. These tests also consist of a Low-Core Test and a High-Core Test, verify that data is correctly stored in memory and is correctly transferred to and from the T-Register. Like the Memory Address Tests, the computer halts when an error is detected, and identifies the error on the front-panel display.

d. Input/Output Tests. A separate test program is supplied for most input/output devices in a user's hardware system. For example, the HP 2752A Teleprinter Test Program checks operation of the print, punch, and read functions with the computer. After it is determined that the print function is operating correctly, the program prints requests for data to be typed in so that the punch and read functions can be checked. Errors are indicated by a printout. (Test programs for other devices require that a message printing facility, such as provided by the HP 2752A Teleprinter, be present in the hardware system.)

COMPUTER OPERATION

This chapter describes how an HP computer manipulates information internally to execute the basic instructions defined in the preceding chapter. Condensed descriptions of computer structure and implementation of instructions is provided to describe the mode of operation of all three Hewlett-Packard computers.

The fundamental operations described in this chapter are in practice nearly always accomplished with the aid of software and input/output devices. However, for simplicity it will be assumed that the computer is an independent instrument and will be operated only by front panel controls. Additionally, it will be assumed for descriptive purposes that the computer runs slowly enough to observe the operations step by step. When running, the computer reads and executes each instruction usually in one or two phases. Thus only the beginning and ending conditions are normally readable on the front panel display. (Note: It is possible to single-step the computer through each instruction, one phase at a time, by using the SINGLE CYCLE switch on the front panel.)

3.1 HP COMPUTER STRUCTURE

Figure 3.1, the Simplified Block Diagram of an HP computer, is the basis for the partial versions used to illustrate descriptions in this chapter. This figure will be reconstructed step by step as the explanations progress. The first step is Figure 3.2, which outlines the blocks and signal routes mentioned in the following discussion of memory. The block diagrams make use of several "and" gate symbols in addition to circuit blocks. These gates can produce an output only when all inputs are present ("true"). For example (referring to Figure 3.1), data on the T Bus can enter the T-Register only if a Store signal is also present at the gate leading to the T-Register input. Since the Store signal is selective (although this is not indicated on the diagram), only this one gate is enabled, while the remaining four are disabled. Thus the data enters only the selected register.

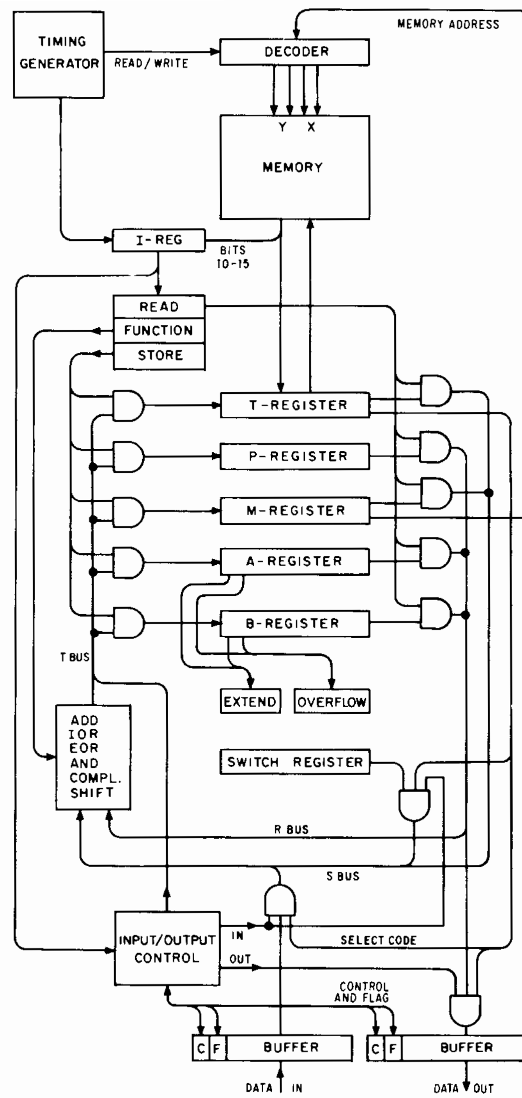


Figure 3.1. Simplified Block Diagram for Computers

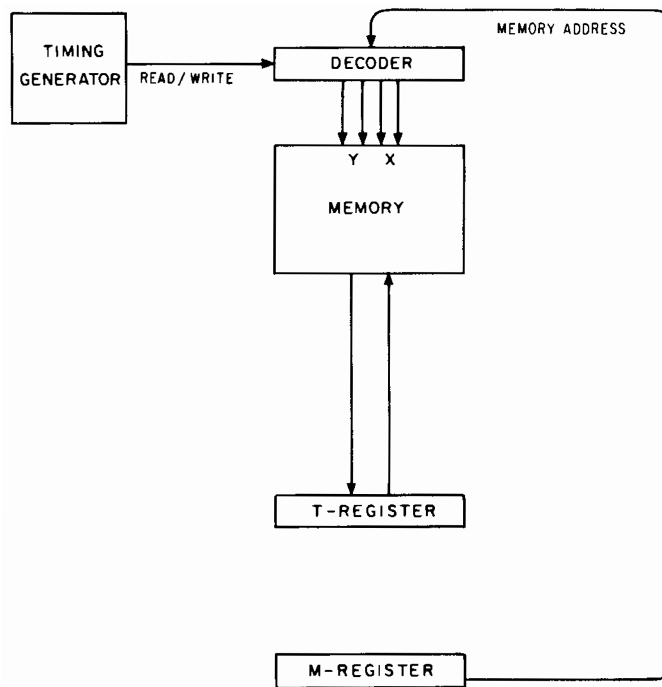


Figure 3.2. Memory Block Diagram

3.1.1 THE MEMORY MODULE

The primary storage of the computer is a "core memory", and is internal in the computer. (When more than two modules are installed in the 2116 only, the additional modules are housed in an external extender unit; however, memory access is the same as if all modules were inside the main frame.) Auxiliary storage is available in the form of disc storage and magnetic tape; however, these units are accessed through the computer's input/output system and are not treated as an extension of memory in this discussion. Figure 3.3 shows the physical structure of the memory module, and the following paragraphs describe each of the four components identified in the figure, beginning with the smallest individual component, the ferrite core.

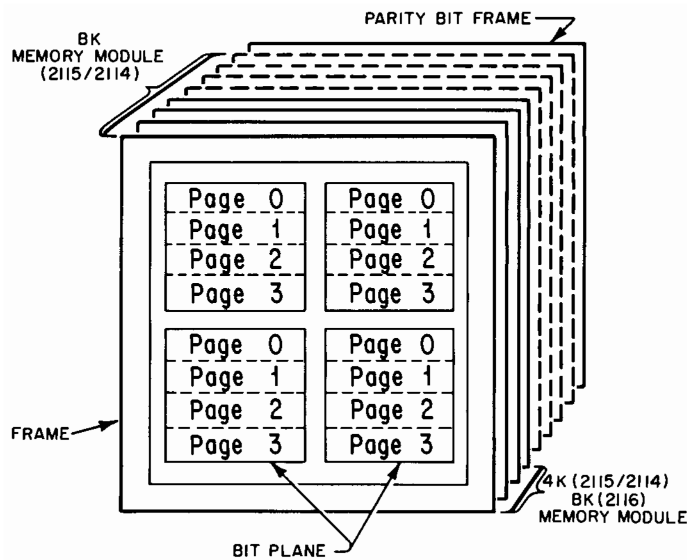


Figure 3.3. Core Memory Module

CORE. The computer handles all information in binary form; i.e., as a number representable by only two digits, zero and one. The ferrite core, which is a small ring of magnetic material, has the ability to store this binary information in that clockwise and counter-clockwise magnetization can be assigned digital values of one and zero. By threading a current-carrying wire through the core, the core's direction of magnetization can be reversed simply by changing direction of the current. Since the mass of the core is very small (diameter of .03 inch), little magnetizing force is required to switch the binary state, thus permitting fast switching speeds (about 400 nanoseconds). The magnetic state remains indefinitely after the current is removed, so that switching can be accomplished by bidirectional current pulses. This is shown in Figure 3.4.

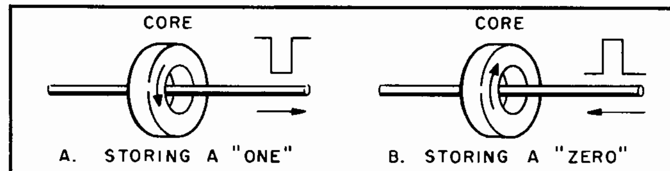


Figure 3.4. Binary Storage in a Magnetic Core

Since it is necessary to be able to select desired units of information in the module, four wires are required to be threaded through each core, as in Figure 3.5. In practice, the wires do not "loop" through the core, as shown for clarity in the figure, but simply pass through the center of a series of cores. Figure 3.5 shows how one bit of information is addressed and transferred to and from the T-Register. Action is as follows:

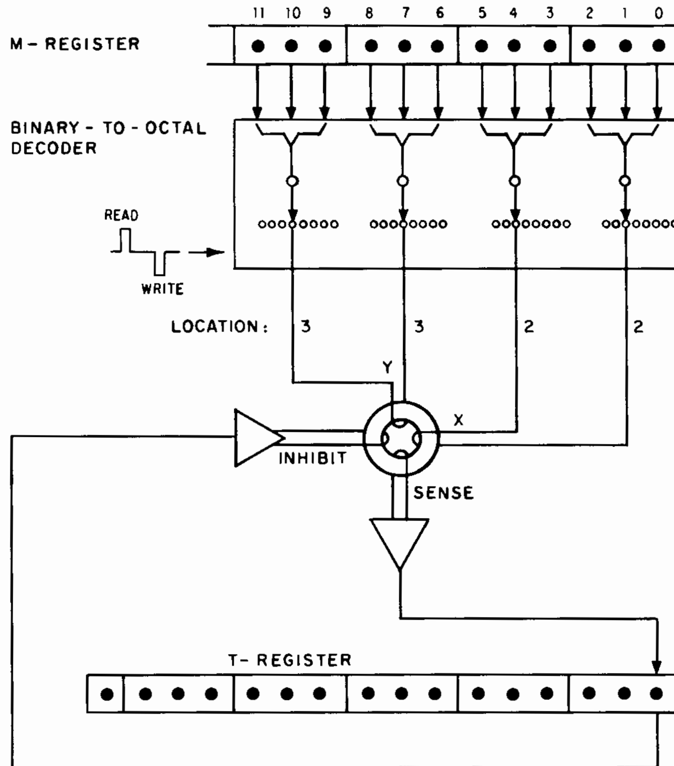


Figure 3.5. Core Addressing, Reading, and Writing

a. Assume that the computer is running, and that the program has set the M-Register to a memory location number (address), desiring access to that location.

b. The address from the M-Register, consisting of 12 binary bits, is applied to a binary-to-octal decoder, which reduces the 12 binary address lines to four octal lines which thread, in pairs, through the selected core. For purposes of illustration, the diode decoding matrix is shown as four switches. Note that each of these switches can select one of eight ends of X and Y wires, thus making possible 8x8x8x8 = 4096 combinations to address 4096 core locations.

c. At a specific time in the computer's timing sequence (start of each memory cycle), all 16 bits of the T-Register are reset to zero.

d. A Read pulse is then applied to the decoder. Many cores will receive either Y-current or X-current pulses, neither of which alone is sufficient to switch the state of the core, but only one core out of 4096 on a plane (explained below) receives both Y-current and X-current pulses. The Read current is always in the direction which would magnetize the core in the "zero" direction. (If more than one module is present, module selection is accomplished simply by routing the Read pulse to the appropriate module, as determined by Bits 12, 13, 14 of the M-Register.)

e. If the core was previously magnetized in the "one" direction, the Read current, in switching the core, causes a flux change which induces a current into the Sense output line. This output is amplified and used to set the corresponding bit flip-flop of the T-Register (assumed as Bit 0 in Figure 3.5). If the core was in the "zero" state, there is no flux change and the T-Register bit remains zero (as reset in step "c").

f. Since steps "d" and "e" destroyed the stored information, it is necessary to "write" the information back. This information, which is now in the T-Register, is connected back to the core via the Inhibit line. Then the X and Y lines are pulsed with a Write current pulse, which is of opposite polarity to the Read pulse (i.e., tending to magnetize in the "one" direction).

g. If the inhibit current is not turned on, the core switches back to the "one" state. If the Inhibit current is turned on, it cancels part of the Write magnetizing force, so that the core cannot switch, and the core remains in the "zero" state.

The sequence of events in the preceding paragraph briefly describes the "memory cycle". There are two exceptions which modify the memory cycle slightly: 1) during the Execute phase of the "store" instructions (STA, STB, JSB), the output of the Sense Amplifier is inhibited and, instead, the data to be stored is transferred into the

T-Register from the A or B Register during the Read time period; 2) during the Execute phase of the ISZ instruction (Increment, Skip if Zero), the T-Register is incremented between the Read and Write time periods.

MEMORY LOCATION. The word length of the HP computer is 16 bits, only one of which is shown in Figure 3.5. To store one 16-bit word, 16 cores are required, as indicated in Figure 3.3. These 16 cores comprise a "memory location", sometimes also referred to as a "memory cell". When information is transferred into or out of a memory location, the information in all 16 bits must be transferred simultaneously. Therefore the X and Y selection lines will be strung through the 16 cores, causing reading and writing of all 16 cores simultaneously. Figure 3.6 illustrates this, showing only three cores for simplicity. Note that each of these cores is on a different "plane" (next defined).

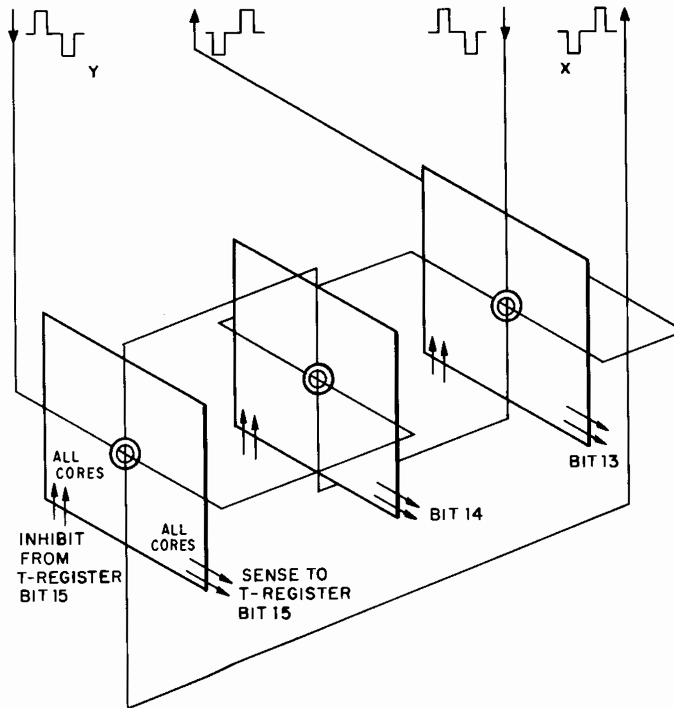


Figure 3.6. Memory Cell Selection

BIT PLANE. Cores are strung on a grid of wires, called a bit plane, and there are four of these bit planes on a frame for 2115/2114 Computers. One of the bit planes is shown in Figure 3.7. The memory module for a 2116 has frames containing 8 bit planes, four on each side. Thus, the memory modules for the 2115/2114 with 4K memory and the 2116 with 8K memory have the same number of frames. Both have five frames, with the fifth frame containing a single bit plane for the parity bit in 4K modules, and two bit planes for parity in 8K modules. To expand the memory capability of a 2115 or 2114 Computer from 4K to 8K requires installation of an 8K module in place of the 4K module. The 8K module contains nine frames; the first eight containing 4 bit planes each and the ninth frame containing two parity bit planes. The 2116 memory is expanded in 8K increments only and the maximum capability of 16K in the mainframe is provided by the addition of another 8K module. Each bit position of the T-Register is wired by the Sense and Inhibit lines through all cores on the corresponding bit plane. Since only one core on an individual plane is sensed (addressed) at a given instant of time, the Sense line needs only to detect a flux change anywhere on the bit plane. Similarly, the Inhibit signal is applied to the entire bit plane when writing, but actually affects only the selected core.

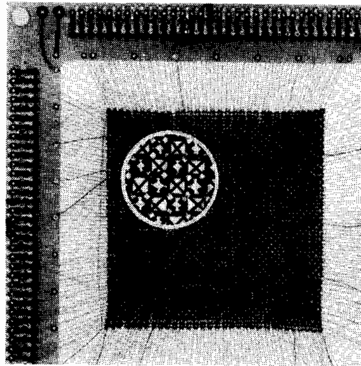


Figure 3.7. A Bit Plane and Frame (Upper Left Corner)

PAGE. Pages of memory are not physical divisions of the module. Wiring of the bit planes is symmetrical and does not account for page boundaries. The page boundaries are determined only by the bit format of Memory Reference instructions, and are shown as broken lines in Figure 3.3 for visualizing the physical placement of memory pages.

3.1.2 THE REGISTERS

Figure 3.8 shows the seven working registers of an HP computer. The five principal registers (T, P, M, A, B) are purposely shown as being independent of each other since, in fact, information is not transferred directly from register to register. Rather, information is transmitted via the Bus System (described later under Paragraph 3.1.3) under command of the Instruction Logic (Paragraph 3.1.4). The following paragraphs explain why the registers are needed, not how they are operated. In essence, these registers are short-term information storage devices consisting of flip-flop circuits, with front-panel indicator lamps to indicate the status of each bit (on the 2114, only the T- and M-Registers are displayed).

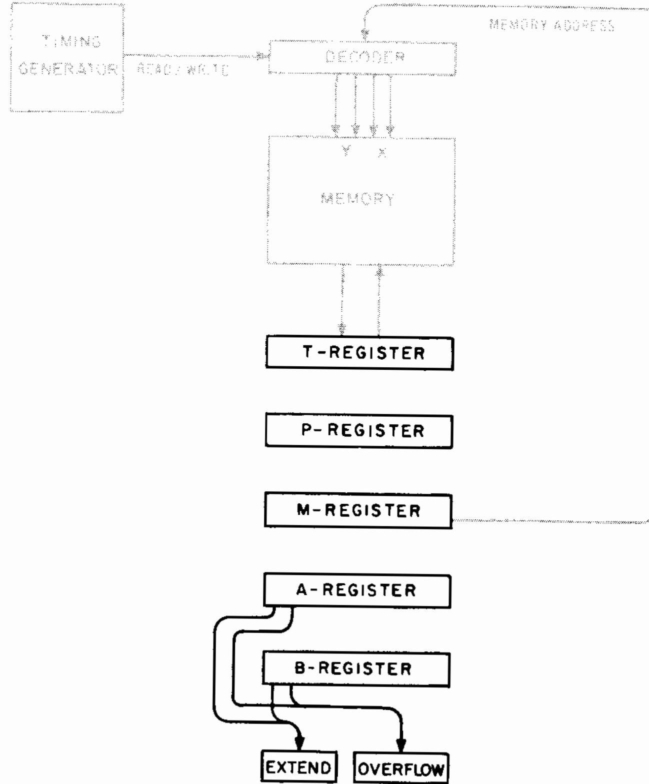


Figure 3.8. Register Block Diagram

T-REGISTER. As can be assumed from the front-panel engraving (MEMORY DATA), the T-Register holds data that is read out of and written into memory. For the majority of operations when a computer is running, the principal concern is with the data read out of a memory cell; once a word of information is in the T-Register, it is accessible for arithmetic operations and for transfers to other registers via the Bus System. For the reverse (Write) operation, the T-Register is loaded by transfers from other registers, and the information is stored in memory during the latter half of the memory cycle.

P-REGISTER. The P-Register is the computer's Program Counter. This means that this register goes through a step-by-step counting sequence and causes the computer to read successive memory locations, corresponding to the existing count. In the simplest case, The P-Register would start at zero when the RUN pushbutton is pressed, causing memory location 00000 to be read into the T-Register; the computer would act on the instruction code in the read-out data, then advance the P-Register to one (memory location 00001). This process of stepping through memory locations (at a rate of one or two machine phases per step for most instructions) continues until one of the instructions read out is a halt, which terminates the program. Of necessity, this simple case is not typical. First, programs do not normally begin at locations lower than 00077 , since these locations are reserved for special purposes. Therefore the starting address of a program must be manually set into the P-Register before pressing RUN. Second, the strict sequential stepping can be altered in the course of a program, either by a skip instruction (which causes the P-Register to increment by two instead of one, thus skipping one memory location) or by a jump instruction (which transfers numbers from another register into the P-Register, thus causing the program to continue at a different point in memory).

M-REGISTER. The M-Register (MEMORY ADDRESS) is the only means of addressing specific memory locations. The setting of the M-Register can occur from any of the other registers, depending on the effects of instructions. In the preceding paragraph, it could be assumed that the P-Register directly addresses memory; in actual fact, however, the computer must transfer the desired address from the P-Register to the M-Register, which in turn addresses the desired memory location. Thus it is seen that these two registers will frequently contain the same number. The reason why both registers are needed is that it is necessary for one register (the P-Register) to keep track of the location of the current instruction in case the instruction is a multiple phase type. In this case, the M-Register may have to be changed several times in the course of executing an instruction. A common example would be

when the instruction is to "add the contents of location 100_8 to the A-Register" (ADA 100). The P and M Registers would be identical while reading this instruction out of memory (say the instruction is in location 500_8; both registers indicate this value). Then the M-Register would have to change to 100 to get the contents of this location for the addition. After the addition has been executed, the contents of the P-Register are incremented by one (501_8). The P and M Registers are then both set to this new value, and the computer is ready to read the next instruction.

A-REGISTER. The A-Register is one of the computer's two accumulators. An accumulator in a computer accumulates the results of arithmetic operations. A simple example was given in the preceding paragraph, where one number from memory was added to the existing contents of the A-Register. Assuming that the A-Register previously held the number 1000_8, and the number in location 100 was 22_8, the number left in the A-Register after execution of the instruction would be 1022_8. Other types of operations which may be done with the A-Register are: boolean logic operations ("and", "exclusive or", "inclusive or"), comparison for equality with a memory word, shifting or rotating of bits left or right, testing the status of individual bits, complementing of bits, and accepting or holding data for transfer to and from external devices. All of these operations are accomplished by the Instruction Logic (Paragraph 3.1.4).

B-REGISTER. The B-Register is the second of the two accumulators. It has the same capabilities as the A-Register, except that the three boolean logic instructions (AND, XOR, IOR) can apply only to the A-Register. The main reason for having two accumulators is to provide faster, more flexible arithmetic than can be accomplished with one accumulator. This advantage will be seen later in programming of the computer.

EXTEND. The Extend register is shown connected to Bit 15 (left end bit) of both A and B Registers in Figure 3.8. This is to indicate that this one-bit register becomes set whenever there is a carry out of Bit 15 of either accumulator; i.e., whenever the quantity accumulated exceeds 16 ones. This fact is frequently of significance. For example, if the quantity in an accumulator is 16 ones and an ADD instruction adds one, the result in the accumulator will be 16 zeros. This answer is obviously incorrect; it is correct if the Extend bit, which is now in the set state ("1") is temporarily assumed to be "Bit 16". The program can be written to make this assumption, and it can proceed without error on the basis of the resulting information. To be certain that the Extend information is valid, the Extend register is normally cleared by an instruction (CLE) before the addition is done. Another valuable

feature of the Extend register, is its ability to link the two accumulators (effectively providing a single 32-bit accumulator).

OVERFLOW. The Overflow register is similar in purpose to the Extend register. The difference is that, whereas the Extend register indicates that the largest 16-bit quantity has been exceeded, the Overflow register indicates that the largest "signed" quantity has been exceeded. (A program may work with both signed and unsigned numbers.) Since Bit 15 is the sign bit, Bit 14 (as shown in Figure 3.8) is the source of the significant carry. Having two possible signs (+ and -) means that detection of overflow requires two different sets of conditions. For addition of two positive numbers, overflow occurs if there is a carry from Bit 14 to Bit 15 in one of the accumulators. For addition of two negative numbers (which are represented in two's complement form), overflow occurs if there is <u>not</u> a carry from Bit 14 to Bit 15. Obviously overflow cannot occur when adding numbers of opposing signs, since the resulting quantity cannot be greater than the larger of the two numbers. As with the Extend register, the Overflow register should be cleared before an addition.

3.1.3 THE BUS SYSTEM

Figure 3.9 outlines the routes by which data travels internally from one register to another. Although the buses are represented by a single line in this figure, assume each line to be composed of 16 individual lines, one for each register bit. Included in the figure is an "Arithmetic Logic" block, which has not previously been discussed. It is shown here mainly to illustrate the linkage between buses.

The HP computer uses an "R-S-T" bus configuration. This is a conventional notation designating a three-bus system which applies two input buses (R and S) to an arithmetic unit with output on the third bus (T). The use of two input buses permits arithmetic operations combining the contents of two registers. A common example would be the execution of the "ADA 100" instruction previously used. In that example, the contents of location 100 is the number 22 . During execution of the instruction, this number (22) would be read into the T-Register. The other number (1000_8) is in the A-Register. Simultaneously (by a method described under the next paragraph heading, Instruction Logic) both the T-Register and the A-Register are read onto their respective buses (S and R). The two numbers are added in the Arithmetic Logic circuits, and the result (1022_8) is stored via the T Bus back into the A-Register as the accumulated sum.

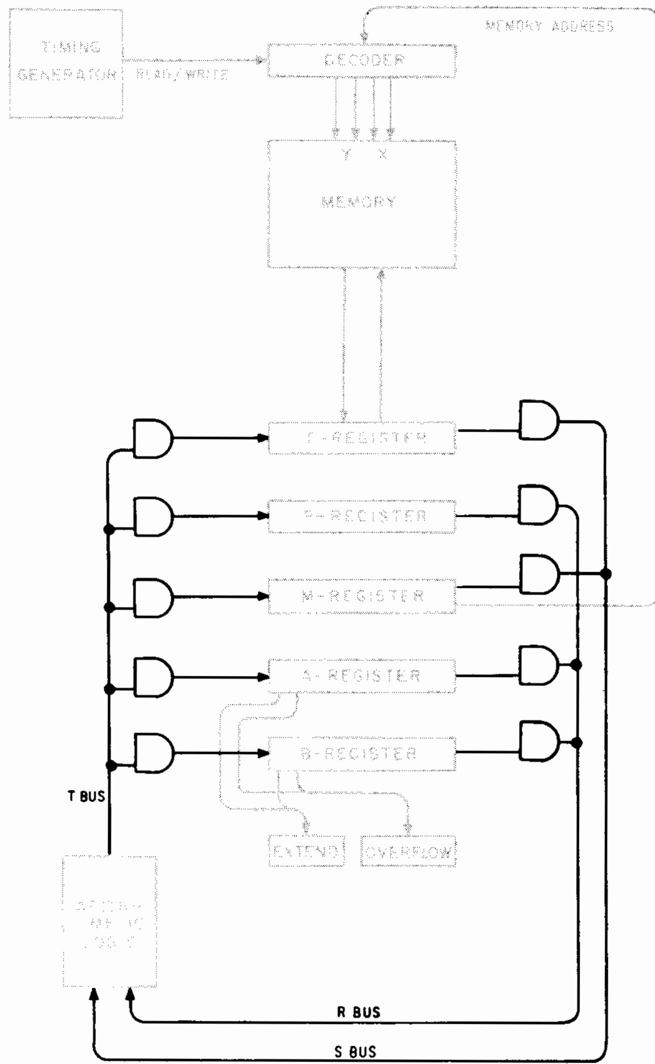


Figure 3.9. Bus System Block Diagram

Note that several register combinations are possible as inputs to the Arithmetic Logic. One point worth noting is that since the A and B Registers are addressable as memory locations, the contents of these registers can be transferred via the R and T Buses into the T-Register. From this point, the contents can be combined in the manner described above with either accumulator (including combining the number with itself; e.g., "add A to A"). This is all accomplished in one instruction.

3.1.4 THE INSTRUCTION LOGIC

Figure 3.10 shows the elements of the Instruction Logic in the computer. As indicated in the figure, timing is essential to the operation of the Instruction Logic. The following descriptions do not detail all timing relationships, since these vary with instructions, but it should be understood that timing pulses are gated with each operation to make it occur in proper sequence.

As shown in Figure 3.10, the six most significant bits read out of memory during each memory cycle are applied to the 6-bit Instruction Register (I-Reg), which decodes the instruction. (Actually, the Instruction Register receives its information via the T-Register; for simplicity Figure 3.10 shows a direct connection to memory.) Only during the Fetch phase, however, are these bits recognized as an instruction code (as determined by a "Fetch Phase" signal from the Timing Generator). At this time, the decoded instruction enables three functional operations, which in turn will become active at specific times, depending on the instruction. These operations are described individually in the next three paragraphs.

READ. The Read signal, shown connected to the output gate of all five working registers, strobes the data of one or two registers onto their corresponding buses (R and S). This places the data at the inputs of the arithmetic logic circuits

FUNCTION. The Function signal activates one of the six listed arithmetic functions. The selected function alters or combines the data on the R and/or S Buses, and routes the resulting data out on the T Bus.

STORE. The Store signal, shown connected to the input gate of all five working registers, effectively opens the input of one or more of these registers to accept the data which appears on the T Bus (preceding paragraph). In many cases, depending on the instruction, only part of the information on the T Bus is stored into a register.

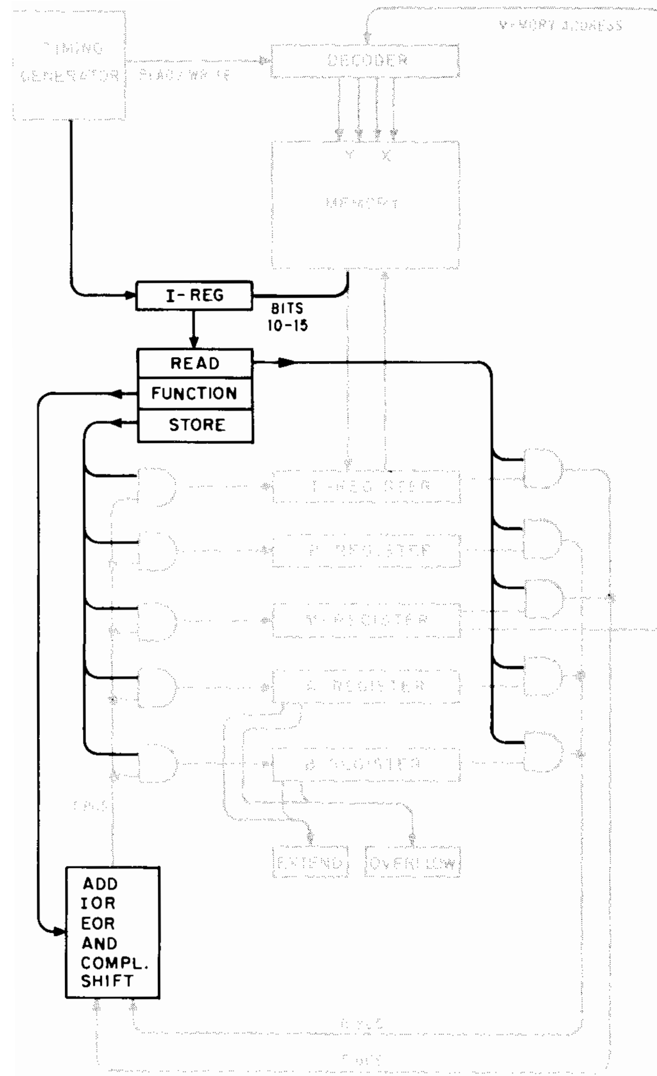


Figure 3.10. Instruction Logic Block Diagram

3.1.5 THE INPUT/OUTPUT SYSTEM

Figure 3.11 shows the means by which data is transferred in and out of the computer. This is the Input/Output System; all elements shown are contained within the mainframe. Interface arrangements are shown for only two external devices, one input and one output. The Switch Register is shown as part of the Input/Output System, and is considered to be an input device.

As indicated by Figure 3.11, the Input/Output Control logic is used to process all input/output operations. Input/Output Control operates in two ways:

a. Processes input/output instructions.

b. Processes service requests by peripheral devices.

These two types of operations are separately discussed in the following paragraphs.

PROCESSING INSTRUCTIONS. Input/Output instructions decoded by the Instruction Register are routed to Input/Output Control, which translates the instruction into appropriate driving signals. One such signal is an "In" signal, which strobes all interface positions for input (represented by two "and" gates in Figure 3.11, one accepting data from a Buffer register and one accepting data from the Switch Register). Only one of these interface positions can be enabled, according to the Select Code (Bits 0 through 5 from the T-Register), and the corresponding data is strobed by the "In" pulse onto the S Bus. From there it is transferred via the T Bus into the A or B Register (as enabled by a Store signal at the A or B input gate).

Another driving signal is the "Out" signal. This signal strobes all interface positions for output (one shown in Figure 3.11). The Select Code from the T-Register enables one interface position, and permits the "Out" signal to strobe the data on the R Bus into the corresponding output Buffer. (The data on the R Bus was read out of the A or B Registers by a Read signal.)

In addition to transferring data, as in the preceding two paragraphs, Input/Output Control can (according to instruction) send out signals to test the state of Control and Flag bits (C and F), or to set or reset these bits. The Select Code determines which interface will receive the signal from Input/Output Control. The Control and Flag bits are command signals for transferring data between the Buffer and the peripheral device (peripheral not shown).

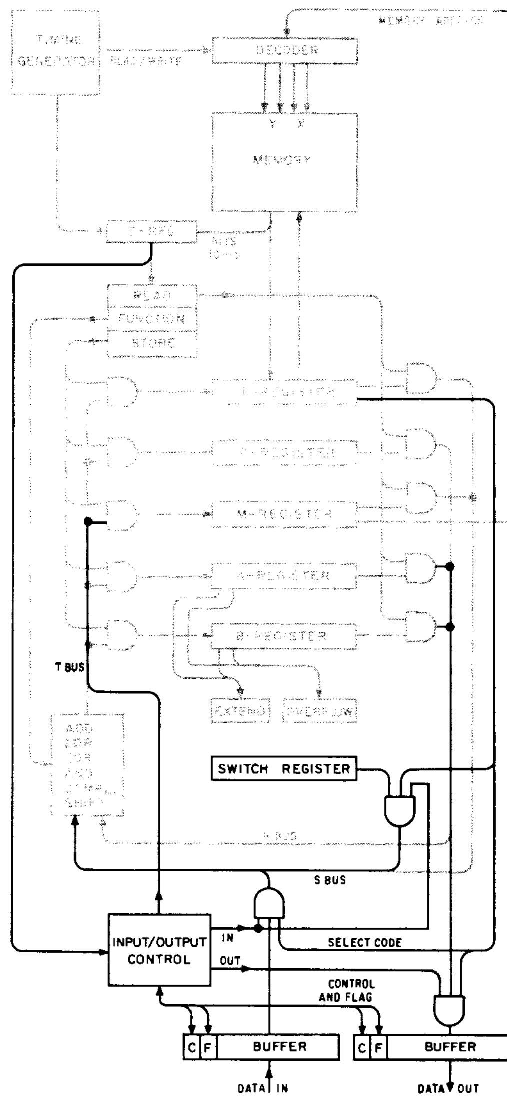


Figure 3.11. Input/Output System Block Diagram

PROCESSING SERVICE REQUESTS. If a specific instruction has at some previous time enabled the interrupt system (considered to be in the Input/Output Control block in Figure 3.11), a peripheral device may request new data from the computer (if output) or request to feed new data to the computer (if input). This request for service is done by setting the interface Flag bit. The Flag signal, via Input/Output Control, interrupts the computer's operation by forcing the M-Register to be set (via the T Bus) to a memory address uniquely specified by the Flag. At the same time, the Fetch phase is set so that the computer must execute the instruction contained in the specified memory cell. Generally this instruction will be a jump to a service subroutine. This subroutine consists of instructions that will prepare or accept the new data. On completion of service, it is the subroutine's responsibility to return the P and M Registers to the values they contained before being interrupted.

3.2 IMPLEMENTATION OF INSTRUCTIONS

The following paragraphs describe how the 70 basic instructions are implemented internally in the computer. Figures 3.12 through 3.14 expand on the Machine Timing diagram (Figure 2.2) given in Chapter 2. Figure 3.1, the Simplified Block Diagram, is also used as a reference throughout the following descriptions. Most signals named can be identified in this figure; e.g., "Read A onto R Bus" is the line from the Read block to the A-Register output gate (which outputs onto the R Bus). The block diagram should be referred to frequently as the discussion progresses, in order to visualize the bit manipulations. The right-pointing arrows in the figures should be read as "into" or "onto" (e.g., "into" T-Register, or "onto" R Bus). New mnemonics are introduced in these descriptions which will be defined within the text.

The cycle of Time Periods shown at the top of Figures 3.12 through 3.14 (T0 through T7) repeats continuously every 1.6 or 2.0 microseconds, as applicable, while computer power is on. The Read/Write memory cycle, although shown only once at the top of each of these figures, actually occurs once in every phase (except Interrupt). It is important to remember this throughout the following descriptions.

3.2.1 MEMORY REFERENCE

By comparing Figures 3.12 through 3.14, it is seen that Memory Reference instructions are the only type of instructions requiring more than one machine phase to execute; Indirect and Execute phases are associated only with Memory Reference instructions.

In the case of all these instructions except JMP, the action during the Fetch and Indirect phases (Phases 1 and 2) is similar, so these phases are shown only once, implying that they are common to all Memory Reference instructions. The exception, JMP, is unique in that it does not use an Execute phase; execution can occur in either the Fetch or the Indirect phase. The action for JMP is shown separately in Figure 3.12 and is discussed first below.

Note

> The descriptions for JMP and AND instructions are more detailed than for succeeding instructions, which are similar in many respects. These two should therefore be studied in detail before advancing to the others.

JMP. The Fetch phase for all instructions, regardless of type, begins in exactly the same way, since at this time the computer logic cannot know anything about the instruction which is about to be read out of memory. The only fact known is that the word from memory will be read as an instruction (not data); getting an instruction from memory is the first function of the Fetch phase. During the first three Time Periods of the Fetch phase, the following actions occur:

a. During T0 the T-Register is cleared.

b. The Read portion of the Memory Cycle begins to read the contents of the currently addressed memory cell into the T-Register. This continues until the middle of T2.

c. During T1 the Instruction Register is cleared.

d. Bits 10 through 15 (the instruction group and code identification) of the T-Register are transferred into the 6-bit Instruction Register.

During the latter portion of T2, the functions to be used in implementing the JMP instruction are set up. This includes Read and Store as well as any arithmetic functions (none in the case of JMP). Functions are gated with Time Periods to occur in the correct sequence.

PHASE		T0	T1	T2	T3	T4	T5	T6	T7
		TIME PERIODS							
		2116B: .2μ Sec / 2115A/2114A: .25	.4 / .5	.6 / .75	.8 / 1.0	1.0 / 1.25	1.2 / 1.5	1.4 / 1.75	1.6 / 2.0
		READ (Mem to TR)			WRITE (TR to Mem)				
FETCH (JMP)	1	Clear TR	Clear IR	TR(10-15) → IR (Set Functions)			If Z: 0 → P	If Z: 0 → M (10-15) If D: TR → P, M (0-9) and set PH1 If I: TR → M (0-9) and set PH2	
INDIRECT (JMP)	2	Clear TR						If D: TR → P, M and set PH1 If I: TR → M and set PH2	
FETCH	1	Clear TR	Clear IR	TR (10-15) → IR (Set Functions)				TR → M (0-9) If Z: 0 → M (10-15) If I: Set PH2 If D: Set PH3	
INDIRECT	2	Clear TR						TR → M If I: Set PH2 If D: Set PH3	
EXECUTE AND	3	Clear TR			Read A → R Bus Read TR → S Bus Store T Bus (ANF) → A			Read P → R Bus Read "1" → S Bus Store T Bus (ADF) → P, M Set PH1	

XOR		Clear TR		A (EOF) TR → A		P+ 1 → P, M Set PH1
IOR		Clear TR		A (IOF) TR → A		P + 1 → P, M Set PH1
JSB		Clear TR Inhibit Mem. Data	P +1 → TR	M → P		P +1 → P, M Set PH1
ISZ		Clear TR		TR+1 → TR If C16: Set Carry Inhibit Write	Write*	P+1+ Carry → P, M Set PH1
ADA/B		Clear TR		If A: A (ADF) TR → A If B: B (ADF) TR → B If C16: Set E		P + 1 → P, M Set PH1
CPA/B		Clear TR		If A: A (EOF) TR → T Bus If B: B (EOF) TR → T Bus If T Bus not zero, set Carry		P + 1 + Carry → P, M Set PH1
LDA/B		Clear TR		If A: TR → A If B: TR → B		P +1 → P, M Set PH1
STA/B		Clear TR Inhibit Mem. Data	If A: A → TR If B: B → TR			P+1 → P, M Set PH1

* 2116: Add 0.4μS
2114/2115: Add 0.5μS

Figure 3.12. Implementing Memory Reference Instructions

		TIME PERIODS							
		T0	T1	T2	T3	T4	T5	T6	T7
		2116: .2μ Sec	.4	.6	.8	1.0	1.2	1.4	1.6
		2115/2114: .25	.5	.75	1.0	1.25	1.5	1.75	2.0
		READ (Mem to TR)			WRITE (TR to Mem)				
FETCH	**1**	Clear TR	Clear IR	TR (10-15) → IR		— Execute —		P +1 +Carry → P, M Set PH1	

	T3	T4	T5
SHIFT-ROTATE INSTRUCTIONS	All Shifts and Rotates Read A or B → R Bus Shift R Bus → T Bus Store T Bus → A or B	Clear E and Skips If TR5 = 1 → CLE If TR3 = 1 (SLA/B): Read A or B → R Bus If RB0=0 → Set Carry	All Shifts and Rotates Read A or B → R Bus Shift R Bus → T Bus Store T Bus → A or B
ALTER-SKIP INSTRUCTIONS	CLA/B: No Read (R Bus all zeros) Store T Bus (EOF) → A/B	*SSA/B: Read A/B → R Bus Set Carry if RB15 = 0 and TR0 = 0, or RB15 = 1 and TR0 = 1	SZA/B: Read A/B → R Bus (ADF) → T Bus Set Carry if T Bus all zeros and TR0 = 0, or if T Bus all ones and TR0 = 1
	CMA/B: Read A/B → R Bus Store T Bus (CMF) → A/B	*SLA/B: Read A/B → R Bus Set Carry if RB0 = 0 and TR0 = 0, or RB0 = 1 and TR0 = 1	

	CCA/B: No Read (R Bus all zeros) Store T Bus (CMF) → A/B	INA/B: Read A/B → R Bus Read "1" → S Bus Store T Bus (ADF) → A/B If C16: Set E		
	SEZ: Set Carry if E = 0 and TR0 = 0, or E = 1 and TR0 = 1			
	CLE: Reset E Flip-flop			
	CME: Complement E Flip-flop			
	CCE: Set E Flip-flop		* Combination of SSA/B, SLA/B, and RSS is a special case; see text.	

Figure 3.13. Implementing Register Reference Instructions

PHASE		TIME PERIODS							
		T0	T1	T2	T3	T4	T5	T6	T7
		2116: .2μ Sec	.4	.6	.8	1.0	1.2	1.4	1.6
		2115/2114: .25	.5	.75	1.0	1.25	1.5	1.75	2.0
		READ (Mem to TR)			WRITE (TR to Mem)				
FETCH HLT	1	Clear TR	Clear IR	TR(10-15) → IR				P+1 → P, M Reset Run FF	
STF		Clear TR	Clear IR	TR → IR	Set Flag: Select Code			P+1 → P, M Set PH1	
CLF		Clear TR	Clear IR	TR → IR	Set Flag: Select Code	Clear Flag: Select Code		P+1 → P, M Set PH1	
SFC		Clear TR	Clear IR	TR → IR	SFC → Interface	SKF → Carry		P+1+Carry → P, M Set PH1	
SFS		Clear TR	Clear IR	IR → IR	SFS → Interface	SKF → Carry		P+1+Carry → P, M Set PH1	
MIA/B		Clear TR	Clear IR	TR → IR		Read A/B → R Bus Buffer → S Bus Store T Bus (IOF) → A/B; TR9: CLF		P+1 → P, M Set PH1	

LIA/B		Clear TR	Clear IR	TR → IR		Buffer → S Bus Store T Bus (IOF) → A/B TR9: CLF		P+1 → P, M Set PH1	
OTA/B		Clear TR	Clear IR	TR → IR		Read A/B → R Bus R Bus → Buffer TR9: CLF		P+1 → P, M Set PH1	
STC		Clear TR	Clear IR	TR → IR		Set Control (Sel. Code)		P+1 → P, M Set PH1	
CLC		Clear TR	Clear IR	TR → IR		Clr. Control (Sel. Code)		P+1 → P, M Set PH1	
STO		Clear TR	Clear IR	TR → IR	STF → Overflow			P+1 → P, M Set PH1	
CLO		Clear TR	Clear IR	TR → IR		CLF → Overflow		P+1 → P, M Set PH1	
SOC		Clear TR	Clear IR	TR → IR	SFC → OVF	SKF Carry		P+1+Carry → P, M Set PH1	
SOS		Clear TR	Clear IR	TR → IR	SFS → OVF	SKF → Carry		P+1+Carry → P, M Set PH1	
INTERRUPT	4		Read P → R Bus Store T Bus (CMF) → P		Read P → R Bus Read "1" → S Bus Store T Bus (ADF) → P		Read P → R Bus Store T Bus (CMF) → P.		Reset M (6-15) Store T Bus (0-5) → M Set PH1

Figure 3.14. Implementing Input/Output Instructions

At this point in time (end of T2), the instruction information is in Bits 10 through 15 of the T-Register, and in the Instruction Register. The Memory Address information is in Bits 0 through 9 of the T-Register. The next event to occur is to clear the P-Register at time T5 if the page Zero condition exists (i. e., if Bit 10 of the Instruction Register is a zero). This is done by a "Store T Bus into P" function. Since nothing has been read onto any of the buses, the T Bus is in the all-zero state, and 16 zeros are therefore stored into the P-Register. (Actually, for resetting the program to page Zero, it is only necessary to clear Bits 10 through 14 of the P-Register; however it is convenient to clear the entire P-Register at this time.) Note that the 6 most significant bits of the page Zero address are zeros; e. g., the last address on page Zero is:

0 000 001 111 111 111

During Time Periods T6 and T7, the page Zero indicator (if present) clears Bits 10 through 15 of the M-Register (not the entire register). The method is the same as described above: "Store T Bus into M-Register, Bits 10 through 15"; the T Bus is still all zeros. Thus, at this time both P and M Registers point to page Zero, if so coded by Bit 10 being a zero (otherwise these registers are not changed, leaving Bits 10 through 15 at the Current page indication).

Also during T6 and T7, the Direct/Indirect bit (Bit 15) of the T-Register is looked at, to see if the Memory Address currently in the T-Register is the "effective address" (the final address being jumped to), or if another jump should be made from that address to whatever address is contained in that location (indirect addressing). Since the concept of indirect addressing is important and not always simple to grasp initially, it is treated separately in following paragraphs. For direct addressing, the execution is completed by the following steps:

a. The T-Register contents are read onto the S Bus, and appear on the T Bus.

b. Bits 0 through 9 of the T Bus are stored into the P and M Registers. This directs the Computer to the "jump" location. (Remember from the preceding paragraphs that Bits 10 through 15 of the P and M Registers either have been reset to zero for page Zero or have been left alone for Current page.)

c. The Phase 1 (Fetch) condition remains set so that the contents of the "jump" location will be read out and interpreted as an instruction during the next machine phase.

Basically, the Indirect addressing indicator (Bit 15 of T-Register being a one) tells the computer logic that the contents of the location

being jumped to is not the next instruction, but rather the address for another jump. This additional jump is a continuation of the same instruction, but requires an additional phase. During T6 and T7 of Phase 1, the T-Register contents are transferred to the M-Register (not both P and M as for the Direct condition). During T7 the Phase 2 condition (PH2) is set, and the Indirect phase begins.

During T0, the T-Register is cleared. Since the "jump" is still in progress, the Instruction Register is not cleared during T1. The contents of the location now addressed by the M-Register are read into the T-Register during the Read memory cycle. Then, during T6 and T7 (assuming Bit 15 of the T-Register is now 0 for Direct), all 16 bits of the T-Register are transferred into the P and M Registers in the usual way: read T-Register onto S Bus, and store T Bus (with no arithmetic) into P and M Registers. These registers now contain the effective address, so Phase 1 is set, and the next machine phase will be a Fetch phase, to read out the next instruction from that address. Note that if Bit 15 of the T-Register were again a one (for Indirect) a jump would be made to still another location by repeating the process.

In summary, as illustrated in Figure 3.15, an indirect jump occurs by the following register actions:

a. The word containing the jump instruction is read out of memory by a Fetch phase into the T-Register.

b. The address portion of the read-out word is transferred into the corresponding portion of the M-Register.

c. The Zero/Current page bit of the read-out word tells the computer logic to clear (Zero) or leave (Current) the remaining bits (10 through 15) of the M-Register.

d. Steps "b" and "c" now comprise the address of a location which is read out of memory into the T-Register at the start of the Indirect phase.

e. All bits of this new read-out word are transferred into the P and M Registers. The computer is now "at" the location specified by these Registers.

AND. The Fetch phase for the AND instruction is the same as for all other Memory Reference instructions listed below it in Figure 3.12, with the exception that different functions will be set up at T2. This phase begins in the same way as for JMP: the T-Register is cleared at time T0, the Read memory cycle reads the instruction word into the T-Register, the Instruction Register is cleared

during T1, and T-Register Bits 10 through 15 (instruction code) are transferred into the Instruction Register at T2. At this time all necessary functions for this instruction are set up, to be used at the appropriate times. During T6 and T7, T-Register Bits 0 through 9 (memory address portion of the instruction word) are transferred into the corresponding bits of the M-Register (via S and T Buses). If the Zero page indicator is present (Bit 10 of the Instruction Register is a zero), a "Reset M(10-15)" command clears Bits 10 through 15 of the M-Register.

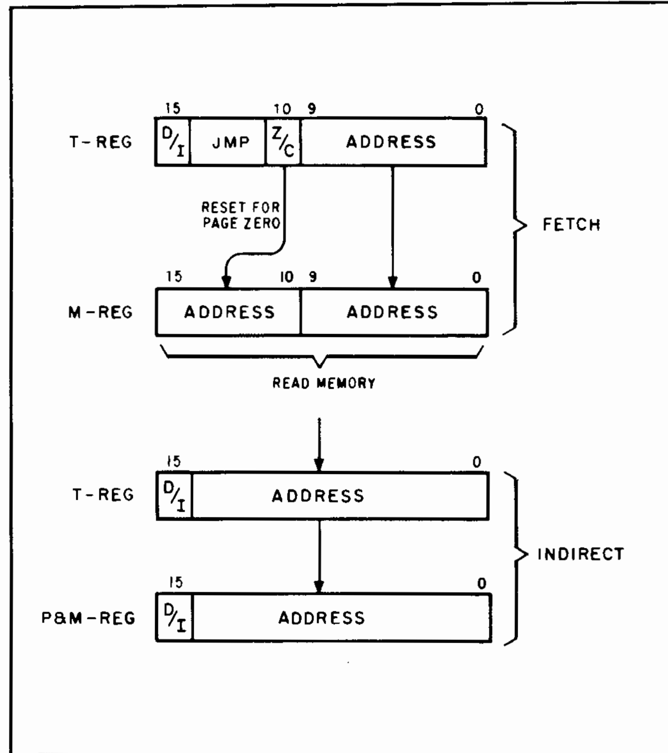


Figure 3.15. Register Manipulations for Indirect Jump

Unlike the JMP instruction, an Execute or an Indirect phase must follow the Fetch phase of an AND instruction. (Execute never occurs for JMP; Indirect is optional.) If Bit 15 of the T-Register is zero (for Direct), Phase 3 (Execute) is set. Assume an Indirect phase is required (Bit 15 = 1). (If the Direct condition exists, the action of the next paragraph would be skipped.)

The Indirect phase begins by clearing the T-Register during T0. Then a new word is read into the T-Register from the memory location specified by the M-Register. This word is an address, not data, since indirect addressing really means: "go to another location for the data". During T6 and T7 of the Indirect phase, this address is transferred from the T-Register to the M-Register (all 16 bits). Note that it is possible for Bit 15 to again specify Indirect addressing; if so, Phase 2 remains set and the procedure of this paragraph is repeated, and could be repeated several times. When Bit 15 is a zero (Direct), Phase 3 is set.

The Execute phase begins by clearing the T-Register. The Instruction Register remains unchanged, since the various functions are still needed. This time, the Read portion of the memory cycle reads data from memory into the T-Register. During T3 and T4, this data is read onto the S Bus and the A-Register contents are read onto the R Bus. The "and" function (ANF) previously set up by the Instruction Register, now combines the data on the two buses by "anding". The result on the T Bus is then stored into the A-Register.

To advance the computer to the next instruction, the P and M Registers must be incremented by one. This is done during T6 and T7 of the Execute phase. It is accomplished by reading the P-Register onto the R Bus and a "one" onto the S Bus, then adding the two buses (Add Function: ADF) and storing the result into the P and M Registers.

In summary, as illustrated in Figure 3.16, an AND Indirect instruction is executed by the following register actions:

a. The word containing the AND instruction is read out of memory by a Fetch phase into the T-Register.

b. The address portion of the read-out word is transferred into the corresponding portion of the M-Register.

c. The Zero/Current page bit of the read-out word tells the computer logic to clear (Zero) or leave (Current) the remaining bits of the M-Register.

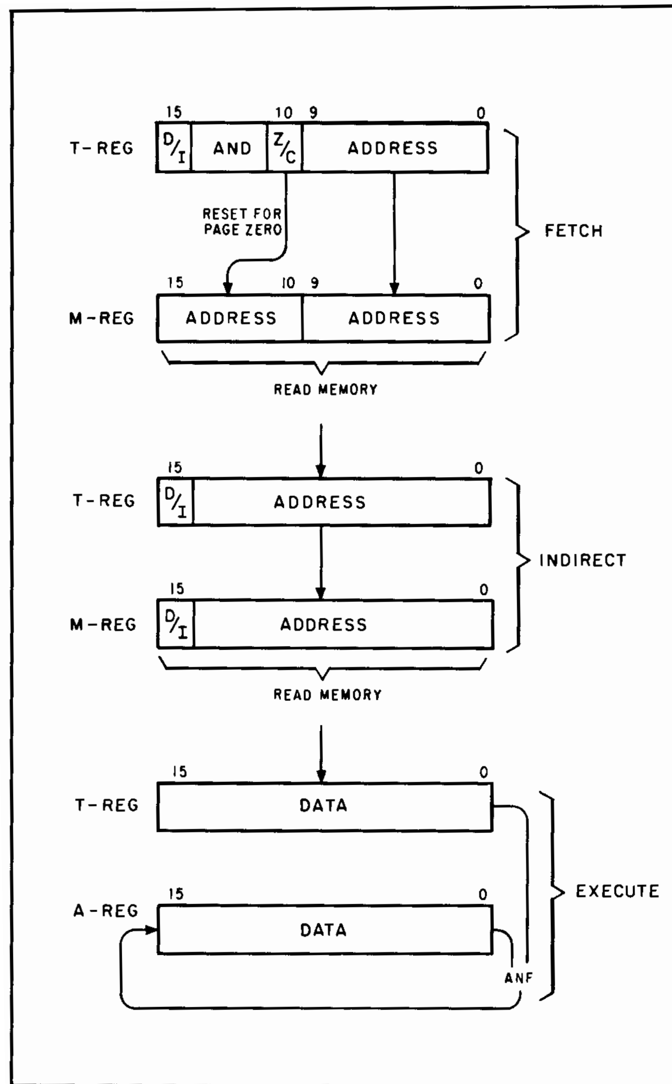


Figure 3.16. Register Manipulations for Indirect AND

d. Steps "b" and "c" now comprise the address of a location which is read out of memory into the T-Register at the start of the Indirect phase.

e. All bits of this new read-out word are transferred into the M-Register, thus addressing the location of the desired data.

f. At the start of the Execute phase the data thus addressed is read into the T-Register from memory.

g. The contents of the T-Register and A-Register are "anded" together and deposited back into the A-Register.

Note

> For the remainder of Memory Reference instructions, the Fetch and Indirect phases are the same as described above for the AND instruction. The following paragraphs therefore describe only the Execute phase for each instruction.

XOR. The Execute phase of the XOR ("Exclusive Or") instruction begins as usual by clearing the T-Register just before the Read portion of the Memory cycle. The action occurring during T3 and T4 is shown in abbreviated form in Figure 3.12, to be read as follows: the contents of the A-Register is combined by an "exclusive or" function with the contents of the T-Register, and stored back into the A-Register. Actually this action consists of three steps as shown for the AND instruction. For XOR, these three steps are: 1) Read T-Register onto S Bus; 2) Read A onto R Bus; 3) Store T Bus (which carries the "exclusive or" combination of the S and R Buses) into the A-Register. The action during T6 and T7 is also abbreviated: add "one" to P, and store into P and M. The three steps which accomplish this are detailed for the AND instruction in Figure 3.12. The last action is to reset the computer to the Phase 1 (Fetch) condition.

IOR. The Execute phase of the IOR ("Inclusive Or") instruction is the same as XOR described in the preceding paragraph, except that the "inclusive or" function is used in place of "exclusive or". The difference in arithmetic is shown in Table 2.2 of the previous chapter.

JSB. The principal operation of the Execute phase for JSB (Jump to Subroutine) is to store the return address (Program Counter contents plus one) in the memory location being jumped to. This is done during T0 through T2. Since the only way into memory is through the T-Register, the T-Register must be loaded with the

return address prior to the Write portion of the memory cycle. Therefore the memory contents read out during the Read portion of the memory cycle must be inhibited and, instead, (during T1 and T2) the current contents of the P-Register, plus one, is stored into the T-Register. (Action: Read P onto R Bus, Read "1" onto S Bus, Store with add function into T-Register.) This information is then stored into memory during Write. To complete the jump process, the contents of the M-Register (which received the "jump" memory address during the Fetch or Indirect phase) must be transferred into the P-Register. This is done during T3: Read M onto S Bus, Store T Bus in P. As usual, to advance the computer to the location of the next instruction both P and M Registers are incremented by one during T6 and T7, and the Fetch phase condition is set.

ISZ. During the Execute phase of the ISZ instruction (Increment, Skip if Zero), the contents of the addressed memory cell must be altered and checked between the Read and Write portions of the memory cycle. These actions require more time than is normally available in this interval, so the Write portion is delayed. Once the word read from memory is in the T-Register (T3 and T4), it is incremented by reading onto the S Bus, adding "one" in the arithmetic logic and storing back into the T-Register. If previously the word read out was all ones, the addition of another one causes a rollover to all zeros, and produces a signal (C16) which sets a Carry flip-flop in the arithmetic logic. Then, at T5, the Write portion of the memory cycle is permitted to begin, and two Time Periods (0.4 μs for 2116; 0.5 μs for 2114 and 2115) are inserted at this time for writing the incremented value back into memory. During T6 and T7, the P-Register is read onto the R Bus, and a "one" is read onto the S Bus. These are added together, and if the Carry flip-flop is set, another "one" is added and the result is stored in the P and M Registers. Thus, if the Carry flip-flop was set, the P and M Registers are incremented by two instead of one, skipping one memory location for the next Fetch phase. (The Carry flip-flop is automatically reset at the start of the next phase.)

ADA/B. If Bit 11 of the Instruction Register indicated A (zero), the contents of the A-Register are combined with the T-Register contents by the add function (ADF), and stored into the A-Register. Similar action involving the B-Register occurs during this time (T3 through T4) if Bit 11 of the Instruction Register is a one.

CPA/B. Depending on the status of Bit 11 of the Instruction Register, either the A-Register or the B-Register is combined with the T-Register contents by the "exclusive or" function. The result appears on the T Bus, but is not stored anywhere. Logic not shown in Figure 3.1 tests the T Bus for a non-zero condition which, if it exists, sets the Carry flip-flop. Then during T6 and T7 (as for ISZ),

the P and M Registers are incremented by either one (Carry not set) or two (Carry set).

LDA/B. During T3 and T4, the information read into the T-Register by the Read portion of the memory cycle is simply transferred to either the A or B Register via the S and T Buses.

STA/B. Like JSB, the STA/B instruction (Store A or B) deposits new information into a memory cell, with no concern for the existing memory contents. The memory data read out during the Read portion of the memory cycle is therefore inhibited while the A or B Register contents are read and stored into the T-Register (during T1 and T2). The Write portion of the memory cycle deposits this information into memory.

3.2.2 REGISTER REFERENCE INSTRUCTIONS

All Register Reference instructions, as shown by Figure 3.13, are fully executed in only one phase (Fetch). Actual execution is accomplished during Time Periods T3 through T5. Actions during the other Time Periods are similar to those previously described for Memory Reference instructions:

a. During Time Periods T0 through T2, the T-Register and Instruction Register are cleared, and Bits 10 through 15 of the instruction word read out of memory are transferred to the Instruction Register. Unlike Memory Reference, the Instruction Register does not set up functions, but rather it provides gating signals to identify the type (Register Reference) and group (Shift-Rotate, or Alter-Skip) of instructions. The remaining bits of the T-Register are used to execute the individual instructions by setting up the appropriate functions. Figures 2.6 and 2.7 define which bits encode each instruction.

b. During Time Periods T6 and T7, the P-Register is read onto the R Bus and a "one" is read onto the S Bus. If the Carry flip-flop has been set by a "skip" condition during T3 through T5, another "one" is added and the total (P-Register incremented by one or two) is stored into the P and M Registers. This advances the computer to the next instruction.

3.2.3 SHIFT-ROTATE INSTRUCTIONS

Figure 3.13 shows that shifts and rotates can be executed either during T3 or T5, or both. CLE (Clear Extend) or SLA/B (Skip if Least significant bit of A or B Registers is zero) can be executed only during T4. The shifts and rotates are executed simply by reading A or B Registers onto the R Bus, applying a "Shift Function"

to shift some or all of the bits to a different position on the T-Bus, then storing the T Bus back into the A or B Register. Since the Shift Function is the key to understanding how shifts and rotates occur, the following instruction descriptions concentrate on this aspect (CLE and SLA/B are described later). Table 3.1 is the main reference for these descriptions.

A/BLS. As shown by the Table 3.1 diagram for A/BLS (A or B Left Shift), the desired end result is to have Bits 0 through 13 shifted left one place, with Bit 15 unchanged and a zero moved into Bit 0. Assuming that Bits 6 through 9 of the T-Register dictate an A/BLS during T3, an SLM (Shift Left Magnitude) signal at this time is "anded" with each of the 14 R-Bus bits (0 through 13), with the output of each "and" gate appearing on the next higher T Bus line. The Function listed in Table 3.1 for this instruction (SLM RB(0-13)) is therefore to be read: Shift Left Magnitude "anded" with R Bus Bits 0 through 13. Bit 15 of the R Bus is routed directly out to Bit 15 of the T Bus. Since nothing has been placed onto Bit 0 of the T Bus, its state is "zero", and therefore no deliberate action is necessary to ensure storing a zero in Bit 0 of the A or B Register.

A/BRS. A Shift Right Magnitude "anded" with R Bus Bits 1 through 15 shifts these bits to Bits 0 through 14 of the T Bus. Bit 0 of the R Bus is not recognized, and Bit 15 (as well as moving onto Bit 14 of the T Bus) also is routed directly to Bit 15 of the T Bus.

RA/BL. To rotate A or B left, an SLM "anded" with R Bus Bits 0 through 13, together with a "Shift Left bit 14" to R Bus Bit 14, move Bits 0 through 14 to Bits 1 through 15 of the T Bus. Rotating Bit 15 of the R Bus around to Bit 0 of the T Bus is accomplished by "anding" RLL (Rotate Left to Least significant bit) with R Bus Bit 15; the "and" gate outputs to T Bus Bit 0.

RA/BR. A Shift Right Magnitude "anded" with R Bus Bits 1 through 15 shifts these bits to Bits 0 through 14 of the T Bus. An RRS (Rotate Right to Sign bit) "anded" with R Bus Bit 0 rotates this bit to Bit 15 of the T Bus.

A/BLR. A Shift Left Magnitude with R Bus Bits 0 through 13 shifts these bits to Bits 1 through 14 of the T Bus. Bits 0 and 14 of the T Bus remain in the "zero" state, since nothing is placed on these lines.

ERA/B. A Shift Right Magnitude with R Bus Bits 1 through 15 causes shift to T Bus Bits 0 through 14. The content of the Extend register is transferred into Bit 15 of the T Bus. Then, during the latter half of T3 (or T5), Bit 0 of the R Bus is transferred into the Extend register.

ELA/B. A Shift Left Magnitude "anded" with R Bus Bits 0 through 13, and a Shift Left 14 with R Bus Bit 14 shifts these bits to Bits 1 through 15 of the T Bus. The Extend content is transferred onto T Bus Bit 0, and then Bit 15 of the R Bus is transferred into the Extend register.

A/BLF. A Rotate Left 4 "anded" with all bits of the R Bus shifts each bit four places to the left on the T Bus. The four most significant bits are placed into the least significant bit positions.

CLE. During T4, if Bit 5 of the T-Register is a one, a reset signal is generated which clears the Extend register.

SLA/B. During T4, if Bit 3 of the T-Register is a one, the A or B Register is read onto the R Bus. (Bit 11 determines which register is read out.) If Bit 0, the least significant bit, is a zero, the Carry flip-flop is set. This will cause the P and M Registers to be incremented by two (for a skip) during T6 and T7.

3.2.4 ALTER-SKIP INSTRUCTIONS

Figure 3.13 individually lists all Alter-Skip instructions. The grouping into three Time Periods explains the grouping of columns in the Selection Table of Figure 2.7. That is, during T3 one instruction involving the accumulators can be executed (clear, complement, or clear-complement), and two possible instructions involving the Extend register can be executed (skip if zero, and clear or complement or clear-complement). Incrementing of accumulators (INA/B) effectively occurs after tests for sign and least significant bits (SSA/B and SLA/B, at T4), but before the test for zero accumulator (SZA/B, at T5).

The alter instructions (clear, complement, and increment) use a Store or direct transfer function. The skip instructions, however, simply read information onto the T Bus for testing; a Store function is not required. If skip conditions are met, the Carry flip-flop is set, causing the P and M Registers to be incremented by two during T6 and T7.

CLA/B. To clear the A or B Register, the Read function is omitted. This means that both R and S Buses are in the all-zero state. The "exclusive or" function, in combining zeros with zeros, can only produce zeros on the T Bus. Thus when the T Bus is stored into A or B, the result is all zeros.

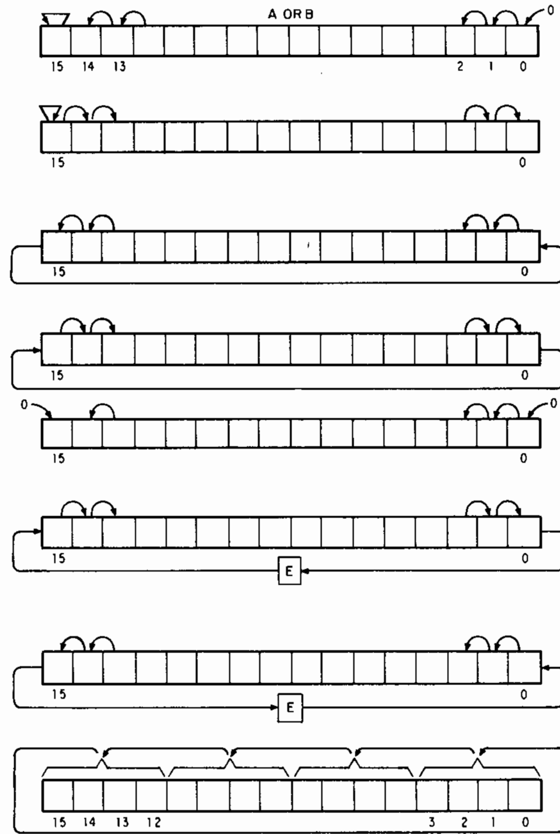
CMA/B. To complement A or B, the register is read onto the R Bus, the complement function (CMF) reverses each bit before being released to the T Bus, and the T Bus is stored back into the A or B Register.

Table 3.1.

INSTRUCTION	FUNCTIONS	
A/BLS	$\overline{SLM}$ • RB(0-13) RB15 → TB15	
A/BRS	$\overline{SRM}$ • RB(1-15) RB15 → TB15	
RA/BL	$\overline{SLM}$ • RB(0-13) SL14 • RB14 RLL • RB15	
RA/BR	$\overline{SRM}$ • RB(1-15) RRS • RB0	
A/BLR	$\overline{SLM}$ • RB(0-13)	
ERA/B	$\overline{SRM}$ • RB(1-15) E → TB15 RB0 → E	
ELA/B	$\overline{SLM}$ • RB(0-13) SL14 • RB14 E → TB0 RB15 → E	
A/BLF	$\overline{RL4}$ • RB(0-15)	

SLM Shift Left Magnitude
SRM Shift Right Magnitude
RLL Rotate Left to Least significant bit
RRS Rotate Right to Sign bit
RB R Bus
TB T Bus
SL Shift Left
RL Rotate Left

DIAGRAMS



CCA/B. The procedures of the two preceding paragraphs are combined to clear and complement an accumulator; i.e., with no Read, R and S Buses remain all-zero, and the complement function reverses this state to all ones on the T Bus. The T Bus is then stored into the A or B Register.

SEZ. If Bit 5 of the T-Register is a one, the Extend flip-flop and Bit 0 of the T-Register (Reverse Skip Sense) are looked at by the computer logic, causing the Carry flip-flop to be set if: a) both bits are zero, b) both bits are one. Although the next three instructions described below can alter the state of the Extend flip-flop, the test is completed before the alteration.

CLE. If Bits 6 and 7 of the T-Register encode the Clear E instruction, a reset signal is generated during the latter half of T3 to reset the Extend flip-flop.

CME. If Bits 6 and 7 of the T-Register encode Complement E, the state of the Extend flip-flop is reversed during the latter half of T3.

CCE. If Bits 6 and 7 of the T-Register encode Clear and Complement E, the Extend flip-flop is set during the latter half of T3.

SSA/B. If Bit 4 of the T-Register is a one, the A or B Register is read onto the R Bus. Bit 15 of the R Bus (sign bit) and Bit 0 of the T-Register (Reverse Skip Sense) are tested. The Carry flip-flop will be set if both bits are zero (meaning: "skip if sign bit is zero"), or if both bits are one (meaning: "skip if sign bit is not zero"). This is accomplished during T4.

SLA/B. If Bit 3 of the T-Register is a one, the A or B Register is read onto the R Bus. Bit 0 of the R Bus (least significant bit) and Bit 0 of the T-Register (Reverse Skip Sense) are tested. The Carry flip-flop will be set if both bits are zero (meaning: "skip if least significant bit is zero"), or if both bits are one (meaning "skip if least significant bit is not zero"). This is accomplished during T4. The combination of SLA/B, SSA/B, and RSS is a special case.

INA/B. If Bit 2 of the T-Register is a one, the A or B Register is read onto the R Bus, and a "one" is read onto the S Bus. These are combined by an add function (ADF) and stored back into the A or B Register during the latter half of T5.

SZA/B. If Bit 1 of the T-Register is a one, the A or B Register is read onto the R Bus and transmitted to the T Bus. All bits of the T Bus are applied to an "inclusive or" gate. The output of this gate and Bit 0 of the T-Register are tested. The Carry flip-flop will be set if both TR0 and the gate output are zero (meaning: "skip if ac-

cumulator is zero"), or if both TR0 and the gate output are one (meaning: "skip if accumulator is not zero").

3.2.5 INPUT/OUTPUT INSTRUCTIONS

Like the Register Reference instructions, Input/Output instructions, as shown by Figure 3.14, are fully executed in only one phase (Fetch). The Interrupt phase, shown at the bottom of Figure 3.14, is not involved in the execution of these instructions. It is separately discussed at the end of this chapter.

The following descriptions will concentrate on actions occurring during Time Periods T3, T4, and T5, since as can be seen from Figure 3.14, the actions during other Time Periods are nearly identical from instruction to instruction. That is, the T-Register is cleared during T0, the Instruction Register is cleared during T1, and the P and M Registers are incremented by one (or two, if a Carry bit is present) during T6 and T7. The method of incrementing by one and by two was described earlier. In all cases, Bits 10 through 15 of the T-Register are transferred to the Instruction Register during T2.

HLT. If Bits 8, 7, 6 of the T-Register encode the Halt instruction, these bits cause the Run flip-flop to be reset during the latter half of T7.

STF. During T3 a Set Flag signal is routed to all input/output interface cards, and will set the Flag flip-flop of the card which is currently enabled by the Select Code (Bits 0 through 5 of the T-Register).

CLF. During T4 a Clear Flag signal is routed to all input/output interface cards, and will reset the Flag flip-flop of the card which is currently enabled by the Select Code.

SFC. A Skip if Flag Clear signal (SFC) is routed to the selected interface card beginning at T3. The interface card will return a Skip Flag signal (SKF) during T4 if its Flag flip-flop is not set. This signal sets the Carry flip-flop to cause a skip during T6 and T7.

SFS. A Skip if Flag Set signal (SFS) is routed to the selected interface card beginning at T3. The interface card will return a Skip Flag signal (SKF) during T4 if its Flag flip-flop is set. This signal sets the Carry flip-flop to cause a skip during T6 and T7.

MIA/B. During T4 and T5 an IOIC signal (I/O Input Control) transfers the input data from the interface Buffer register to the S Bus.

During the same time the A or B Register is read onto the R Bus, and the R and S Bus data is combined by the "inclusive or" function (IOF) and applied to the T Bus. The result (a "merge", or "inclusive or") is stored back into the A or B Register. If Bit 9 of the T-Register is a one, a Clear Flag signal (CLF) is routed to the Flag flip-flop of the selected interface card.

LIA/B. The action for LIA/B (Load Input into A or B) is the same as described for MIA/B in the preceding paragraph, except that nothing is read onto the R Bus. The "inclusive or" function therefore transmits the R Bus unchanged to the T Bus for storing into the A or B Register. As for MIA/B, Bit 9 can clear the Flag flip-flop.

OTA/B. During T4 and T5 the A or B Register is read onto the R Bus, which in turn is transferred by an IOOC signal (I/O Output Control) to the interface Buffer register. As for MIA/B, Bit 9 can clear the Flag flip-flop.

STC. A Set Control signal is routed to all input/output interface cards, and during T4 will set the Control flip-flop of the interface card which is currently enabled by the Select Code (Bits 0 through 5 of the T-Register).

CLC. A Clear Control signal is routed to all interface cards during T4, and will reset the Control flip-flop of the interface card currently enabled by the Select Code.

STO. A Set Flag signal during T3, combined with the Select Code for the Overflow flip-flop (01_8), sets the Overflow flip-flop.

CLO. A Clear Flag signal during T4, combined with the Select Code for the Overflow flip-flop (01_8), resets the Overflow flip-flop.

SOC. During T3, a Skip if Flag Clear signal (SFC), combined with the Select Code for Overflow, tests the state of the Overflow flip-flop. If this flip-flop is in the reset state, a Skip Flag signal (SKF) sets the Carry flip-flop at T4, to cause a skip at T6 and T7.

SOS. During T3, a Skip if Flag Set signal (SFS), combined with the Select Code for Overflow, tests the state of the Overflow flip-flop. If this flip-flop is in the set state, a Skip Flag signal (SKF) sets the Carry flip-flop at T4, to cause a skip at T6 and T7.

3.2.6 INTERRUPT PHASE

The actions occurring during the Interrupt phase (Phase 4) are shown at the bottom of Figure 3.14. Two operations are accomplished during the Interrupt phase:

a. The P-Register is decremented. This is done so that any instruction which has not been fully executed at the time of interrupt will be repeated. On the other hand, if the instruction is fully executed (which means that the P-Register has been advanced for the next instruction), it is still necessary to decrement. This is because the P-Register is incremented for a second time following execution of the instruction contained in the interrupt location.

b. The "interrupt address" must be transferred into the M-Register, and Phase 1 is set. This causes the instruction contained in the interrupt location to be read out of memory for execution during the next machine phase. Note that the interrupt address is not placed into the P-Register. While the instruction in the interrupt location is being executed, the P-Register remains at the value one lower than the point at which interrupt occurred.

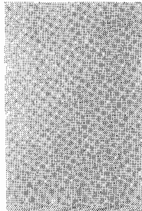
Decrementing the P-Register is accomplished by complementing, incrementing, then complementing again. In simplified form, using only four binary digits for an example, this process is:

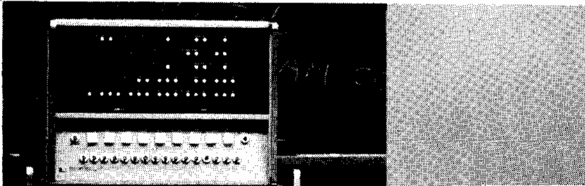
Original Value:	0110	(6_8)
Complement:	1001	
Increment:	1010	
Complement:	0101	(5_8)

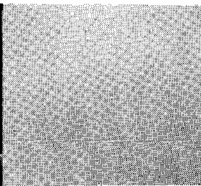
During T1 and T2 of the Interrupt phase (remember that there is no Read/Write memory cycle), the P-Register is read onto the R Bus. The complement function (CMF) reverses all bits before application to the T Bus, and then the T Bus is stored back into the P-Register. During T3 and T4 the P-Register is again read onto the R Bus. A "one" read onto the S Bus is combined with this by the add function (ADF), and the incremented result is stored back into the P-Register. During T5, the P-Register is read onto the R Bus for the third time, is complemented, applied to the T Bus, and stored back into the P-Register.

The interrupt address is placed into the M-Register during T7. Since no interrupt address is greater than 77_8, M-Register Bits 6 through 15 are first reset. The interrupt address is read directly onto the T Bus from Input/Output Control logic (see Figure 3.1), and Bits 0 through 5 are stored into the M-Register. Setting the Phase 1 condition completes the Interrupt phase.

Assembler Reference Manual







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INTRODUCTION

The Assembler and the Extended Assembler translate symbolic source language instructions into an object program for execution on the computer. The source language provides mnemonic machine operation codes, assembler directing pseudo codes, and symbolic addressing. The assembled program may be absolute or relocatable.

The source program may be assembled as a complete entity or it may be subdivided into several subprograms (or a main program and several subroutines), each of which may be assembled separately. The loader of the Basic Control System loads the program and links the subprograms as required. The Basic Binary Loader loads programs in absolute form.

Input for the Assembler is prepared on paper tape; the Assembler punches the binary program on paper tape in a format acceptable to the loader.

The minimum hardware required for the Assembler is as follows:

> 2116, 2115, or 2114 Computer with 4,096 words of memory, and teleprinter.

The minimum hardware for the Extended Assembler is as follows:

> 2116, 2115, or 2114 Computer with 8,192 words of memory, and teleprinter.

GENERAL DESCRIPTION

1.1 ASSEMBLY PROCESSING

The Assembler is a two pass system, or, if both punch and list output are requested, a three pass system on a minimum configuration. A pass is defined as a processing cycle of the source program input.

In the first pass, the Assembler creates a symbol table from the names used in the source statements. It also checks for certain possible error conditions and generates diagnostic messages if necessary.

During pass two, the Assembler again examines each statement in the source program along with the symbol table and produces the binary program and a program listing. Additional diagnostic messages may also be produced.

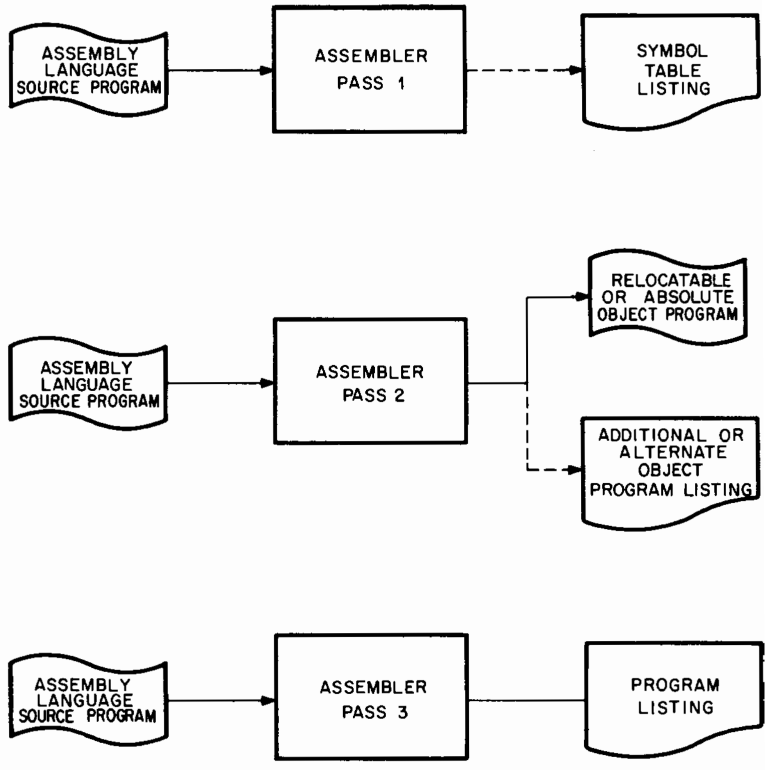
If only one output device is available and if both the binary output and the list output are requested, the listing function is deferred and performed as pass three.

When using the Assembler with a magnetic tape the source program is written on the tape during the first pass; the tape is backspaced and the second pass executed.

1.2 SYMBOLIC ADDRESSING

Symbols may be used for referring to machine instructions, data, constants, and certain other pseudo operations. A symbol represents the address for a computer word in memory. A symbol is defined when it is used as a label for a location in the program, a name of a common storage segment, the label of a data storage area or constant, the label of an absolute or relocatable value, or a location external to the program.

Through use of simple arithmetic operators, symbols may be combined with other symbols or numbers to form an expression which may identify a location other than that specifically named by a symbol. Symbols appearing in operand expressions, but not specifically defined, and symbols that are defined more than once are considered to be in error by the Assembler.



HP ASSEMBLER PROCESSING

1.3 PROGRAM RELOCATION

Programs may be relocated in core by the Basic Control System loader; the location of the program origin and all subsequent instructions is determined at the time the program is loaded.

A relocatable program is assembled assuming a starting location of zero. All other instructions and data areas are assembled relative to this zero base. When the program is loaded, the relocatable operands are adjusted to correspond with the actual locations assigned by the loader.

The starting locations of the common storage area and the base page portion of the program are always established by the loader. References to the common area are common relocatable. References to the base page portion of the program are base page relocatable. If a program refers to the common area or makes use of the base page via the ORB pseudo instruction, the program must also be relocatable.

If a program is to be relocatable, all subprograms comprising the program must be relocatable; all memory reference operands must be relocatable expressions or literals, or have an absolute value of less than 100_8.

1.4 PROGRAM LOCATION COUNTERS

The Assembler maintains a counter, called the program location counter, that it uses to assign consecutive memory addresses to source statements.

The initial value of the program location counter is established according to the use of either the NAM or ORG pseudo operation at the start of the program. The NAM operation causes the program location counter to be set to zero for a relocatable program; the ORG operation specifies the absolute starting location for an absolute program.

Through use of the ORB pseudo operation a relocatable program may specify that certain operations or data areas be allocated to the base page. If so, a separate counter, called the base page location counter, is used in assigning these locations.

1.5 ASSEMBLY OPTIONS

Parameters specified with the first statement, the control statement, define the output to be produced by the Assembler:†

Absolute – The addresses generated by the Assembler are to be interpreted as absolute locations in memory. The program is a complete entity; external symbols, common storage references, and entry points are not permitted.

Relocatable – The program may be located anywhere in memory. All operands which refer to memory locations are adjusted as the program is loaded. Operands, other than those referring to the first 64 locations, must be relocatable expressions. Subprograms may contain external symbols and entry points, and may refer to common storage.

Binary output – An absolute or relocatable program is to be punched on paper tape.

List output – A program listing is produced either during pass two or pass three.

Table print – List the symbol table at the end of the first pass.

Selective assembly - Sections of the program may be included or excluded at assembly time depending on the option used.

---

† See Chapter 5 for complete details.

A source language statement consists of a label, an operation code, an operand, and comments. The label is used when needed as a reference by other statements. The operation code may be a mnemonic machine operation or an assembly directing pseudo code. An operand may be an expression consisting of an alphanumeric symbol, a number, a special character, or any of these combined by arithmetic operations. (For the Extended Assembler, an operand may also be a literal.) Indicators may be appended to the operand to specify certain functions such as indirect addressing. The comments portion of the statement is optional.

2.1 STATEMENT CHARACTERISTICS

The fields of the source statement appear in the following order:

Label

Opcode

Operand

Comments

Field Delimiters

One or more spaces separate the fields of a statement. An end-of-statement mark terminates the entire statement. On paper tape this mark is a return, (CR), and line feed, (LF).† A single space following the end-of-statement mark from the previous source statement is the null field indicator of the label field.

Character Set

The characters that may appear in a statement are as follows:

A through Z

0 through 9

. (period)

* (asterisk)

† A circled symbol (e.g., (CR)) represents an ASCII code or Teleprinter key.

HEWLETT-PACKARD ASSEMBLER CODING FORM

SAMPLE CODING FORM
(Actual Size 11 × 13-1/2)

+ (plus)

- (minus)

, (comma)

= (equals)

( ) (parentheses)

(space)

Any other ASCII characters may appear in the Remarks field (See Appendix A).

The letters A through Z, the numbers 0 through 9, and the period may be used in an alphanumeric symbol. In the first position in the Label field, an asterisk indicates a comment; in the Operand field, it represents the value of the program location counter for the current instruction. The plus and minus are used as operators in arithmetic address expressions. The comma separates several operation codes, or an expression and an indicator in the Operand field. An equals sign indicates a literal value. The parentheses are used only in the COM pseudo instruction.

Spaces separate fields of a statement. They may also be used to establish the format of the output list. Within a field they may be used freely when following +, -, , , or (.

Statement Length

A statement may contain up to 80 characters including blanks, but excluding the end-of-statement mark. Fields beginning in characters 73 - 80 are not processed by the Assembler.

2.2 LABEL FIELD

The Label field identifies the statement and may be used as a reference point by other statements in the program.

The field starts in position one of the statement; the first position following an end-of-statement mark for the preceding statement. It is terminated by a space. A space in position one is the null field indicator for the label field; the statement is unlabeled.

Label Symbol

A label must be symbolic. It may have one to five characters consisting of A through Z, 0 through 9, and the period. The

first character must be alphabetic or a period. A label of more than five characters could be entered on the source language tape, but the Assembler flags this condition as an error and truncates the label from the right to five characters.

Examples:

Label	Operation	Operand	Comments
^†	LDA		NO LABEL
.ABCD			VALID LABEL
.1234			VALID LABEL
A.123			VALID LABEL
.			VALID LABEL
1.AB			ILLEGAL LABEL - FIRST CHARACTER
			NUMERIC.
ABC123			ILLEGAL LABEL - TRUNCATED TO
			ABC12.
A*BC			ILLEGAL LABEL - ASTERISK NOT
			ALLOWED IN LABEL.
^ABC†			NO LABEL -THE ASSEMBLER ATTEMPTS
			TO INTERPRET ABC AS AN OPERATION
			CODE.

Each label must be unique within the program; two or more statements may not have the same symbolic name. Names which appear in the Operand field of an EXT or COM pseudo instruction may not also be used as statement labels in the same subprogram.

Examples:

Label	Operation	Operand	Comments
	COM	ACOM(20),BC(30)	
LB	EQU	160	VALID LABEL
	EXT	XL1,XL2	
START	LDA	LB	VALID LABEL
N25			VALID LABEL
XL2			ILLEGAL LABEL - USED IN EXT.
BC			ILLEGAL LABEL - USED IN COM.
N25			ILLEGAL LABEL - PREVIOUSLY
			DEFINED.

† The caret symbol, ^, indicates the presence of a space.

Asterisk

An asterisk in position one indicates that the entire statement is a comment. Positions 2 through 80 are available; however, positions 1 through 68 only are printed as part of the assembly listing on the 2752A Teleprinter. An asterisk within the Label field is illegal in any position other than one.

2.3 OPCODE FIELD

The operation code defines an operation to be performed by the computer or the Assembler. The Opcode field follows the Label field and is separated from it by at least one space. If there is no label, the operation code may begin anywhere after position one. The Opcode field is terminated by a space immediately following an operation code. Operation codes are organized in the following categories:

- Machine operation codes
  - Memory Reference
  - Register Reference
  - Input/Output, Overflow, and Halt
  - Extended Arithmetic Unit
- Pseudo operation codes
  - Assembler control
  - Object program linkage
  - Address and symbol definition
  - Constant definition
  - Storage allocation
  - Arithmetic subroutine calls
  - Assembly Listing Control (Extended Assembler)

Operation codes are discussed in detail in Chapters 3 and 4.

2.4 OPERAND FIELD

The meaning and format of the Operand field depend on the type of operation code used in the source statement. The field follows the Opcode field and is separated from it by at least one space. It is terminated by a space except when the space follows , + - (or, if there are no comments, by an end-of-statement mark.

The Operand field may contain an expression consisting of one of the following:

Single symbolic term

Single numeric term

Asterisk

Combination of symbolic terms, numeric terms, and the asterisk jointed by the arithmetic operators + and -.

An expression may be followed by a comma and an indicator.

Programs being assembled by the Extended Assembler may also contain a literal value in the Operand field.

Symbolic Terms

A symbolic term may be one to five characters consisting of A through Z, 0 through 9, and the period. The first character must be alphabetic or a period.

Examples:

Label	Operation	Operand	Comments
	LDA	A1234	VALID IF DEFINED
	ADA	B.1	VALID IF DEFINED
	JMP	ENTRY	VALID IF DEFINED
	STA	1ABC	ILLEGAL OPERAND FIRST CHARACTER
			NUMERIC.
	STB	ABCDEF	ILLEGAL OPERAND MORE THAN FIVE
			CHARACTERS.

A symbol used in the Operand field must be a symbol that is defined elsewhere in the program in one of the following ways:

As a label in the Label field of a machine operation

As a label in the Label field of a BSS, ASC, DEC, OCT, DEF, ABS, EQU or REP pseudo operation

As a name in the Operand field of a COM or EXT pseudo operation

As a label in the Label field of an arithmetic subroutine pseudo operation

The value of a symbol is absolute or relocatable depending on the assembly option selected by the user. The Assembler assigns a value to a symbol as it appears in one of the above fields of a statement. If a program is to be loaded in absolute form, the values assigned by the assembler remain fixed. If the program is to be relocated, the actual value of a symbol is established on loading. A symbol may also be made absolute through use of the EQU pseudo instruction.

A symbolic term may be preceded by a plus or minus sign. If preceded by a plus or no sign, the symbol refers to its associated value. If preceded by a minus sign, the symbol refers to the two's complement of its associated value. A single negative symbolic operand may be used only with the ABS pseudo operation.

Numeric Terms

A numeric term may be decimal or octal. A decimal number is represented by one to five digits within the range 0 to 32767. An octal number is represented by one to six octal digits followed by the letter B; (0 to 177777B).

If a numeric term is preceded by a plus or no sign, the binary equivalent of the number is used in the object code. If preceded by a minus sign, the two's complement of the binary equivalent is used. A negative numeric operand may be used only with the DEX, DEC, OCT, and ABS pseudo operations.

In an absolute program, the maximum value of a numeric operand depends on the type of machine or pseudo instruction. In a relocatable program, the value of a numeric operand may not exceed 77B. Numeric operands are absolute. Their value is not altered by the assembler or the loader.

Asterisk

An asterisk in the Operand field refers to the value in the program location counter (or base page location counter) at the time the source program statement is encountered. The asterisk is considered a relocatable term in a relocatable program.

Expression Operators

The asterisk, symbols, and numbers may be joined by the arithmetic operators + and - to form arithmetic address expressions. The Assembler evaluates an expression and produces an absolute or relocatable value in the object code.

Examples:

```
LDA  SYM+6      ADD 6 TO THE VALUE OF SYM
ADA  SYM-3      SUBTRACT 3 FROM THE VALUE OF SYM
 .
 .
 .
JMP  *+5        ADD 5 TO THE CONTENTS OF THE
 .              PROGRAM LOCATION COUNTER.
 .
 .
STB  -A+C-4     ADD - VALUE OF A, THE VALUE OF C
 .              AND SUBTRACT 4.
 .
 .
STA  XTA-*      SUBTRACT VALUE OF PROGRAM
                LOCATION COUNTER FROM VALUE OF
                XTA.
```

Evaluation of Expressions

An expression consisting of a single operand has the value of that operand. An expression consisting of more than one operand is reduced to a single value. In expressions containing more than one operator, evaluation of the expression proceeds from left to right. The algebraic expression A-(B-C+5) must be represented in the Operand field as A-B+C-5. Parentheses are not permitted in operand expressions for the grouping of operands.

The range of values that may result from an operand expression depends on the type of operation. The Assembler evaluates expressions as follows:†

Pseudo Operations	modulo $2^{15}-1$
Memory Reference	modulo $2^{10}-1$
Input/Output	$2^6 - 1$ (maximum value)

† The evaluation of expressions by the Assembler is compatable with the addressing capability of the hardware instructions (e.g., up to 32K words through Indirect Addressing). The user must take care not to create addresses which exceed the memory size of the particular configuration.

Expression Terms

The terms of an expression are the numbers and the symbols appearing in it. Decimal and octal integers, and symbols defined as being absolute in an EQU pseudo operation are absolute terms. The asterisk and all symbols that are defined in the program are relocatable or absolute depending on the type of assembly. Symbols that are defined as external may appear only as single term expressions.

Within a relocatable program, terms may be program relocatable, base page relocatable, or common relocatable. A symbol that names an area of common storage is a common relocatable term. A symbol that is allocated to the base page is a base page relocatable term. A symbol that is defined in any other statement is a program relocatable term. Within one expression all relocatable terms must be base page relocatable, program relocatable, or common relocatable; the three types may not be mixed.

Absolute and Relocatable Expressions

An expression is absolute if its value is unaffected by program relocation. An expression is relocatable if its value changes according to the location into which the program is loaded. In an absolute program, all expressions are absolute. In a relocatable program, an expression may be base page relocatable, program relocatable, common relocatable, or absolute (if less than 100_8) depending on the definition of the terms composing it.

Absolute Expressions

An absolute expression may be any arithmetic combination of absolute terms. It may also contain relocatable terms alone, or in combination with absolute terms. If relocatable terms do appear, there must be an even number of them; they must be of the same type; and they must be paired by sign (a negative term for each positive term). The paired terms do not have to be contiguous in the expression. The pairing of terms by type cancels the effect of relocation; the value represented by the pair remains constant.

An absolute expression reduces to a single absolute value. The value of an absolute multiterm expression may be negative only for ABS pseudo operations. A single numeric term also may be negative in an OCT, DEX, or DEC pseudo instruction. In a relocatable program the value of an absolute expression must be less than 100_8 for instructions that reference memory locations (Memory Reference, DEF, Arithmetic subroutine calls).

Examples:

If P_1 and P_2 are program relocatable terms; B_1 and B_2, base page relocatable; C_1 and C_2, common relocatable; and A, an absolute term; then the following are absolute terms:

$A-C_1+C_2$	$A-P_1+P_2$	C_1-C_2+A
$A+A$	P_1-P_2	B_1-B_2
$*-P_1$	B_1-B_2-A	$-C_1+C_2+A$
B_1-*	$-P_1+P_2$	$-A-P_1+P_2$

The asterisk is base page relocatable or program relocatable depending on the location of the instruction.

Relocatable Expressions

A relocatable expression is one whose value is changed by the loader. All relocatable expressions must have a positive value.

A relocatable expression may contain any odd number of relocatable terms, alone, or in combination with absolute terms. All relocatable terms must be of the same type. Terms must be paired by sign with the odd term being positive.

A relocatable expression reduces to a single positive relocatable term, adjusted by the values represented by the absolute terms and paired relocatable terms associated with it.

Examples:

If P_1, P_2, and P_3 are program relocatable terms; B_1, B_2, and B_3, base page relocatable; C_1, C_2 and C_3, common relocatable; and A, an absolute term; then the following are relocatable terms:

P_1-A	C_1-A	B_1+A
$P_1-P_2+P_3$	$C_1-C_2+C_3$	C_1+A
$*+A$	$*-P_1+P_2$	$*-A$
$A+B_1$	$A+C_1$	$-A-P_1+P_2+P_3$
$B_1-B_2+B_3-A$	$C_1-C_2+C_3-A$	$A+*$
$*+P_1-*$	P_1-P_2+*	$-C_1+C_2+C_3$

Literals

Actual literal values may be specified as operands in relocatable programs to be assembled by the Extended Assembler. The Extended Assembler converts the literal to its binary value, assigns an address to it, and substitutes this address as the operand. Locations assigned to literals are those immediately following the last location used by the program.

A literal is specified by using an equal sign and a one-character identifier defining the type of literal. The actual literal value is specified immediately following this identifier; no spaces may intervene.

The identifiers are:

=D a decimal integer, in the range -32767 to 32767, including zero. †

=F a floating point number; any positive or negative real number in the range 10^{-38} to 10^{38}, including zero. †

=B an octal integer, one to six digits, $b_1b_2b_3b_4b_5b_6$, where b_1 may be 0 or 1, and b_2-b_7 may be 0 to 7. †

=A two ASCII characters. †

=L an expression which, when evaluated, will result in an absolute value. All symbols appearing in the expression must be previously defined.

If the same literal is used in more than one instruction, only one value is generated, and all instructions using this literal refer to the same location.

Literals may be specified only in the following memory reference instructions and pseudo instructions:

ADA	ADB	AND	MPY	may use =D, =B, =A, =L
LDA	LDB	XOR	DIV	
CPA	CPB	IOR		

DLD	FAD	may use =F
FMP	FSB	
FDV		

† See CONSTANT DEFINITION, Section 4.4.

Examples:

LDA	=D798Ø	A-Register is loaded with the binary equivalent of $798Ø_{1Ø}$.
IOR	=B777	Inclusive or is performed with contents of A-Register and 777_8.
LDA	=ANO	A-Register is loaded with binary representation of ASCII characters NO.
LDB	=LZETZ-ZOOM+68	B-Register is loaded with the value resulting from the absolute expression.
FMP	=F39.75	Contents of A- and B-Registers multiplied by floating point constant 39.75.

Indirect Addressing

The HP computers provide an indirect addressing capability for Memory Reference instructions. The operand portion of an indirect instruction contains an address of another location rather than an actual operand. The secondary location may be the operand or it may be indirect also and give yet another location, and so forth. The chaining ceases when a location is encountered that does not contain an indirect address. Indirect addressing provides a simplified method of address modifications as well as allowing access to any location in core.

The Assembler allows specification of indirect addressing by appending a comma and the letter I to any Memory Reference operand other than one referring to an external symbol. The actual operand of the instruction may be given in a DEF pseudo operation; this pseudo operation may also be used to indicate further levels of indirect addressing.

Examples:

```
AB    LDA SAM,I      EACH TIME THE ISZ IS EXECUTED,
AC    ADA SAM,I      THE EFFECTIVE OPERAND OF AB AND
AD    ISZ SAM        AC CHANGE ACCORDINGLY.
       .
       .
       .
SAM   DEF ROGER
```

A relocatable assembly language program, however, may be designed without concern for the pages in which it will be stored; indirect addressing is not required in the source language. When the program is being loaded, the Basic Control System (BCS) provides indirect addressing whenever it detects an operand which does not fall in the current page or the base page. The BCS loader substitutes a reference to the base page and then stores an indirect address in this referenced location. References to the same operand from other pages will be linked through the same location in the base page.

Base Page Addressing

The computer provides a capability which allows the Memory Reference instructions to address either the current page or the base page. The Assembler or the BCS loader adjusts all instructions in which the operands refer to the base page; specific notation defining an operand as a base page reference is not required in the source program.

Clear Flag Indicator

The majority of the input/output instructions can alter the status of the input/output interrupt flag after execution or after the particular test is performed. In source language, this function is selected by appending a comma and a letter C to the Operand field.

Examples:

```
      STC I07,C    CLEAR FLAG I07 AFTER CONTROL
                   BIT IS SET
      OTB I05,C    CLEAR FLAG I05 AFTER MOVE
```

2.5 COMMENTS FIELD

The Comments field allows the user to transcribe notes on the program that will be listed with source language coding on the output produced by the Assembler. The field follows the Operand field and is separated from it by at least one space. The end-of-statement mark, (CR) (LF), or the 80th character in the entire statement terminates the field. If the listing to be produced on the 2752A Teleprinter, the total statement length, excluding the end-of-statement mark, should not ex-

ceed 52 characters, the width of the source language portion of the listing. Statements consisting solely of comments may contain up to 68 characters including the asterisk in the first position. On the list output, statements consisting entirely of comments begin in position 5 rather than 21 as with other source statements.

If there is no operand present, the Comments field should be omitted in the NAM and END pseudo operations and in a HLT instruction. If a comment is used, the Assembler attempts to interpret it as an operand.

MACHINE INSTRUCTIONS 3

The HP Assembler language machine instruction codes take the form of three-letter mnemonics. Each source statement corresponds to a machine operation in the object program produced by the Assembler.

Notation used in representing source language instruction is as follows:

label	Optional statement label
m	Memory location -- an expression
I	Indirect addressing indicator
sc	Select code -- an expression
C	Clear interrupt flag indicator
comments	Optional comments
[ ]	Brackets defining a field or portion of a field that is optional
{ }	Brackets indicating that one of the set may be selected.
lit	literal

3.1 MEMORY REFERENCE

Memory Reference instructions perform arithmetic, logical and jump operations on the contents of the locations in core and the registers. An instruction may directly address the 2048 words of the current and base pages. If required, indirect addressing may be utilized to refer to all 32,768 words of memory. Expressions in the operand field are evaluated modulo 2^{10}.

If the program is to be assembled in relocatable form, the operand field may contain relocatable expressions or absolute expressions which are less than 100_8 in value. If the program is to be absolute, the operands may be any expressions consistent with the location of the program. Literals may not be used in an absolute program. Absolute programs must be complete entities; they may not refer to external subroutines or common storage.

Jump and Increment-Skip

Jump and Increment-Skip instructions may alter the normal sequence of program execution.

label	JMP	m [, I]	comments

Jump to m. Jump indirect inhibits interrupt until the transfer of control is complete.

label	JSB	m [, I]	comments

Jump to subroutine. The address for label+1 is placed into the location represented by m and control transfers to m+1. On completion of the subroutine, control may be returned to the normal sequence by performing a JMP m, I.

label	ISZ	m [, I]	comments

Increment, then skip if zero. ISZ adds 1 to the contents of m. If m then equals zero, the next instruction in memory is bypassed.

Add, Load, and Store

Add, Load, and Store instructions transmit and alter the contents of memory and of the A- and B-Registers. A literal, indicated by "lit", may be either =D, =B, =A, or =I type.

label	ADA	{m [, I] / lit}	comments

Add the contents of m to A.

label	ADB	{m [, I] / lit}	comments

Add the contents of m to B.

label	LDA	{m [, I] / lit}	comments

Load A from m.

label	LDB	{m [, I] / lit}	comments

Load B from m.

label	STA	m [,I]	comments

Store contents of A in m.

label	STB	m [,I]	comments

Store contents of B in m.

In each instruction, the contents of the sending location is unchanged after execution.

Logical Operations

The Logical instructions allow bit manipulation and the comparison of two computer words.

label	AND	{m [,I] / lit}	comments

The logical product of the contents of m and the contents of A are placed in A.

label	XOR	{m [,I] / lit}	comments

The modulo-two sum (exclusive "or") of the bits in m and the bits in A is placed in A.

label	IOR	{m [,I] / lit}	comments

The logical sum (inclusive "or") of the bits in m and the bits in A is placed in A.

label	CPA	{m [,I] / lit}	comments

Compare the contents of m with the contents of A. If they differ, skip the next instruction; otherwise, continue.

label	CPB	{m [,I] / lit}	comments

Compare the contents of m with the contents of B. If they differ, skip the next instruction; otherwise, continue.

3.2 REGISTER REFERENCE

The Register Reference instructions include a Shift-Rotate group, an Alter-Skip group, and NOP (no-operation). With the exception of NOP, they have the capability of causing several actions to take place during one memory cycle. Multiple operations within a statement are separated by a comma.

Shift-Rotate Group

This group contains 19 basic instructions that can be combined to produce more than 500 different single cycle operations.

CLE	Clear E to zero
ALS	Shift A left one bit, zero to least significant bit. Sign unaltered
BLS	Shift B left one bit, zero to least significant bit. Sign unaltered
ARS	Shift A right one bit, extend sign; sign unaltered.
BRS	Shift B right one bit, extend sign; sign unaltered.
RAL	Rotate A left one bit
RBL	Rotate B left one bit
RAR	Rotate A right one bit
RBR	Rotate B right one bit
ALR	Shift A left one bit, clear sign, zero to least significant bit
BLR	Shift B left one bit, clear sign, zero to least significant bit
ERA	Rotate E and A right one bit
ERB	Rotate E and B right one bit
ELA	Rotate E and A left one bit
ELB	Rotate E and B left one bit
ALF	Rotate A left four bits
BLF	Rotate B left four bits
SLA	Skip next instruction if least significant bit in A is zero
SLB	Skip next instruction if least significant bit in B is zero

These instructions may be combined as follows:

label	[{ALS, ARS, RAL, RAR, ALR, ALF, ERA, ELA}] [, CLE] [, SLA] [, {ALS, ARS, RAL, RAR, ALR, ALF, ERA, ELA}]	comments

label	[{BLS, BRS, RBL, RBR, BLR, BLF, ERB, ELB}] [, CLE] [, SLB] [, {BLS, BRS, RBL, RBR, BLR, BLF, ERB, ELB}]	comments

CLE, SLA, or SLB appearing alone or in any valid combination with each other are assumed to be a Shift-Rotate machine instruction.

The Shift-Rotate instructions must be given in the order shown. At least one and up to four are included in one statement. Instructions referring to the A-register may not be combined in the same statement with those referring to the B-register.

No-Operation Instruction

When a no-operation is encountered in a program, no action takes place; the computer goes on to the next instruction. A full memory cycle is used in executing a no-operation instruction.

label	NOP	comments

A subroutine to be entered by a JSB instruction should have a

NOP as the first statement. The return address can be stored in the location occupied by the NOP during execution of the program. A NOP statement causes the Assembler to generate a word of zeros.

Alter-Skip Group

The Alter-Skip group contains 19 basic instructions that can be combined to produce more than 700 different single cycle operations.

CLA	Clear the A-Register
CLB	Clear the B-Register
CMA	Complement the A-Register
CMB	Complement the B-Register
CCA	Clear, then complement the A-Register (set to ones)
CCB	Clear, then complement the B-Register (set to ones)
CLE	Clear the E-Register
CME	Complement the E-Register
CCE	Clear, then complement the E-Register
SEZ	Skip next instruction if E is zero
SSA	Skip if sign of A is positive (0).
SSB	Skip if sign of B is positive (0).
INA	Increment A by one.
INB	Increment B by one.
SZA	Skip if contents of A equals zero
SZB	Skip if contents of B equals zero
SLA	Skip if least significant bit of A is zero
SLB	Skip if least significant bit of B is zero
RSS	Reverse the sense of the skip instructions. If no skip instructions precede in the statement, skip the next instruction.

These instructions may be combined as follows:

```
label  [ {CLA} ]  [,SEZ]  , [ {CLE} ]   [,SSA] [,SLA] [,INA] [,SZA] [,RSS]  comments
       [ {CMA} ]            [ {CME} ]
       [ {CCA} ]            [ {CCE} ]

label  [ {CLB} ]  [,SEZ]  , [ {CLE} ]   [,SSB] [,SLB] [,INB] [,SZB] [,RSS]  comments
       [ {CMB} ]            [ {CME} ]
       [ {CCB} ]            [ {CCE} ]
```

The Alter-Skip instructions must be given in the order shown. At least one and up to eight are included in one statement. Instructions referring to the A-register may not be combined in the same statement with those referring to the B-register. When two or more skip functions are combined in a single operation, a skip occurs if any one of the conditions exists. If a word with RSS also includes both SSA and SLA (or SSB and SLB) a skip occurs only when sign and least significant bit are both set (1).

3.3 INPUT/OUTPUT, OVERFLOW, AND HALT

The input/output instructions allow the user to transfer data to and from an external device via a buffer, to enable or disable external interrupt, or to check the status of I/O devices and operations. A subset of these instructions permits checking for an arithmetic overflow condition.

Input/Output instructions require the designation of a select code, sc, which indicates one of 64 input/output channels or functions. Each channel consists of a connect/disconnect control bit, a flag bit, and a buffer of up to 16 bits. The setting of the control bit indicates that a device associated with the channel is operable. The flag bit is set automatically when transmission between the device and the buffer is completed. Instructions are also available to test or clear the flag bit for the particular channel. If the interrupt system is enabled, setting of the flag causes program interrupt to occur; control transfers to the interrupt location related to the channel.

Expressions used to represent select codes (channel numbers) must have a value of less than 2^6. The value specifies the device or operation referenced. Instructions which transfer data between the A or B register and a buffer, access the Switch register when sc = 1. The character C appended to such an instruction clears the overflow bit after the transfer from the Switch register is complete.

Input/Output

Prior to any input/output data transmission, the control bit is set. The instruction which enables the device may also transfer data between the device and the buffer.

label	STC	sc [, C]	comments

Set I/O control bit for channel specified by sc. STC transfers or enables transfer of an element of data from an input device to the buffer or to an output device from the buffer. The exact function of the STC depends on the device; for the 2752A Teleprinter, an STC enables transfer of a series of bits. If sc = 1, this statement is treated as NOP. The C option clears the flag bit for the channel.

label	CLC	sc [, C]	comments

Clear I/O control bit for channel specified by sc. When the control bit is cleared, interrupt on the channel is disabled, although the flag may still be set by the device. If sc = 0, control bits for all channels are cleared to zero; all devices are disconnected. If sc = 1, this statement is treated as NOP.

label	LIA	sc [, C]	comments

Load into A the contents of the I/O buffer indicated by sc.

label	LIB	sc [, C]	comments

Load into B the contents of the I/O buffer indicated by sc.

label	MIA	sc [, C]	comments

Merge (inclusive "or") the contents of the I/O buffer indicated by sc into A.

label	MIB	sc [, C]	comments

Merge (inclusive "or") the contents of the I/O buffer indicated by sc into B.

label	OTA	sc [, C]	comments

Output the contents of A to the I/O buffer indicated by sc.

label	OTB	sc [, C]	comments

Output the contents of B to the I/O buffer indicated by sc.

label	STF	sc	comments

Sets the flag bit of the channel indicated by sc. If sc = 0, STF enables the interrupt system. A sc code of 1 causes the overflow bit to be set.

label	CLF	sc	comments

Clear the flag bit to zero for the channel indicated by sc. If sc = 0, CLF disables the interrupt system. If sc = 1, the overflow bit is cleared to zero.

label	SFC	sc	comments

Skip the next instruction if the flag bit for channel sc is clear. If sc = 1, the overflow bit is tested.

label	SFS	sc	comments

Skip the next instruction if the flag bit for channel sc is set. If sc = 1, the overflow is tested.

Overflow

In addition to the use of a select code of 1, the overflow bit may be accessed by the following instructions:

label	CLO	comments

Clear the overflow bit.

label	STO	comments

Set overflow bit.

label	SOC	[C]	comments

Skip the next instruction if the overflow bit is clear. The C option clears the bit after the test is performed.

label	SOS	[C]	comments

Skip the next instruction if the overflow bit is set. The C option clears the bit after the test is performed.

The C option is identified by the 'space C space' following either 'SOC' or 'SOS'. Anything else is treated as a comment.

Halt

label	HLT	[sc [,C]]	comments

Halt the computer. The machine instruction word is displayed in the T-Register. If the C option is used, the flag bit associated with channel sc is cleared.

If neither the select code nor the C option is used, the comments portion should also be omitted.

3.4 EXTENDED ARITHMETIC UNIT

Ten instructions may be used with the EAU version of the Assembler or Extended Assembler to increase the Computer's overall efficiency. The Computer must include the Extended Arithmetic Unit option to obtain the resulting increase in available core storage and decrease in program run time.

label	MPY	{m[,I] / lit}	comments

The MPY instruction multiplies the contents of the A-Register by the contents of m. The product is stored in registers B and A. B contains the sign of the product and the 15 most significant bits; A contains the least significant bits.

label	DIV	{m[,I] / lit}	comments

The DIV instruction divides the contents of registers B and A by the contents of m. The quotient is stored in A and the remainder in B. Initially B contains the sign and the 15 most significant bits of the dividend; A contains the least significant bits.

label	DLD	{m[,I] / lit}	comments

The DLD instruction loads the contents of locations m and m + 1 into registers A and B, respectively.

label	DST	m[,I]	comments

The DST instruction stores the contents of registers A and B in locations m and m + 1, respectively.

MPY, DIV, DLD, DST results in two machine words: a word for the instruction code and one for the operand.

The above four instructions are available without the Extended Arithmetic Unit option as software subroutines.† As a part of the Extended Arithmetic option, they require less core storage and can be executed in less time.

The following six instructions can be used only on machines with the Extended Arithmetic Unit. These shift-rotate instructions provide the capability to shift or rotate the B- and A-Registers n number of bit positions, where $1 \le n \le 16$.

label	ASR	n	comments

The ASR instruction arithmetically shifts the B- and A-Registers right n bits. The sign bit (bit 15 of B) is extended.

label	ASL	n	comments

The ASL instruction arithmetically shifts the B- and A-Register left n bits. Zeroes are placed in the least significant bits. The sign bit (bit 15 of B) is unaltered. The overflow bit is set if bit 14 differs from bit 15 before each shift, otherwise, exit with Overflow bit cleared.

label	RRR	n	comments

The RRR instruction rotates the B- and A-Registers right n bits.

label	RRL	n	comments

The RRL instruction rotates the B- and A-Registers left n bits.

label	LSR	n	comments

The LSR instruction logically shifts the B- and A-Registers right n bits. Zeroes are placed in the most significant bits.

label	LSL	n	comments

The LSL instruction logically shifts the B- and A-Registers left n bits. Place zeroes into the least significant bits.

---

† See ARITHMETIC SUBROUTINE CALLS, Section 4.7.

The SWP may be used only in a configuration which includes the Extended Arithmetic Unit option.

Exchange the contents of the A- and B-Registers. The contents of the A-Register are shifted into the B-Register and the contents of the B-Register are shifted into the A-Register.

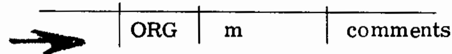
The pseudo instructions control the Assembler, establish program relocatablility, and define program linkage as well as specify various types of constants, blocks of memory, and labels used in the program. With the Extended Assembler, pseudo instructions also control listing output.

4.1 ASSEMBLER CONTROL

The Assembler control pseudo instructions establish and alter the contents of the base page and program location counters, and terminate assembly processing. Labels may be used but they are ignored by the Assembler. NAM records produced by the Assemblers are accepted by the Real-Time, DOS, and BCS Loaders.

	NAM	[name]	comments

NAM defines the name of a relocatable program. A relocatable program must begin with a NAM statement.† A relocatable program is assembled assuming a starting location of zero (i.e., zero relative). The name may be a symbol of one to five alphanumeric characters the first of which must be alphabetic or a period. The program name is printed on the list output. The name is optional and if omitted, the comments must be omitted also.



	ORG	m	comments

The ORG statement defines the origin of an absolute program, or the origin of subsequent sections of absolute or relocatable programs.

An absolute program must begin with an ORG statement. † The operand m, must be a decimal or octal integer specifying the initial setting of the program location counter.

†The Control Statement, the HED instruction, and comments may appear prior to the NAM or ORG statements. If the Control Statement (ASMB,...) does not appear on tape preceding the program it must be entered from the Teleprinter.

ORG statements may be used elsewhere in the program to define starting addresses for portions of the object code. For absolute programs the Operand field, m, may be any expression. For relocatable programs, m, must be a program relocatable expression; it may not be base page or common relocatable or absolute. An expression is evaluated modulo 2^{15}. Symbols must be previously defined. All instructions following an ORG are assembled at consecutive addresses starting with the value of the operand.

	ORR	comments

ORR resets the program location counter to the value existing when an ORG or ORB instruction was encountered.

Example:

```
      NAM RSET        SET PLC TO VALUE OF ZERO, ASSIGN
FIRST ADA             RSET AS NAME OF PROGRAM.
       .
       .
       .
      ADA CTRL        ASSUME PLC AT FIRST+2280.
      ORG FIRST+2926  SAVE PLC VALUE OF FIRST+2280
       .              AND SET PLC TO FIRST+2926.
       .
       .
      JMP EVEN+1      ASSUME PLC AT FIRST+3004
      ORR             RESET PLC TO FIRST+2280.
```

More than one ORG or ORB statement may occur before an ORR is used. If so, when the ORR is encountered, the program location counter is reset to the value it contained when the first ORG or ORB of the string occurred.

Example:

```
    NAM RSET        SET PLC TO ZERO
FIRST ADA
      .
      .
      .
    LDA WYZ         ASSUME PLC AT FIRST+2250
    ORG FIRST+2500  SET PLC TO FIRST+2500
      .
      .
      .
    LDB ERA         ASSUME PLC AT FIRST+2750
    ORG FIRST+2900  SET PLC TO FIRST+2900
      .
      .
      .
    CLE             ASSUME PLC AT FIRST+2920
    ORR             RESET PLC TO FIRST+2250
```

If a second ORR appears before an intervening ORG or ORB, the second ORR is ignored.

ORR cannot be used to reset the location counter for locations in the base page that are governed by the ORB statement.

	ORB	comments

ORB defines the portion of a relocatable program that must be assigned to the base page by the Assembler. The Label field if given is ignored, and the statement requires no operand. All statements that follow the ORB statement are assigned contiguous locations in the base page. Assignment to the base page terminates when the Assembler detects an ORG, ORR, or END statement.

When more than one ORB is used in a program. Each ORB causes the Assembler to resume assigning base page locations at the address following the last assigned base page location.

An ORB statement in an absolute program has no significance and is flagged as an error.

Example:

```
Label    Operation Operand        Comments
         NAM  PROG       ASSIGN ZERO AS RELATIVE STARTING
          .              LOCATION FOR PROGRAM PROG.
          .
          .
         ORB             ASSIGN ALL FOLLOWING STATEMENTS
                         TO BASE PAGE.
IAREA    BSS  100
          .
          .
         ORR             CONTINUE MAIN PROGRAM.
          .
          .
         ORB             RESUME ASSIGNMENT AT NEXT
          .              AVAILABLE LOCATION IN BASE PAGE.
          .
          .
         ORR             CONTINUE MAIN PROGRAM.
```

The IFN and IFZ pseudo instructions cause the inclusion of instructions in a program provided that either an "N" or "Z", respectively, is specified as a parameter for the ASMB control statement.† The IFN or IFZ instruction precedes the set of statements that are to be included. The pseudo instruction XIF serves as a terminator. If XIF is omitted, END acts as a terminator to both the set of statements and the assembly. IFN and IFZ may be used only when the source program is translated by the Extended Assembler which is provided for 8K or larger machines.

```
      | IFN  |          comments
         .
         .
        XIF
```

All source language statements appearing between the IFN and the XIF pseudo instructions are included in the program if the character "N" is specified on the ASMB control statement.

All source language statements appearing between the IFZ and the XIF pseudo instructions are included in the program if the character "Z" is specified on the ASMB control statement.

```
      | IFZ  |          comments
         .
         .
        XIF
```

†See CONTROL STATEMENT, Section 5.1.

When the particular letter is not included on the control statement, the related set of statements appears on the Assembler output listing but is not assembled.

Any number of IFN-XIF and IFZ-XIF sets may appear in a program, however, they may not overlap. An IFZ or IFN intervening between an IFZ or IFN and the XIF terminator results in a diagnostic being issued during compilation; the second pseudo instruction is ignored.

Both IFN-XIF and IFZ-XIF pseudo instructions may be used in the program; however, only one type will be selected in a single assembly. Therefore, if both characters "N" and "Z" appear in the control statement, the character which is listed last will determine the set of coding that is to be included in the program.

Example:

```
      NAM TRAVL
       .
       .
       .
      IFZ
      LDA CAR
      CMA,SZA
      JMP NO.GO
      LDA MILES
      DIV SPEED
      STA GAS
      XIF
       .
       .
       .
      IFN
      LDA PLANE
      CMA,SZA
      JMP NO.GO
      LDA TIME
      CPA COST
      XIF
NO.GO HLT 77
       .
       .
       .
      END
```

Program TRAVL will perform computations involving either or neither CAR or PLANE considerations depending on the presence or absence of Z or N parameters in the Control Statement.

Example:

```
      NAM  WAGE
       .
       .
       .
      JSB  HOUR
      MPY  TIME1
      IFZ
      JSB  OVTIM
      MPY  TIME2
       .
       .
       .
TIME1 DEC  40
TIME2 BSS  1
      END
```

Program WAGES computes a weekly wage value. Overtime consideration will be included in the program if "Z" is included in the parameters of the Control Statement.

The REP pseudo instruction, available in the Extended Assembler only, causes the repetition of the statement immediately following it a specified number of times.

label	REP	n	comments

The statement following the REP in the source program is repeated n times. The n may be any absolute expression. Comment lines (indicated by an asterisk in character position 1) are not repeated by REP. If a comment follows a REP instruction, the comment is ignored and the instruction following the comment is repeated.

A label specified in the REP pseudo instruction is assigned to the first repetition of the statement. A label cannot be part of the instruction to be repeated; it would result in a doubly defined symbol error.

Example:

```
        CLA
TRIPL   REP     3
        ADA     DATA
```

The above source code would generate the following:

```
        CLA                 Clear the A-Register;
        REP                 triple the contents of
TRIPL   ADA     DATA        DATA; store the sum
        ADA     DATA        in the A-Register.
        ADA     DATA
```

Example:

```
FILL    REP     100B
        NOP
```

The example above loads 100_8 memory locations with the NOP instruction. The first location is labeled FILL.

Example:

```
        REP 2
  *MULTIPLY BY DATA².
        MPY DATA
```

The above source code would generate the following:

```
        MPY DATA
        MPY DATA
```

	END	[m]	comments

This statement terminates the program; it marks the physical end of the source language statements. The Operand field, m, may contain a name appearing as a statement label in the current program or it may be blank. If a name is entered, it identifies the location to which the BCS loader transfers control after a relocatable program is loaded. A NOP should be stored in this location; the loader transfers control via a JSB.

If the Operand field is blank, the Comments field must be blank also, otherwise, the Assembler attempts to interpret the first five characters of the comments as the transfer address symbol.

The Label field of the END statement is ignored.

4.2 OBJECT PROGRAM LINKAGE

Linking pseudo instructions provide a means for communication between a main program and its subroutines or among several subprograms that are to be run as a single program. These instructions may be used only in a relocatable program.

The Label field of this class is ignored in all cases. The Operand field is usually divided into many subfields, separated by commas. The first space not preceded by a comma or a left parenthesis terminates the entire field.

	COM	$name_1$ [($size_1$)] [, $name_2$ [($size_2$)], . . . , $name_n$[($size_n$)]]	comments

COM reserves a block of storage locations that may be used in common by several subprograms. Each name identifies a segment of the block for the subprogram in which the COM statement appears. The sizes are the number of words allotted to the related segments. The size is specified as an octal or decimal integer. If the size is omitted, it is assumed to be one.

Any number of COM statements may appear in a subprogram. Storage locations are assigned contiguously; the length of the block is equal to the sum of the lengths of all segments named in all COM statements in the subprogram.

To refer to the common block, other subprograms must also include a COM statement. The segment names and sizes may be the same or they may differ. Regardless of the names and sizes specified in the separate subprograms, there is only one common block for the combined set. It has the same relative origin; the content of the nth word of common storage is the same for all subprograms.

Example:

```
PROG1  COM  ADDR1(5),ADDR2(10),ADDR3(10)
        .
        .
       LDA  ADDR2+1     PICK UP SECOND WORD OF SEGMENT
        .               ADDR2+1
        .
       END
        .
        .
PROG2  COM  AAA(2),AAB(2),AAC,AAD(20)
        .
        .
       LDA  AAD+1       PICK UP SECOND WORD OF SEGMENT
                        AAD+1.
```

Organization of common block:

PROG1 name	PROG2 name	Common Block
ADDR1	AAA	(location 1)
		(location 2)
	AAB	(location 3)
		(location 4)
	AAC	(location 5)
ADDR2	AAD	(location 6)
		(location 7)
		(location 8)
		(location 9)
		(location 10)
		(location 11)
		(location 12)
		(location 13)
		(location 14)
		(location 15)
ADDR3		(location 16)
		(location 17)
		(location 18)
		(location 19)
		(location 20)
		(location 21)
		(location 22)
		(location 23)
		(location 24)
		(location 25)

The LDA instructions in the two subprograms each refer to the same location in common storage, location 7.

The segment names that appear in the COM statements can be used in the Operand fields of DEF, ABS, EQU, or any Memory Reference statement; they may not be used as labels elsewhere in the program.

The loader establishes the origin of the common block; the origin cannot be set by the ORG or ORB pseudo instruction. All references to the common area are relocatable.

Two or more subprograms may declare common blocks which differ in size. The subprogram that defines the largest block must be the first submitted for loading.

	ENT	$name_1$ [, $name_2$, . . . , $name_n$]	comments

ENT defines entry points to the program or subprogram. Each name is a symbol that is assigned as a label for some machine operation in the program. Entry points allow another subprogram to refer to this subprogram. All entry points must be defined in the program.

Symbols appearing in an ENT statement may not also appear in EXT or COM statements in the same subprogram.

The Label field of the ENT instruction is ignored.

	EXT	$name_1$ [, $name_2$, . . . , $name_n$]	comments

This instruction designates labels in other subprograms which are referenced in this subprogram. The symbols must be defined as entry points by the other subprograms.

The symbols defined in the EXT statement may appear in Memory Reference statements, the EQU or DEF pseudo instructions. An external symbol must appear alone; it may not be in a multiple term expression or be specified as indirect in other than a DEF pseudo instruction. References to external locations are processed by the BCS loader as indirect addresses linked through the base page.

Symbols appearing in EXT statements may not also appear in ENT or COM statements in the same subprogram. The label field is ignored.

Example:

```
PROGA NOP
      LDA  SAMD          SAMD AND SAND ARE REFERENCED IN
       .                 PROGA, BUT ARE ACTUALLY
       .                 LOCATIONS IN PROGB.
       .
      JMP  SAND
      EXT  SAMD,SAND
      ENT  PROGA
      END
       .
       .
PROGB NOP
       .
       .
SAMD  OCT  767
SAND  STA  SAMD
       .
       .
      ENT  SAMD,SAND
       .
       .
      JSB  PROGA
       .
       .
      EXT  PROGA
       .
       .
      END
```

4.3 ADDRESS AND SYMBOL DEFINITION

The pseudo operations in this group assign a value or a word location to a symbol which is used as an operand elsewhere in the program.

label	DEF	m [,I]	comments

The address definition statement generates one word of memory as a 15-bit address which may be used as the object of an indirect address found elsewhere in the source program. The symbol appearing in the label is that which is referenced; it appears in the Operand field of a Memory Reference instruction.

The operand field of the DEF statement may be any positive expression in an absolute program; in a relocatable program it may be a relocatable expression or an absolute expression with a value of less than 100_8. Symbols that do appear in the Operand field, may appear as operands of EXT or COM statements, in the same subprogram and as entry points in other subprograms.

The expression in the Operand field may itself be indirect and make reference to another DEF statement elsewhere in the source program.

Example:

```
Label   Operation  Operand                  Comments
        NAM    PROGN        ZERO-RELATIVE START OF PROGRAM.
        EXT    SINE,SQRT
        COM    SCMA(20),SCMB(50)
         .
         .
        JSB    SINE         EXECUTE SINE ROUTINE
         .
         .
        LDA    XCMA,I       PICK UP COMMON WORD INDIRECTLY.
         .
         .
XCMA    DEF    SCMA         SCMA IS A 15-BIT ADDRESS.
         .
         .
        JSB    XSQ,I        GET SQUARE ROOT USING TWO-LEVEL
XSQ     DEF    XSQR,I       INDIRECT ADDRESSING.
         .
         .
XSQR    DEF    SQRT         SQRT IS A 15-BIT ADDRESS.
        END    PROGN
```

The DEF statement provides the necessary flexibility to perform address arithmetic in programs which are to be assembled in relocatable form. Relocatable programs should not modify the operand of a memory reference instruction.

In the example below, if TBL and LDTBL are in different pages, the BCS Loader processes TBL as an indirect address linked through the base page. The ISZ erroneously increments the loader provided reference to the base page rather than the value of TBL.

Example:

```
LDTBL LDA  TBL
       .
       .
       .
      ISZ  LDTBL
       .
       .
       .
TBL   BSS  100
```

Assuming the loader might assign absolute locations comparable to the following octal values:

Page	Loc	Opcode	Reference
(0)	(700)	DEF	4000
		.	
		.	
		.	
(1)	(200)	LDA	(0) 700(I)
		.	
		.	
		.	
(1)	(300)	ISZ	(1) 200
		.	
		.	
		.	
(2)	(0)		(TBL)

It can be seen that the ISZ instruction would increment the quantity 700 rather than the address of the table (4000_8).

The following assures correct address modification during program execution.

Example:

```
ITBL  DEF TBL
LDTBL LDA ITBL,I
       .
       .
       .
      ISZ ITBL
       .
       .
       .
TBL   BSS 100
```

This sequence might be stored by the loader as:

Page	Loc	Opcode	Reference
(1)	(200)	DEF	4000
(1)	(201)	LDA	200(I)
		.	
		.	
		.	
(1)	(300)	ISZ	(1) (200)
		.	
		.	
		.	
(2)	(0)		(TBL)

The value of 4000 is incremented; each execution of LDA will access successive locations in the table.

label	ABS	m	comments

ABS defines a 16-bit absolute value to be stored at the location represented by the label. The Operand field, m, may be any absolute expression; a single symbol must be defined as absolute elsewhere in the program.

Example:

Label	Operation	Operand	Comments
AB	EQU	35	ASSIGNS THE VALUE OF 35
			TO THE SYMBOL AB
M35	ABS	-AB	M35 CONTAINS -35.
P35	ABS	AB	P35 CONTAINS 35.
P70	ABS	AB+AB	P70 CONTAINS 70.
P30	ABS	AB-5	P30 CONTAINS 30.

label	EQU	m	comments

The EQU pseudo operation assigns to a symbol a value other than the one normally assigned by the program location counter. The symbol in the Label field is assigned the value represented by the Operand field. The Operand field may contain any expression. The value of the operand may be common, base page or program relocatable as well as absolute, but it may not be negative. Symbols appearing in the operand must be previously defined in the source program.

The EQU instruction may be used to symbolically equate two locations in memory; or it may be used to give a value to a symbol. The EQU statement does not result in a machine instruction.

Examples:

```
      NAM  FAM
       .
       .
       .
J3    DEF
       .
       .
       .
      LDA  J3           THE SYMBOLS JFOUR AND J3+1 BOTH
      ADA  ONE          IDENTIFY THE SAME LOCATION. THE
      STA  J3+1         AND OPERATION IS PERFORMED ON
JFOUR EQU  J3+1         THIS LOCATION.
       .
       .
       .
MWH   AND  JFOUR
       .
       .
       .
```

Examples:

```
      NAM  STOTB
       .
       .
       .
      COM  TABLA(1Ø)    DEFINES A 1Ø WORD TABLE, TABLA.
       .
       .
       .
TABLB EQU  TABLA+5      NAMES WORDS 6 THROUGH 1Ø OF
       .                TABLA AS TABLB.
       .
       .
       .
      LDA  TABLB+1      LOADS CONTENTS OF 7TH WORD
       .                COMMON INTO A. THE STATEMENT LDA
       .                TABLA+6 WOULD PERFORM THE SAME
       .                OPERATION
       .
      NAM  REG
       .
       .
       .
A     EQU  Ø            DEFINES SYMBOL A AS Ø (LOCATION
B     EQU  1            OF A-REGISTER), AND SYMBOL B AS
       .                1(LOCATION OF B-REGISTER).
       .
      LDA  B            LOADS CONTENTS OF B-REGISTER
                        INTO A-REGISTER.
```

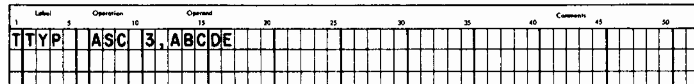
4.4 CONSTANT DEFINITION

The pseudo instructions in this class enter a string of one or more constant values into consecutive words of the object program. The statements may be named by labels so that other program statements can refer to the fields generated by them.

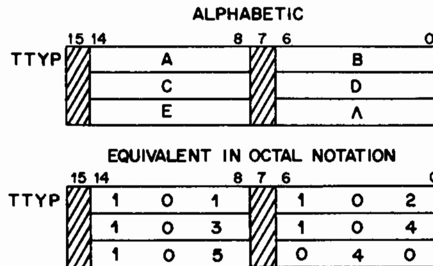
label	ASC	n, <2n characters>	comments

ASC generates a string of 2n alphanumeric characters in ASCII code into n consecutive words.† One character is right justified in each eight bits; the most significant bit is zero. n may be any expression resulting in an unsigned decimal value in the range 1 through 28. Symbols used in an expression must be previously defined. Anything in the Operand field following 2n characters is treated as comments. If less than 2n characters are detected before the end-of-statement mark, the remaining characters are assumed to be spaces, and are stored as such. The label represents the address of the first two characters.

Example:



causes the following:



† To enter the code for the ASCII symbols which perform some action (e.g., (CR) and (LF)), the OCT pseudo instruction must be used.

label	DEC	d_1 [, d_2, . . . , d_n]	comments

DEC records a string of decimal constants into consecutive words. The constants may be either integer or real (floating point), and positive or negative. If no sign is specified, positive is assumed. The decimal number is converted to its binary equivalent by the Assembler. The label, if given, serves as the address of the first word occupied by the constant.

A decimal integer must be in the range of 0 to $2^{15}-1$; it may assume positive, negative, or zero values. It is converted into one binary word and appears as follows:

Examples:

Label	Operation	Operand
INT	DEC	50,+328,-300

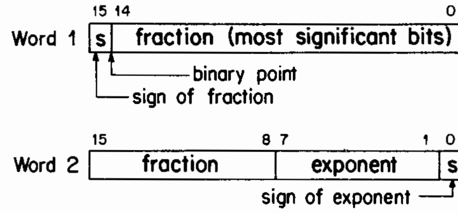
causes the following (octal representation)

	15	14				0
INT	0	0	0	0	6	2
	0	0	0	5	1	0
	1	7	7	3	2	4

A floating point number has two components, a fraction and an exponent. The exponent specifies the power of 10 by which the fraction is mutliplied. The fraction is a signed or unsigned number which may be written with or without a decimal point. The exponent is indicated by the letter E and follows a signed or unsigned decimal integer. The floating point number may have any of the following formats:

±n. n   ±n.   ±. n   ±n. nE±e   ±. nE±e   ±n. E±e   ±nE±e

The number is converted to binary, normalized (leading bits differ), and stored in two computer words. If either the fraction or the exponent is negative, that part is stored in two's complement form.



The floating point number is made up of a 7-bit exponent with sign and a 23-bit fraction with sign. The number must be in the approximate range of 10^{-38} through 10^{+38} and zero.

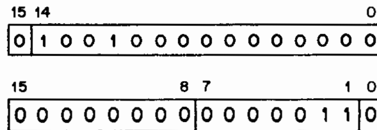
Examples:

```
     DEC .45E1
     DEC 45.00E-1
     DEC 4500E-3
     DEC 4.5
```

are all equivalent to

$.45 \times 10^1$

and are stored in normalized form as:



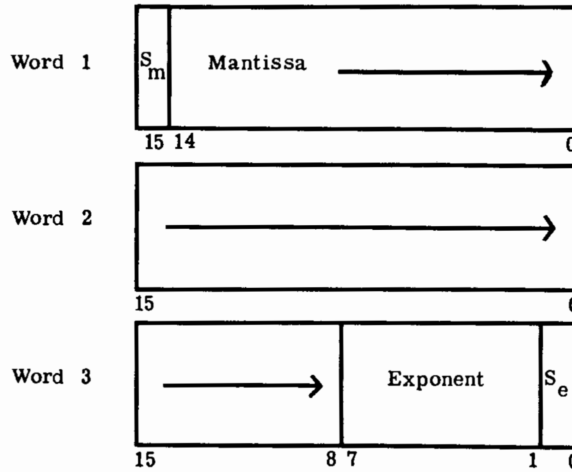
Label	Operation	Operand	Comments
	DEC	-.695,400E-4	

are stored as:

```
1|0 1 0 0 1 1 1 0 0 0 0 1 0 1 0
0 0 1 1 1 0 1 1|0 0 0 0 0 0 0|0

0|1 0 1 0 0 0 1 1 1 1 0 1 0 1 1
1 0 0 0 0 1 0 1|1 1 1 1 1 0 0|1
```

label	DEX	$d_1[,d_2 ,\ldots , d_n]$	comments

DEX, for the Extended Assembler, records a string of extended precision decimal constants into consecutive words within a program. Each such extended precision constant occupies three words as shown below:



Legend: S_m = Sign of the mantissa (fraction)

S_e = Sign of the Exponent*

*NOTE: a value is entered only if normalizing of the Mantissa is needed.

An extended precision floating point number is made up of a 39-bit Mantissa (fraction) and sign and a 7-bit exponent and sign. The exponent and sign will be zero if the Mantissa does not have to be normalized.

This is the only form used for DEX. All values, whether they be floating point, integer, fraction, or integer and fraction, will be stored in three words as just described. This storage format is basically an extension of that used for DEC, as previously described:

Examples:

DEX 12,-.45

are stored as:

WORD 1	WORD 2	WORD 3
0110000000000000	0000000000000000	0000000000001000

WORD 1	WORD 2	WORD 3
1000110011001100	1100110011001100	100110111111111

label	OCT	o_1 [, o_2, . . . , o_n]	comments

OCT stores one or more octal constants in consecutive words of the object program. Each constant consists of one to six octal digits (0 to 177777). If no sign is given, the sign is assumed to be positive. If the sign is negative, the two's complement of the binary equivalent is stored. The constants are separated by commas; the last constant is terminated by a space. If less than six digits are indicated for a constant, the data is right justified in the word. A label, if used, acts as the address of the first constant in the string. The letter B must not be used after the constant in the Operand field; it is significant only when defining an octal term in an instruction other than OCT.

Examples:

Label	Operation	Operand	Comments
	OCT	+Ø	
	OCT	-2	
NUM	OCT	177,2Ø4Ø5,-36	
	OCT	51,77777,-1,1Ø1Ø1	
	OCT	1Ø7642,177Ø77	
	OCT	1976	ILLEGAL: CONTAINS
	OCT	-177777	DIGIT 9
	OCT	177B	ILLEGAL: CONTAINS
			CHARACTER B

The previous statements are stored as follows:

	15	14				0
	0	0	0	0	0	0
	1	7	7	7	7	6
NUM	0	0	0	1	7	7
	0	2	0	4	0	5
	1	7	7	7	4	2
	0	0	0	0	5	1
	0	7	7	7	7	7
	1	7	7	7	7	7
	0	1	0	1	0	1
	1	0	7	6	4	2
	1	7	7	0	7	7
	X	X	X	X	X	X
	0	0	0	0	0	1
	X	X	X	X	X	X

THE RESULT OF ATTEMPTING TO DEFINE AN ILLEGAL CONSTANT IS UNPREDICTABLE

4.5 STORAGE ALLOCATION

The storage allocation statement reserves a block of memory for data or for a work area.

label	BSS	m	comments

The BSS pseudo operation advances the program or base page location counter according to the value of the operand. The Operand field may contain any expression that results in a positive integer. Symbols, if used, must be previously defined in the program. The label, if given, is the name assigned to the storage area and represents the address of the first word. The initial content of the area set aside by the statement is unaltered by the loader.

4.6 ASSEMBLY LISTING CONTROL

Assembly listing control pseudo instructions allow the user to control the assembly listing output during pass 2 or 3 of the assembly process. These pseudo instructions may be used only when the source program is translated by the Extended Assembler provided for 8K or larger machines (8,192-word memory or larger).

	UNL	comments

Output is suppressed from the assembly listing, beginning with the UNL pseudo instruction and continuing for all instructions and comments until either an LST or END pseudo instruction is encountered. Diagnostic messages for errors encountered by the Assembler will be printed, however. The source statement sequence numbers (printed in columns 1-4 of the source program listing) are incremented for the instructions skipped.

	LST	comments

The LST pseudo instruction causes the source program listing, terminated by a UNL, to be resumed.

A UNL following a UNL, a LST following a LST, and a LST not preceded by a UNL are not considered errors by the Assembler.

	SUP	comments

The SUP pseudo instruction suppresses the output of additional code lines from the source program listing. Certain pseudo instructions, because they result in using subroutines, generate more than one line of coding. These additional code lines are suppressed by a SUP instruction until a UNS or the END pseudo instruction is encountered. SUP will suppress additional code lines in the following pseudo instructions:

ASC	DIV	FAD	FSB
OCT	DLD	FDV	MPY
DEC	DST	FMP	

The SUP pseudo instruction may also be used to suppress the listing of literals at the end of the source program listing.

	UNS	comments

The UNS pseudo instruction causes the printing of additional coding lines, terminated by a SUP, to be resumed.

A SUP preceded by another SUP, UNS preceded by UNS, or UNS not preceded by a SUP are not considered errors by the Assembler.

	SKP	comments

The SKP pseudo instruction causes the source program listing to be skipped to the top of the next page. The SKP instruction is not listed, but the source statement sequence number is incremented for the SKP.

	SPC	n

The SPC pseudo instruction causes the source program listing to be skipped a specified number of lines. The list output is skipped n lines, or to the bottom of the page, whichever occurs first. The n may be any absolute expression. The SPC instruction is not listed but the source statement sequence number is incremented for the SPC.

	HED	m(heading)

The HED pseudo instruction allows the programmer to specify a heading to be printed at the top of each page of the source program listing.

The heading, m, a string of up to 56 ASCII characters, is printed at the top of each page of the source program listing following the occurrence of the HED pseudo instruction. If HED is encountered before the NAM or ORG at the beginning of a program, the heading will be used on the first page of the source program listing. A HED instruction placed elsewhere in the program causes a skip to the top of the next page.

The heading specified in the HED pseudo instruction will be used on every page until it is changed by a suceeding HED instruction.

The source statement containing the HED will not be listed, but source statement sequence number will be incremented.

4.7 ARITHMETIC SUBROUTINE CALLS

The members of this group of pseudo instructions request the Assember to generate calls to arithmetic subroutines† external to the source program. These pseudo instructions may be used in relocatable programs only. The Operand field may contain any relocatable expression or an absolute expression resulting in a value of less than 100_8.

label	MPY	{ m [,I] / =Dn or =Bn }	comments

Multiply the contents of the A-register by the contents of m or the quantity defined by the literal and store the product in registers B and A. B contains the sign of the product and the 15 most significant bits; A contains the least significant bits.

label	DIV	{ m [,I] / =Dn or =Bn }	comments

Divide the contents of registers B and A by the contents of m or the quantity defined by the literal. Store the quotient in A and the remainder in B. Initially B contains the sign and the 15 most significant bits of the dividend; A contains the least significant bits.

label	FMP	{ m [,I] / =Fn }	comments

Multiply the two-word floating point quantity in registers A and B by the two-word floating point quantity in locations m and m+1 or the quantity defined by the literal. Store the two-word floating point product in registers A and B.

label	FDV	{ m [,I] / =Fn }	comments

Divide the two-word floating point quantity in registers A and B by the two-word floating point quantity in locations m and m+1 or the quantity defined by the literal. Store the two-word floating point quotient in A and B.

†Not intended for use with DEX formatted numbers. For such numbers JSB's to Extended Precision Program Library routines must be used. See the Program Library Programmer's Reference Manual, Table of Contents.

label	FAD	{m [,I] / =Fn}	comments

Add the two-word floating point quantity in registers A and B to the two-word floating point quantity in locations m and m+1 or the quantity defined by the literal. Store the two-word floating point sum in A and B.

label	FSB	{m [,I] / =Fn}	comments

Subtract the two-word floating point quantity in m and m+1 or the quantity defined by the literal from the two-word floating point quantity in registers A and B and store the difference in A and B.

label	DLD	{m [, I] / =Fn}	comments

Load the contents of locations m and m+1 or the quantity defined by the literal into registers A and B respectively.

label	DST	m [, I]	comments

Store the contents of registers A and B in locations m and m+1 respectively.

Each use of a statement from this group generates two words of instructions. Symbolically, they could be represented as follows:

```
JSB     <.arithmetic pseudo operation>
DEF     m [, I]
```

An EXT <. arithmetic pseudo operation> is implied preceding the JSB operation.

In the above operations, the Overflow bit is set when one of the following conditions occurs:

Integer overflow
Floating point overflow or underflow
Division by zero.

Execution of any of the subroutines alters the contents of the E-Register.

The Assembler accepts as input a paper tape containing a control statement and a source language program. A relocatable source language program may be divided into several subroutines; the designation of these elements is optional. The output produced by the Assembler may include a punched paper tape containing the object program, an object program listing, and diagnostic messages.

5.1 CONTROL STATEMENT

The control statement specifies the output to be produced:

ASMB, p_1, p_2, . . . , p_n

"ASMB," is entered in positions 1-5. Following the comma are one or more parameters, in any order, which define the output to be produced. The control statement must be terminated by an end-of-statement mark, (CR) (LF).

The parameters may be any legal combination of the following starting in position 6:

A Absolute: The addresses generated by the Assembler are to be interpreted as absolute locations in memory. The program is a complete entity. It may not include NAM, ORB, COM, ENT, EXT, arithmetic pseudo operation statements or literals. The binary output format is that specified for the Basic Binary loader.

R Relocatable: The program may be located anywhere in memory. Instruction operands are adjusted as necessary. The binary output format is that specified for the BCS Relocating loader.

B Binary output: A program is to be punched according to one of the above parameters.

L List output: A program listing is to be produced either during pass two or pass three (if binary output selected) according to one of the above parameters.

T Table print: List the symbol table at the end of the first pass. For the Extended Assembler: List the symbol table in alphabetic order in three sections: section 1 for one- character symbols, section 2 for two- and three- character symbols, and section 3 for four- and five- character symbols.

N Include sets of instructions following the IFN pseudo instruction.

Z Include sets of instructions following the IFZ pseudo instruction.

Either A or R must be specified in addition to any combination of B, L, or T.

If a programmer wishes to assemble Pass 1 of a source program to check for errors, he can specify only an A or R to be the sole parameter of the Assembler Control Statement, executing only Pass 1. (This produces Pass 1 error messages without listing the program or providing an object tape). Extended Assembler only.

The Assembler Control Statement must specifically request Pass 2 operations (list or punch) in order for Pass 2 to be executed. Lack of Pass 2 option information causes processing only of Pass 1 errors. If a C option is also provided, an automatic cross-reference symbol table is done after Pass 1 when operating in the MTS environment.

The control statement may be on the same tape as the source program, or on a separate tape; or it may be entered via the Teleprinter keyboard.

5.2 SOURCE PROGRAM

The first statement of the program (other than remarks or a HED statement) must be a NAM statement for a relocatable program or an ORG statement for indicating the origin of an absolute program. The last statement must be an END statement and may contain a transfer address for the start of a relocatable program. Each statement is followed by an end-of-statement mark.

5.3 BINARY OUTPUT

The punch output is defined by the ASMB control statement. The punch output includes the instructions translated from the source program. It does not include system subroutines referenced within the source program (arithmetic subroutine calls, .IOC., .DIO., .ENTR, etc.)

5.4 LIST OUTPUT

Fields of the object program are listed in the following print columns.

Columns	Content
1-4	Source statement sequence number generated by the Assembler
5-6	Blank
7-11	Location (octal)
12	Blank
13-18	Object code word in octal
19	Relocation or external symbol indicator
20	Blank
21-72	First 52 characters of source statement.

Lines consisting entirely of comments (i.e., * in column 1) are printed as follows:

Columns	Content
1-4	Source statement sequence number
5-72	Up to 68 characters of comments

A Symbol Table listing has the following format:

Columns	Content
1-5	Symbol
6	Blank
7	Relocation of external symbol indicator
8	Blank
9-14	Value of the symbol

The characters that designate an external symbol or type of relocation for the Operand field or the symbol are as follows:

Character	Relocation Base
Blank	Absolute
R	Program relocatable
B	Base page relocatable
C	Common relocatable
X	External symbol

At the end of each pass, the following is printed:

** NO ERRORS*
or
** nnnn ERRORS*

The value nnnn, indicates the number of errors.

5.5 OPERATING INSTRUCTIONS

The exact operating procedures for an assembly depend on the available hardware configuration. The user should know the assignment of input/output equipment, † and memory size before initiating an assembly.

One possible allocation of equipment might be as follows:

Assembler Input/Output	Standard Unit Designation	Physical Unit Assignment
Binary Output	Teleprinter Output	Teleprinter
Table Print, List Output	List Output	Tape Punch
Source Program	Input	Punched Tape Reader

† As established when configuring the System Input/Output routines.

Assembly Options

If there are two output devices as shown above, there are only two passes; the Binary and List output are both produced in the second pass. If only one output device is available, the Binary output is produced in the second pass; and the List output, in the third pass.

The Assembler automatically provides a leader and trailer for binary output tapes. To suppress this leader and trailer, set Switch 0 to 1 (up) before the start of Pass 2.

In a three-pass assembly, the diagnostic messages and binary output are written on the same unit. To prevent these messages from being punched on the binary tape (they still appear on the printed output), perform the following steps:

1. Set Switch 15 to 1 (up) before start of Pass 2.
2. When the computer halts with the T-Register containing "102055", turn the punch unit off, and press Run.
3. When the computer again halts with the T-Register containing "102055", turn the punch unit on, and press Run.
4. At the end of Pass 2, set Switch 15 to 0 (down).

Steps 2 and 3 are repeated, each time a diagnostic message is produced.

Operating Procedures: Paper Tape System

The following procedures indicate the sequence of steps for assembly of a source program using the paper tape system.

A. Set Teleprinter to LINE and check that all equipment to be used is operable.

B. Load the Assembler using the Basic Binary Loader:†

1. Place Assembler binary tape in the device serving as the Standard Input unit (e. g., Punched Tape Reader).
2. Set Switch Register to starting address of Basic Binary Loader (e.g., 007700 for 4K memory, 017700 for 8K memory).
3. Press LOAD ADDRESS.
4. Set Loader switch to ENABLED.
5. Press PRESET.
6. Press RUN.
7. When the computer halts and indicates that the Assembler is loaded (T-Register contains 102077), set Loader switch to PROTECTED.

C. Set Switch Register to starting address of Assembler:

1. If control statement is on tape: 100_8
2. If control statement is to be entered via Teleprinter: 120_8

D. Press LOAD ADDRESS.

E. Place source language tape in unit serving as the Standard Input unit (e.g., Punched Tape Reader).

F. Press RUN.

G. If control statement is not on tape (i.e., starting address = $11\emptyset_8$), enter it via the Teleprinter, following it by (CR) (LF).

H. At end of Pass 1 (T-Register contains 102011), the Symbol Table, if requested, is on the Standard List Output unit. To execute Pass 2, replace the source language tape in the Standard Input unit, turn Teleprinter punch unit ON, and press RUN.

I. At the completion of each pass, repeat steps E and F. If a three-pass assembly is being executed, turn Teleprinter punch on at completion of Pass 1 and off at completion of Pass 2.

---

† The appropriate System Input/Output subroutines (drivers) are assumed to be included with the Assembler.

During the operation of the Assembler, the following halts may occur:

T-Register	Explanation	Action
102011	End of first pass.	Return to Step E.
	Write not enabled (MT)	Irrecoverable
102023	End of second of three passes. (only with ASR-33)	To perform Pass 3, return to Step E. To omit Pass 3 and assemble another program, remove output and return to Step C.
102040	EOT on MT	Press RUN. Assembler continues without MT; does not rewind
102054	Switch 1 selected during list to halt before printing a line. †	To continue, press RUN.
102055	Switch 15 option selected to prevent punching of printed messages on binary output tape. (Only halts with ASR-33).	See preceding instructions. (Assembly Options.)
102057	End of source tape section.	Place next section in unit serving as Standard Input unit and press Run.
102066	Control statement error. Press RUN to retry.	Correct control statement and return to Step E.
102077	End of assembly.	Remove output. To assemble another program, return to Step E.

Several programs may be assembled consecutively without reloading the Assembler. If some of the object programs are to be relocatable and others are to be absolute, the programs

† To halt Pass 2 at anytime, set Switch 1 up.

Computer Museum

that are to be assembled in relocatable form must be processed first. If relocatable program assemblies follow absolute program assemblies, an "R?" error will be diagnosed and the assembler must be reloaded.

5.6 Object Program Loading

If absolute binary output was specified, the Basic Binary Loader is used to load the object program tape.

If relocatable binary output was specified, the BCS Relocating Loader is used to load the object program tape. If the program refers to other Assembler FORTRAN or ALGOL generated object programs, these tapes are loaded by the Relocating Loader at the same time. If the program refers to .DIO. (the FORTRAN Formatter routine), or if it makes use of Arithmetic pseudo instructions, the Program Library tape must be submitted for loading also.

Listed below are summaries of procedures for normal loading of object programs:†

BASIC BINARY LOADER OPERATING PROCEDURES SUMMARY
A. Place binary object tape in Standard Input unit.
B. Set Switch Register to starting address of Basic Binary Loader
C. Press LOAD ADDRESS.
D. Set Loader switch to ENABLED.
E. Press PRESET.
F. Press RUN.
G. When the computer halts with T-Register containing 102077, set Loader switch to PROTECTED.
H. Set Switch Register to starting address of object program.
I. Press LOAD ADDRESS.
J. Check that all I/O devices are ready and loaded for operation of the program.
K. Press RUN.

†For complete details, see Basic Control System Programmer's Reference Manual.

BASIC CONTROL SYSTEM LOADER OPERATING PROCEDURES SUMMARY
A. Load the Basic Control System tape using the Basic Binary Loader.
B. Set Switch Register to 000002, press LOAD ADDRESS, and set Switch Register to 000000.
C. Place Assembler generated relocatable object tape in Standard Input unit.
D. Press RUN. The loader types "LOAD" if it expects another relocatable or library program.
E. If more than one relocatable object tape is to be loaded, repeat Steps C and D for each. Otherwise, set Switch Register to 000004 to load library routines.
F. Place Program Library tape in device serving as Program Library unit.
G. Press RUN. When the loading operation is complete, the Loader types "*LST". Press RUN. The Loader types "*RUN" indicating the program is ready for execution.
H. Press RUN to initiate execution.

5.7 ERROR MESSAGES

Errors detected in the source program are indicated by a 1- or 2-letter mnemonic followed by the sequence number and the first 62 characters of the statement in error. The messages are printed on the list output device during the passes indicated:

For Extended Assembler, error listings produced during Pass 1 are preceded by a number which identifies the source input file where the error was found. Pass 2 and 3 error messages are preceded by a reference to the previous page of the listing where an error message was written. The first error will refer to page "0".

Error Code	Pass	Description
CS	1	Control statement error: a) The control statement contained a parameter other than the legal set. b) Neither A nor R, or both A and R were specified. c) There was no output parameter (B, T or L.)
DD	1	Doubly defined symbol: A name defined in the symbol table appears more than once as: a) A label of a machine instruction. b) A label of one of the pseudo operations: BSS EQU ASC ABS DEC OCT DEF Arithmetic subroutine call DEX c) A name in the Operand field of a COM or EXT statement. d) A label in an instruction following a REP pseudo operation. e) Any combination of the above. An arithmetic subroutine call symbol appears in a program both as a pseudo instruction and as a label.

Error Code	Pass	Description
EN	1	The symbol specified in an ENT statement has already been defined in an EXT or COM statement.
EN ØØØØ <symbol>	start of 2	The entry point specified in an ENT statement does not appear in the label field of a machine or BSS instruction. The entry point has been defined in the Operand field of an EXT or COM statement, or has been equated to an absolute value.
1F	1	An IFZ or an 1FN follows either an 1FZ or an 1FN without an intervening XIF. The second pseudo instruction is ignored.
1L	1	Illegal instruction: a) Instruction mnemonic cannot be used with type of assembly requested in control statement. The following are illegal in an absolute assembly: NAM EXT ENT COM ORB Arithmetic subroutine calls b) The ASMB statement has an R parameter, and NAM has been detected after the first valid Opcode.
IL	2 or 3	Illegal character: A numeric term used in the Operand field contains an illegal character(e.g. an octal constant contains other than +, -, or Ø - 7). Illegal instruction: ORB in an absolute assembly.

Error Code	Pass	Description
M	1, 2 or 3	Illegal operand:

a) An operand is missing for an Opcode requiring one.

b) Operands are optional and omitted but comments are included for:

END

HLT

c) An absolute expression in one of the following instructions from a relocatable program is greater than 77_8.

Memory Reference
DEF
Arithmetic subroutine calls

d) A negative operand is used with an Opcode field other than ABS, DEC, and OCT.

e) A character other than I follows a comma in one of the following statements:

ISZ	ADA	AND	DEF
JMP	ADB	XOR	Arithmetic
JSB	LDA	IOR	Subroutine
	LDB	CPA	calls
	STA	CPB	
	STB		

f) A character other than C follows a comma in one of the following statements:

STC	MIB
CLC	OTA
LIA	OTB
LIB	HLT
MIA	

Error Code	Pass	Description

g) A relocatable expression in the operand field of one of the following:

ABS	ASR	RRL
REP	ASL	LSR
SPC	RRR	LSL

h) An illegal operator appears in an Operand field (e. g. + or - as the last character).

i) An ORG statement appearing in a relocatable program includes an expression that is base page or common relocatable or absolute.

j) A relocatable expression contains a mixture of program, base page, and common relocatable terms.

k) An external symbol appears in an operand expression or is followed by a comma and the letter I.

l) The literal or type of literal is illegal for the operation code used (e.g., STA =B7).

m) An illegal literal code has been used (e.g., LDA =077).

n) An integer expression in one of the following instructions does not meet the condition $1 \leq n \leq 16$. The integer is evaluated modulo 2^4.

ASR	RRR	LSR
ASL	RRL	LSL

o) The value of an 'L' type literal is relocatable.

Error Code	Pass	Description
NO	1, 2, 3	No origin definition: The first statement in the assembly containing a valid opcode following the ASMB control statement (and remarks and/or HED, if present) is neither an ORG nor a NAM statement. If the A parameter was given on the ASMB statement, the program is assembled starting at 2000; if an R parameter was given, the program is assembled starting at zero.
OP	1, 2, 3	Illegal Opcode preceding first valid Opcode. The statement being processed does not contain an asterisk in position one. The statement is assumed to contain an illegal Opcode; it is treated as a remarks statement.
OP	1, 2, or 3	Illegal Opcode: A mnemonic appears in the Opcode field which is not valid for the hardware configuration or assembler being used. A word is generated in the object program.
OV	1, 2, or 3	Numeric operand overflow: The numeric value of a term or expression has overflowed its limit: $1 \geq N \geq 16$ EAU Shift-Rotate Set 2^6-1 Input/Output, Overflow, Halt $2^{10}-1$ Memory Reference (in absolute assembly) $2^{15}-1$ DEF and ABS operands; data generated by DEC; or DEX; expressions concerned with program location counter. $2^{16}-1$ OCT
R?	Before 1	An attempt is being made to assemble a relocatable program following the assembly of an absolute program.

Error Code	Pass	Description
SO	1	There are more symbols defined in the program than the symbol table can handle.
SY	1, 2, 3	Illegal Symbol: A Label field contains an illegal character or is greater than 5 characters. A label with illegal characters may result in an erroneous assembly if not corrected. A long label is truncated on the right to 5 characters.
SY	2 or 3	Illegal Symbol: A symbolic term in the Operand field is greater than five characters; the symbol is truncated on the right to 5 characters. Too many control statements: A control statement has been input both on the teleprinter and the source tape or the source tape contains more than one control statement. The Assembler assumes that the source tape control statement is a label, since it begins in column 1. Thus, the commas are considered as illegal characters and the "label" is too long. The binary object tape is not affected by this error, and the control statement entered via the teleprinter is the one used by the Assembler.
TP	1, 2, or 3	An error has occurred while reading magnetic tape.
UN	1, 2, or 3	Undefined Symbol: a) A symbolic term in an Operand field is not defined in the Label field of an instruction or is not defined in the Operand field of a COM or EXT statement. b) A symbol appearing in the Operand field of one of the following pseudo operations was not defined previously in the source program: BSS ASC EQU ORG END

HP CHARACTER SET

ASCII CHARACTER FORMAT

b_4	b_3	b_2	b_1	$b_7b_6b_5$ = 000	001	010	011	100	101	110	111
0	0	0	0	NULL	DC_0	b̸	0	@	P	UNASSIGNED	UNASSIGNED
0	0	0	1	SOM	DC_1	!	1	A	Q		
0	0	1	0	EOA	DC_2	"	2	B	R		
0	0	1	1	EOM	DC_3	#	3	C	S		
0	1	0	0	EOT	DC_4 (STOP)	$	4	D	T		
0	1	0	1	WRU	ERR	%	5	E	U		
0	1	1	0	RU	SYNC	&	6	F	V		
0	1	1	1	BELL	LEM	' (APOS)	7	G	W		
1	0	0	0	FE_0	S_0	(	8	H	X		
1	0	0	1	HT/SK	S_1	)	9	I	Y		
1	0	1	0	LF	S_2	*	:	J	Z		
1	0	1	1	V_{TAB}	S_3	+	;	K	[		
1	1	0	0	FF	S_4	, (COMMA)	<	L	\		ACK
1	1	0	1	CR	S_5	−	=	M	]		①
1	1	1	0	SO	S_6	.	>	N	↑		ESC
1	1	1	1	SI	S_7	/	?	O	←		DEL

Standard 7-bit set code positional order and notation are shown below with b_7 the high-order and b_1 the low-order, bit position.

	b_7	b_6	b_5	b_4	b_3	b_2	b_1
EXAMPLE: The code for "R" is:	1	0	1	0	0	1	0

LEGEND

NULL	Null/Idle	DC_1-DC_3	Device Control
SOM	Start of message	DC_4(Stop)	Device control (stop)
EOA	End of address	ERR	Error
EOM	End of message	SYNC	Synchronous idle
EOT	End of transmission	LEM	Logical end of media
WRU	"Who are you?"	S_0-S_7	Separator (information)
RU	"Are you . . . ?"	b̸	Word separator (space, normally non-printing)
BELL	Audible signal		
FE_0	Format effector	<	Less than
HT	Horizontal tabulation	>	Greater than
SK	Skip (punched card)	↑	Up arrow (Exponentiation)
LF	Line feed	←	Left arrow (Implies/Replaced by)
V_{TAB}	Vertical tabulation	\	Reverse slant
FF	Form feed	ACK	Acknowledge
CR	Carriage return	①	Unassigned control
SO	Shift out	ESC	Escape
SI	Shift in	DEL	Delete/Idle
DC_0	Device control reserved for data link escape		

BINARY CODED DECIMAL FORMAT

Kennedy 1406/1506 ASCII-BCD Conversion

Symbol	BCD (octal code)	ASCII Equivalent (octal code)	Symbol	BCD (octal code)	ASCII Equivalent (octal code)
(Space)	2Ø	Ø4Ø	A	61	1Ø1
!	52	Ø41	B	62	1Ø2
#	13	Ø43	C	63	1Ø3
$	53	Ø44	D	64	1Ø4
%	34	Ø45	E	65	1Ø5
&	6Ø	Ø46	F	66	1Ø6
'	14	Ø47	G	67	1Ø7
(	34	Ø50	H	7Ø	11Ø
)	74	Ø51	I	71	111
*	54	Ø52	J	41	112
+	6Ø	Ø53	K	42	113
,	33	Ø54	L	43	114
-	4Ø	Ø55	M	44	115
.	73	Ø56	N	45	116
/	21	Ø57	O	46	117
			P	47	12Ø
Ø	12	Ø6Ø	Q	50	121
1	Ø1	Ø61	R	51	122
2	Ø2	Ø62	S	22	123
3	Ø3	Ø63	T	23	124
4	Ø4	Ø64	U	24	125
5	Ø5	Ø65	V	25	126
6	Ø6	Ø66	W	26	127
7	Ø7	Ø67	X	27	13Ø
8	1Ø	Ø7Ø	Y	30	131
9	11	Ø71	Z	31	132
:	15	Ø72	[	75	133
;	56	Ø73	\	36	134
<	76	Ø74	]	55	135
=	13	Ø75			
>	16	Ø76			
?	72	Ø77			
@	14	1ØØ			

Other symbols which may be represented in ASCII are converted to spaces in BCD (20)

HP 2020A/B ASCII - BCD Conversion

Symbol	ASCII (Octal code)	BCD (Octal code)
(Space)	4Ø	2Ø
!	41	52
"	42	37
#	43	13
$	44	53
%	45	34
&	46	60 †
'	47	36
(	5Ø	75
)	51	55
*	52	54
+	53	6Ø
,	54	33
-	55	4Ø
.	56	73
/	57	21
Ø	6Ø	12
1	61	Ø1
2	62	Ø2
3	63	Ø3
4	64	Ø4
5	65	Ø5
6	66	Ø6
7	67	Ø7
8	7Ø	1Ø
9	71	11
:	72	15
;	73	56
<	74	76
=	75	35
>	76	16
?	77	72
@	1ØØ	14

Symbol	ASCII (Octal code)	BCD (Octal code)
A	1Ø1	61
B	1Ø2	62
C	1Ø3	63
D	1Ø4	64
E	1Ø5	65
F	1Ø6	66
G	1Ø7	67
H	11Ø	70
I	111	71
J	112	41
K	113	42
L	114	43
M	115	44
N	116	45
O	117	46
P	12Ø	47
Q	121	50
R	122	51
S	123	22
T	124	23
U	125	24
V	126	25
W	127	26
X	13Ø	27
Y	131	30
Z	132	31
[	133	75 ‡
]	135	55 ‡
↑	136	77
←	137	32

† BCD code of 60 always converted to ASCII code 53 (+).

‡ BCD code of 75 always converted to ASCII code 50 (() and BCD code of 55 always converted to ASCII code 51 ()).

Symbols	Meaning
label	Symbolic label, 1-5 alphanumeric characters and periods
m	Memory location represented by an expression
I	Indirect addressing indicator
C	Clear flag indicator
(m, m+1)	Two-word floating point value in m and m+1
comments	Optional comments
[ ]	Optional portion of field
{ }	One of set may be selected
P	Program Counter
( )	Contents of location
$\wedge$	Logical product
$\veebar$	Exclusive "or"
$\vee$	Inclusive "or"
A	A- register
B	B- register
E	E- register
A_n	Bit n of A-register
B_n	Bit n of B-register
b	Bit positions in B- and A-register
$\overline{(A/B)}$	Complement of contents of register A or B
(AB)	Two-word floating point value in register A and B
sc	Channel select code represented by an expression
d	Decimal constant
o	Octal constant
r	Repeat count
n	Integer constant
lit	Literal value

MACHINE INSTRUCTIONS

MEMORY REFERENCE

Jump and Increment-Skip

ISZ	m [,I]	(m) + 1 → m; then if (m) = 0, execute P + 2 otherwise execute P + 1
JMP	m [,I]	Jump to m; m → P
JSB	m [,I]	Jump subroutine to m: P + 1 → m; m + 1 → P

Add, Load and Store

ADA	{ m [,I] / lit }	(m) + (A) → A
ADB	{ m [,I] / lit }	(m) + (B) → B
LDA	{ m [,I] / lit }	(m) → A
LDB	{ m [,I] / lit }	(m) → B
STA	m [,I]	(A) → m
STB	m [,I]	(B) → m

Logical

AND	{ m [,I] / lit }	(m) $\wedge$ (A) → A
XOR	{ m [,I] / lit }	(m) $\forall$ (A) → A
IOR	{ m [,I] / lit }	(m) $\vee$ (A) → A
CPA	{ m [,I] / lit }	If (m) ≠ (A), execute P + 2, otherwise execute P + 1
CPB	{ m [,I] / lit }	If (m) ≠ (B), execute P + 2, otherwise execute P + 1

REGISTER REFERENCE

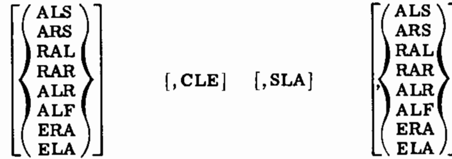
Shift-Rotate

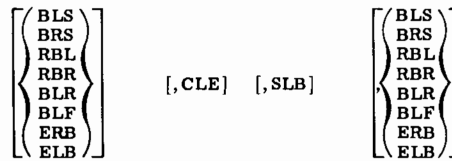
CLE	0 → E
ALS	Shift (A) left one bit, 0 → A_0, A_{15} unaltered
BLS	Shift (B) left one bit, 0 → B_0, B_{15} unaltered
ARS	Shift (A) right one bit, (A_{15}) → A_{14}
BRS	Shift (B) right one bit, (B_{15}) → B_{14}
RAL	Rotate (A) left one bit
RBL	Rotate (B) left one bit

Shift-Rotate (Continued)

RAR	Rotate (A) right one bit
RBR	Rotate (B) right one bit
ALR	Shift (A) left one bit, $0 \rightarrow A_{15}$
BLR	Shift (B) left one bit, $0 \rightarrow B_{15}$
ERA	Rotate E and A right one bit
ERB	Rotate E and B right one bit
ELA	Rotate E and A left one bit
ELB	Rotate E and B left one bit
ALF	Rotate A left four bits
BLF	Rotate B left four bits
SLA	If $(A_0) = 0$, execute P + 2, otherwise execute P + 1
SLB	If $(B_0) = 0$, execute P + 2, otherwise execute P + 1

Shift-Rotate instructions can be combined as follows:





No-operation

NOP	Execute P + 1

Alter-Skip

CLA	0's → A
CLB	0's → B
CMA	$\overline{(A)} \rightarrow A$
CMB	$\overline{(B)} \rightarrow B$
CCA	1's → A
CCB	1's → B
CLE	0 → E
CME	$\overline{(E)} \rightarrow E$

Alter-Skip (Continued)

CCE	1 → E
SEZ	If (E) = 0, execute P + 2, otherwise execute P + 1
SSA	If (A_{15}) = 0, execute P + 2, otherwise execute P + 1
SSB	If (B_{15}) = 0, execute P + 2, otherwise execute P + 1
INA	(A) + 1 → A
INB	(B) + 1 → B
SZA	If (A) = 0, execute P + 2, otherwise execute P + 1
SZB	If (B) = 0, execute P + 2, otherwise execute P + 1
SLA	If (A_0) = 0, execute P + 2, otherwise execute P + 1
SLB	If (B_0) = 0, execute P + 2, otherwise execute P + 1
RSS	Reverse sense of skip instructions. If no skip instructions precede, execute P + 2

Alter-Skip instructions can be combined as follows:

$$\left[\begin{Bmatrix} \text{CLA} \\ \text{CMA} \\ \text{CCA} \end{Bmatrix}\right] \text{[,SEZ]} \left[\begin{Bmatrix} \text{CLE} \\ \text{CME} \\ \text{CCE} \end{Bmatrix}\right] \text{[,SSA] [,SLA] [,INA] [,SZA] [,RRS]}$$

$$\left[\begin{Bmatrix} \text{CLB} \\ \text{CMB} \\ \text{CCB} \end{Bmatrix}\right] \text{[,SEZ]} \left[\begin{Bmatrix} \text{CLE} \\ \text{CME} \\ \text{CCE} \end{Bmatrix}\right] \text{[,SSB] [,SLB] [,INB] [,SZB] [,RSS]}$$

INPUT/OUTPUT, OVERFLOW, and HALT

Input/Output

STC	sc	[,C]	Set control bit_{sc}, enable transfer of one element of data between device_{sc} and buffer_{sc}
CLC	sc	[,C]	Clear control bit_{sc}. If sc = 0 clear all control bits
LIA	sc	[,C]	(buffer_{sc}) → A
LIB	sc	[,C]	(buffer_{sc}) → B
MIA	sc	[,C]	$(\text{buffer}_{sc}) \vee$ (A) → A
MIB	sc	[,C]	$(\text{buffer}_{sc}) \vee$ (B) → B
OTA	sc	[,C]	(A) → buffer_{sc}
OTB	sc	[,C]	(B) → buffer_{sc}
STF	sc		Set flag bit_{sc}. If sc = 0, enable interrupt system. sc = 1 sets overflow bit.
CLF	sc		Clear flag bit_{sc}. If sc = 0, disable interrupt system. If sc =1, clear overflow bit.
SFC	sc		If (flag bit_{sc}) = 0, execute P + 2, otherwise execute P + 1. If sc = 1, test overflow bit.
SFS	sc		If (flag bit_{sc}) = 1, execute P + 2, otherwise execute P + 1. If sc = 1, test overflow bit.

Overflow

CLO		0 → overflow bit
STO		1 → overflow bit
SOC	[C]	If (overflow bit) = 0, execute P + 2, otherwise execute P + 1
SOS	[C]	If (overflow bit) = 1, execute P + 2, otherwise execute P + 1

Halt

HLT	[sc [,C]]	Halt computer

EXTENDED ARITHMETIC UNIT (requires EAU version of Assembler or Extender Assembler)

MPY	{m[,I] / lit}	(A) x (m) → ($B_{\pm msb}$ and A_{lsb})
DIV	{m[,I] / lit}	($B_{\pm msb}$ and A_{lsb})/(m) → A, remainder → B
DLD	{m[,I] / lit}	(m) and (m + 1) → A and B
DST	{m[,I]}	(A) and (B) → m and m + 1
ASR	b	Arithmetically shift (BA) right b bits, B_{15} extended
ASL	b	Arithmetically shift (BA) left b bits, B_{15} unaltered, 0's to A_{lsb}
RRR	b	Rotate (BA) right b bits
RRL	b	Rotate (BA) left b bits
LSR	b	Logically shift (BA) right b bits, 0's to B_{msb}
LSL	b	Logically shift (BA) left b bits, 0's to A_{lsb}
SWP		(A)→B; (B)→A

ASSEMBLER CONTROL

NAM [name]	Specifies relocatable program and its name.
ORG m	Gives absolute program origin or origin for a segment of relocatable or absolute program.
ORR	Reset main program location counter at value existing when first ORG or ORB of a string was encountered.
ORB	Defines base page portion of relocatable program.
END [m]	Terminates source language program. Produces transfer to program starting location, m, if given.
REP r <statement>	Repeat immediately following statement r times.
IFN <statements> XIF	Include statements in program if control statement contains N.
IFZ <statements> XIF	Include statements in program if control statement contains Z.

OBJECT PROGRAM LINKAGE

COM $name_1[(size_1)][,name_2[(size_2)], \ldots ,name_n[(size_n)]]$

Reserves a block of common storage locations. $name_i$ identifies segments of block, each of length size.

ENT $name_1[,name_2, \ldots ,name_n]$

Defines entry points, $name_i$, that may be referred to by other programs

EXT $name_1[,name_2, \ldots ,name_n]$

Defines external locations, $name_i$, which are labels of other programs, referenced by this program.

ADDRESS AND SYMBOL DEFINITION

label	DEF	m[,I]	Generates a 15-bit address which may be referenced indirectly through the label.
label	ABS	m	Defines a 16-bit absolute value to be referenced by the label.
label	EQU	m	Equates the value, m, to the label.

CONSTANT DEFINITION

ASC n, <2n characters>	Generates a string of 2n ASCII characters.
DEC d_1 [, d_2, . . . , d_n]	Records a string of decimal constants of the form: Integer: ±n; Floating point: ±n. n, ±n. , ±. n, ±nE±e, ±n. nE±e, ±n. E±e, ±. nE±e
DEX d_1 [, d_2, ... , d_n]	Records a string of extended precision decimals constants of the form: Floating point: ±n, ±n.n, ±n., ±.n, ±nE±e, ±n.nE±e, ±n.E±e, ±.nE±e
OCT o_1 [, o_2, . . . , o_n]	Records a string of octal constants of the form: ±000000

STORAGE ALLOCATION

BSS	m	Reserves a storage area of length, m.

ARITHMETIC SUBROUTINE CALLS REQUESTS††

MPY†	{m[,I] / lit}	(A) x (m) → ($B_{\pm msb}$ and A_{lsb})
DIV†	{m[,I] / lit}	($B_{\pm msb}$ and A_{lsb})/(m) → A, remainder → B
FMP	{m[,I] / lit}	(AB) x (m, m + 1) → AB
FDV	{m[,I] / lit}	(AB)/(m, m + 1) → AB
FAD	{m[,I] / lit}	(m, m + 1) + (AB) → AB
FSB	{m[,I] / lit}	(AB) - (m, m + 1) → AB
DLD†	{m[,I] / lit}	(m) and (m + 1) → A and B
DST†	m[,I]	(A) and (B) → m and m + 1

† For configurations including Extended Arithmetic Unit, these mnemonic generate hardware instructions when the EAU version of the Assembler or Extended Assembler is used.

††Not intended for use with DEX formatted numbers. For such numbers, JSB Machine Instructions must be used.

ASSEMBLY LISTING CONTROL

UNL		Suppress assembly listing output.
LST		Resume assembly listing output.
SKP		Skip listing to top of next page.
SPC	n	Skip n lines on listing
SUP		Suppress listing of extended code lines (e. g. , as produced by subroutine calls).
UNS		Resume listing of extended code lines.
HED	<heading>	Print <heading> at top of each page, where <heading> is up to 56 ASCII characters.

ABS	Define absolute value
ADA	Add to A
ADB	Add to B
ALF	Rotate A left 4
ALR	Shift A left 1, clear sign
ALS	Shift A left 1
AND	"And" to A
ARS	Shift A right 1, sign carry
ASC	Generate ASCII characters
ASL	Arithmetic long shift left
ASR	Arithmetic long shift right
BLF	Rotate B left 4
BLR	Shift B left 1, clear sign
BLS	Shift B left 1
BRS	Shift B right 1, carry sign
BSS	Reserve block of storage starting at symbol
CCA	Clear and complement A (1's)
CCB	Clear and complement B (1's)
CCE	Clear and complement E (set E = 1)
CLA	Clear A
CLB	Clear B
CLC	Clear I/O control bit
CLE	Clear E
CLF	Clear I/O flag
CLO	Clear overflow bit
CMA	Complement A
CMB	Complement B

CME	Complement E
COM	Reserve block of common storage
CPA	Compare to A, skip if unequal
CPB	Compare to B, skip if unequal
DEC	Defines decimal constants
DEF	Defines address
DEX	Defines extended precision constants
DIV	Divide
DLD	Double load
DST	Double store
ELA	Rotate E and A left 1
ELB	Rotate E and B left 1
END	Terminate program
ENT	Entry point
ERA	Rotate E and A right 1
ERB	Rotate E and B right 1
EQU	Equate symbol
EXT	External reference
FAD	Floating add
FDV	Floating divide
FMP	Floating multiply
FSB	Floating subtract
HED	Print heading at top of each page
HLT	Halt
IFN	When N appears in Control Statement, assemble ensuing instructions
IFZ	When Z appears in Control Statement, assemble ensuing instructions
INA	Increment A by 1
INB	Increment B by 1
IOR	Inclusive "or" to A
ISZ	Increment, then skip if zero
JMP	Jump

JSB	Jump to subroutine
LDA	Load into A
LDB	Load into B
LIA	Load into A from I/O channel
LIB	Load into B from I/O channel
LSL	Logical long shift left
LSR	Logical long shift right
LST	Resume list output (follows a UNL)
MIA	Merge (or) into A from I/O channel
MIB	Merge (or) into B from I/O channel
MPY	Multiply
NAM	Names relocatable program
NOP	No operation
OCT	Defines octal constant
ORB	Establish origin in base page
ORG	Establish program origin
ORR	Reset program location counter
OTA	Output from A to I/O channel
OTB	Output from B to I/O channel
RAL	Rotate A left 1
RAR	Rotate A right 1
RBL	Rotate B left 1
RBR	Rotate B right 1
REP	Repeat next statement
RRL	Rotate A and B left
RRR	Rotate A and B right
RSS	Reverse skip sense
SEZ	Skip if E = 0
SFC	Skip if I/O flag = 0 (clear)
SFS	Skip if I/O flag = 1 (set)
SKP	Skip to top of next page

SLA	Skip if LSB of A = 0
SLB	Skip if LSB of B = 0
SOC	Skip if overflow bit = 0 (clear)
SOS	Skip if overflow bit = 1 (set)
SPC	Space n lines
SSA	Skip if sign A = 0
SSB	Skip if sign B = 0
STA	Store A
STB	Store B
STC	Set I/O control bit
STF	Set I/O flag
STO	Set overflow bit
SUP	Suppress list output of additional code lines
SWP	Switch the (A) and (B)
SZA	Skip if A = 0
SZB	Skip if B = 0
UNL	Suppress list output
UNS	Resume list output of additional code lines
XIF	Terminate an IFN or IFZ group of instructions
XOR	Exclusive "or" to A

SAMPLE PROGRAMS D

Following are two sample problems, the second of which implements several options of the Extended Assembler.

A.

PARTS FILE UPDATE

A master file of parts is updated by a parts usage list to produce a new master parts file. A report, consisting of the parts used and their cost, is also produced.

The master file and the parts usage file contain four word records. Each record of the cost report is eleven words long.

The organization of the files is as follows:

Parts Master Files (PRTSM)

Identification	Quantity	Cost/ Item

Identification field of the Parts Master Files exists in ASCII althrough the entire record is read and written in binary.

Parts Usage File (PRTSU)

Identification	Quantity

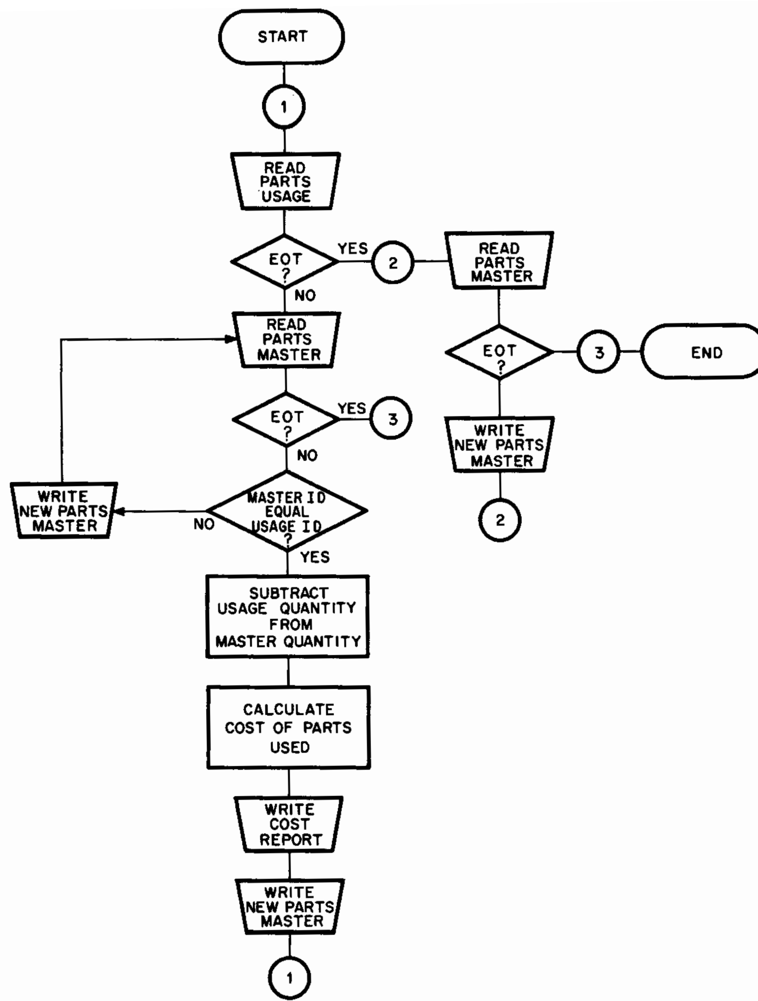
The parts usage file has been recorded in ASCII.

Parts Cost Report (PRTSC)

Identification		Quantity used		$	Cost for Quantity

The Parts Cost Report is recorded in ASCII with spacing and editing for printing.

The sample program reads and writes the files, adjusts the new stock levels, and calculates the cost. External subprograms perform the binary-to-decimal and decimal-to-binary conversions and handle unrecoverable input/output errors, invalid data conditions, and normal program termination. Input/output operations are performed using the Basic Control System input/output subroutine, .IOC.



SAMPLE PROGRAM
GENERAL FLOW CHART

SAMPLE ASSEMBLER SYMBOL TABLE OUTPUT

```
PAGE 0001


          0001      ASMB,R,B,L,T
START  R 000000
PRTSM  B 000000
PRTSU  B 000004
PRTSC  B 000010
EOTS1  B 000023
EOTS2  B 000024
MTEMP  B 000025
UTEMP  B 000026
SWTMP  B 000027
SPACS  B 000031
DLRSG  B 000033
A        000000
B        000001
.IOC.  X 000001
BCONV  X 000002
DCONV  X 000003
ABORT  X 000004
HALT   X 000005
DTOBI  C 000000
DTOBO  C 000002
BTODI  C 000003
BTODO  C 000005
OPEN   R 000002
SPCFL  R 000003
DLD    X 000006
DST    X 000007
READU  R 000013
CKSTU  R 000020
RJCTU  R 000035
EOTU   R 000040
MSGU   R 000051
READM  R 000063
CKSTM  R 000070
RJCTM  R 000105
EOTM   R 000110
MSGM   R 000117
HLTSW  R 000137
COMPR  R 000140
PROCM  R 000157
PROCC  R 000165
MPY    X 000010
CONVM  R 000213
CONU1  R 000224
CONU2  R 000235
CONVC  R 000246
WRITC  R 000261
CKSTC  R 000266
RJCTC  R 000276
WRITN  R 000301
CKSTN  R 000306
RJCTN  R 000316
**  NO ERRORS*
```

SAMPLE ASSEMBLER LIST OUTPUT

```
PAGE 0002

0001  00000               NAM UPDTE
0002  00000 000000  START NOP
0003  00001 026002R       JMP OPEN
0004  00000               ORB            ASSIGN STORAGE & CONSTANTS TO BP
0005  00000 000000  PRTSM BSS 4          MASTER PARTS FILE - BINARY.
0006  00004 000000  PRTSU BSS 4          PARTS USAGE LIST - ASCII.
0007  00010 000000  PRTSC BSS 11         PARTS COST REPORT - ASCII.
0008  00023 026063R EOTS1 JMP READM
0009  00024 026301R EOTS2 JMP WRITN
0010  00025 000000  MTEMP BSS 1
0011  00026 000000  UTEMP BSS 1
0012  00027 000000  SWTMP BSS 2
0013  00031 020040  SPACS ASC 2,
      00032 020040
0014  00033 020044  DLRSG ASC 1, $
0015  00000         A     EQU 0
0016  00001         B     EQU 1
0017                      EXT .IOC.      PERFORM I/O OPERATIONS USING BCS
0018*                                    I/O CONTROL ROUTINE.
0019                      EXT BCONV      ENTRY POINT FOR DECIMAL(ASCII)
0020*                                    TO BINARY CONVERSION SUBPROGRAM.
0021                      EXT DCONV      ENTRY POINT FOR BINARY TO
0022*                                    DECIMAL(ASCII) CONVERSION SUB-
0023*                                    PROGRAM.
0024                      EXT ABORT      ENTRY POINT FOR SUBPROGRAM WHICH
0025*                                    HANDLES UNRECOVERABLE I/O ERRORS
0026*                                    OR INVALID DATA.
0027                      EXT HALT       END OF PROGRAM SUBROUTINE.
0028                      COM DTOBI(2),DTOBO,BTODI(2),BTODO(2)
0029*                                    COMMON STORAGE LOCATIONS USED TO
0030*                                    PASS DATA BETWEEN MAIN PROGRAM
0031*                                    AND CONVERSION SUBPROGRAMS.
0032  00002               ORR            RESETS PLC AFTER USE OF ORB AT
0033*                                    BEGINNING OF PROGRAM.
0034  00002 000000  OPEN  NOP
0035  00003 016006X SPCFL DLD SPACS      STORES EDITING CHARACTERS IN
      00004 000031B
0036  00005 016007X       DST PRTSC+2    OUTPUT AREA FOR PARTS COST
      00006 000012B
0037  00007 016007X       DST PRTSC+6    REPORT.
      00010 000016B
0038  00011 060033B       LDA DLRSG
0039  00012 070020B       STA PRTSC+8
0040  00013 016001X READU JSB .IOC.      READ ONE RECORD FROM USAGE LIST
0041  00014 010001        OCT 10001      LOCATED ON STANDARD UNIT 1
0042  00015 026035R       JMP RJCTU      (TELEPRINTER INPUT). PRTSU IS
0043  00016 000004B       DEF PRTSU      ADDRESS OF STORAGE AREA; AREA IS
0044  00017 000004        DEC 4          4 WORDS LONG.
0045  00020 016001X CKSTU JSB .IOC.      CHECK STATUS OF UNIT 1.
0046  00021 040001        OCT 40001
0047  00022 002020        SSA
0048  00023 026020R       JMP CKSTU      IF BUSY, LOOP UNTIL FREE.
0049  00024 001200        RAL
0050  00025 002020        SSA
0051  00026 026030R       JMP *+2
0052  00027 026063R       JMP READM      IF COMPLETE, TRANSFER TO SECTION
0053*                                    WHICH READS MASTER FILE RECORD.
```

```
0054  00030 001727          ALF,ALF      TEST END OF TAPE STATUS BIT
0055  00031 001200          RAL          (ORIGINAL BIT 05).
0056  00032 002020          SSA
0057  00033 026040R         JMP EOTU     IF SET, GO TO EOT PROCEDURE.
0058  00034@026004X         JMP ABORT    IF NOT SET, SOME ERROR CONDITION
0059*                                    (UNRECOVERABLE) EXISTS.
0060  00035 006020   RJCTU  SSB          CHECK CAUSE OF REJECT.  IF UNIT
0061  00036 026013R         JMP READU    BUSY LOOP UNTIL FREE. ANY OTHER
0062  00037 026004X         JMP ABORT    CAUSE IS UNRECOVERABLE ERROR.
0063  00040 060023B  EOTU   LDA EOTS1    IF END OF USAGE FILE, ALTER
0064  00041 072002R         STA OPEN     PROGRAM SEQUENCE TO BYPASS
0065  00042 060024B         LDA EOTS2    SECTIONS THAT READ AND PROCESS
0066  00043 072140R         STA COMPR    USAGE FILE. PRINT MESSAGE ON
0067  00044 016001X         JSB .IOC.    TELEPRINTER INDICATING EOT.
0068  00045 020002          OCT 20002
0069  00046 026044R         JMP EOTU+4
0070  00047 000052R         DEF MSGU
0071  00050 000011          DEC 9
0072  00051 026063R         JMP READM
      00052 042516   MSGU   ASC 9,END OF USAGE FILE
      00053 042040
      00054 047506
      00055 020125
      00056 051501
      00057 043505
      00060 020106
      00061 044514
0073  00062 042440
0074  00063 016001X  READM  JSB .IOC.    READ A RECORD FROM MASTER PARTS
0075  00064 010105          OCT 10105    FILE ON STANDARD UNIT 05(PUNCHED
0076  00065 026105R         JMP RJCTM    TAPE READER).PRTSM IS ADDRESS
0077  00066 000000B         DEF PRTSM    OF STORAGE AREA; AREA IS 4 WORDS
0078  00067 000004          DEC 4        LONG. RECORD IS IN BINARY FORMAT
0079  00070 016001X  CKSTM  JSB .IOC.    CHECK STATUS@OF UNIT 5.
0080  00071 040005          OCT 40005
0081  00072 002020          SSA
0082  00073 026070R         JMP CKSTM    IF BUSY, LOOP UNTIL FREE.
0083  00074 001200          RAL
0084  00075 002020          SSA
0085  00076 026100R         JMP *+2
0086  00077 026140R         JMP COMPR    IF COMPLETE, TRANSFER TO EITHER
0087  00100 001727          ALF,ALF      PROCESSING OR WRITE OUTPUT
0088  00101 001200          RAL          DEPENDING ON SETTING OF COMPR.
0089  00102 002020          SSA          TEST FOR END OF TAPE.
0090  00103 026110R         JMP EOTM     IF END, GO TO EOT PROCEDURE.
0091  00104 026004X         JMP ABORT    IF NOT, AN UNRECOVERABLE ERROR
0092*                                    EXISTS
0093  00105 006020   RJCTM  SSB          CHECK CONTENTS OF B FOR CAUSE OF
0094  00106 026063R         JMP READM    REJECT.  IF UNIT BUSY, LOOP UNTIL
0095  00107 026004X         JMP ABORT    FREE, OTHERWISE I/O ERROR EXISTS
0096  00110 062137R  EOTM   LDA HLTSW    ALTER PROGRAM SEQUENCE TO HALT
0097  00111 072315R         STA CKSTN+7  EXECUTION AFTER LAST RECORD IS
0098  00112 016001X         JSB .IOC.    WRITTEN PRINT MESSAGE
0099  00113 020002          OCT 20002    INDICATING END OF MASTER INPUT.
0100  00114 026112R         JMP EOTM+2
0101  00115 000120R         DEF MSGM
0102  00116 000017          DEC 15
0103  00117 026140R         JMP COMPR
```

```
      00120 042516  MSGM ASC 15,END OF MASTER PARTS FILE INPUT
      00121 042840
      00122 047506
      00123 020115
      00124 040523
      00125 052105
      00126 050101
      00127 050101
      00130 051124
      00131 051440
      00132 043111
      00133 046105
      00134 020111
      00135 047120
0104  00136 052524
0105  00137 026005X HLTSW JMP HALT    END OF PROGRAM SUBROUTINE.
0106  00140 000000  COMPR NOP
0107  00141 016224R       JSB CONU1   CONVERT ID NUMBER FIELDS OF
0108  00142 016213R       JSB CONVM   MASTER AND USAGE FILES TO BIN.
0109  00143 060026B       LDA UTEMP   LOAD THESE FIELD FROM TEMPORARY
0110  00144 014025B       LDA MTEMP   STORAGE.
0111  00145 050001        CPA B       COMPARE
0112  00146 026157R       JMP PROCM   IF EQUAL, JUMP TO PROCESSING
0113  00147 007004        CMB,INB     IF ID NUMBER OF MASTER GREATER
0114  00150 040001        ADA B       THAN ID NUMBER OF USAGE, DATA IN
0115  00151 002020        SSA         USAGE FILE ERRONEOUS.  TERMINATE
0116  00152 025004X       JMP ABORT   RUN.
0117  00153 062156R       LDA *+3     IF ID MASTER LESS THAN ID USAGE,
0118  00154 072315R       STA CKSTN+7 ALTER SEQUENCE: READ NEXT MASTER
0119  00155 026301R       JMP WRITN   RECORD IMMEDIATELY AFTER WRITING
0120  00156 026063R       JMP READM   CURRENT MASTER RECORD.
0121  00157 016235R PROCM JSB CONU2   CONVERT QUANTITY FIELD OF USAGE
0122  00160 060002B       LDA PRTSM+2 FILE TO BINARY AND SUBTRACT FROM
0123  00161 064027B       LDB UTEMP+1 QUANTITY FIELD OF MASTER AND
0124  00162 007004        CMB,INB     STORE RESULT.
0125  00163 040001        ADA B
0126  00164 070002B       STA PRTSM+2
0127  00165 016006X PROCC DLD PRTSU   STORE ID OF PARTS USED IN REPORT
      00166 000004B
0128  00167 016007X       DST PRTSC   FILE STORAGE AREA.
      00170 000010B
0129  00171 016006X       DLD PRTSU+2 STORE QUANTITY OF PARTS USED IN
      00172 000006B
0130  00173 016007X       DST PRTSC+4 REPORT FILE STORAGE AREA.
      00174 000014B
0131  00175 060003B       LDA PRTSM+3 COMPUTE COST OF PARTS USED.
0132  00176 016010X       MPY UTEMP+1
      00177 000027B
0133  00200 070030B       STA SWTMP+1
0134  00201 074027B       STB SWTMP
0135  00202 016246R       JSB CONVC   CONVERT RESULT TO DECIMAL
0136  00203 016006X       DLD SWTMP
      00204 000027B
0137  00205 016007X       DST PRTSC+9 STORE IN REPORT FILE AREA.
      00206 000021B
0138  00207 062212R       LDA *+3     ALTER SEQUENCE: READ NEXT USAGE
0139  00210 072315R       STA CKSTN+7 RECORD AFTER WRITING CURRENT
0140  00211 026261R       JMP WRITC   MASTER RECORD.
```

```
0141  00212 026013R        JMP READU
0142  00213 000000  CONVM NOP
0143  00214 016006X        DLD PRTSM      STORE ID FIELDS IN COMMON
      00215 000000B
0144  00216 016007X        DST DTOBI      LOCATIONS TO BE PROCESSED BY
      00217 000000C
0145  00220 016002X        JSB BCONV      CONVERSION SUBPROGRAM. ON
0146  00221 062002C        LDA DTOBO      COMPLETION, STORE RESULTS IN
0147  00222 070025B        STA MTEMP      LOCATIONS USED BY PROCESSING
0148  00223 126213R        JMP CONVM,I    SECTIONS. CONVM APPLIES TO ID OF
0149  00224 000000  CONU1 NOP             MASTER PARTS FILE; CONU1, TO ID
0150  00225 016006X        DLD PRTSU      OF USAGE; CONU2, TO QUANTITY OF
      00226 000004B
0151  00227 016007X        DST DTOBI      USAGE; AND CONVC, TO COST OF
      00230 000000C
0152  00231 016002X        JSB BCONV      PARTS(THIS IS A BINARY TO
0153  00232 062002C        LDA DTOBO      DECIMAL CONVERSION).
0154  00233 070026B        STA UTEMP
0155  00234 126224R        JMP CONU1,I
0156  00235 000000  CONU2 NOP
0157  00236 016006X        DLD PRTSU+2
      00237 000006B
0158  00240 016007X        DST DTOBI
      00241 000000C
0159  00242 016002X        JSB BCONV
0160  00243 062002C        LDA DTOBO
0161  00244 070027B        STA UTEMP+1
0162  00245 126235R        JMP CONU2,I
0163  00246 000000  CONVC NOP
0164  00247 016006X        DLD SWTMP
      00250 000027B
0165  00251 016007X        DST BTODI
      00252 000003C
0166  00253 016003X        JSB DCONV
0167  00254 016006X        DLD BTODO
      00255 000005C
0168  00256 016007X        DST SWTMP
      00257 000027B
0169  00260 126246R        JMP CONVC,I
0170  00261 016001X WRITC JSB .IOC.       WRITE ONE RECORD OF PARTS COST
0171  00262 020102         OCT 20102      REPORT ON STANDARD UNIT 2
0172  00263 026276R        JMP RJCTC      (TELEPRINTER OUTPUT). PRTSC IS
0173  00264 000010B        DEF PRTSC      ADDRESS IN STORAGE AREA; AREA IS
0174  00265 000013         DEC 11         11 WORDS LONG. RECORD IS IN ASCI
0175  00266 016001X CKSTC JSB .IOC.       CHECK STATUS OF UNIT 2.
0176  00267 040002         OCT 40002
0177  00270 002020         SSA
0178  00271 026266R        JMP CKSTC      IF BUSY, LOOP UNTIL FREE.
0179  00272 001200         RAL
0180  00273 002020         SSA
0181  00274 026004X        JMP ABORT      TERMINATE IF ANY I/O ERROR.
0182  00275 026301R        JMP WRITN      IF COMPLETE, TRANSFER TO WRITN.
0183  00276 006020  RJCTC SSB             IF BUSY, LOOP UNTIL FREE.
0184  00277 026261R        JMP WRITC      TERMINATE ON ANY OTHER REJECT
0185  00300 026004X        JMP ABORT      CONDITION.
0186  00301 016001X WRITN JSB .IOC.       WRITE ONE RECORD (BINARY) OF
0187  00302 020104         OCT 20104      NEW MASTER PARTS LIST ON UNIT 4
0188  00303 026316R        JMP RJCTN      (TAPE PUNCH). PRTSM (INPUT AREA)
```

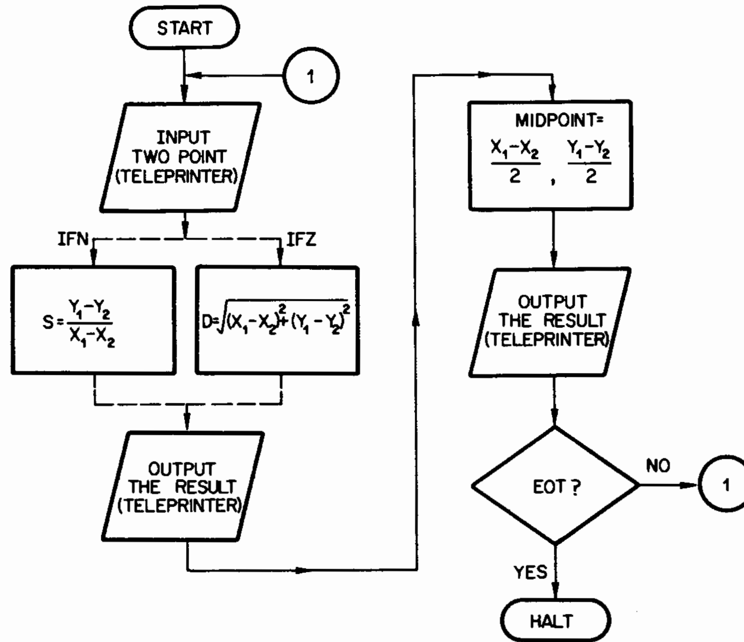
```
0189  00304 000000B          DEF PRTSM      IS ALSO USED AS OUTPUT AREA.
0190  00305 000004           DEC 4
0191  00306 016001X CKSTN JSB .IOC.         CHECK STATUS OF UNIT 4.
0192  00307 040004           OCT 40004
0193  00310 002020           SSA
0194  00311 026306R          JMP CKSTN      IF BUSY, LOOP UNTIL FREE.
0195  00312 001200           RAL
0196  00313 002020           SSA
0197  00314 026004X          JMP ABORT
0198  00315 026013R          JMP READU
0199  00316 006020  RJCTN SSB               IF BUSY, LOOP UNTIL FREE, OTHER-
0200  00317 026301R          JMP WRITN      WISE TERMINATE.
0201  00320 026004X          JMP ABORT
0202                         END START
**  NO ERRORS*
```

B.

Program "Line" will either calculate the distance between two points or find the slope of the line connecting the points; then the point equidistant from each point (the mid-point) is calculated.

Data is input using the formatter library routine four n-digit real numbers at a time. The first quantity is the X coordinate of the first point; the second quantity is the Y coordinate of the first point; the third and fourth quantities are the X and Y co-ordinates of the second point.

The result is output to the teleprinter by the formatter library routine; each quantity cannot be more than an eight digit real number.



GENERAL FLOW CHART

Below is the source program as it is typed up on the teleprinter. After it are the assembler listings. The first listing results from including the Z option in the control statement. In the second listing the N option has been included in the control statement.

NOTE: When the complete data tape has been read and the tape reader encounters 10 blank feed frames, an EQT message is typed on the teleprinter and the computer halts. Thus no halt instruction is needed in the program.)

```
       HED LINE FORMULI:  DISTANCE, SLOPE, MID-POINT
*   PROGRAM LINE WILL EITHER CALCULATE THE DISTANCE BETWEEN
*   TWO POINTS OR FIND THE SLOPE OF THE LINE CONNECTING
*   THE POINTS; THEN THE POINT EQUIDISTANT FROM EACH
*   POINT (THE MID-POINT) IS CALCULATED.
*      DATA IS INPUT USING THE FORMATTER LIBRARY ROUTINE
*   FOUR N-DIGIT REAL NUMBERS AT A TIME.  THE FIRST
*   QUANTITY IS THE X COORDINATE OF THE FIRST POINT;THE
*   SECOND QUANTITY IS THE Y COORDINATE OF THE FIRST POINT;
*   THE THIRO AND FOURTH QUANTITIES ARE THE X AND Y COORDINATES
*   OF THE SECOND POINT.
*      THE RESULT IS OUTPUT TO THE TELEPRINTER BY THE
*   FORMATTER LIBRARY ROUTINE; EACH QUANTITY CANNOT BE MORE
*   THAN AN EIGHT OIGIT REAL NUMBER.
       NAM LINE
START  NOP
       JMP INPUT
       EXT .IOC.,FLOAT,IFIX,SQRT
       EXT .DIO.,.IOI.,.DTA.,.RAR.
       EXT .IOR.,.IAR.
.DATA  DEF DATA
.PRIN  DEF PRINT
DATA   BSS 4
FMT    ASC 3,(F8.3)
FMT2   ASC 8,(F8.3,",",F8.3/)
FMT3   ASC 3,(4I2)
       SKP
*   INPUT THE FIRST TWO POINTS; FOUR DATA WORDS
INPUT  NOP
       LDA =B5
       CLB,INB
       JSB .DIO.
       DEF FMT3
       DEF *+4
       LDA =B4
       LDB .DATA
       JSB .IAR.
       SPC 3
*   THE DISTANCE BETWEEN THE TWO POINTS:
       IFZ
       LDA DATA+2
       CMA,INA
       ADA DATA
       SPC 1
       JMP *+5
PRINT  REP 4
       NOP
       SPC 1
       STA PRINT
       SUP
```

```
      MPY PRINT
      STA PRINT
      SPC 1
      LDA DATA+3
      CMA,INA
      ADA DATA+1
      STA PRINT+1
      MPY PRINT+1
      ADA PRINT
      SPC 1
      JSB FLOAT
      JSB SQRT
      DST PRINT
      XIF
      SPC 3
*  FIND THE SLOPE OF THE LINE
      IFN
      LDA DATA+2
      CMA,INA
      ADA DATA
      JMP *+5
PRINT REP 4
      NOP
      STA PRINT
      SPC 1
      LDA DATA+3
      CMA,INA
      ADA DATA+1
      CLB
      DIV PRINT
      DST PRINT
      XIF
      SPC 3
*  OUTPUT THE RESULT
      LDA =B2
      CLB
      JSB .DIO.
      DEF FMT
      DEF *+4
      DLD PRINT
      JSB .IOR.
      JSB .DTA.
      SPC 3
*  FIND THE MID-POINT OF THE LINE SEGMENT:
      LDA DATA
      ADA DATA+2
      CLB
      JSB FLOAT
      FMP =F.5
      DST PRINT
      SPC 1
      LDA DATA+1
      ADA DATA+3
      CLB
      JSB FLOAT
      FMP =F.5
      DST PRINT+2
      SPC 1
      UNL
```

```
LDA =B2
CLB
JSB .DIO.
DEF FMT2
DEF *+5
LDA =B2
LDB .PRIN
JSB .RAR.
JSB .DTA.
LST
SPC 3
UNS
JMP INPUT
END START
```

```
0001                    ASMB,R,L,T,Z
START R 000000
.IOC. X 000001
FLOAT X 000002
IFIX  X 000003
SQRT  X 000004
.DIO. X 000005
.IOI. X 000006
.OTA. X 000007
.RAR. X 000010
.IOR. X 000011
.IAR. X 000012
.OATA R 000002
.PRIN R 000003
DATA  R 000004
FMT   R 000010
FMT2  R 000013
FMT3  R 000023
INPUT R 000026
PRINT R 000043
.MPY  X 000013
.DST  X 000014
.DLD  X 000015
.FMP  X 000016
**  NO ERRORS*
```

```
0002*  PROGRAM LINE WILL EITHER CALCULATE THE DISTANCE BETWEEN
0003*  TWO POINTS OR FIND THE SLOPE OF THE LINE CONNECTING
0004*  THE POINTS; THEN THE POINT EQUIDISTANT FROM EACH
0005*  POINT (THE MID-POINT) IS CALCULATED.
0006*     DATA IS INPUT USING THE FORMATTER LIBRARY ROUTINE
0007*  FOUR N-DIGIT REAL NUMBERS AT A TIME.  THE FIRST
0008*  QUANTITY IS THE X COORDINATE OF THE FIRST POINT;THE
0009*  SECOND QUANTITY IS THE Y COORDINATE OF THE FIRST POINT;
0010*  THE THIRD AND FOURTH QUANTITIES ARE THE X AND Y COORDINATES
0011*  OF THE SECOND POINT.
0012*     THE RESULT IS OUTPUT TO THE TELEPRINTER BY THE
0013*  FORMATTER LIBRARY ROUTINE; EACH QUANTITY CANNOT BE MORE
0014*  THAN AN EIGHT DIGIT REAL NUMBER.
0015  00000               NAM LINE
0016  00000 000000  START NOP
0017  00001 026026R       JMP INPUT
0018                      EXT .IOC.,FLOAT,IFIX,SQRT
0019                      EXT .DIO.,.IOI.,.DTA.,.RAR.
0020                      EXT .IOR.,.IAR.
0021  00002 000004R .DATA DEF DATA
0022  00003 000043R .PRIN DEF PRINT
0023  00004 000000  DATA  BSS 4
0024  00010 024106  FMT   ASC 3,(F8.3)
      00011 034056
      00012 031451
0025  00013 024106  FMT2  ASC 8,(F8.3,",",F8.3/)
      00014 034056
      00015 031454
      00016 021054
      00017 021054
      00020 043070
      00021 027063
      00022 027451
0026  00023 024064  FMT3  ASC 3,(4I2)
      00024 044462
      00025 024440
```

```
0028*  INPUT THE FIRST TWO POINTS; FOUR DATA WORDS
0029   00026 000000  INPUT NOP
0030   00027 062131R       LDA =B5
0031   00030 006404        CLB,INB
0032   00031 016005X       JSB .DIO.
0033   00032 000023R       DEF FMT3
0034   00033 000037R       DEF *+4
0035   00034 062132R       LDA =B4
0036   00035 066002R       LDB .DATA
0037   00036 016012X       JSB .IAR.


0039*  THE DISTANCE BETWEEN THE TWO POINTS:
0040                       IFZ
0041   00037 062006R       LDA DATA+2
0042   00040 003004        CMA,INA
0043   00041 042004R       ADA DATA

0045   00042 026047R       JMP *+5
0046                 PRINT REP 4
0047   00043 000000        NOP
0047   00044 000000        NOP
0047   00045 000000        NOP
0047   00046 000000        NOP

0049   00047 072043R       STA PRINT
0050                       SUP
0051   00050 016013X       MPY PRINT
0052   00052 072043R       STA PRINT

0054   00053 062007R       LDA DATA+3
0055   00054 003004        CMA,INA
0056   00055 042005R       ADA DATA+1
0057   00056 072044R       STA PRINT+1
0058   00057 016013X       MPY PRINT+1
0059   00061 042043R       ADA PRINT

0061   00062 016002X       JSB FLOAT
0062   00063 016004X       JSB SQRT
0063   00064 016014X       DST PRINT
0064                       XIF


0066*  FIND THE SLOPE OF THE LINE
0067                       IFN
0068                       LDA DATA+2
0069                       CMA,INA
0070                       ADA DATA
0071                       JMP *+5
0072                 PRINT REP 4
0073                       NOP
0074                       STA PRINT
0075                       SPC 1
0076                       LDA DATA+3
0077                       CMA,INA
0078                       ADA DATA+1
```

```
0079                         CLB
0080                         DIV PRINT
0081                         DST PRINT
0082                         XIF


0084*  OUTPUT THE RESULT
0085   00066 062133R         LDA =B2
0086   00067 006400          CLB
0087   00070 016005X         JSB .DIO.
0088   00071 000010R         DEF FMT
0089   00072 000076R         DEF *+4
0090   00073 016015X         DLD PRINT
0091   00075 016011X         JSB .IOR.
0092   00076 016007X         JSB .DTA.


0094*  FIND THE MID-POINT OF THE LINE SEGMENT:
0095   00077 062004R         LDA DATA
0096   00100 042006R         ADA DATA+2
0097   00101 006400          CLB
0098   00102 016002X         JSB FLOAT
0099   00103 016016X         FMP =F.5
0100   00105 016014X         DST PRINT

0102   00107 062005R         LDA DATA+1
0103   00110 042007R         ADA DATA+3
0104   00111 006400          CLB
0105   00112 016002X         JSB FLOAT
0106   00113 016016X         FMP =F.5
0107   00115 016014X         DST PRINT+2

0119                         LST



0121                         UNS
0122   00130 026026R         JMP INPUT
       00131 000005
       00132 000004
       00133 000002
       00134 040000
       00135 000000
0123                         END START
**  NO ERRORS*
```

```
0001                     ASMB,R,L,T,N
START R 000000
.IOC. X 000001
FLOAT X 000002
IFIX  X 000003
SQRT  X 000004
.DIO. X 000005
.IOI. X 000006
.DTA. X 000007
.RAR. X 000010
.IOR. X 000011
.IAR. X 000012
.DATA R 000002
.PRIN R 000003
DATA  R 000004
FMT   R 000010
FMT2  R 000013
FMT3  R 000023
INPUT R 000026
PRINT R 000043
.DIV  X 000013
.DST  X 000014
.DLD  X 000015
.FMP  X 000016
**  NO ERRORS*
```

```
0002*  PROGRAM LINE WILL EITHER CALCULATE THE DISTANCE BETWEEN
0003*  TWO POINTS OR FIND THE SLOPE OF THE LINE CONNECTING
0004*  THE POINTS; THEN THE POINT EQUIDISTANT FROM EACH
0005*  POINT (THE MID-POINT) IS CALCULATED.
0006*     DATA IS INPUT USING THE FORMATTER LIBRARY ROUTINE
0007*  FOUR N-DIGIT REAL NUMBERS AT A TIME.  THE FIRST
0008*  QUANTITY IS THE X COORDINATE OF THE FIRST POINT;THE
0009*  SECOND QUANTITY IS THE Y COORDINATE OF THE FIRST POINT;
0010*  THE THIRD AND FOURTH QUANTITIES ARE THE X AND Y COORDINATES
0011*  OF THE SECOND POINT.
0012*     THE RESULT IS OUTPUT TO THE TELEPRINTER BY THE
0013*  FORMATTER LIBRARY ROUTINE; EACH QUANTITY CANNOT BE MORE
0014*  THAN AN EIGHT DIGIT REAL NUMBER.
0015  00000                 NAM LINE
0016  00000 000000  START NOP
0017  00001 026026R       JMP INPUT
0018                      EXT .IOC.,FLOAT,IFIX,SQRT
0019                      EXT .DIO.,.IOI.,.DTA.,.RAR.
0020                      EXT .IOR.,.IAR.
0021  00002 000004R .DATA DEF DATA
0022  00003 000043R .PRIN DEF PRINT
0023  00004 000000  DATA  BSS 4
0024  00010 024106  FMT   ASC 3,(F8.3)
      00011 034056
      00012 031451
0025  00013 024106  FMT2  ASC 8,(F8.3,",",F8.3/)
      00014 034056
      00015 031454
      00016 021054
      00017 021054
      00020 043070
      00021 027063
      00022 027451
0026  00023 024064  FMT3  ASC 3,(4I2)
      00024 044462
      00025 024440
```

```
0028*  INPUT THE FIRST TWO POINTS; FOUR DATA WORDS
0029   00026 000000  INPUT NOP
0030   00027 062123R       LDA =B5
0031   00030 006404        CLB,INB
0032   00031 016005X       JSB .DIO.
0033   00032 000023R       DEF FMT3
0034   00033 000037R       DEF *+4
0035   00034 062124R       LDA =B4
0036   00035 066002R       LDB .DATA
0037   00036 016012X       JSB .IAR.


0039*  THE DISTANCE BETWEEN THE TWO POINTS:
0040                       IFZ
0041                       LDA DATA+2
0042                       CMA,INA
0043                       ADA DATA
0044                       SPC 1
0045                       JMP *+5
0046                 PRINT REP 4
0047                       NOP
0048                       SPC 1
0049                       STA PRINT
0050                       SUP
0051                       MPY PRINT
0052                       STA PRINT
0053                       SPC 1
0054                       LDA DATA+3
0055                       CMA,INA
0056                       ADA DATA+1
0057                       STA PRINT+1
0058                       MPY PRINT+1
0059                       ADA PRINT
0060                       SPC 1
0061                       JSB FLOAT
0062                       JSB SQRT
0063                       DST PRINT
0064                       XIF


0066*  FIND THE SLOPE OF THE LINE
0067                       IFN
0068   00037 062006R       LDA DATA+2
0069   00040 003004        CMA,INA
0070   00041 042004R       ADA DATA
0071   00042 026047R       JMP *+5
0072                 PRINT REP 4
0073   00043 000000        NOP
0073   00044 000000        NOP
0073   00045 000000        NOP
0073   00046 000000        NOP
0074   00047 072043R       STA PRINT

0076   00050 062007R       LDA DATA+3
0077   00051 003004        CMA,INA
0078   00052 042005R       ADA DATA+1
```

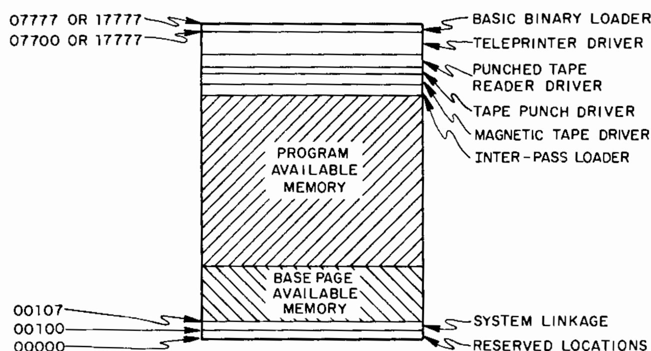
```
0028*  INPUT THE FIRST TWO POINTS; FOUR DATA WORDS
0029   00026 000000  INPUT NOP
0030   00027 062123R       LDA =B5
0031   00030 006404        CLB,INB
0032   00031 016005X       JSB .DIO.
0033   00032 000023R       DEF FMT3
0034   00033 000037R       DEF *+4
0035   00034 062124R       LDA =B4
0036   00035 066002R       LDB .DATA
0037   00036 016012X       JSB .IAR.


0039*  THE DISTANCE BETWEEN THE TWO POINTS:
0040                       IFZ
0041                       LDA DATA+2
0042                       CMA,INA
0043                       ADA DATA
0044                       SPC 1
0045                       JMP *+5
0046                 PRINT REP 4
0047                       NOP
0048                       SPC 1
0049                       STA PRINT
0050                       SUP
0051                       MPY PRINT
0052                       STA PRINT
0053                       SPC 1
0054                       LDA DATA+3
0055                       CMA,INA
0056                       ADA DATA+1
0057                       STA PRINT+1
0058                       MPY PRINT+1
0059                       ADA PRINT
0060                       SPC 1
0061                       JSB FLOAT
0062                       JSB SQRT
0063                       DST PRINT
0064                       XIF


0066*  FIND THE SLOPE OF THE LINE
0067                       IFN
0068   00037 062006R       LDA DATA+2
0069   00040 003004        CMA,INA
0070   00041 042004R       ADA DATA
0071   00042 026047R       JMP *+5
0072                 PRINT REP 4
0073   00043 000000        NOP
0073   00044 000000        NOP
0073   00045 000000        NOP
0073   00046 000000        NOP
0074   00047 072043R       STA PRINT

0076   00050 062007R       LDA DATA+3
0077   00051 003004        CMA,INA
0078   00052 042005R       ADA DATA+1
```

The System Input/Outout (SIO) subroutines may be used to perform basic input/output operations for programs in absolute form. †

MEMORY ALLOCATION

These drivers are stored in high memory immediately preceding the Basic Binary Loader. The Teleprinter driver must be loaded first; it is stored in the highest portion of this area. The drivers for the Punched Tape Reader (or Marked Card Reader), the Tape Punch, and the Magnetic Tape Unit may then be loaded. The sequence of loading must fall within this order, depending on your equipment configuration: Line Printer Driver, Punched Tape Reader Driver (or Marked Card Reader), Tape Punch Driver, Magnetic Tape Driver, and if needed, the MTS Boot.

The drivers are accessed through 15-bit absolute addresses which are stored in the System Linkage area starting at location 101_8. The allocation of memory is as follows:



† The SIO subroutines are designed for use with FORTRAN, Assembler, Symbolic Editor, etc.; however, they may be used with any absolute object program.

OPERATION AND CALLING SEQUENCE:

PAPER TAPE DEVICES

All data transmission is accomplished without interrupt control, and therefore, operations are not buffered by the drivers. Control is not returned to the calling program until an operation is completed. Data is transferred to and from buffer storage areas specified in the user program.

The general form of the paper tape input/output calling sequence is:

```
LDA <buffer length> (words or characters)
LDB <buffer address>
JSB 10fB,I     (f is Input/Output function)
<normal return>
```

Register Contents

When the JSB is performed, the A-Register must contain the lengths of the buffer storage area and the B-Register, the address of the buffer. Control returns to the location following the JSB. After an input request is completed, the A-Register contains either a positive integer to indicate the number of characters transmitted, or a negative integer to indicate the number of words transmitted or zeros, if an End-of-Tape (EOT) condition occurred.

The digit supplied for f in the JSB instruction determines the paper tape input/output function to be performed. The value of the operand address is the location in the System Linkage that contains the absolute address of the driver entry point. The following are available:

- 101 Input
- 102 List Output
- 103 Punch Output
- 104 Keyboard Input—ASCII data is read from Teleprinter and printed as it is received.

If the Teleprinter driver alone is loaded, these locations point to entry points of this driver. If Punched Tape Reader and Tape Punch drivers are in memory, location 101 points to the Punched Tape Reader driver and location 103, to the Tape Punch driver. If the latter are to be used, they must be loaded after the Teleprinter driver.

OPERATION AND CALLING SEQUENCE: MAGNETIC TAPE DRIVER

As with the Paper Tape SIO drivers, all data transmission is accomplished without interrupt control. Control is not returned to the calling program until an operation is completed. (Rewind and rewind standby are the only exceptions to this. In these cases return is made as soon as the command is accepted.)

The general form of the calling sequence is:

```
LDA  <buffer length>  or  <file count>
LDB  <buffer address>  or  <record count>
JSB  107B,I
OCT  <command code>
<EOF/EOT return>
<error return>
<normal return>
```

NOTE: Location 107_8 must contain the address of the magnetic tape driver.

Register Contents

Before initiating read or write operations, the A-Register must contain the buffer length. This will be a positive integer if length is defined in characters and a negative integer if length is defined in words. The B-Register must contain the buffer address.

Before initiating tape positioning operations, the A-Register must contain the number of files that are to be spaced. A positive integer indicates forward spacing; a negative integer indicates backward spacing. The B-Register contains the number of records that are to be spaced. A positive integer indicates forward spacing; a negative integer indicates backward spacing. The positioning may be defined in terms of any combination of forward or backward spacing of files and records (e.g., space forward two files then backspace three records). If files only or records only are to be spaced, the contents of the other register should be zeros.

The registers are not used when entering the subroutine to perform one of the following operations:

Write end-of-file	Rewind/Standby
Write file gap	Status
Rewind	

Linkage Address

107B is the System Linkage word that contains the absolute address of the entry point for the Magnetic Tape driver.

On return from a read operation, the A-Register contains a positive value indicating the number of words or characters transmitted.

On return from all operations except Rewind and Rewind/ Standby the B-Register contains status of the operation (See Status).

MAGNETIC TAPE OPERATIONS

The magnetic tape driver will perform the following operations. The pertinent operation is specified by the command code which appears after the OCT in the calling sequence.

Operation	Command Code
Read	0
Write	1
Write End-of-File	2
Rewind (Auto mode)	3
Position	4
Rewind/Standby (Local mode)	5
Gap	6
Status	7

Read

One tape record is read into the buffer. The number of characters or words read is stored in the A-Register. The value will be equal to the buffer length except when the data on tape is less than the length of the buffer. One tape record is read to transfer the number of characters specified into the buffer. The number of characters in that record (not the number transferred) will be stored in the A-Register. If the tape record exceeds the buffer length, the data will be read into the buffer until the buffer is filled, the remainder of the record will be skipped. If the length of an input buffer is an odd number of characters, a read operation will result in the overlaying of the character following the last character of the buffer; the subroutine actually transmits full words only.

Three attempts are made to read the record before returning control to the parity error address.

If an EOT condition exists at the time of entry, the command will be ignored and control will be returned to the EOT/EOF address.

If the buffer length specified is 0 control will return to the normal address without any tape movement.

The input buffer storage area can be as large or as small as needed. The number of characters in the tape record will be stored in the A-Register.

Write

The contents of the buffer is written on tape preceded by the record length. Since a minimum of 7 tape characters (12 on 3030) may be written, short records are padded by the subroutine.

If the end-of-tape is detected during the write operation, the normal return is used. The next write operation, however, results in a return of control of the EOF/EOT location; no data is written. If an EOT condition exists at the time of entry, the command will be ignored and control will be returned to the EOT/EOF address.

If the write request length specified is 0 control will return to the normal address without any tape movement.

If an error is detected during the write operation, the tape will be back-spaced over the bad record, 3 inches of tape will be erased, and another attempt will be made. These attempts will continue until either a good record is made or until the EOT is detected at which time the control will return to the error address.

Write End-of-File

A standard EOF character (17_8) is written on tape. Control returns to the normal location with the EOF status on the B-Register. No gap is written.

If the end of tape was reached on a previous write command, control returns to the EOF/EOT location; the character is written.

Rewind

This command initiates a rewind operation and then immediately returns control to the normal location.

The calling sequence for a Rewind operation consists of:

```
JSB     107B,I
OCT     3
<normal return>
```

The user need not test status on the rewind operation before issuing the next call.

Position

This is the general command to move the tape. Both file and record operations may be defined in the same operation. Either may be specified for forward or backward spacing. At the completion of the operation the tape will be positioned ready for reading or writing.

An attempt to space beyond the End-of-Tape or Start-of-Tape will terminate the positioning operation and return control to the EOF/EOT/SOT location.

Rewind and Standby

This causes the tape to be positioned at load point and switches the device to local status. Control returns to the normal location immediately after the operation is initiated.

The calling sequence for a Rewind / Standby operation consists of:

```
JSB     107B,I
OCT     5
<normal return>
```

An attempt to issue another call on this device results in a halt (102044). The device must be switched to AUTO before the program can continue.

Gap

This command causes a 3-inch gap to be written on the tape.

If the End-of-Tape was reached on a previous write command, control returns to the EOF/EOT location; the gap is not written.

Status

This command returns certain status bits in the B-Register. The driver performs a clear command whenever it is entered and as a result the only bits that are valid indicators are:

Start-of-Tape
End-of-Tape
Write Not Enabled

All other commands (except Rewind and Rewind/Standby) provide valid status replies on return to the program.

The status reply consists only of bits 8-0 and has the following significance:

Bits 8-0	Condition
1xxxxxxxx	Local - The device is in local status
x1xxxxxxx	EOF- An End-of-File character (17_8 for 7 track, 23_8 for 9) has been detected while reading, forward spacing, or backspacing.
xx1xxxxxx	SOT - The Start-of-Tape marker is under the photo sense head.
xxx1xxxxx	EOT - The End-of-Tape reflective marker is sensed while the tape is moving forward. The bit remains set until a rewind command is given.
xxxx1xxxx	Timing - A character was lost.
xxxxx1xxx	Reject - a) Tape motion is required and the unit is busy. b) Backward tape motion is required and the tape is at load point. c) A write command is given and the tape reel does not have a write enable ring.
xxxxxx1xx	Write not enabled - Tape reel does not have write enable ring or tape unit is rewinding.
xxxxxxx1x	Parity error - A vertical or longitudinal parity error occurred during reading or writing. (Parity is not checked during forward or backward spacing operations.)
xxxxxxxx1	Busy - The tape is in motion or the device is in local status.

Following is a table summarizing the tape commands:

Operation	Command Code	Call		Return	
		A	B	A	B
Read	Ø	Buffer Length	Buffer Address	Buffer or Record Length	Status
Write	1	Buffer Length	Buffer Address	Buffer Length	Status
Write EOF	2	-	-	-	Status
Rewind (Auto mode)	3	-	-	-	-
Position	4	Number of Files, Direc- tion	Number of Records, Direction	-	Status
Rewind/ Standby (Local mode)	5	-	-	-	-
Gap	6	-	-	-	Status
Status	7	-	-		Status

Error Messages

Tape Unit in Local Status:

The subroutine halts with 102044 in the T-Register. Switch tape unit to AUTO mode and press RUN to continue.

Write Not Enabled:

The subroutine halts with 102011 in the T-Register. The error is irrecoverable.

Additional Linkage Addresses

Other locations in the System Linkage area contain the following:

100_8 Used by the standard software system to store a JMP to the transfer address.

105_8 First word address of available memory.

106_8 Last word address of available memory.

The latter two locations may be accessed by an absolute program. The user may store the first word of available memory in 105 by performing the following:

```
ORG  105B
ABS  < last location of user program +1 >
```

The last word of available memory is established by the drivers; it is the location immediately preceding the first location used by the last driver loaded.

BUFFER STORAGE AREA

The Buffer Address is the location of the first word of data to be written on an output device or the first word of a block reserved for storage of data read from an input device. The length of the buffer area is specified in the A-Register in terms of ASCII input or output characters or binary output words. For binary input, the length of the buffer is the length of the record which is specified in the first character of the record. ASCII and binary input record lengths are given as positive integers. The length of a binary output record is specified as the two's complement of the number of words in the record.

In addition to describing the buffer area in the calling sequence, (or first word of binary input record), the area must also be specifically defined in the program, for example with a BSS instruction.

Record Formats

ASCII Records (Paper Tape)

An ASCII record is a group of characters terminated by an end-of-record mark which consists of a carriage return, (CR), and a line feed, (LF).

For an input operation, the length of the record transmitted to the buffer is the number of characters designated in the A-Register, or less if an end-of-record mark is encountered before the character count is exhausted. The codes for (CR) and (LF) are not transmitted to the buffer. An end-of-record mark preceding the first data character is ignored.

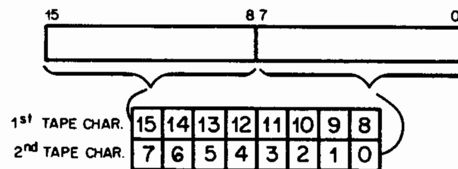
For an output operation, the length of the record is determined by the number of characters designated in the request. An end-of-record mark is supplied at the end of each output operation by the driver.

If a (RUB OUT) code followed by a (CR)(LF) is encountered on input from the Teleprinter or Punched Tape Reader, the current record is ignored (deleted) and the next record transmitted. †

If less than ten feed frames (all zeros) are encountered before the first data character from the Punched Tape Reader, they are ignored. Ten feed frames are interpreted as an end-of-tape condition.

Binary Records (Paper Tape)

A binary record is transmitted exactly as it appears in memory or on 8-level paper tape. Each computer word is translated into two tape "characters" (and vice versa) as follows:



For an output operation, the record length is the number of words designated by the value in the A-Register (the value is the two's complement of the number of words). For input operations, the first word of the record contains a positive integer in bits 15-8 specifying the length (in words) of the record including the first word.

† (RUB OUT) which appears on the Teleprinter keyboard is synonymous with the ASCII symbol (DEL)

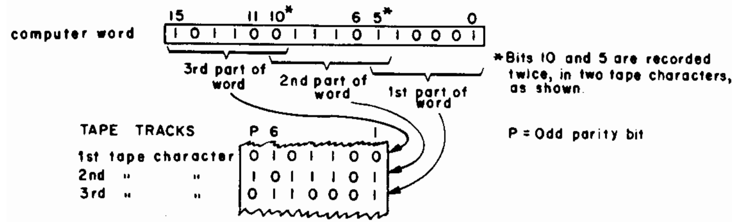
On input operations if less than ten feed frames precede the first data character, they are ignored; ten feedframes are interpreted as an end-of-tape condition. On output, the driver writes four feed frames to serve as a physical record separator.

Binary Records (Magnetic Tape)

The Magnetic Tape subroutine reads and writes binary (odd parity) records only. A record count is supplied by the driver as the first word of the record. This allows automatic padding of short records to the minimum record length with automatic removal of the padded portion of the record on read.

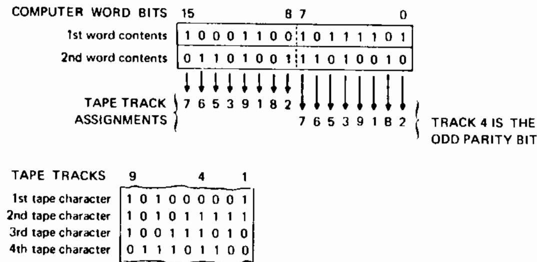
2020 7-LEVEL TAPE

Each Computer word is translated into three tape "characters" (and vice versa) as follows:



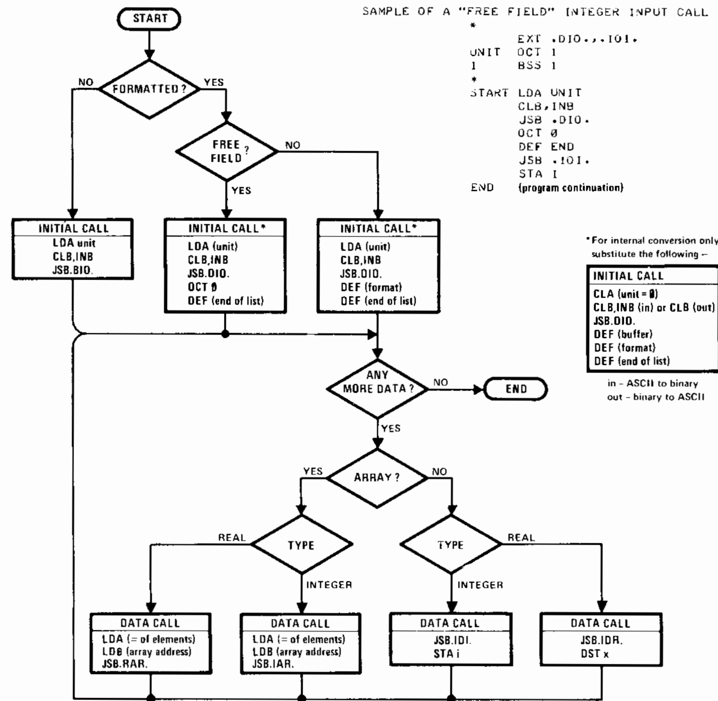
3030 9-LEVEL TAPE

Each Computer Word is translated into Two tape "characters" by repositioning the bits in the following scheme:



The formatter is a library routine designed primarily to provide data conversion and input-output capability for FORTRAN programs. Assembly language programs may use the Formatter by coding the correct calling sequence and providing the proper parameters. The Formatter contains seven entry points in order to provide for execution of a specific part of the total input-output operation. Entry points to the Formatter are identified by the symbols .DIO. (Decimal Input/Output), .BIO. (Binary Input/Output), .IOR. (Input/Output Real), .IOI. (Input/Output Integer, .RAR. (Real Array), .IRA. (Integer Array) and, .DTA. (Terminator).

CALLING SEQUENCE SELECTOR—INPUT

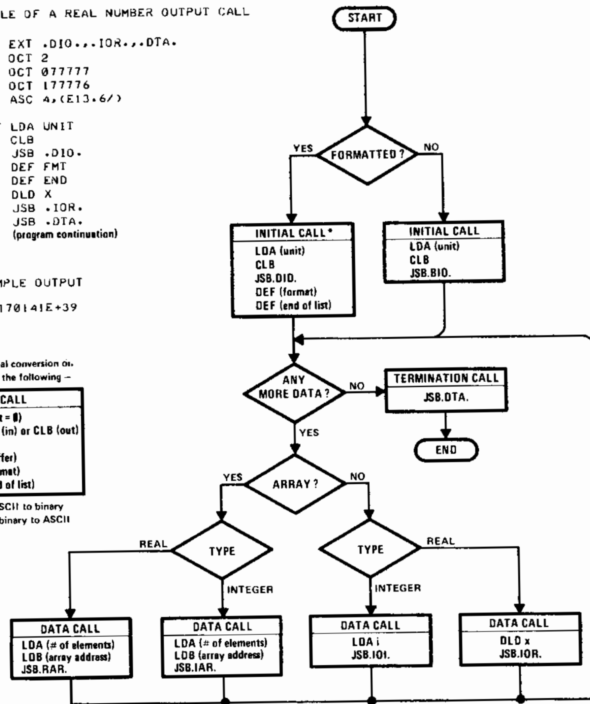


CALLING SEQUENCE SELECTOR—OUTPUT

```
*SAMPLE OF A REAL NUMBER OUTPUT CALL
*
      EXT .DIO.,.IOR.,.DTA.
UNIT  OCT 2
X     OCT 077777
      OCT 177776
FMT   ASC 4,(E13.6/)
*
START LDA UNIT
      CLB
      JSB .DIO.
      DEF FMT
      DEF END
      DLD X
      JSB .IOR.
      JSB .DTA.
END   (program continuation)
```

SAMPLE OUTPUT

```
.170141E+39
```



* For internal conversion or, substitute the following –

INITIAL CALL
CLA (unit = 0)
CLB,INB (in) or CLB (out)
JSB.DIO.
DEF (buffer)
DEF (format)
DEF (end of list)

in - ASCII to binary
out - binary to ASCII

FORMAT SPECIFICATIONS

Below are listed the format conversion and editing specifications.

rAw	Alphanumeric character
rEw.d	Real number with exponent
rFw.d	Real number without exponent
rIw	Decimal integer
r@w, rKw	Octal integer
nX	Blank field descriptor
$nHh_1 \ldots h_n$, $r''h_1 \ldots h_n''$	Heading and labeling descriptors
r/	Begin new resord

where

r	is the number of times the entire format is repeated
w	is the number of digits in the format
d	is the number of digits to the right of the decimal point (w-d should be greater than or equal to 4)
n	is the number of characters or spaces
h's	represents the ASCII characters
Aw	translates alphanumeric data to or from memory. If w is greater than 2 only the last two characters are processed; if w is 1, the single character is read into or written from the right-half of the computer word.
Ew	converts data to a real number. On output, data may consist of integer, fraction, and exponent subfields.

$$\frac{+}{N}\, n \ldots n.n \ldots n \frac{+}{E}\, ee$$

On output, data appears in floating point form.

$$\triangle.\, x_1 \ldots x_d\ E \pm ee$$

Fw — For output operations real numbers in memory are converted to character form which will appear right justified in decimal form. Input is identical to the E specification input.

$\hat{_}$ x . . . x . x . . . x

Iw — translates decimal integers to or from memory

$\hat{_}\ x_1 \ldots x_d$

@w and Kw — translates octal integers to or from memory.

$\hat{_}\ x_1 \ldots x_d$

$nHh_1 \ldots h_n$ — provides for the transfer of any combination of 8-bit ASCII characters, including blanks.

$r``h_1 \ldots h_n''$ — also transfers ASCII characters; field length is not specified, quotation marks are not transferred.

(For a more detailed description of the Format specifications see the FORTRAN Programmer's Reference Manual, Section 7.)

EXAMPLE

Below is an example of a calling sequence to the Formatter that will output the contents of a block data, SOLVE, such that each number is printed on the teleprinter in the following manner:

xxxxxx. xx

SOLVE occupies 100_{10} memory locations; the data stored there is in floating point form.

```
      EXT  .DIO.,.RAR.,.DTA.
FRMT  ASC  5,(2X,F8.2)
SOLVE BSS  100
ADDRS DEF  SOLVE
      .
      .
      LDA  =B5
      CLB
      JSB  .DIO.
      DEF  FRMT
      DEF  *+5
      LDA  =D50
      LDB  ADDRS
      JSB  .RAR.
      JSB  .DTA.
```

EXAMPLE

Below are two examples of calling sequences to the Formatter. The first calling sequence will output the 3rd, 5th and 7th elements of an array causing the data to be printed on the teleprinter in the form:

PRINT ELEMENTS 3, 5, and 7

3   5   7

The second calling sequence reads a binary tape into the integer array defined as BUFFR.

```
      NAM  FINIO
      EXT  .IOC.,.DIO.,.IOI.,.IAR.,.BIO.,.DTA.
*DATA STORAGE AND CONSTANTS
*
IARRY DEF  BUFFR
UNIT2 OCT  2
UNIT5 OCT  5
N     DEC  1Ø
BUFFR DEC  1,2,3,4,5,6,7,8,9,10
FMT2  ASC  16,("PRINT ELEMENTS 3,5, AND 7"/3I5)
      .
      .
*CALLING SEQUENCE TO PRINT THE 3RD, 5TH, AND 7TH ELEMENTS OF AN ARRAY
*
SIX   NOP
      LDA  UNIT2      LOAD "A" WITH UNIT #
      CLB             Ø TO "B" FOR OUTPUT
      JSB  .DIO.      INITIAL CALL FORMATTED
      DEF  FMT2       ADDRESS OF ASCII FORMAT STRING
      DEF  EOL3       END OF LIST ADDRESS
      LDA  BUFFR+2    GET 3RD ELEMENT
      JSB  .IOI.      DATA CALL
      LDA  BUFFR+4    GET 5TH ELEMENT
      JSB  .IOI.      DATA CALL
      LDA  BUFFR+6    GET 7TH ELEMENT
      JSB  .IOI.      DATA CALL
      JSB  .DTA.      NO MORE ITEMS ON DATA LIST
EOL3
*CALLING SEQUENCE TO READ A BINARY TAPE INTO AN INTEGER TYPE ARRAY
*
ONE   NOP
      LDA  UNIT5      LOAD "A" WITH UNIT #
      CLB,INB         1 TO "B" FOR INPUT
      JSB  .BIO.      INITIAL CALL (BINARY)
      LDA  N          # OF ELEMENTS
      LDB  IARRY      ARRAY ADDRESS
      JSB  .IAR.      DATA CALL
```

The Cross Reference Table Generator routine processes an Assembler source program and prints a cross reference list of all symbols appearing in the program. The list contains the symbols in alphabetic order. Each is followed by the 4-digit sequence number of the statement in which the symbol was defined and the sequence numbers of all statements referring to the symbol. If the source program is contained on more than one tape, the tape number follows the statement sequence number. The tape number is determined by the order in which the tapes are submitted to the generator routine; it is not printed for the first tape. The general format of the list is as follows:

sssss dddd/tt rrrr/tt rrrr/tt rrrr/tt rrrr/tt rrrr/tt rrrr/tt

sssss = symbol
dddd = defining statement number
tt = tape number
rrrr = reference statement numbers

Example:

The program;

```
(0001)        NAM TESTT
(0002)  BEGIN DLD A
(0003)        FMP  A
(0004)        DST A
(0005)  TEST  ISZ I
(0006)        JMP BEGIN
(0007)        HLT 3
(0008)        COM A (2),I
(0009)        END
```

yields the cross reference table:

```
A      0008  0002  0003  0004
BEGIN  0002  0006
I      0008  0005
TEST   0005
```

OPERATING PROCEDURES

A. Set Teleprinter to LINE and check that all equipment to be used is operable.

B. Load Cross Reference Table Generator using the Basic Binary Loader. †

1. Place Cross Reference Table Generator in the unit serving as the Standard Input unit (e. g. , Punched Tape Reader).
2. Set Switch Register to starting address of Basic Binary Loader (e. g. , 007700 for 4K memory, 017700 for 8K memory).
3. Press LOAD ADDRESS.
4. Set Loader switch to ENABLE.
5. Press PRESET.
6. Press RUN.
7. When the computer halts and indicates that the Cross Reference Table Generator is loaded (T-Register contains 102077), set Loader Switch to PROTECTED.

C. Set Switch Register to starting address of Cross Reference Table Generator.

000100

D. Press LOAD ADDRESS.

E. Place source language tape in unit serving as the Standard Input unit (e. g. , Punched Tape Reader).

F. Press RUN.

G. At the end of each tape other than the last, the message "END OF TAPE" is printed and the computer halts. Repeat E and F.

---

† The appropriate System Input/Output subroutines (drivers) are assumed to be included with the Cross Reference Table Generator program.

H. At the end of the last tape (the tape containing the END statement), the table is printed on the Standard List Output device (e.g., Teleprinter). When the table is printed, the computer halts.

During the operation of the routine, the following may be printed:

Teleprinter Message	Explanation	Action
DD symbol	A doubly defined symbol has been encountered. The computer does not halt.	Correct source program after completion of routine.
TABLE OVERFLOW	The combined number of symbols and references to them exceeds the capacity of the routine.	Irrecoverable error. If the Table is necessary, the source program must be revised.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
D/I	AND	001		0	Z/C	← Memory Address →									
D/I	XOR	010		0	Z/C										
D/I	IOR	011		0	Z/C										
D/I	JSB	001		1	Z/C										
D/I	JMP	010		1	Z/C										
D/I	ISZ	011		1	Z/C										
D/I	AD*	100		A/B	Z/C										
D/I	CP*	101		A/B	Z/C										
D/I	LD*	110		A/B	Z/C										
D/I	ST*	111		A/B	Z/C										

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	SRG	000		A/B	0	D/E	*LS		000	CLE	D/E	SL*	*LS		000
				↓	↓	↓	*RS		001		↓		*RS		001
				↓	↓	↓	R*L		010		↓		R*L		010
				↓	↓	↓	R*R		011		↓		R*R		011
				↓	↓	↓	*LR		100		↓		*LR		100
				↓	↓	↓	ER*		101		↓		ER*		101
				↓	↓	↓	EL*		110		↓		EL*		110
				↓	↓	↓	*LF		111		↓		*LF		111
				NOP	000				000		000				000

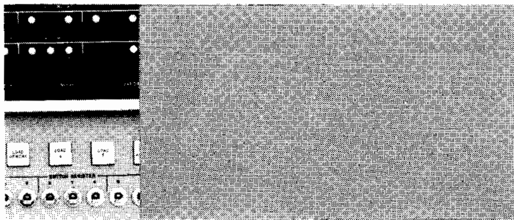
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	ASG	000		A/B	1	CL*	01	CLE	01	SEZ	SS*	SL*	IN*	SZ*	RSS
				↓	↓	CM*	10	CME	10						
						CC*	11	CCE	11						

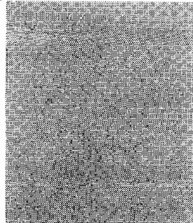
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	IOG	000			1	H/C	HLT		000	← Select Code →					
↓					1	0	STF		001						
↓					1	1	CLF		001						
↓					1	0	SFC		010						
↓					1	0	SFS		011						
↓				A/B	1	H/C	MI*		100						
↓				A/B	1	H/C	LI*		101						
↓				A/B	1	H/C	OT*		110						
↓				0	1	H/C	STC		111						
↓				1	1	H/C	CLC		111						
↓					1	0	STO		001		000			001	
↓					1	1	CLO		001		000			001	
↓					1	H/C	SOC		010		000			001	
↓					1	H/C	SOS		011		000			001	

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	EAU	000		MPY**		000		010			000			000	
↓				DIV**		000		100			000			000	
↓				DLD**		100		010			000			000	
↓				DST**		100		100			000			000	
↓				ASR		001		000		0	1	← number of bits →			
↓				ASL		000		000		0	1				
↓				LSR		001		000		1	0				
↓				LSL		000		000		1	0				
↓				RRR		001		001		0	0				
↓				RRL		000		001		0	0				

Notes: * = A or B.
D/I, A/B, Z/C, D/E, H/C coded: 0/1.
**Second word is Memory Address.

Basic Control System Reference Manual





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INTRODUCTION

The Basic Control System (BCS) provides an efficient loading and input/output control capability for relocatable programs produced by the HP Assembler, HP FORTRAN, or HP ALGOL. The system is modular in design and may be constructed to fit each user's hardware configuration.

The Basic Control System performs the following functions:

Loads and links relocatable programs

Creates indirect and base page addressing when necessary

Selects and loads referenced library routines

Processes I/O requests and services I/O interrupts

Routines associated with the Basic Control System, though not physically part of it, include

Prepare Control System – establishes BCS configuration

Debugging System – loaded with user program to aid in program testing.

The minimum equipment configuration required for the Basic Control System (and Prepare Control System) is as follows:

2116B, 2115A, or 2114A Computer with 4K memory

2752 Teleprinter

The Basic Control System is comprised of two distinct parts; associated with the Basic Control System are two other systems. They are as follows:

Input/output subroutines

Relocating Loader

Prepare Control System

Debugging System

The Relocating Loader loads and links relocatable object programs generated by the Assembler, FORTRAN, and ALGOL. It also links the object programs with the input/output subroutines and any library subroutines referred to in the programs. The Prepare Control System is used to adapt the Basic Control System program to a particular hardware configuration. The Debugging System is a relocatable program that BCS loads after the object program(s); with the debugging program the programmer can find errors in his program.

1.1 INPUT/OUTPUT SUBROUTINES

The input/output package consists of an Input/Output Control subroutine and driver subroutines for the peripheral devices. Input/output operations are specified as symbolic calling sequences in Assembler language. These requests are translated into object code calls to the I/O Control subroutine. The subroutine interprets the call and directs the request to the proper driver. The driver initiates the operation and returns control to the calling program. Whenever interrupt occurs, the driver temporarily resumes control to transfer the next element of data. When the operation is completed, the I/O Control subroutine makes the status of the operation available for checking by the program.

The input/output package allows device independent programming; a device is specified in terms of a unit-reference number rather than a channel number or select code. Furthermore, the user need not be concerned about how data is transmitted (by bit, by character, etc.), he need only specify the number of words or characters and the location in memory where the data is stored.

1.2 RELOCATING LOADER

The Relocating Loader loads object code programs produced by the Assembler, FORTRAN and ALGOL. The linking capability of the Loader allows the user to divide a program into several subprograms, to assemble and test each separately, and finally to execute all as one program. Object subprograms produced by the Assembler may be combined with object subprograms produced by FORTRAN and ALGOL. The subprograms are linked through symbolic entry points and external references.

The loader also provides indirect addressing whenever an operand of an instruction does not fall in the same page as that into which the instruction is being loaded. This allows a program to be designed without concern for page boundarys.

An optional feature of the Loader allows the user to obtain an absolute version of a relocatable program which may include library subroutines and segments of the Basic Control System that were referenced by the program. The process of generating the absolute program is such that instructions (not just common storage) may be allocated to the area normally occupied by the Loader. This feature may also be utilized for a program which has reached "production" status; absolute format requires less loading time because an absolute program is loaded by the Basic Binary Loader.

a. When the Relocating Loader is not requested to produce an absolute version of a program, it sets all locations in available memory to 106055B (a special halt instruction) before it loads the user's program into memory. This is useful for protecting areas of memory and for debugging programs.

b. A certain portion of the BCS Relocating Loader must always be resident in core while the BCS is in use. This portion of the Relocating Loader contains a segment labeled HALT, which is used by the new version of the .STOP routine in the Program Library. The final halt instruction for the BCS is directly associated with this entry point for use in one of two ways. The final halt instruction remains unchanged if paper tape operation is used,

but it is changed to JSB 00106B, I (a call to the Inter-Pass Loader of the Magnetic Tape System) if the BCS is run using MTS.

For further information on the BCS and its relation to the Magnetic Tape System, see the Magnetic Tape System Reference Manual, HP5950-9202.

1.3 PREPARE CONTROL SYSTEM

Prepare Control System is a special purpose program which produces an absolute version of the Basic Control System from relocatable BCS subprograms. During the construction of the absolute BCS, the user also establishes the relationships among I/O channel numbers, drivers, interrupt entry points in the drivers, and unit-reference numbers. Prepare Control System is used when the configuration of the hardware is defined initially or whenever there is a modification or expansion to the configuration.

1.4 DEBUGGING SYSTEM

The debugging routine provides aids in program testing. Options provided by the routine will print selected areas of memory, trace portions of the program during execution, modify the contents of selected areas in memory, modify simulated computer registers, halt execution of the program at specified breakpoints, and initiate execution at any point in the program.

The Basic Control System provides the facility to request input/output operations in the form of five-word calling sequences in assembly language. The Basic Control System interprets the call, initiates the operation, and returns control to the calling program. When the data transfer is complete, the System provides status information which may be checked by the program. Interrupts which occur during or on termination of the transfer are processed entirely by the System; interrupt handling subroutines are not required in the user's program.

2.1 GENERAL CALLING SEQUENCE

The general form of the input/output request is:

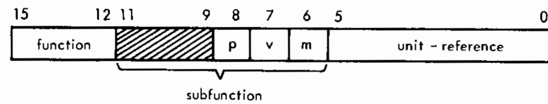
```
     JSB        .IOC.

     OCT        <function> <subfunction> <unit-reference>

    {JSB}
    {JMP}       reject address

     DEF        buffer address

    {DEC}
    {OCT}       buffer length

     <normal return>
           .
           .
           .
     EXT        .IOC.
```

2.1.1 .IOC.

.IOC. is the symbolic entry point name of the input/output control subroutine within the Basic Control System. All input/output operations are requested by performing a JSB to this entry point. The input/output control subroutine returns control to the calling program at the first location following the last word of the calling sequence. Programs referring to .IOC. must declare it as an external symbol.

2.1.2 FUNCTION, SUBFUNCTION, AND UNIT-REFERENCE

The second word of the request determines the function to be performed and the unit of equipment for which the action is to be taken. In assembly language, this information may be supplied in the form of an octal constant. The bit combinations that comprise the constant are as follows:



Function

The function (bits 15-12) is the basic input/output operation; it may be either of the following:

Function Name	Code (octal)
Read	01
Write	02

Subfunction

The subfunction (bits 11-6) defines the options for certain input/output operations:

p = 1 Print input: The ASCII data read from the 2752A Teleprinter is to be printed as it is received.

v = 1 Variable length binary input: The value in bits 15-8 of the first word on an input paper tape indicates the length of the record (including the first word). If the value exceeds the length of the buffer, only the number of words specified as the buffer length are read. If v = 0, the buffer length field always determines the length of record to be transmitted. If the device does not read paper tape, the parameter is ignored.

m = 1 Mode: The data is transmitted in binary form exactly as it appears in memory or on the external device. If m = 0, the data is transmitted in ASCII or BCD format.

Unit-Reference

The value specified for the unit-reference field indicates the unit of equipment on which the operation is to be performed. The number may represent a standard unit assignment or an installation unit assignment. Standard unit numbers are as follows:

Number	Name	Usual Equipment Type
1	Keyboard Input	Teleprinter
2	Teleprinter Output	Teleprinter
3	Program Library	Punched Tape Reader
4	Punch Output	Tape Punch
5	Input	Punched Tape Reader
6	List Output	Teleprinter

Installation unit numbers may be in the range 7_8-74_8 with the largest value being determined by the number of units of equipment available at the installation. The particular physical unit that is referenced depends on the manner in which equipment is defined within the Basic Control System by the installation. When the Basic Control System configuration is established, an equipment table (EQT) is created. This table defines the type of equipment (Teleprinter, magnetic tape, etc.), the channel on which each unit is connected, and other related details. The ordinal of the unit's entry in this table is the value specified as a unit-reference number for an installation unit. Since numbers 1-6 are reserved as standard unit numbers, the first unit

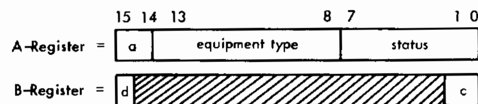
described in the table is referred to by the number 7_8; the second, 10_8; the third, 11_8; and so forth. The entries for one possible equipment table might establish the following relationships:

Installation unit number (ordinal)	Device	I/O Channel
7	Teleprinter	12 or 12 and 13
10	Punched Tape Reader	10
11	Tape Punch	11

The standard unit numbers are associated with physical equipment via a standard equipment table (SQT) and EQT. The SQT is a list of references to the EQT. SQT is also created by the installation when the BCS configuration is established. Each standard unit may be a separate device, or a single device may be accessed by several standard unit numbers as well as an installation unit number. (For complete details on the SQT and EQT, see Appendix B.)

2.1.3 REJECT POINT

The Basic Control System transfers control to the third word of the calling sequence if the input/output operation can not be performed. On transfer, the System provides status information which may be checked by the user's program.



The contents of the A-Register indicate the physical status of the equipment (see Status Request). The contents of the B-Register indicate the cause of the reject (bits 14-1 are zeros):

d = 1	The device or driver subroutine is busy and therefore unavailable, or, for Kennedy 1406 Tape unit, a broken tape condition encountered.
c = 1	A Direct Memory Access channel is not available to operate the device.
d = c = 0	The function or subfunction selected is not legal for the device.

The content of the third word of the calling sequence is normally a JSB or a JMP to a reject address which is the start of a user subroutine designed to determine the cause of a reject and take appropriate action.

2.1.4 BUFFER STORAGE AREA

The buffer address is the location of the first word of data to be written on an output device or the first word of a block reserved for storage of data read from an input device. The length of the buffer area may be specified in terms of words or characters. If the length is given as words, the value in the buffer length field must be a positive integer; if given as characters, a negative integer. †

In addition to describing the buffer area in the calling sequence, the area must also be specifically defined in the assembly language program, usually with a BSS or COM pseudo instruction.

2.2 CALLING SEQUENCE: PAPER TAPE SYSTEM

```
 JSB         .IOC.
 OCT         <function> <subfunction> <unit-reference>
{JSB}
{JMP}        reject address
 DEF         buffer address
{DEC}
{OCT}        buffer length
 <normal return>
 EXT         .IOC.
```

† If the device is not ready at the time the request is issued, a "request initiated" (normal) return occurs with (A) = $\emptyset$ and the A-field of the device EQT status word set to $\emptyset 1_2$.

Allowable combinations of function and subfunction codes are as follows:

Operation	Octal value of Bits 15-6
Read ASCII record	0100
Read ASCII record and print	0104
Read binary record	0101
Read variable length binary record	0103
Write ASCII or BCD record	0200
Write binary record	0201

An illegal combination of codes is rejected.

Record Formats

ASCII Records (Paper Tape)

An ASCII record is a group of characters terminated by an end-of-record mark which consists of a carriage return, (CR), and a line feed, (LF)

For an input operation, the length of the record transmitted to the buffer is the number of characters or words designated in the request, or less if an end-of-record mark is encountered before the character or word count is exhausted. The codes for (CR) and (LF) are not transmitted to the buffer. An end-of-record mark preceding the first data character is ignored.

For an output operation, the length of the record is determined by the number of characters or words designated in the request. An end-of-record mark is supplied at the end of each output record by the input/output system.

If the last character of an output record is ←, however, the end-of-statement mark is omitted. This allows control of Teleprinter line spacing. The user may write a message (the ← is not printed) and expect the reply to be typed on the same line. The reply must be terminated with the (CR) (LF).

If a (RUB OUT) code followed by a (CR) (LF) is encountered on input from the Teleprinter or Punched Tape Reader, the current record is ignored (deleted) and the next record transmitted.†

If less than ten feed frames (all zeros) are encountered before the first data character from a paper tape input device, they are ignored. Ten feed frames are interpreted as an end-of-tape condition (see STATUS REQUEST).

Binary Records

A binary record is transmitted exactly as it appears in memory or an 8-level paper tape. The record length is specified by the number of characters or words designated in the request. The first character of a binary record must be non-zero. On input operations, less than ten feed frames preceding the first data character are ignored. Ten feed frames are interpreted as an end-of-tape condition (see STATUS REQUEST). On output, the system writes four feed frames to serve as a physical record separator.

Binary input records may be variable in length. The first word of the record contains a number in bits 15-8 specifying the length of the record (including the first word). The entire record including the word count is transmitted to the buffer. If the actual length exceeds the size of the buffer, only the number of words equivalent to the buffer length is transmitted.

---

† (RUB OUT) which appears on the Teleprinter keyboard is synonymous with the ASCII symbol (DEL).

2.2.2 BUFFER LENGTH

Character or word transmission may be specified for any paper tape device. The buffer length for data that may be printed on the teleprinter should be no more than 72 characters (36 words).

Examples:

```
Label   Operation  Operand          Comments
        .
        .
        EXT  .IOC.                  DECLARE .IOC. AS EXTERNAL.
LINE    BSS  36                     RESERVE STORAGE AREAS: 36
        COM  BKB(100)               WORDS FOR LINE AND 100 WORDS
                                    (IN THE COMMON BLOCK) FOR BKB.
        .
        .
READI   JSB  .IOC.                  READ 72 ASCII CHARACTERS FROM
        OCT  10005†                 THE STANDARD INPUT UNIT. STORE
        JMP  REJAD                  AT LINE. IF REQUEST IS REJECTED,
        DEF  LINE                   TRANSFER TO REJAD.
        DEC  -72
        .
        .
WRITI   JSB  .IOC.                  WRITE 100 BINARY WORDS ON UNIT
        OCT  20111†                 11, THE THIRD DEVICE DESCRIBED
        JMP  REJAB                  IN THE EQT. DATA IS CURRENTLY
        DEF  BKB                    STORED IN THE COMMON BLOCK
        DEC  100                    STARTING AT LOCATION BKB.
        .
        .
```

† The leading 0 of the second word of the calling sequence need not be written in the source language since it is supplied in the object code as a result of using the OCT pseudo instruction.

2.3 CALLING SEQUENCE:

KENNEDY INCREMENTAL TRANSPORT

```
        JSB     .IOC.
        OCT     <function><subfunction><unit-reference>
      { JSB }
      { JMP }   reject address
        DEF     buffer address
      { DEC }
      { OCT }   buffer length
        EXT     .IOC.
```

Function and Subfunction

Allowable function codes for the 1406 Kennedy Incremental Tape Transport are as follows:

WRITE (ASCII Mode only)	0200
WRITE End-of-file	0301
CLEAR	0000

Record Formats

Binary Coded Decimal Records (Magnetic Tape)

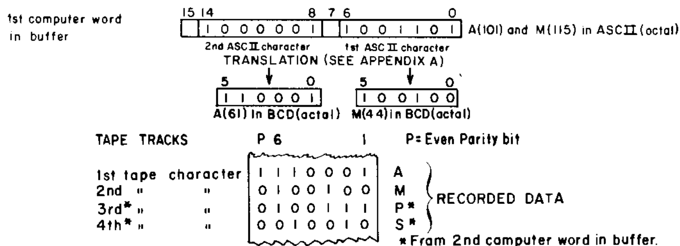
A BCD record is a group of BCD characters terminated (on magnetic tape) by a record gap. A request to write a BCD record results in the translation of each 7-level ASCII character in the buffer area into a 6-level BCD character on magnetic tape (Refer to the Table on page A-2). The translation process does not alter the original contents of the buffer.

The length of the record is determined by the number of characters or words designated in the request. A record gap is supplied at the end of each record by the input/output system.

If the last character in the buffer area is ←, however, the record gap is omitted. The ← is not written on tape.

A WRITE request specifying a buffer length of zero causes a record gap only to be written.

KENNEDY BCD RECORD FORMAT



2.4 CALLING SEQUENCE: MAGNETIC TAPE SYSTEM

```
JSB        .IOC.
OCT        <function><subfunction><unit-reference>
{JSB}
{JMP}      reject address
DEF        buffer address
{DEC}
{OCT}      buffer length
  .
  .
  .
EXT        .IOC.
```

2.4.1 2020A Magnetic Tape Unit

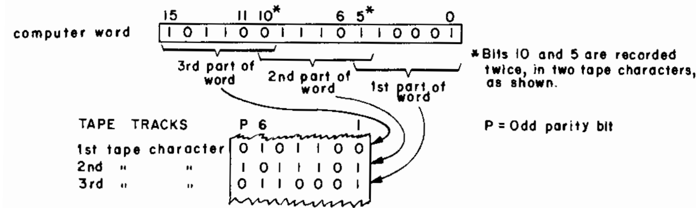
All allowable combinations of function and subfunction codes are as follows:

Operation	Octal value of Bit 15-6
Read BCD record and convert to ASCII	0100
Read binary record	0101
Write BCD record after converting from ASCII	0200
Write binary record	0201
Write End-of-File (EOF) mark	0301
Forward space one record	0302
Back space one record	0303
Rewind to start of tape (SOT) the LOAD POINT, Ready (AUTO mode)	0304
Rewind to start of tape (SOT) the LOAD POINT, Unload (LOCAL mode)	0305

RECORD FORMATS
BINARY RECORDS (MAGNETIC TAPE)

A binary record on magnetic tape is a group of 6-level tape "characters" recorded in odd parity† and terminated by a record gap. The record length is determined by the number of characters or words in the buffer as designated in the request. Each computer word is translated into three tape "characters" (and vice versa) as follows:

2020A BINARY RECORD FORMAT



For output operations, the minimum buffer length is 3 computer words.

BINARY CODED DECIMAL RECORDS

A BCD record on magnetic tape is a group of BCD characters recorded in even parity† and terminated by a record gap. (Refer to the table on page A-3.) A request to write a BCD record results in the translation of each 7-level ASCII character in the buffer area into a 6-level BCD character on magnetic tape. A request to read a BCD record results in the translation of each BCD character into an ASCII character after the block has been read.

The length of the record may not be more than 120 characters. A record gap is supplied at the end of each record.

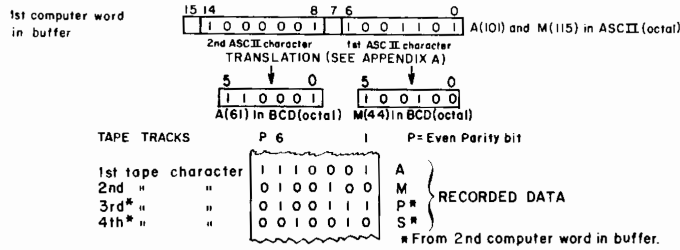
Buffer Length

A WRITE request for the HP 2020A Magnetic Tape Unit must have a minimum buffer length of seven ASCII characters (four words). If less than seven characters are specified, spaces will be added to fill the seven characters.

† Odd parity: a seventh bit is recorded on tape if the total of the bits in the six levels is an even number.

Even parity: a seventh bit is recorded on tape if the total of the bits in the six levels is an odd number.

2020 BCD RECORD FORMAT



2.4.2 3030 MAGNETIC TAPE UNIT FUNCTION AND SUBFUNCTION

The 3030 Driver operates the HP 3030 9-channel magnetic tape controller. It initiates, continues and completes any tape operations requested through input/output control. As a module of the HP 2116 Basic Control System, the driver conforms to the general specifications for performing input/output under control of the Input/Output Control (IOC) module. Two consecutive I/O channels are required with the data channel assigned to the higher priority of the two. The other channel is the command channel. Data is transferred to or from memory by a DMA channel. The name of the Driver is D. 22. The entry points are D. 22 (Initiator Section) and C. 22 (Continuator Section). When configuring a BCS tape with the 3030 driver using PCS, the only requirement is a link from the command channel interrupt location to the entry point C. 22 of the driver Interrupt Processor. If an error is detected on a write operation the tape is backspaced over the record; three inches of tape are erased and the record is rewritten. This will continue until end-of-tape is sensed. If an error is detected on a read operation the driver will attempt to read ten times before aborting the operation. All allowable combinations of function and subfunction codes are as follows:

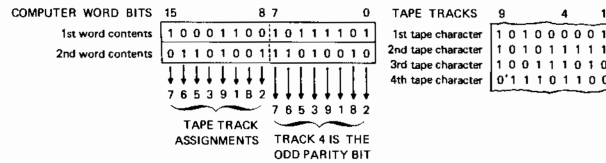
OPERATION	CODE
CLEAR	ØØxx
READ (binary only)	Ø1Ø1 (or Ø1ØØ)
WRITE (binary only)	Ø2Ø1 (or Ø2ØØ)
DYNAMIC STATUS	Ø3ØØ
WRITE END-OF-FILE (EOF) MARK	Ø3Ø1
BACK SPACE ONE RECORD	Ø3Ø2
FORWARD SPACE ONE RECORD	Ø3Ø3
REWIND TO START OF TAPE (SOT, or the LOAD POINT), READY (AUTO mode)	Ø3Ø4
REWIND TO START OF TAPE (SOT, or the LOAD POINT). UNLOAD (LOCAL mode)	Ø3Ø5 "

Buffer Length

Character transmission is not applicable since the transmission is via a DMA channel. The minimum data block is twelve tape characters. Output blocks with a block length less than twelve characters are padded with zeros.

Record Format

Each computer word is translated into two tape "characters" by repositioning the bits in the following scheme:

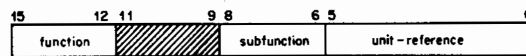


2.5 MAGNETIC TAPE CONTROL REQUESTS

A request directed to .IOC. may also control the positioning of a reel on a magnetic tape device. The calling sequence is similar to the input/output request, but consists of only three words:

```
EXT     .IOC.
 :
JSB     .IOC.
OCT     <function> <subfunction> <unit-reference>
{JSB}
{JMP}   reject address
<normal return>
```

The second word of the request has the following composition:



The function defines the calling sequence as a tape positioning request:

Function Name	Code (octal)
Position Tape	03

The subfunction defines the type of positioning:

Subfunction (octal)	Operation
0	Dynamic tape status
1	Write End-of-File
2	Backspace one record
3	Forward space one record
4	Rewind
5	Rewind and standby

As soon as tape movement operations (Rewind and Standby) are initiated, the device is considered to be available; the "a" field of a status reply (0400 code) is set to 00. The input/output driver is thus free to process requests for other devices. To obtain the actual status of the device when one of these commands has been issued, the Dynamic tape status request is used. If the tape movement operation is still in progress the "a" field is set to 10.

2.6 CLEAR REQUEST

The clear request terminates a previously issued input or output operation before all data is transmitted. It has the following form:

```
EXT     .IOC.
  :
JSB     .IOC.
OCT     <function> <unit-reference>
<normal return>
```

The second word consists of the following:

The function has the following value:

Function Name	Code (octal)
Clear	00

The only other parameter required is the unit-reference number. If the unit-reference number is specified as 00 (i. e., the second word of the calling sequence is OCT 0), all previous input and output operations are terminated. This request, the system clear request, makes all devices available for the initiation of a new operation. On return from a system clear request, the contents of the A- and B-Registers are meaningless.

Example:

```
READM  JSB  .IOC.     READ AND PRINT A MESSAGE OF ONE
       OCT  10401     LINE FROM THE TELEPRINTER. WHEN
       JMP  REJ       CONTROL RETURNS AFTER INITIATING
       DEF  MSG       THE REQUEST, THE JSB MIGHT
       DEC  36        TRANSFER TO A SUBROUTINE WHICH
       JSB  TIMER     COULD CHECK THE TIME ALLOWED
                      FOR A MESSAGE TO BE COMPLETED.

CLRRD  JSB  .IOC.     IF THE MESSAGE IS NOT FURNISHED
       OCT  1         WITHIN A SPECIFIC TIME LIMIT, THE
                      REQUEST IS CLEARED BY THE SECOND
                      REQUEST TO .IOC.
```

2.7 STATUS REQUEST

A request may be directed to .IOC. to determine the status of a previous input/output request or to determine the physical status of one or all units of equipment. The request has the following form:

```
JSB     .IOC.
OCT     <function><unit-reference>
<normal return>
```

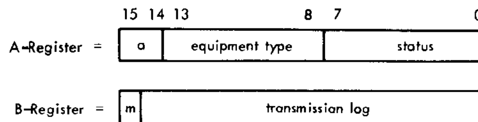
The second word of the request has the following form:

The function has the following value:

Function Name	Code (octal)
Status	04

The calling sequence requires no other parameters. A reject location is not necessary since the status information is always available. If the unit-reference number is specified as 00 (i.e., the second word on the calling sequence is OCT 40000), the request is interpreted as a system request.

If information is requested for a single unit, the Basic Control System returns to the location immediately following the request with the status information in the A and B registers:



a — Availability of device:

- 0 — The device is available; the previous operation is complete.
- 1 — The device is available; the previous operation is complete but a transmission error has been detected.
- 2 — The device is not available for another request; the operation is in progress.

equipment type — This field contains a 6-bit code that identifies the device referenced:

00-07 – Paper Tape devices
- 00 2752A Teleprinter
- 01 2737A Punched Tape Reader
- 02 2753A Tape Punch

10-17 – Unit Record devices

20-37 – Magnetic Tape and Mass Storage devices
- 20 Kennedy 1406 Incremental Tape Transport
- 21 HP 2020A Magnetic Tape Unit
- 22 HP 3030A Magnetic Tape Unit

40-77 – Instrumentation devices
- 40 Data Source Interface
- 41 DVM Programmer
- 42 Scanner Programmer
- 43 Time Base Generator

status — The status field indicates the actual status of the device when the data transmission is complete. The contents depend on the type of device referenced:

Teleprinter reader or Punched Tape Reader:

Bits 7-0	Condition
xx1xxxxx	End-of-Tape (10 Feed Frames)

Tape Punch:

Bits 7-0	Condition
xx1xxxxx	Tape supply low

Kennedy 1406 Incremental Tape Transport:

Bits 7-0	Condition
xx1xxxxx	End-of-Tape mark sensed
xxxx1xxx	Broken tape; no tape on write head
xxxxxxx1	Device busy

HP 2020A and 3030A Magnetic Tape Units:

Bits 7-0	Condition
1xxxxxxx	The End-of-File (EOF) mark (17_8 for the 2020A, 23_8 for the 3030A) is detected or written.
x1xxxxxx	start-of-tape marker sensed
xx1xxxxx	end-of-tape marker sensed
xxx1xxxx	timing error on read/write
xxxx1xxx	I/O request rejected: a. tape motion required but controller busy b. backward tape motion required but tape at load point c. write request given but reel does not have write enable ring.
xxxxx1xx	Reel does not have write enable ring or tape unit is rewinding.
xxxxxx1x	Parity error on read/write
xxxxxxx1	Unit busy or in LOCAL mode.

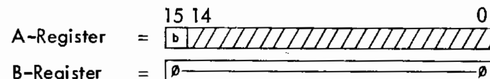
m — This bit defines the mode of the data transmission:

0 ASCII or BCD

1 Binary

transmission log — This field is a log of the number of characters or words transmitted. The value is given as a positive integer and indicates characters or words as specified in calling sequence. The value is stored in this field only when the request is completed, therefore, when all data is transmitted or when a transmission error is detected.

If a system status request is made, the information in the A and B registers is as follows:



b System Status
0 No device is busy
1 At least one device is busy

2.8 CALLING SEQUENCE: INSTRUMENTS

2.8.1 DATA SOURCE INTERFACE

A binary output operation causes the removal of "hold-off." The calling influence is as below:

```
JSB     .IOC.
OCT     <function><subfunction><unit-reference>
{JSB}
{JMP}   reject address
OCT     0   dummy buffer
OCT     0   buffer length
```

Example:

```
Label   Operation   Operand                              Comments
        JSB   .IOC.
        OCT   20115      "HOLD OFF" ON UNIT REF #15
        JMP   REJAD
        OCT   Ø          DUMMY BUFFER
        OCT   Ø
         .
         .
         .
```

A binary input operation must have a 2-word buffer. Thirty-two bits (4 BCD characters) are read directly into the 2-word buffer.

```
               JSB      .IOC.
               OCT      <function><subfunction><unit-reference>
             { JSB }
             { JMB }    reject address
               DEF      buffer address
               DEC      4
                .
                .
                .
buffer address BSS      2
```

Example:

```
    JSB  .IOC.
    OCT  10115     INPUT ON UNIT REF #15
    JMP  REJAD
    DEF  BUFF
    DEC  2
     .
     .
     .
BUFF BSS 2
```

An ASCII input operation must have an 8 word buffer. 8 BCD characters are converted into 16 ASCII characters in the following format:

$$rf.\, d_5 d_4 d_3 d_2 d_1 d_\emptyset E - ss_{\wedge\wedge} gg$$

	r	range - a negative power of 10
	f	function
	d_5-$d_\emptyset$	six digit data value
	E-ss	range expressed as an exponent of two digits
	$\wedge\wedge$	two blanks
	gg	function expressed as a two-digit number
	JSB	.IOC.
	OCT	<function> <subfunction> <unit-reference>
	JMP JSB	reject address
	DEF	buffer address
	DEC ⋮	-16
buffer address	BSS	8

Example:

```
      JSB  .IOC.
      OCT  100015        READ ON UNIT REF #15
      JMP  REJAD
      DEF  BUFF
      DEC  -16
       .
       .
       .
BUFF  BSS  8
```

2.8.2 DIGITAL VOLTMETER PROGRAMMER

A write request for the Digital Voltmeter Programmer requires that a one-word buffer be specified. This word contains the voltmeter program: sample period (bit 7-6), function (bits 5-3), and range (bits 2-0). If bit 15 contains a 1, encode command is sent to the Voltmeter (bit 15 always be 0 if the configuration includes a Scanner).

```
               JSB   .IOC.
               OCT   <function><subfunction><unit-reference>
               JSB
               JMP   reject address
               DEF   buffer address
               OCT   1
                .
                .
                .
buffer address OCT   voltmeter program
```

Example:

```
      JSB .IOC.
      OCT 2Ø116     WRITE ON CHANNEL 16
      JMP REJAD
      DEF BUFF
      OCT 1
       .
       .
       .
BUFF  OCT 1ØØ244    ENCODE TO DVM PROGRAM:
                    .01 SEC DELAY, +DC VOLTS,
                    10 VOLT RANGE.
```

2.8.3 SCANNER PROGRAMMER

A write request for the Scanner Programmer requires a 2-word buffer. The first word contains the scanner program: the function (bits 4-3) and the delay (bits 2-0). The second word contains the channel number for the start of the scan. The driver subroutine converts the binary channel number value produced by the Assembler to the BCD format required by the device.

```
                JSB    .IOC.
                OCT    <function><subfunction><unit-reference>
                JSB
                JMP    <reject address>
                DEF    buffer address
                DEC    2
                 .
                 .
                 .
buffer address  OCT    xxx  starting channel number
                OCT    xx   scanner program
```

Example:

```
Label  Operation  Operand                    Comments
       JSB        .IOC.
       OCT        20118      WRITE ON UNIT 20
       JMP        REJAD
       DEF        BUFF
       DEC        2
         .
         .
         .
BUFF   OCT        144        CHANNEL 100
       OCT        23         PROGRAM: OHMS, 27ms DELAY
```

2.8.4 INSTRUMENT CLEAR REQUEST:

A clear request on one of the instrument drivers follows the standard form:

JSB .IOC.

OCT <function><unit-reference>

<normal return>

where the function code = 00.

The request will result in the following conditions:

Data Source Interface – A clear request causes no action. It is included for compatibility only.

Digital Voltmeter Programmer – A clear request to this driver will remove the present program from the DVM but the program will not be destroyed.

Crossbar Scanner — A clear request will inhibit the STEP or RESET command on the Scanner programmer driver.

INSTRUMENT STATUS REQUEST:

No status information is available from the instrument drivers.

2.9 ERROR CONDITIONS DURING EXECUTION

Illegal conditions encountered during .IOC. request processing are termed irrecoverable and cause a halt.† Diagnostic information is displayed in the A- and B-Registers at the time of the halt.

The B-Register contains the absolute location of the JSB instruction of the request call containing the illegal condition.

The A-Register contains a code defining the illegal condition:

A-Register	Explanation
000000	Illegal request code.
000001	Illegal unit-reference number in request.
000002	The Standard unit requested is not defined as a particular device in the Equipment Table.

†The halt is at the absolute location assigned to the symbol IOERR during Prepare Control System processing.

Examples:

```
       EXT  .IOC.          DECLARE .IOC. AS EXTERNAL
INARA  BSS  10             SYMBOL. RESERVE STORAGE
        .                  AREA.
        .
        .
READM  JSB  .IOC.          READ AN ASCII RECORD FROM
       OCT  10015          UNIT-REFERENCE NUMBER 15 AND
       JMP  RJCT           STORE AT LOCATION INARA.
       DEF  INARA
       DEC  10
        .
        .
        .
STATM  JSB  .IOC.          CHECK STATUS OF READ REQUEST.
       OCT  40015          IF INITIAL BIT 15 SET, UNIT 15
       SSA                 IS BUSY; LOOP ON STATUS REQUEST
       JMP  STATM          UNTIL OPERATION IS COMPLETE.
       RAL                 CHECK INITIAL BIT 14. IF SET,
       SSA                 TRANSFER TO END-OF-TAPE CHECK.
       JMP  EOT            IF INITIAL BIT 5 SET, PERFORM
       JMP  PROCS          ENDING PROCESS AT ENDPR.
EOT    ALF,ALF             IF NOT SET, TRANSFER TO TERMINA-
       RAL                 TION PROCEDURE AT ABORT. IF
       SSA                 REQUEST COMPLETED, CONTINUE
       JMP  ENDPR          PROCESSING AT PROCS.
       JMP  ABORT
        .
        .
        .
RJCT   SSB                 DETERMINE CAUSE OF REJECT
       JMP  READM          CONDITION. IF THE DEVICE OR
       JMP  ABORT          DRIVER IS BUSY, LOOP ON REQUEST
                           UNTIL AVAILABLE. IF REJECTED FOR
                           ANY OTHER REASON, TERMINATE THE
                           PROGRAM AT ABORT.
```

The Loader is the module of the Basic Control System that provides the capability of loading, linking, and initiating the execution of relocatable object programs produced by the Assembler, FORTRAN, and ALGOL. It is available in 4K and 8K versions. ALGOL programs and the Program Library stored on magnetic tape require the 8K loader.

3.1 EXTERNAL FORM OF LOADER

The Loader is stored in an absolute record format on an external medium with the Input/Output Control subroutine, .IOC., and the equipment driver subroutines. It is loaded by the Basic Binary Loader. The external medium is determined by the type of device assigned as the Standard Input unit. For the Punched Tape Reader or the Teleprinter, the medium is 8-level paper tape.

3.2 INTERNAL FORM OF LOADER

The Loader is located in high-numbered memory along with the Input/Output Control subroutine and the equipment driver subroutines. The Loader uses .IOC. for input/output operations; it refers to the Standard input and output units. The binary object program is read from the Standard Input unit; comments to the user (e.g., Loader diagnostics) are written on the Teleprinter Output unit; and library routines referenced by the object program are assumed to be on the Program Library unit.

3.3 RELOCATABLE PROGRAMS

The process of assembling or compiling a set of symbolic source program statements may be specified to result in the generation of a relocatable object program. A relocatable program assumes a starting location of 00000. Location 00000 is termed the relative, or relocatable origin. The absolute origin (also termed the relocation base) of a relocatable program is

determined by the Loader. The value of the absolute origin is added to the zero-relative value of each operand address to obtain the absolute operand address. The absolute origin, and thus the values of every operand address, may vary each time the program is loaded.

A relocatable program may be made up of several independently assembled or compiled subprograms. Each of the subprograms would have a relative origin of 00000. Each subprogram is then assigned a unique absolute origin upon being loaded. Subprograms executed as a single program may be loaded in any order. The absolute origins will differ whenever the order of loading differs.

The operand values produced by the Assembler, FORTRAN, or ALGOL may be program relocatable, base page relocatable, or common relocatable. Each of these segments of the program has a separate relocation base or origin. Operands that are references to locations in the main portion of the program are incremented by the program relocation base; those referring to the base page, by the base page relocation base; and those referring to common storage, by the common relocation base.

If the Loader encounters an operand that is a reference to a location in a page other than the "current" page, a link is established through the base page. A word in the base page is allocated to contain the full 15-bit address of the referenced location. The address of the word in the base page is then substituted as an indirect address in the instruction in the "current" page. If other similar references are made to the same location, they are linked through the same word in the base page.

3.4 RECORD TYPES

The Loader processes three to five record types for a program. These record types are produced by the Assembler, FORTRAN, or ALGOL in the following sequence:

NAM	Name record
ENT	Entry point record
EXT	External name record
DBL	Data block record
END	End record

The NAM, DBL, and END records exist for every object program; ENT and EXT appear only if the corresponding pseudo instructions are used in the source program.

NAM

The NAM record contains the name of the program and the length of the main, base page, and common segments. The NAM record signifies the beginning of the object program.

ENT

The ENT record defines the names of 1 to 14 entry points within this program. Each of the four-word entries in the record contains the name, the relocatable address of the name; and an indicator which specifies whether the address is program or base page relocatable.

EXT

The EXT record contains from 1 to 19 three-word entries which specify the external references defined in the program. The three words allow a maximum of five ASCII characters for the symbol and a number used by the Loader to identify the symbol.

DBL

A DBL record contains 1 to 45 words of the object program. It indicates the relative starting address for the string of words and whether this portion of the object code is part of the main program or base page segment. For each of the words there is also a relocation indicator which defines the relocation base to be applied to each operand value. Possible relocation factors are:

Absolute	Operand is an absolute expression or constant. There is no relocation base.
15-bit Program Relocatable	Operand is a 15-bit value to which is added the program relocation base.
15-bit Base Page Relocatable	Operand is a 15-bit value to which is added the base page relocation base.

15-bit Common Relocatable	Operand is a 15-bit value to which is added the common relocation base.
External Symbol Reference	Operand is a reference to an external symbol. Value is supplied when the Loader determines the absolute location of the linkage word in the Base Page which contains the 15-bit address of the related entry point.
Memory Reference Instruction	A memory reference instruction in the form of a two-word group which consists of the instruction code, a full 15-bit operand address, and a relocation indicator for the operand address. The relocation indicator can define the operand address to be program, base page, or common relocatable.

END

The END record terminates the block of records in an object program. The END record may contain a 15-bit address which is the location to which control is transferred by the Loader to begin program execution.

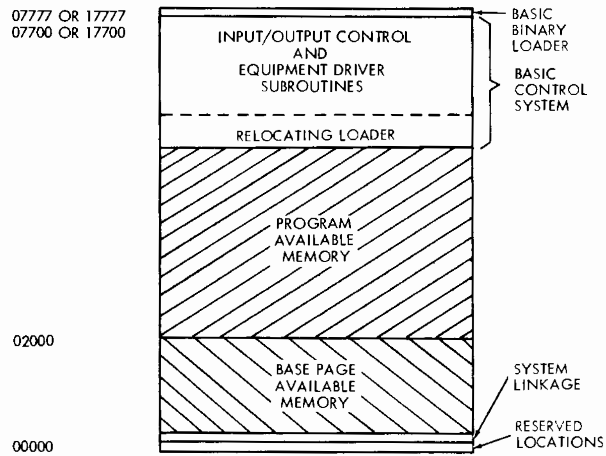
3.5 MEMORY ALLOCATION

The Loader loads the object program into available memory. Available memory is defined as that area of memory not allocated for hardware and system usage. Available memory is divided into two segments:

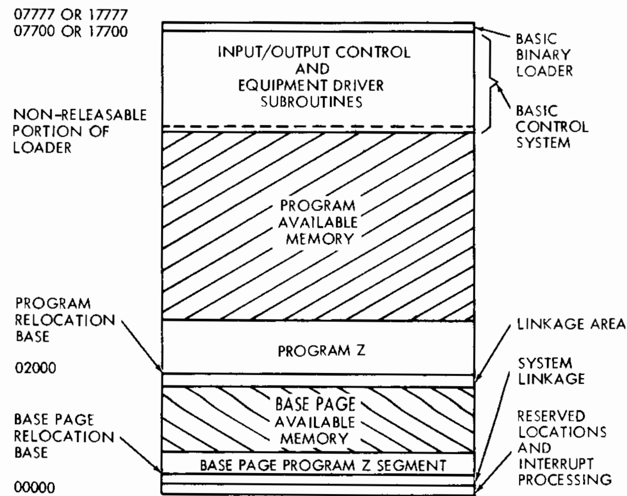
Available Memory in Base Page – used for the operand linkage area, program blocks origined into the Base Page by the Assembler pseudo instruction ORB, and for program blocks assigned to the Base Page by the Loader when the amount of program available memory is insufficient.

Program Available Memory – used for the main body of the program and may be used by the common block should the area used by the Loader be insufficient.

Prior to loading the object program, memory is allocated as follows:



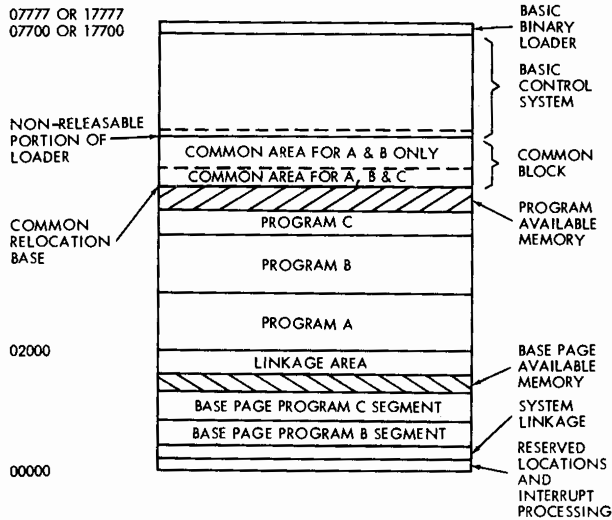
Assuming Program Z is to be loaded and executed – after loading, the memory might be allocated as follows:



Options selected during PCS processing can define the equipment driver subroutines and other system routines as relocatable programs. If selected, these routines would be allocated to the available memory areas, and the length of the absolute segment of BCS reduced accordingly.

If several programs are to be loaded and executed together, the following might occur:

> Assume three programs, A, B, and C, comprise a running program. Programs A and B share a common block, a portion of which is also shared by C. Programs B and C contain segments which are designated to be allocated to the Base Page. Allocation is as follows:



Common Block Allocation

The first common length declaration (i.e., the first program containing a common segment) processed by the Loader establishes the total common storage allocation in high memory overlaying the major portion of the area occupied by the Loader. Subsequent programs must contain common length declarations

which are less than or equal to the length of the first declaration.

To allocate the common area, the Loader subtracts the total length of the block from the address of the last releasable word in the Loader. The resulting memory address +1 is the origin of the common block. This value is used throughout the entire loading process as the common relocation base.

Program Storage

The program length is compared with the amount of available memory. If sufficient space is available, the program is loaded and the upper and lower bounds recorded. If the program has a Base Page segment, or if the program consists entirely of coding to be stored in the Base Page, the length of the segment is compared to the amount of available base page memory. If there is enough space in this area, the segment is loaded and the bounds recorded. The initial main program segment is usually origined at absolute location 02000 (page 1, Module 0). The initial Base Page segment is usually origined immediately following the area set aside for Reserved Locations, Interrupt Processing, and System Linkage. Subsequent main program and Base Page segments are loaded into the next available higher numbered areas contiguous to the previously loaded segments.

Providing the Memory Allocation List option is selected (see Operating Procedures) the name of each program, its upper and lower bounds, and its Base Page upper and lower bounds are printed after the program is loaded. The format is as follows:

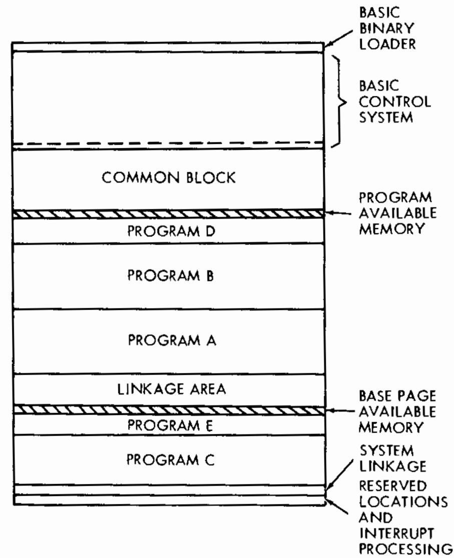
<program name>

lllll uuuuu (main program bounds)

lllll uuuuu (Base Page bounds)

If the Loader finds that the main program segment about to be loaded can not fit in the memory area available for the main segment, it compares the segment's length to the length of available memory in the Base Page. If there is sufficient space, the main segment will be loaded in the Base Page. The next segment will be loaded in the main program area if it will fit, or in the Base Page if not (providing there is sufficient space in the Base Page).

For example, assume that several programs to be loaded in sequence A, B, C, D, E, and have sizes such that they can not all fit in the main program available memory.



3.6 OBJECT PROGRAM RECORD PROCESSING

ENT/EXT Record Processing

The Loader constructs and maintains a Loader Symbol Table which contains entry points and external symbols which are declared in the programs and entry point names of any BCS system subroutines that have been defined as relocatable. As each entry point is encountered its relocated (absolute) address is recorded in the table. As each external reference is processed, a link word is established in the Base Page. The gen-

eral processing of the entries in an ENT and EXT record involves searching the Table to locate a match between the symbols. When a match is found, the absolute entry point address is stored in the Base Page link word.

The Loader assumes that there is a user program, BCS system routine, or Program Library routine entry point for every external reference. If none exists, the external reference is undefined and considered to be in error. A list of undefined external symbols is printed at the end of the loading operation. If duplicate entry points are detected, a diagnostic is issued. A user entry point duplicated by a Program Library routine results in the library routine being ignored.

Each entry in the Loader Symbol Table occupies five words. The Table is positioned before the beginning of the Loader and extends backwards toward low-numbered memory. If sufficient space is not available in the main program portion of memory to store a five-word entry, a diagnostic message is issued and the loading operation is terminated.

DBL Record Processing

A load address for the data or instruction words in a DBL record is relocated by adding either the program relocation base or the base page relocation base. The resulting value is the absolute address for storing the first word. The second word is stored at address +1, the third at address +2 and so forth. A relocation base is added to each operand address as specified by the relocation indicator.

The processing for an external reference word involves a search of the Loader Symbol Table for the related entry. When found, the address of the link location in the Base Page is extracted and stored as an indirect address in the instruction.

When a memory reference instruction is processed, the Loader first applies the proper relocation base, (program, base page, or common) to the 15-bit operand address. If the resulting absolute operand address references the Base Page, the address (bits 09-00) is set into the operand field and the instruction is stored in memory at the current load address. When the absolute operand address and the current load address are in the same page, the operand address is truncated to bits 09-00 and set as the instruction operand address. If

the operand address is in a page other than the current load address page, the operand address is stored in the Linkage area of the Base Page and a reference to this location set as an indirect address in the operand field of the instruction.

A memory overflow condition can occur when insufficient space is available in the base page to allocate a linkage word. A diagnostic message is issued and the loading operation is terminated.

END Record Processing

When an END record is encountered, the Loader determines if it contains a transfer of control address. If it does, the address is saved.

If loading is from the Program Library and there exist no undefined external references, the End-Of-Loading operation is performed.

If loading is from the Standard Input unit or Program Library unit and if undefined external references exist, the Loader requests the next record. If the next record is a NAM record, processing of the next program begins. If the result of the request is an End-of-Information indication, an End Condition exists.

Program Library Loading

Loading from the Program Library differs from loading of user programs in that only those programs in the Library which contain entry points matching undefined external symbols in the Loader Symbol Table will be loaded. After each program is loaded from the Library, the Loader Symbol Table is checked for undefined symbols. If none exist, the loading operation is complete and the program is ready to be executed.

End Condition

When the Loader requests input and no data is available on the input device an End Condition exists. The Loader acknowledges this condition by writing the message "LOAD" on the Teleprinter Output device. The user responds to this message by

setting switches 2-0 of the Switch Register (see Operating Procedures). Four replies are available:

a. Load next program from Standard Input unit. Relocatable BCS system subroutines are considered to be part of the program and must be loaded from the Standard Input unit (unless they are made part of Program Library tape).

b. All programs are loaded; proceed to the end-of-loading operation.

c. Terminate loading operation. This forces program execution even though there may be undefined external references.

d. Load from Program Library unit; all user programs are loaded.

End-of-Loading Operation

The end of loading is signaled by the second or fourth response to an End Condition. The Loader then searches the Loader Symbol Table for any undefined external references. Any such undefined external symbols are written on the Teleprinter Output unit and the "LOAD" message is repeated.

When the loading operation is completed, or when the user has requested termination of the Loading process, the Loader produces a memory allocation list. (This list may be omitted; see Operating Procedures.) The format of the list is as follows:

```
<symbol 1>   aaaaa

<symbol 2>   aaaaa
     .
     .
     .
<symbol n>   aaaaa
```

The symbols are the entry points in the user's program, the Basic Control System, or the Program library and the a's are their absolute addresses.

If a common block was allocated, the lower and upper bounds of the block are listed as follows:

```
*COM      lllll      uuuuu
```

The bounds of the Linkage Area are listed as follows:

*LINKS lllll uuuuu

The l's are the absolute lower bounds and the u's are the absolute upper bounds.

3.7 PROGRAMMING CONSIDERATIONS

When a program has been completely loaded, its execution is initiated by performing a Jump Subroutine to the transfer address (from the last END record containing an address). The initial contents of the transfer address should be a NOP, OCT 0, etc., not the first executable instruction of the program.

3.8 LOADER OPERATING PROCEDURES

The exact operating procedures for the loader depend on the available hardware configuration and the construction of the Basic Control System through use of the Prepare Control System routine. The user should know the assignment of input/output equipment and memory size before using the Loader.†

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†As established when configuring BCS.

Loading Options

The Basic Control System Loader is designed to load one or more tapes containing relocatable programs. The message "LOAD" is typed when an end-of-tape condition is encountered. The user then loads the next tape; indicates loading from the program library, specifies that loading is complete, etc. When all programs are loaded and no undefined external references remain, the Loader types the message "LST" allowing the user to bypass part of the Memory Allocation List. Following the response, the Loader types the message "RUN". The user then initiates program execution.

Memory Allocation List

A memory Allocation List may be obtained for the programs being loaded. The list may include the name, main program bounds, and Base Page bounds for each of the programs. This portion of the List may be followed (at the completion of the loading operation) by a list of all entry points and their absolute addresses, the bounds of the common block, and the bounds of the linkage area. The setting of Switch 15 determines the contents of the List.

To obtain the bounds for each program on a tape, Switch 15 must be set to 0 before the tape is loaded (in response to the "LOAD" message). To bypass the program bounds listing, set Switch 15 to 1 before loading the tape. The switch setting may be altered whenever the "LOAD" message is typed.

To obtain the entry point list, the common bounds, and the linkage area bounds, set Switch 15 to 0 in response to the message "LIST", which is printed after all programs are loaded. To bypass this portion of the list, set Switch 15 to 1.

Absolute Binary Output

The user may specify that an absolute binary tape be punched. This option may be selected when it is necessary to utilize the area occupied by the Loader or when an absolute version is desired for "production stage" programs. The process involves a simulated loading operation, however, the absolute program is punched on tape rather than being loaded.

The absolute records produced consist of the relocated programs (including all programs loaded from the Program Library), the Linkage area, all referenced segments of the Basic Control System. These might include:

Input/Output control subroutine (.IOC.)
All input/output equipment drivers
Other BCS system subroutines
Memory Table (.MEM.)
System Linkage Area
Interrupt Processing area
Absolute location 2 and 3

In addition, the Loader Symbol Table, the common and linkage area bounds are punched in ASCII format on the end of the binary tape. Ten inches of feed frames separate the binary instructions and the ASCII data. This feature provides a record of the memory allocation for the absolute program.

At the completion of the "loading" process the Loader types the message "END".

To execute the program, it must be loaded using the Basic Binary Loader. To initiate execution, set 000002 into the P-Register and press RUN. The Loader has stored the transfer address of the program in locations 2 and 3 as follows:

2 contains JMP 3,I
3 contains <transfer address>

Separation of List and Binary Output

If the absolute binary output option is selected and the Teleprinter is used as both a list and punch device, the Loader halts before and after each line is printed to avoid punching the line and altering the binary output.

The halts and related procedures are as follows:

T-Register Contents	Explanation	Action
102055	A line is about to be printed.	Turn punch unit OFF. Press RUN.
102056	A line has been printed.	Turn punch unit ON. Press RUN.

Operating Instructions

The following procedures indicate the sequence of steps for loading and execution of the Basic Control System Loader:

A. Set Teleprinter to LINE and check that all equipment to be used is operable.

B. Load the Basic Control System tape using the Basic Binary Loader:

1. Place the Basic Control System tape in the device serving as the Standard Input unit (e.g., Punched Tape Reader).
2. Set Switch Register to starting address of Basic Binary Loader (e.g., 007700 for 4K memory, 017700 for 8K memory).
3. Press LOAD ADDRESS.
4. Set LOADER switch to ENABLED.
5. Press PRESET.
6. Press RUN.
7. When the computer halts and indicates that the BCS tape is loaded (T-Register contains 102077), set the LOADER switch to PROTECTED.

C. Set Switch Register to 000002, press LOAD ADDRESS, and set Switch Register to 000000.

D. Establish Loader parameters:

1. Set Switch 15 to 1 if no Memory Allocation Listing is desired during first load operation.
2. Set Switch 14 to 1 if an absolute binary tape of the programs is to be punched. (Turn on punch device if this option is selected.
3. For installations including an ASR-35 with a parallel teleprinter interface, register switch 13 may be set up (13 = 1) when initiating the loader to indicate both list and punch output functions. This eliminates the halts before and after a line is to be printed. The Selector switch on the ASR-35 should be set to "KT". (Switch 14 must be set as usual to mean an absolute tape is to be produced.)

E. Place relocatable object tape in device serving as Standard Input unit.

F. Press PRESET, then press RUN

During the operation of the Basic Control System Loader, the following halts may occur:

Teleprinter Message	Explanation	Action
LOAD (T-Register contains 102001.)	End-of-tape condition on Standard Input device.	1. To load next tape, set Switches 2-0 to 0_8. If no Memory Allocation Listing of next tape is desired, set Switch 15 to 1. Press RUN to continue loading.
		2. To indicate that all programs are loaded and to proceed to the end-of-loading phase, set Switches 2-0 to 1_8. Press RUN.†
		3. To terminate loading operation, set Switches 2-0 to 2_8. Press RUN. (This forces execution even though undefined external references have not been matched.)

†A list of any undefined external symbols is typed following a Switch Register reply of 1_8 or 4_8 to the "LOAD" message. The message "LOAD" is then repeated. The programs containing the matching entry points should be loaded. Loading of user programs from Standard Input must be completed before loading of routines from Program Library.

Teleprinter Message	Explanation	Action
		4. To load from Program Library, set Switches 2-0 to 4_8. If no Memory Allocation Listing of library routines is desired, set Switch 15 to 1. Press RUN to continue loading. When all library routines are loaded, the Loader proceeds directly to the end-of-loading phase.
*LST	The Loader is ready to print the LST, common bounds, and linkage area bounds.	If a list of these items is not desired, set Switch 15 to 1. Press RUN. If the ASCII output of the Loader Symbol Table (LST) is to be punched (e.g., for 2018 use) and an ASR-35 is used to both list and punch the absolute tape, as in step 1, the selector switch on the ASR-35 should be set to "T" before pressing RUN after the message "LST" is typed. "T" enables the punch unit.
*RUN	All programs are loaded and ready for execution.	Check that all I/O devices are ready for operation. Press RUN.
*END	The absolute binary output has been selected and the punched tape is complete.	To execute the program: 1) Load binary tape using Basic Binary Loader as in B.

Teleprinter Message	Explanation	Action
		2) Set Switch Register to 000002. Press LOAD ADDRESS. 3) Press RUN.
*L01	Checksum error: The checksum read on the last record does not agree with the checksum calculated by the Loader.	To re-read record, reposition tape to beginning of record and press RUN.
*L02	Illegal record: The last record read was not recognized as one of the five types accepted by the Loader.	To re-read record, reposition tape to beginning of record and press RUN.
*L03	Memory overflow: The length of the main or Base Page portion of the program or the common block exceeds the bounds of available memory.	Irrecoverable error, program must be revised.
*L04	Linkage area overflow: Linkage words supplied by the Loader for references between pages exceed the size of available base page memory.	If program consists of several subprograms, altering the sequence in which the subprograms are loaded may reduce the number of linkage words. Otherwise, irrecoverable error, program must be revised.
*L05	Loader symbol table overflow: The number of EXT/ENT symbols exceed available memory.	Irrecoverable error, program must be revised.

Teleprinter Message	Explanation	Action
*L06	Common block error: The length of the common block in the current program is greater than the length of the first common block allocated.	Revise sequence in which subprograms are loaded and reload program. Otherwise, revise program.
*L07	Duplicate entry points: An entry point in the current program matches a previously declared entry point.	Irrecoverable error, program must be revised.
*L08	No transfer address: The initial starting location (e.g., END statement operand) was not present in any of the programs which were loaded.	To enter the starting address, set the absolute value in the Switch Register, press LOAD A, and press RUN.
*L09	Record out of sequence: ANAM record was encountered before the previous program was terminated with an END record.	Irrecoverable error, program must be revised.

If the absolute binary output option is selected, the following halts may occur:

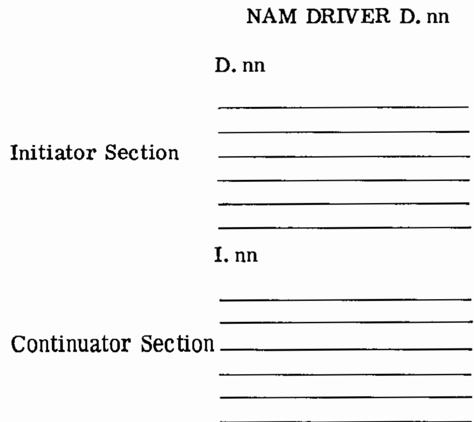
T-Register Contents	Explanation	Action
102066	Tape supply low on 2753A Tape Punch which is producing absolute binary output. Trailer follows last valid output.	Place new reel of tape in unit. Press RUN. Leader is produced.
102055	A line is about to be printed on Teleprinter output device. (See Separation of List and Binary Output.)	Turn punch unit off. Press RUN.
102056	A line has been printed while Teleprinter punch unit off. (See Separation of List and Binary Output.)	Turn punch unit on. Press RUN.

4.1 GENERAL DESCRIPTION

An I/O driver, operating in the BCS environment, is responsible for controlling all data transfer between an I/O device and the cpu. It operates under control from the program IOC. Its operating parameters are the user I/O request and the information contained in the device associated Equipment Table entry.

4.2 STRUCTURE

An I/O driver is a relocatable program segmented into two closed subroutines, termed the "initiator" and "continuator" sections. The entry point names for these two sections must be "D. nn" and "I. nn", respectively. The numeric value "nn" in the names is the Equipment Type Code assigned to the device. For example, D. ØØ and I. ØØ are the entry points for the Teletype driver; "ØØ" is the Equipment Type Code assigned to a Teletype.



4.2.1 Initiator Section

This section is called directly from IOC with calling parameters including the address of the second word of the user I/O request and the address of the EQT entry for the referenced device. IOC sets these parameters in A and B and performs a JSB to the entry point "D. nn". Return to IOC from this section must be indirectly through D. nn.

On entry to D. nn,

(A) = Address of word 1 of 4-word EQT entry
(B) = Address of word 2 of I/O request

The initiator section of any driver must perform the functions described below.

1) Reject the IOC request and return to IOC (see step 6) if any of the following conditions exist:

   a. the driver is busy operating another device

   b. the referenced device is busy or inoperable

   c. the user request code or other parameters illegal for the device

   d. a DMA channel is not available and DMA is required for data transfer.

2) Extract the parameters from the user I/O request and save them within the driver storage.

3) Configure all I/O instructions in the driver to include the channel number for the reference device.

4) Indicate equipment in operation:

   a. set the "a" field in the EQT entry to 2 (busy) for the device called

   b. set an internal driver "busy" flag for the driver

   c. set a "busy" flag in IOC if a DMA channel is used

(To set a DMA flag in IOC:

Within the IOC program the two entry points DMAC 1, DMAC 2 contain the DMA channel locations (6 and 7 or 7 and 6). The sign bit of the channel used must be set to 1 to indicate that the channel is busy.)

5) Initialize operating conditions and activate the device.

6) Return to IOC with the A and B registers set to indicate initiation or rejection and the cause of the reject:

   (A) = Ø, operation initiated
   = 1, operation rejected - reason in B-Register
   = 1ØØØØØ, immediately release buffer in buffered IOC
   (B) = 1ØØØØØ, the device is busy or inoperable, or the driver is busy
   = ØØØØØ1, a DMA channel is required but no channel is available
   = ØØØØØØ, the request code or sub-function is not legal for the device

4.2.2 Continuator Section

This section is entered by device interrupt to continue or complete an operation. It may also be called from the Initiator Section to begin an operation. The entry point to this section is I. nn. There are no parameters on entry.

The continuator section of any driver must perform the functions described below.

1) Save all registers which will be used by the continuator section.

2) Perform the input or output of the next data item. If the transfer is not completed, restore the "saved" register and return control to the program (see steps 5 and 6).

   NOTE: A driver for a device which inputs or outputs data independent of program control such as DMA would not include step 2. The device is turned "on" by the initiator section (step 5) and the data transfer is immediately accomplished. The continuator section for such drivers merely completes the input or output operation.

3) When data transfer is completed (end-of-operation) or if a device malfunction is detected, set the following information in the EQT entry:

   The number of words or characters transferred (corresponding to the request) is set as a positive value in word 3. Bit 15 of word 3 is set to Ø or 1 to indicate the mode of transfer.

   The device status, actual or simulated, is set in bits 07-00 of word 2 and the "a" field (bits 15-14) in word 2 set to:

   - 0 - device available (not busy)
   - 1 - device available; the operation is complete but an error has been detected

   Bits 13-08 of word 2 must not be altered.

4) Clear all "busy" indicators. Clear the driver busy flag. If a DMA channel was used clear the flag in IOC.

5) Restore all registers saved at the entry.

6) Return indirectly through the entry point I. nn, with the following exception:

   If end-of-operation and the operation completed was an output or Function request, return must be made to the entry point ".BUFR" in IOC. This enables the Buffered version of IOC to perform the automatic output buffering function. The standard version of IOC at this entry point just performs a normal return to the point of interruption. The calling sequence to .BUFR is:

```
        EXT   .BUFR
(P)     JSB   .BUFR
(P+1)   NOP         (holds return address from I. nn)
(P+2)   NOP         (holds EQT entry address)
```

The Prepare Control System (PCS) program processes relocatable modules of the Basic Control System and produces an absolute version designed to work on a specific hardware configuration. It creates operating units of the Input/Output Control subroutine (.IOC.), the equipment driver subroutines, and the Relocating Loader. It also establishes the contents of certain locations used in interrupt handling. Options are available to define the equipment driver modules and other BCS system subroutines as relocatable programs to be loaded with the user's object program.

The Prepare Control System is an absolute program which is loaded by the Basic Binary Loader. It operates on a minimum configuration of 4K memory and a 2752A Teleprinter. However, if a 2737A Punched Tape Reader and a 2753A Tape Punch are available, the Prepare Control System will utilize these devices; PCS requests their assignment during the Initialization phase.

After the Initialization phase is completed, each module of BCS is loaded and processed by PCS. The order in which the modules are processed is not significant except that the BCS Loader must be the last module loaded. Two modules, the Input/Output Control subroutine and the Loader, require that parameters be entered via the Keyboard Input unit after being loaded.

5.1 INITIALIZATION PHASE

During the Initialization phase, the System requests that the operator provide the channel assignments of the Punched Tape Reader and the Tape Punch if available. This is followed by a request for the first and last words of available memory. The first word is the location in the Base Page following the locations required for interrupt processing (the interrupt locations and the locations containing the addresses of the Interrupt Processors). This location defines the start of the BCS System Linkage area. The last word of available memory is usually the location prior to the protected area (e.g., 7677 for 4K memory, 17677 for 8K memory).

Example:

HS INP?	message
10	reply
HS PUN?	message
11	reply
FWA MEM?	message
30	reply
LWA MEM?	message
17677	reply

.
.
.

5.2 LOADING OF BCS MODULES

After the Initialization phase is completed, the System types the message "LOAD". The modules of BCS are then loaded using the Punched Tape Reader, if available, or the Teleprinter reader. The modules may include .IOC., the equipment drivers, and the Relocating Loader. They may be loaded in any order provided that the Relocating Loader is last. The message is repeated after each module is loaded until the Loader has been processed. Diagnostics are printed if certain error conditions occur during the loading. The absolute lower and upper bounds of each program within BCS are listed after the program is loaded.

The format is as follows:

<program name>

lllll uuuuu

Equipment driver subroutines and interrupt processing sections which are to be used in relocatable form are identified during PCS processing but are not loaded. At the completion of the processing, PCS requests the missing subroutines. The proper response identifies each as relocatable.

5.3 INPUT/OUTPUT EQUIPMENT PARAMETERS

After the Input/Output Control module is loaded, PCS requests the information needed to construct the Equipment Table (EQT) and Standard Equipment Table (SQT).†

Equipment Table Statements

PCS first types the messages "TABLE ENTRY" and "EQT". The operator responds by supplying the Equipment Table entries in the following format:

nn, D.ee [,D] [,Uu]

nn — The channel number (select code) for the device. For a device connected to two or more channels, nn is the lower numbered channel.

D.ee — The Basic Control System symbolic name for the related equipment driver subroutine. ee is the equipment type code used by BCS. Driver names are as follows:

D. 00 – 2752A Teleprinter
D. 01 – 2737A Punched Tape Reader
D. 02 – 2753A Tape Punch
D. 20 – Kennedy 1406 Incremental Tape Transport
D. 21 – 2020A Magnetic Tape Unit
D. 22 – 3030A Magnetic Tape Unit
D. 40 – Data Source Interface
D. 41 – Integrating Digital Voltmeter
D. 42 – Guarded Crossbar Scanner
D. 43 – Time Base Generator

D — A Direct Memory Access channel is required to operate the device.

Uu — The physical unit number u (0-7) for addressing the device if it is attached to a multi-unit controller.

The same response is used regardless of whether the related subroutine driver is to be relocatable or absolute (part of BCS). If the driver is not encountered during processing, PCS prints the following:

```
I/O DRIVER?
D.EE
```

†See Appendices B and C for description of EQT and SQT.

A response of "!" indicates that the driver is to be in relocatable form. (Any other response at this time is an error.) Drivers which use DMA or reference entry point IOERR in the IOC module may not be used externally in this way.

The order in which the EQT statements are submitted defines the position of the entry in the Equipment Table. It also establishes the unit-reference number that the programmer uses in writing input/output requests to .IOC. The first statement entered describes the unit which is to be referenced as number 7_8; the second statement, number 10_8; the third statement, number 11_8; etc. Numbers 1 through 6 are reserved for Standard unit definition in the Standard Equipment Table.

The statement "/E" is entered to terminate the EQT input.

Example:

		Unit-Reference Number
*TABLE ENTRY	Message	
EQT?	Message	
10,D.01	Statement	7
11,D.02	Statement	10
12,D.00	Statement	11
/E	Terminator	

Standard Equipment Table Statements

In constructing the Standard Equipment Table, PCS types a mnemonic for the Standard unit and waits for the reply. The reply consists of the unit-reference number for a device previously described in the Equipment Table.

Example:

SQT?	message
-KYBD?	message to assign Keyboard Input
11 -TTY?	reply: unit-reference number for Teleprinter message to assign Teleprinter Output
11 -LIB?	reply: unit-reference number for Teleprinter message to assign Program Library

7	reply: unit-reference number for Punched Tape Reader
-PUNCH?	message to assign Punch Output
10	reply: unit-reference number for Tape Punch
-INPUT?	message to assign Input
7	reply: unit-reference number for Punched Tape Reader
-LIST?	message to assign List Output
11	reply: unit-reference number for Teleprinter

Direct Memory Access Statement

After the equipment tables are completed, PCS requests information about the availability of DMA channels to be controlled by the Input/Output Control and equipment driver subroutines. PCS types the message "DMA?" and the operator responds with the available DMA channel numbers. The format of the reply is:

$$c_1 [, c_2]$$

c_1 is 6 if one channel is available

c_2 is 7 if the second channel is available

If no DMA channel is available, the reply is 0 (zero).

Example:

DMA?	message
6,7	reply for two channels

If the reply contains any characters other than 6 or 7 it is considered to be in error and a diagnostic is issued.

5.4 INTERRUPT LINKAGE PARAMETERS

After the Relocating Loader is loaded, PCS requests the parameters needed to set the Interrupt Linkage for Input/Output processing. The information required for each device includes:

The interrupt location within the Reserved Location area in low core.

The entry point name of the interrupt processing section in the equipment driver subroutine for the device.

The address of the word in the Base Page which is to contain the 15-bit absolute address of this entry point name.

The same response is used regardless of whether the subroutine driver is to be relocatable or absolute (part of BCS). If the entry point was not encountered during processing, PCS prints the following:

*UN NAME

A response of "!" indicates that the driver is to be in relocatable form. (Any other response at this time redefines the linkage.)

Given this information, PCS sets in the interrupt location a Jump Subroutine (Indirect) to the word holding the absolute address for the entry point of the Interrupt Processor.

Location	Content
10	JSB 20B, I
.	.
.	.
.	.
20	DEF I. 01

10 is the interrupt location

20 holds the address of the entry point, I. 01, of the Interrupt Processor.

PCS types the message "INTERRUPT LINKAGE?" The operator responds with a message in the following format:

$$a_1, a_2, \text{I.ee}$$

a_1 The address in low core of the interrupt location for the device (channel).

a_2 The address in the Base Page of the word to contain the absolute address of the Interrupt Processor entry point.

I. ee The entry point name of the Interrupt Processor section of the equipment driver subroutine. ee is the equipment type code used by BCS. Entry point names are as follows:

I. 00 – 2752A Teleprinter
I. 01 – 2737A Punched Tape Reader
I. 02 – 2753A Tape Punch
I. 20 – Kennedy 1406 Incremental Tape Transport
I. 21 and C. 21† – 2020 Magnetic Tape Unit
I. 22 and C. 22† – 3030 Magnetic Tape Unit
I. 43 – Time Base Generator

The statement "/E" is entered to terminate the Interrupt Linkage parameter input. Drivers which use DMA or reference entry point IOERR in the IOC module may not be used externally in this way.

Example:

INTERRUPT LINKAGE?	message	
10,20,I.01	reply:	The Punched Tape Reader uses interrupt location 10. The absolute address for entry point I. 01 is location 20 in the Base Page.
11,21,I.02	reply:	The Tape Punch uses interrupt location 11. The address of I. 02 is at location 21.

† Both the magnetic tape systems are connected to two channels; the lower numbered channel transfers data (D. 21, D. 22); the higher numbered channel transfers commands (C. 21, C. 22).

12,22,I.00 13,22,I.00	reply: The Teleprinter, which requires two channels, uses interrupt locations 12 and 13. The Interrupt Processor entry point address is stored at location 22. This applies to bit-serial teletypes only. Parallel teletypes use one interrupt location. If the I/O card is in slot 12, the correct reply to INTERRUPT LINKAGE? is '12,22,I.ØØ'.
/E	Terminates linkage parameters.

The response to the "INTERRUPT LINKAGE?" message may have the following form if a constant, for example a halt, is to be set in the interrupt location.

a, c

a The address in low core of the interrupt location for the device (channel).

c The constant in octal form that is to be stored at location a.

Example:

INTERRUPT LINKAGE?	message
27,102027	reply: A halt executed when interrupt occurs on channel 27.
26,0	reply: A NOP is executed when interrupt occurs on channel 26; the program resumes normal execution.

5.5 PROCESSING COMPLETION

When the Interrupt Linkage parameters have been supplied, PCS performs the following functions:

1. Prints the message "*UNDEFINED SYMBOL" followed by the entry point names of all system subroutines which have been referenced as externals but not loaded. At this point,

PCS may be rerun and the missing subroutines loaded or, the symbols may be added to the Relocating Loader's Loader Symbol Table. Undefined symbols are assigned a value of 77777 for an absolute address.

2. Completes the construction of the Loader Symbol Table.
3. Sets the Memory Table (symbolic location .MEM.) in the Relocating Loader to reflect the final bounds of available memory.

Following this, PCS prints a list of all Basic Control System entry points and the bounds of the System Linkage area in the Base Page.

Example:

```
.SQT.    17472
.EQT.    17500
.IOC.    17515
DMAC1    17676
DMAC2    17677
IOERR    17656
XSQT     17674
XEQT     17675
D.00     16745
I.00     17107
D.01     16406
I.01     16521
D.02     16115
I.02     16226
.LDR.    15413
HALT     16110
.MEM.    16110
LST      14102


*SYSTEM LINK
00030  00071
```

The final step in PCS processing is the punching of an absolute binary tape of the configured Basic Control System. This tape can be loaded by the Basic Binary Loader. When the tape has been punched, BCS types the message "*BCS ABSOLUTE OUTPUT". At the completion of the PCS run, the message "*END" is typed. The tape is punched using the Tape Punch unit if available, or the Teleprinter punch.

5.6 OPERATING PROCEDURES

The following procedures indicate the sequence of steps for loading and execution of the Prepare Control System.

A. Set Teleprinter to LINE and check that all equipment to be used is operable.

B. Load the Prepare Control System tape using the Basic Binary Loader.

  1. Place the Prepare Control System tape in the device serving as the Standard Input unit (e.g., Punched Tape Reader).

  2. Set Switch Register to starting address of Basic Binary Loader (e.g., 007700 for 4K memory, 017700 for 8K memory).

  3. Press LOAD ADDRESS.

  4. Set LOADER switch to ENABLED.

  5. Press PRESET.

  6. Press RUN.

  7. When the computer halts and indicates that the PCS tape is loaded (T-Register contains 102077) set the Loader Switch to Protected.

C. Set Switch Register to 002000, press LOAD ADDRESS.

D. Set Switches 5-0 to the value of the channel number of the Teleprinter. (On a two channel teleprinter use the lower numbered channel.)

E. Press RUN.

The initialization Phase is executed. During this phase the following messages may occur:

Teleprinter Message	Explanation	Action
HS INP?	Request for Punched Tape Reader channel assignment.	Type channel number. If Punched Tape Reader not available, type 0. †
HS PUN?	Request for Tape Punch channel assignment.	Type channel number. If Tape Punch not available, type 0.
FWA MEM?	Request for first word of available memory.	Type address of word in Base Page following the locations required for interrupt processing.
LWA MEM?	Request for last word of available memory.	Type address of word preceding protected area.
*ERROR	A non-numeric or illegal character has been entered as a reply.	Type the correct value.

Following the completion of the Initialization Phase the relocatable object tapes of the Basic Control System are to be loaded. Only those modules which are to be included in the absolute tape are loaded; modules which are to be loaded with the user's object program are not submitted. The modules may include .IOC., the equipment drivers, and the Relocating Loader; they may be loaded in any order provided that the Relocating Loader is last. During this phase, the following halts may occur:

†All replies from the keyboard must be terminated by an end-of-statement mark which consists of a carriage return, (CR), and a line feed, (LF). If an error is made in typing a reply, type (RUBOUT) (CR) (LF) and repeat the reply.

Teleprinter Message	Explanation	Action
*LOAD	PCS is requesting the first or the next BCS module.	Place BCS tape in Punched Tape Reader if available, or Teleprinter reader. Press RUN.
*L01	Check sum error	To re-read record, reposition tape to beginning of record and press RUN.
*L02	Illegal record: the last record read was not recognized as a valid relocatable record type.	To re-read record, reposition tape to beginning of record and press RUN.
*L03	Memory overflow: the length of BCS exceeds available memory.	Irrecoverable error.
*L04	System linkage area overflow in Base Page.	Irrecoverable error.
*L05	Symbol table for BCS symbols exceeds available memory.	Irrecoverable error.
*L06	PCS interprets the program length of BCS to be zero.	Irrecoverable error.
*L07	Duplicate entry points within BCS.	Irrecoverable error.
*EOT	End-of-Tape	Place next tape in read unit and press RUN to continue loading.

When the .IOC. module is loaded, PCS requests the EQT and SQT parameters. PCS halts after typing the messages "*TABLE ENTRY? EQT?". If the Teleprinter serves both as the reader and keyboard unit, turn reader off, press RUN. Begin typing response to message. (Turn reader on after all replies have been typed.)

Teleprinter Message	Explanation	Action
*TABLE	Request for EQT entry information.	Press Run and for each I/O device, type: nn, D. ee, [, D] [, Uu] nn – channel number D. ee – driver name: ee = 00 Teleprinter = 01 Punched Tape Reader = 02 Tape Punch = 20 Kennedy 1406 Incremental Tape Transport = 21 2020A Magnetic Tape Unit = 22 3030 Magnetic Tape Unit = 40 Data Source Interface = 41 Integrating Digital Voltmeter = 42 Guarded Crossbar Scanner = 43 Time Base Generator D – device uses DMA channel Uu – physical unit number (0-7) if attached to multi-unit controller To terminate EQT input, type /E.
*ERROR	A non-numeric value has been typed for nn, ee, or u.	Retype the entire correct entry.
SQT? -KYBD?	Request for EQT unit-reference number of unit serving as Keyboard Input.	Type number.
-TTY?	Request for EQT unit-reference number of unit serving as Teleprinter Output.	Type number.

Teleprinter Message	Explanation	Action
-LIB ?	Request for EQT unit-reference number of unit serving as Program Library.	Type number.
-PUNCH ?	Request for EQT unit-reference number of unit serving as Punch Output.	Type number.
-INPUT ?	Request for EQT unit-reference number of unit serving as Input.	Type number.
-LIST ?	Request for EQT unit-reference number of unit serving as List Output.	Type number.
DMA ?	Request for DMA channel numbers.	If one DMA channel, type 6. If two DMA channels, type 6, 7. If no DMA channels, type 0.
*ERROR	A non-numeric parameter or a parameter not equal to 6 or 7 has been entered.	Re-type correct parameter.

After the Relocating Loader is loaded, PCS requests the information needed to set the interrupt linkage for input/output processing. PCS halts after typing the message "INTERRUPT LINKAGE ?". If the Teleprinter is serving both as the reader and the keyboard unit, turn reader off and press Run. Begin typing response to message.

Teleprinter Message	Explanation	Action
INTERRUPT LINKAGE?	Request for interrupt information.	Press Run and for each I/O device, type: a_1, a_2, I. ee a_1 – interrupt location address a_2 – location containing absolute address of Interrupt Processor entry point I. ee entry point name: ee = 00 Teleprinter = 01 Punched Tape Reader = 02 Tape Punch = 20 Kennedy 1406 Incremental Tape Transport = 21 (and C.21) 2020A Magnetic Tape System = 22 (and C.22) 3030A Magnetic Tape System = 43 Time Base Generator If a constant is to be set into the interrupt location, type: a, c a - interrupt location address c - 1 to 6 digit octal constant to be stored at a. Constants should be entered for the following instrument drivers: Data Source Interface (D. 40): 1067 sc (CLC sc, 4) Integrating Digital Voltmeter (D. 41): Ø (NOP) Guarded Crossbar Scanner (D. 42): Ø (NOP) To terminate linkage input, type /E.

Teleprinter Message	Explanation	Action
*ERROR	A non-numeric value has been typed for a_1, a_2, a or c.	Retype the entire correct entry.
*UNNAME	The name I. ee is not defined as an entry point in any I/O driver previously loaded.	1) If the driver name was typed incorrectly, retype the entire correct entry. 2) If related driver is to be loaded with user's program at object program load time, type an exclamation mark (!). The name is added to the Loader's LST. 3) If the driver should have been loaded, rerun PCS.

When the Interrupt Linkage parameters have been supplied, PCS performs the following functions: (Drivers which use DMA or reference entry point IOERR in the IOC module may not be used externally in this way.)

1. Prints the message "*UNDEFINED SYMBOL" followed by the entry point names of all system subroutines which have been referenced as externals but not loaded. At this point, PCS may be rerun and the missing subroutines loaded or, the symbols may be added to the Relocating Loader's Loader Symbol Table. Undefined symbols are assigned a value of 77777 for an absolute address.

2. Completes the construction of the Loader Symbol Table.

3. Sets the Memory Table (symbolic location .MEM.) in the Relocating Loader to reflect the final bounds of available memory.

Following this, PCS prints a list of all Basic Control System entry points and the bounds of the System Linkage area in the Base Page.

Teleprinter Message	Explanation	Action
*UNDEFINED SYMBOL <symbol>	An entry point in a BCS module cannot be located.	1) To enter the symbol in the Loader Symbol Table, press RUN. 2) If the subroutine should have been loaded, rerun PCS.
I/O DRIVER? D. ee	A driver has been named in the EQT parameter entry, but has not been loaded.	1) If the driver is to be loaded with user's program at object program load time, type an exclamation mark (!). The name is added to the Loader's LST. 2) If the driver should have been loaded (or if a character other than ! is typed), rerun PCS.
*BCS ABSOLUTE	PCS is ready to punch absolute output tape.	Turn on punch unit and press RUN.† Drivers which use DMA or reference entry point IOERR in the IOC module may not be used externally in this way.

When the binary tape is punched the following halts may occur:

T-Register Contents	Explanation	Action
102077	BCS tape is punched.	To produce additional copies, set Switch 15 to 1 and press RUN.
102066	Tape supply low on 2753A Tape Punch.	Place a new reel of tape in Tape Punch and press RUN to continue.

†If the teleprinter is an ASR-35 it should be set in "KT" position (keyboard selector switch) until the message "BCS ABSOLUTE OUTPUT" is typed. Before pressing RUN to produce the absolute tape, the selector switch should be changed to "T" to allow both printing and punching.

5.7 EXAMPLE

The teleprinter listing shown below was output from a Prepare Control System operation that configured a BCS tape for an HP 2116 system which included a Teleprinter, a Tape Punch, a Punched Tape Reader, and a 2020A Magnetic Tape Unit.

The PCS tape was loaded; 2000_8 was set in the P-Register; the Switch Register was set to the channel number of the teleprinter, in this case the lower channel number (13_8). The RUN button was pressed and the Teleprinter printed:

```
HS INP?
10
HS PUN?
11
                          } Initialization Phase
FWA MEM?
23
LWA MEM?
17677

* LOAD

D.21
 16231 17677              } Magnetic Tape

* LOAD

D.01
 15672 16230  —  Punch Tape Reader   ]

* LOAD                                ] Load the BCS
                                      ] Drivers
D.02
 15362 15671  —  Tape Punch          ]

* LOAD

D.00
 14606 15361  —  Teleprinter         ]
```

```
* LOAD

IOC
 14367 14605
```

Load IOC

```
* TABLE ENTRY

EQT?
10,D.21
12,D.01
13,D.02
14,D.00
/E
```

Enter the EQT Table

```
SQT?
-KYBD?
12
-TTY?
12
-LIB?
7
-PUNCH?
11
-INPUT?
10
-LIST?
12

DMA?
0
```

Enter the SQT Table

```
* LOAD

LOADR
 12170 14337
```

Load the Reloctable Loader

```
INTERRUPT LINKAGE ?

10,16,I.21
11,17,C.21
12,20,I.01
13,21,I.02
14,22,I.00 †
15,22,I.00 †
/E
```

} Enter the Interrupt Linkage

```
.SQT.   14340
.EQT.   14346
D.21    16231
I.21    17216
C.21    17130
D.01    15672
I.01    16007
D.02    15362
I.02    15476
.BUFR   14535
D.00    14606
I.00    14755
.IOC.   14367
DMAC1   14604
DMAC2   14605
IOERR   14563
XSQT    14602
XEQT    14603
.LDR.   13624
HALT    14333
.MEM.   14333
LST     12214
```

} BCS entry points

```
*SYSTEM LINK
 00023 00166
```

Call to turn on the tape punch for absolute binary tape of the configured BCS.

```
*BCS ABSOLUTE OUTPUT
*END
```

† This reply is for bit-serial teletypes only. Parallel typetypes use only one interrupt channel.

The Debugging routine provides the following facilities to aid in program testing:

Print (dump) selected areas of memory in octal or ASCII format
Trace portions of the program during execution
Modify the contents of selected areas in memory
Modify simulated computer registers
Instruction and operand breakpoint halts
Initiate execution at any point in program
Debugging routine restart
Specifying relocatable program base

The Debugging routine supervises the operation of a program in the check-out (debugging) phase through the use of an interpretive mode of execution with simulated A, B, E overflow and P registers.

The Debugging routine is a relocatable program. It is loaded into memory after the user's relocatable programs and before the library subroutines are loaded. The Debugging routine makes use of the input/output control subroutine, IOC.

6.1 OPERATOR COMMUNICATION

All communication between the Debugging routine and the user formed by the Standard Keyboard Input and Standard Teleprinter Output units which are normally assigned to a Teleprinter.

After the program is loaded, the Debugging routine pauses to allow the first type-in. The operator then types one or more control statements to direct the operation of the Debugging routine. Each statement must be terminated by an end-of-statement mark which consists of a carriage return, CR , and a line feed LF . The last statement of the set must be a Run statement.

When an operation requested by a control statement is completed, a pause occurs (except for the Trace operation). The operator may then continue by typing a Run statement, or he may enter new control statements. To regain control at any

other time, the operator must use Switch 15. Caution must be used, however, when input/output operations are in progress; setting the switch causes a message to be typed. This action may disrupt any incomplete I/O operation.

6.2 CONTROL STATEMENTS

The basic format of the control statement is a single alphabetic character representing the requested operation followed by a parameter list containing the arguments for the operation separated by commas. The statement is of variable length and is terminated by (CR) (LF). The numeric fields in the parameter list must be in octal; leading zeros may be omitted.

Program Relocation Base

M, a

This statement defines the program relocation base, a, as the absolute origin in memory of the user's relocatable program. This address may be obtained from the listing produced by the Relocating Loader during loading. If not specified, a value of zero is assumed. The value is added to all address parameters entered by the operator.

Specification of this value allows subsequent reference in the control statements to addresses as shown on the program listing produced by the Assembler or the FORTRAN compiler. If this control statement is not used, program address parameters for other control statements must be absolute. (DEBUG does not check for memory address greater than the core site; therefore locations in the base page may be altered if the program relocation base is too high.)

Example:

M, 2ØØØ

Set Memory

S, a, v_1, $v_2, \ldots, v_n$

The above statement allows the user to set one or more values into locations defined by the first address, a. The value specified for v_1 is stored in location a; the value for v_2, in location a + 1; and so forth. To specify that an existing value in memory is to remain unchanged, two consecutive commas are used in the control statement. Any number of values may be entered via one control statement provided the length of the statement does not exceed 72 characters.

Example:

S, 5, 062006
S, 30, 136100, 026040
S, 40, 136101, 026050

Set Register

W, r, v

This statement sets the value, v, into register, r, where the register is defined as follows:

r = A, A-Register
= B, B-Register
= E, E-Register
= O, Overflow

Since the Debugging routine simulates the register, the results of a Set Register operation are not reflected on the computer front panel.

Examples:

W, B, 2
W, A, 102000
W, E, 1

Dump Memory

D, A, a_1, a_2
D, B, a_1, a_2

The second parameter indicates the format of the print-out: A specifies ASCII, B specifies octal (See Output Formats). The address a_1 designates the location of the word or the first of a series of words that is to be dumped. If the second address, a_2, is greater than a_1, a block of memory, a_1 through a_2, is printed. If a_2 is the same as a_1, only one location is printed.

After the data is printed, the Debugging routine waits for the operator to enter another control statement.

Example:

D, A, 430, 477

Breakpoint Halt

B, I, a
B, O, a

The first form specifies the address, a, of an instruction breakpoint. Before the instruction at address a is executed, the Debugging routine writes a standard breakpoint message (See Output Formats).

The second form specifies the address, a, of an operand breakpoint. When the Debugging routine detects an effective operand address equal to the value of a, it writes a standard breakpoint message. The operand breakpoint occurs before the memory reference is completed and the register contents in the message are the contents during the instruction execution and not at completion.

After the breakpoint message is transmitted, the Debugging routine waits for the user to enter another control statement.

One or both types of breakpoint halts may be selected. Once selected, a breakpoint address remains in effect until a new address is selected, until a Restart statement is entered, or until the selection is terminated by the statements:

B, I, Ø or B, O, Ø

T, a_1[, a_2]

Trace

When the Trace operation is specified, the execution of the instruction located at address A1, or the execution of every instruction within the area a_1 through a_2, causes the printing of a standard breakpoint message (See Output Formats). The printing occurs before each instruction is executed. Each time the a_1 - a_2 area is reached, the printing resumes; no pause occurs on completion as in the other Debugging routine operations.

The area to be traced must not contain calls to the input/output control routine, IOC. The Trace operation uses IOC to print the breakpoint message. An attempt to trace I/O operations will result in I/O errors.

The trace of the area remains in effect until a new area is selected or until the selection is terminated by the statement:

T, Ø

To enter a new Trace control statement while the program is in operation, Switch 15 must be used.

Run

R [,a]

This statement is used to initiate or continue the execution of the program being debugged. As a result of using Switch 15, or following the printing of a standard breakpoint message (with the exception of those produced by Trace), the Debugging program pauses. The operator may then type a Run statement, or one or more control statements followed by a Run statement to resume program execution. If the letter "R" only is entered, execution starts with the next sequential instruction in the user's program. To start at another location, the operator enters the address, a.

Restart

A

This statement, consisting of the letter "A" is used to abort the current operation and restart. This results in all debugging routine and input/output operations in progress being cleared.

6.3 CONTROL STATEMENT ERROR

If an incorrect control statement is entered, the following message is typed:

"ENTRY ERROR"

This indicates that the character representing the operation is invalid, or that an illegal parameter has been typed. To recover, type in the correct control statement.

6.4 HALT

Any Halt operations coded within the user's program are interpreted by the Debugging routine and result in a typeout consisting of the letter "H" followed by the standard breakpoint message. The operator may then type in one or more control statements or may reinitiate program execution (with the R control statement).

6.5 INDIRECT LOOP

The Debugging routine maintains a count of levels when indirect addressing is detected. When ten consecutive levels of indirect addressing have occurred, an indirect address loop is assumed and the following is typed out:

"INDIRECT LOOP"

L <standard breakpoint message>

6.6 OUTPUT FORMATS

The Debugging routine operations may produce either of two printed outputs: the standard breakpoint message and the memory dump.

Standard Breakpoint Message

Each output line from operations which produce the standard breakpoint message has the following format:

<id>P = v_1 I = v_2 A = v_3 B = v_4 E = v_5 O = v_6 MA = v_7 MC = v_8

The <id> is a letter identifying the operation producing the output:

id = I, Instruction breakpoint
= O, Operand breakpoint
= T, Trace
= S, Switch 15 set up
= L, Indirect Loop
= H, Halt in object program

The v's are octal values of registers and memory locations as follows:

P - P-Register (instruction address)
I - Instruction (contents)
A - A-Register
B - B-Register
E - E-Register
O - Overflow
MA - Effective operand address of a memory reference instruction
MC - Contents of effective address of a memory reference instruction

Dump

The Dump output record format consists of the contents up to 8 consecutive words preceded by the address of the first word:

	addr.	$word_1$	$word_2$ ...	$word_8$
Octal:	aaaaa	oooooo	oooooo ...	oooooo
ASCII:	aaaaa	cc	cc	cc

Octal words consist of 6 octal digits; ASCII words are listed as two ASCII characters. The contents of eight or more consecutive words are not written if they are the same as the last word of the previous record. Instead, a record containing only an asterisk is produced.

6.7 OPERATING PROCEDURES

The following procedures indicate the sequence of steps for use of the Debugging routine.

A. Set the Teleprinter to LINE and check that all equipment to be used is operable.

B. Load Basic Control System using the Basic Binary Loader.

C. Set Switch Register to 000002, press LOAD ADDRESS, and set Switch Register to 000000.

D. Establish Relocating Loader parameters. (If relocation base is to be entered during operation of the Debugging routine, the address must be obtained during loading by setting Switch 15 to 0 (down).)

E. Load reloctable object programs.

F. Load Debugging program (treated as a relocatable program). †

G. Load Program Library routines.

---

† The Debugging routine need not be loaded as the last relocatable program. If loaded in any other order, however, the absolute address assigned to the symbolic location DEBUG must be entered manually as the starting address for the program.

H. Press RUN.

I. The program pauses to allow the operator to type in the control statements.

J. The program may be restarted at any point by entering the absolute address assigned to the symbolic location DEBRS into the P-Register, and pressing RUN.

6.8 EXAMPLE

The routine employed in this example is a simple loop which totals the contents of a block of data. In order to imbue it with a practical aspect, assume that program "TOTAL" computes personal expenses for a 31-day month. Data (each day's expenses) is read in from the Punched Tape Reader. The sum is printed out on the Teleprinter.

The program is written and assembled as below. To check it out a data tape, consisting of a series of 10's is prepared:

```
10 ( (CR) (LF) )
10 ( (CR) (LF) )
10 ( (CR) (LF) )
 .
 .
 .
```

```
 PAGE 0002 #01


0001  00000                   NAM TOTAL
0002  00000 000000  START NOP
0003  00001 062162R       LDA =D-31
0004  00002 072156R       STA CTR
0005  00003 062163R       LDA =B5
0006  00004 006404        CLB,INB
0007  00005 016004X       JSB .DIO.
0008  00006 000000        ABS 0
0009  00007 000014R       DEF *+5
0010  00010 016006X       JSB .IOR.
0011  00011 016001X       DST INPUT,I
      00012 100055R
0012  00013 016005X       JSB .RAR.
0013  00014 066055R       LDB INPUT             INPUT THE DATA
0014  00015 046164R       ADB =B2
0015  00016 076055R       STB INPUT
0016  00017 036156R       ISZ CTR
0017  00020 026003R       JMP START+3
```

```
0019  00021 062162R        LDA =D-31
0020  00022 072156R        STA CTR             INITIALIZE
0021  00023 016002X        DLD =F0.0
      00024 000165R
0022  00025 016001X        DST ANSW
      00026 000154R

0024  00027 016002X        DLD .MON,I
      00030 100054R
0025  00031 016003X        FAD ANSW
      00032 000154R
0026  00033 016001X        DST ANSW
      00034 000154R
0027  00035 066054R SUM    LDB .MON
0028  00036 046164R        ADB =B2             ADDITION LOOP
0029  00037 076054R        STB .MON
0030  00040 036156R        ISZ CTR
0031  00041 026035R        JMP SUM

0033  00042 062164R        LDA =B2
0034  00043 006400         CLB
0035  00044 016004X        JSB .DIO.
0036  00045 000157R        DEF OUTPT
0037  00046 000053R        DEF *+5
0038  00047 016002X        DLD ANSW            OUTPUT THE RESULT
      00050 000154R
0039  00051 016006X        JSB .IOR.
0040  00052 016007X        JSB .DTA.
0041  00053 102077         HLT 77B

0043  00054 000056R .MON   DEF MONTH
0044  00055 000056R INPUT  DEF MONTH
0045  00056 000000  MONTH  BSS 62
0046  00154 000000  ANSW   BSS 2
0047  00156 000000  CTR    BSS 1
0048                       EXT .DIO.,.RAR.,.IOR.,.DTA.
0049  00157 024106  OUTPT  ASC 3,(F8.2)
      00160 034056
      00161 031051


      00162 177741
      00163 000005
      00164 000002
      00165 000000
      00166 000000
0050                       END START
**  NO ERRORS*
```

The "TOTAL" object tape is loaded by the Basic Control System. The debugging system is loaded next and then the library tape. The program is executed using the Debugging System by the following instructions:

```
M,2000      Set program relocation base

B,I,53      Breakpoint instruction is 53, the location of the terminating
            halt in the program.

R,1         Initiate execution at statement 1

10.00
H P=00053   I=102077   A=177777   B=006115   E=0   O=1
```

The correct answer for the test data would be "31.00", not the 10.00 that was output.

The procedure below illustrates one method for detecting errors in the program.

```
M,2000      Set program relocation base
```

Dump a portion of the storage area MONTH

```
D,B,56,70
DUMP--BASE = 02000

00056                                                 050503 000333
00060 001253 000000 000000 004267 017700 000000 053070 011770
00070 002256
```

Read in the data:

```
B,I,21
R,1
I P= 00021 I=062162 A=000000 B=002154 E=0 O=0 MA=00162 MC=177741
```

Check to see that the data has been stored in memory:

```
D,B,56,70
DUMP--BASE = 02000

00056                                                 050000 000010

00060 050000 000010 050000 000010 050000 000010 050000 000010

00070 050000
```

Knowing that the data has been stored in MONTH, perform the first addition:

```
B,I,35
R,21
I P= 00035 I=066054 A=050000 B=000010 E=0 O=0 MA=00054 MC=002056
```

Check to see that the first day's expenses have been stored at ANSW:

```
D,B,154,155
DUMP--BASE = 02000

 00154                                    050000  000010
```

The first addition was executed. Perform the remaining additions by looping:

```
B,I,42
R,35
I P= 00042 I=062164 A=050000 B=002154 E=0 O=0 MA=00164 MC=000002
```

Check final total in ANSW.

```
D,B,154,155
DUMP--BASE = 02000

 00154                                    050000  000010
```

Here, if not previously, the error should be detected; the program does not perform more than the first addition. The label sum has been placed in the wrong instruction. It should be in location 27 preceding the "DLD . MON, I" instruction.

```
0001  00000                    NAM TOTAL
0002  00000 000000      START  NOP
0003  00001 062162R            LDA =D-31
0004  00002 072156R            STA CTR
0005  00003 062163R            LDA =B5
0006  00004 006404             CLB,INB
0007  00005 016004X            JSB .DIO.
0008  00006 000000             ABS 0
0009  00007 000014R            DEF *+5
0010  00010 016006X            JSB .IOR.
0011  00011 016001X            DST INPUT,I
      00012 100055R
2012  00013 016005X            JSB .RAR.
0013  00014 066055R            LDB INPUT      INPUT THE DATA
0014  00015 046164R            ADB =B2
0015  00016 076055R            STB INPUT
0016  00017 036156R            ISZ CTR
0017  00020 026003R            JMP START+3

0019  00021 062162R            LDA =D-31
0020  00022 072156R            STA CTR        INITIALIZE
0021  00023 016002X            DLD =F0.0
      00024 000165R
0022  00025 016001X            DST ANSW
      00026 000154R

0024  00027 016002X     SUM    DLD .MON,I
      00030 100054R
0025  00031 016003X            FAD ANSW
      00032 000154R
0026  00033 016001X            DST ANSW
      00034 000154R
0027  00035 066054R            LDB .MON
0028  00036 046164R            ADB =B2        ADDITION LOOP
0029  00037 076054R            STB .MON
0030  00040 036156R            ISZ CTR
0031  00041 026035R            JMP SUM

0033  00042 062164R            LDA =B2
0034  00043 006400             CLB
0035  00044 016004X            JSB .DIO.
0036  00045 000157R            DEF OUTPT
0037  00046 000053R            DEF *+5
0038  00047 016002X            DLD ANSW       OUTPUT THE RESULT
      00050 000154R
0039  00051 016006X            JSB .IOR.
0040  00052 016007X            JSB .DTA.
0041  00053 102077             HLT 77B
```

ASC II CHARACTER FORMAT

b_7				0	0	0	0	1	1	1	1
b_6				0	0	1	1	0	0	1	1
b_5				0	1	0	1	0	1	0	1
b_4	b_3	b_2	b_1								
0	0	0	0	NULL	DC_0	ƀ	0	@	P	UNASSIGNED	UNASSIGNED
0	0	0	1	SOM	DC_1	!	1	A	Q		
0	0	1	0	EOA	DC_2	"	2	B	R		
0	0	1	1	EOM	DC_3	#	3	C	S		
0	1	0	0	EOT	DC_4 (STOP)	$	4	D	T		
0	1	0	1	WRU	ERR	%	5	E	U		
0	1	1	0	RU	SYNC	&	6	F	V		
0	1	1	1	BELL	LEM	' (APOS)	7	G	W		
1	0	0	0	FE_0	S_0	(	8	H	X		
1	0	0	1	HT / SK	S_1	)	9	I	Y		
1	0	1	0	LF	S_2	*	:	J	Z		
1	0	1	1	V_{TAB}	S_3	+	;	K	[		
1	1	0	0	FF	S_4	, (COMMA)	<	L	\		ACK
1	1	0	1	CR	S_5	—	=	M	]		①
1	1	1	0	SO	S_6	.	>	N	↑		ESC
1	1	1	1	SI	S_7	/	?	O	←		DEL

Standard 7-bit set code positional order and notation are shown below with b_7 the high-order and b_1 the low-order, bit position.

	b_7	b_6	b_5	b_4	b_3	b_2	b_1
EXAMPLE: The code for "R" is:	1	0	1	0	0	1	0

LEGEND

NULL	Null/Idle	DC_1-DC_3	Device Control
SOM	Start of message	DC_4(Stop)	Device control (stop)
EOA	End of address	ERR	Error
EOM	End of message	SYNC	Synchronous idle
EOT	End of transmission	LEM	Logical end of media
WRU	"Who are you?"	S_0-S_7	Separator (information)
RU	"Are you . . . ?"	ƀ	Word separator (space, normally non-printing)
BELL	Audible signal	<	Less than
FE_0	Format effector	>	Greater than
HT	Horizontal tabulation	↑	Up arrow (Exponentiation)
SK	Skip (punched card)	←	Left arrow (Implies/Replaced by)
LF	Line feed	\	Reverse slant
V_{TAB}	Vertical tabulation	ACK	Acknowledge
FF	Form feed	①	Unassigned control
CR	Carriage return	ESC	Escape
SO	Shift out	DEL	Delete/Idle
SI	Shift in		
DC_0	Device control reserved for data link escape		

BINARY CODED DECIMAL FORMAT

Kennedy 1406/1506 ASCII-BCD Conversion

Symbol	BCD (octal code)	ASCII Equivalent (octal code)	Symbol	BCD (octal code)	ASCII Equivalent (octal code)
(Space)	2Ø	Ø4Ø	A	61	1Ø1
!	52	Ø41	B	62	1Ø2
#	13	Ø43	C	63	1Ø3
$	53	Ø44	D	64	1Ø4
%	34	Ø45	E	65	1Ø5
&	6Ø	Ø46	F	66	1Ø6
'	14	Ø47	G	67	1Ø7
(	34	Ø50	H	7Ø	11Ø
)	74	Ø51	I	71	111
*	54	Ø52	J	41	112
+	6Ø	Ø53	K	42	113
,	33	Ø54	L	43	114
-	4Ø	Ø55	M	44	115
.	73	Ø56	N	45	116
/	21	Ø57	O	46	117
			P	47	12Ø
Ø	12	Ø6Ø	Q	50	121
1	Ø1	Ø61	R	51	122
2	Ø2	Ø62	S	22	123
3	Ø3	Ø63	T	23	124
4	Ø4	Ø64	U	24	125
5	Ø5	Ø65	V	25	126
6	Ø6	Ø66	W	26	127
7	Ø7	Ø67	X	27	13Ø
8	1Ø	Ø7Ø	Y	30	131
9	11	Ø71	Z	31	132
:	15	Ø72	[	75	133
;	56	Ø73	\	36	134
<	76	Ø74	]	55	135
=	13	Ø75			
>	16	Ø76			
?	72	Ø77			
@	14	1ØØ			

Other symbols which may be represented in ASCII are converted to spaces in BCD (20)

HP 2020A/B ASCII - BCD Conversion

Symbol	ASCII (Octal code)	BCD (Octal code)	Symbol	ASCII (Octal code)	BCD (Octal code)
(Space)	4Ø	2Ø	A	1Ø1	61
!	41	52	B	1Ø2	62
"	42	37	C	1Ø3	63
#	43	13	D	1Ø4	64
$	44	53	E	1Ø5	65
%	45	34	F	1Ø6	66
&	46	60 †	G	1Ø7	67
'	47	36	H	11Ø	70
(	5Ø	75	I	111	71
)	51	55	J	112	41
*	52	54	K	113	42
+	53	6Ø	L	114	43
,	54	33	M	115	44
-	55	4Ø	N	116	45
.	56	73	O	117	46
/	57	21	P	12Ø	47
			Q	121	50
Ø	6Ø	12	R	122	51
1	61	Ø1	S	123	22
2	62	Ø2	T	124	23
3	63	Ø3	U	125	24
4	64	Ø4	V	126	25
5	65	Ø5	W	127	26
6	66	Ø6	X	13Ø	27
7	67	Ø7	Y	131	30
8	7Ø	1Ø	Z	132	31
9	71	11			
			[	133	75 ‡
:	72	15	]	135	55 ‡
;	73	56	↑	136	77
<	74	76	←	137	32
=	75	35			
>	76	16			
?	77	72			
@	1ØØ	14			

† BCD code of 60 always converted to ASCII code 53 (+).

‡ BCD code of 75 always converted to ASCII code 50 (() and
BCD code of 55 always converted to ASCII code 51 ()).

The Equipment Table (EQT) provides information for the input/output control routine, .IOC., and the equipment driver subroutines. The table contains an entry for each peripheral device attached to a Computer configuration.

The table is constructed as a block of entries assembled by the Prepare Control System routine. The first word of the table, at the symbolic entry point .EQT., contains the number of entries in the table. An entry in the table is referenced according to its position. The numbers 1 through 6 are reserved for Standard units (see Standard Equipment Table). The number 7_8 appearing in a program refers to the 1st table entry; the number 10_8, the second, and so forth. The numbers may be in the range 7_8-74_8 with the largest value being determined by the number of units of equipment available at the installation.

The 4-word entry for each device contains the following information:

The channel number of the device (10_8-76_8)

A Direct Memory Access channel indicator if pertinent

Absolute address of equipment driver subroutine

Equipment type identification code.

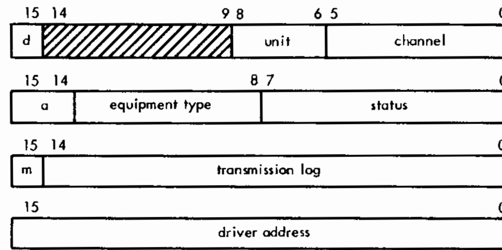
The above information is static for each installation; it is not altered by .IOC. The entry also contains dynamic information which is supplied by the equipment driver subroutine. This information includes:

Status of operation (i.e., in progress or complete)

Status of equipment

Number of characters or words transmitted when the operation is completed.

The format of the entry is as follows:



d	Direct Memory Access channel indicator 1 DMA channel is to be used for each data transmission operation 0 DMA channel not required
unit	Physical unit number (0-7) used to address the device if it is attached to a multi-unit controller.
channel	The channel number (select code) for the physical device (also the low core location containing a JSB to the related interrupt subroutine.)
a	Availability of device: 0 The device is available; the previous operation is complete. 1 The device is available; the previous operation is complete but a transmission error has been detected. 2 The device is not available for another request; the operation is in progress.
equipment type	This field contains a 6-bit code that identifies the device: 00-07 – Paper Tape devices 00 2752A Teleprinter 01 2737A Punched Tape Reader 02 2753A Tape Punch

10-17 – Unit Record devices
20-37 – Magnetic Tape and Mass Storage devices
- 20 Kennedy 1406 Incremental Tape Transport
- 21 2020A Magnetic Tape Unit
- 22 3030 Magnetic Tape Unit

40-77 – Instrumentation devices
- 40 Data Source Interface
- 41 Integrating Digital Voltmeter
- 42 Guarded Crossbar Scanner
- 43 Time Base Generator

status — The status field indicates the actual status of the device when the data transmission is complete. The contents depend on the type of device (see Status Table).

m — This bit defines the mode of the data transmission:

0 ASCII or BCD

1 Binary

transmission log — This field is a log of the number of characters or words transmitted. The value is given as a positive integer and indicates characters or words as specified in the calling sequence. The value is stored in this field only when the input/output request has been completed, therefore, when all data is transmitted or when a transmission error is detected.

driver address — Absolute address of the entry point for the associated driver subroutine for the device.

STATUS TABLE

Device \ Status Bit	7	6	5	4	3	2	1	0
2752A Teleprinter			End of Input Tape					
2737A Punched Tape Reader			End of Tape					
2753A Tape Punch			Tape Supply Low					
Kennedy 1406 Incremental Tape Transport			End of Tape		BT			DB
2020A Magnetic Tape Unit	EOF	ST	End of Tape	TE	I/O R	NW	PA	DB
3030 Magnetic Tape Unit	EOF	ST	End of Tape	TE	I/O R	NW	PA	DB

BT = Broken Tape

DB = Device Busy

EOF = End of File

ST = Start of Tape

TE = Timing Error

I/OR = I/O Reject

NW = No Write (write enable ring missing or tape unit is rewinding)

PA = Parity Error

STANDARD UNIT EQUIPMENT TABLE

The Standard Unit Equipment Table (SQT) allows reference to input/output devices designated as Standard units. The Table contains six 1-word entries. Each entry corresponds to a particular Standard unit and contains a pointer to the Equipment Table. The Standard units are as follows:

Number	Name
1	Keyboard Input
2	Teleprinter Output
3	Program Library
4	Punch Output
5	Input
6	List Output

The number defines the position in the SQT at which the device is listed. Each Standard unit may be a different device, or a single physical device may represent several Standard units. The value of the pointer in the SQT is the position of the physical unit's entry in the EQT, with the lowest value being 7_8 (see EQT).

IOC with Output Buffering is an extension of the standard version and provides for automatic stacking and buffering of all output and function requests. This involves moving an output request and associated buffer into available memory and adding the request location into a thread of stacked requests for the referenced unit. At the completion of an output operation, the next entry in the stack for the unit is initiated by IOC. The processing of output/function requests for a particular unit is according to the order of the requests (first in/first out). This version of IOC requires the use of the program MEMRY to perform the allocation and release of blocks of available memory. If available memory is exhausted when an allocation is attempted, IOC repeats the call until space is made available, i. e., previous blocks are released.

PRIORITY OUTPUT

A "Priority" write or function request has been added for use with the Buffered version of IOC. A "Priority" request is processed immediately without the request and buffer being moved to available memory. The current operation in the stack for the referenced unit is suspended, the "Priority" request processed, and the suspended operation re-initiated. The "Priority" feature is useful for writing messages or diagnostics for immediate action or for performing output without reserving a segment of available memory for request/buffer storage. (All output performed by the BCS Relocating Loader is done as Priority requests because of the latter reason.) (NOTE: If two (2) or more Priority requests are called in immediate succession (without intervening status checks), the last requested operation is performed with the previous ones being "lost".)

A "Priority" request (i.e., Write function) is indicated by setting bit Ø9 of Word 2 of the request call = 1. Bit Ø9 = 0 means normal operation with the Standard IOC and means the request will be stacked and buffered with the extended version.

Example: "Priority" Write to Teleprinter

```
JSB  .IOC.
OCT  21ØØ2
JMP  REJ
DEF  BUFFR
DEC  -37
```

OPERATING ENVIRONMENT

IOC with Output Buffering provides for writing a data block on more than one output device in parallel and does not restrict output rates to the lowest speed device. Because all requests and buffers are moved into available memory for subsequent processing, peak load output processing is not delayed due to device speed or saturated buffer storage within the bounds of user programs. System I/O saturation occurs when available memory is exhausted.

RESTRICTIONS

The routines used to allocate/release blocks in available memory and to initiate stacked output requests operate with the Interrupt System disabled. Therefore, the use of medium/high speed synchronous I/O devices under program control is not recommended because of possible data loss (e.g., HP 2020 A/B Magnetic Tape).

An I/O driver routine operating under the extended version of IOC may not be used to control more than one like device. This is because the buffering control routine in IOC only checks for stacked requests referencing the unit on which an operation was just completed.

HALT CONDITIONS

Irrecoverable error conditions are identical to the Standard version of IOC. The location of the halt is at the entry point "IOERR". These conditions are:

A-Register	B-Register	Meaning
Ø	Location at Request	Request Code Illegal
1	Location at Request	Unit Reference Illegal
Ø	Ø	Write request for an input only device.

I/O ERROR CONDITIONS

The routine .BUFR in the version of IOC with Output Buffering checks for error conditions of the end of each output operation. If any error conditions and End-of-Tape or Tape Supply Low, etc. conditions are present, IOC halts to allow the condition to be corrected. Processing is continued by pressing RUN.

Halt: (T) = 1Ø2Ø7Ø
(A) = Word 2 of EQT entry (Status word)
(B) = Hardware I/O address of unit

An addition has been made to this routine to handle requests for buffered output of records too long to be buffered with the amount of memory available. If such a request is made, the following occurs:

a. IOC outputs the contents of any buffers which have been previously "stacked" for the referenced I/O device.

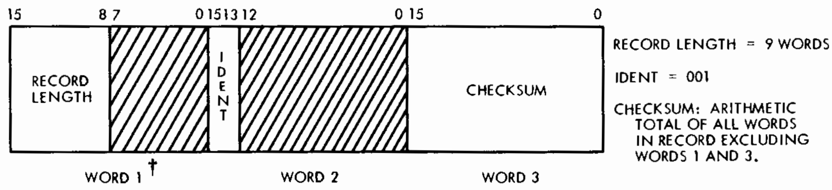
b. The computer halts to inform the user that his program cannot buffer output records of the length requested. The contents of the registers are as follows:

(T) = 102001
(A) = Maximum length record that can be buffered with the amount of memory available.
(B) = Memory location of the output request which caused the halt.

The user restarts the program by pushing the RUN button. The output request is honored immediately without buffering. IOC waits until the output operation is complete before returning control to the program. This ensures that the data area is not modified before the complete record is output, and that the output results are identical to those produced if buffered output of the record had occurred.

NAM RECORD

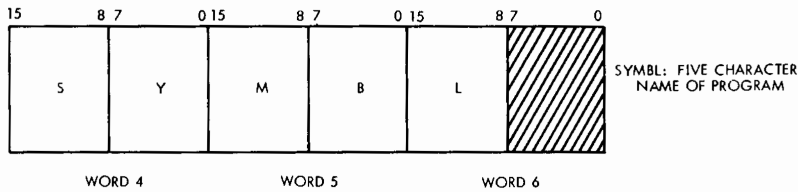
CONTENT | EXPLANATION



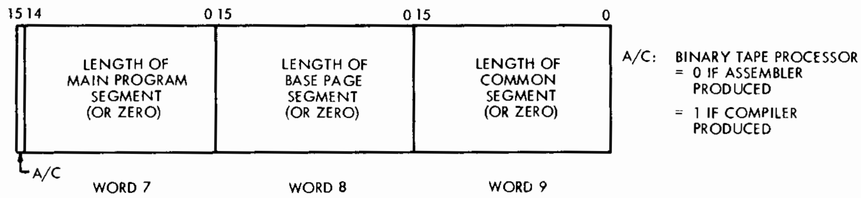
RECORD LENGTH = 9 WORDS

IDENT = 001

CHECKSUM: ARITHMETIC TOTAL OF ALL WORDS IN RECORD EXCLUDING WORDS 1 AND 3.



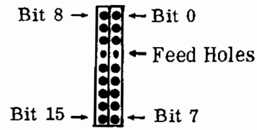
SYMBL: FIVE CHARACTER NAME OF PROGRAM



A/C: BINARY TAPE PROCESSOR
= 0 IF ASSEMBLER PRODUCED
= 1 IF COMPILER PRODUCED

---

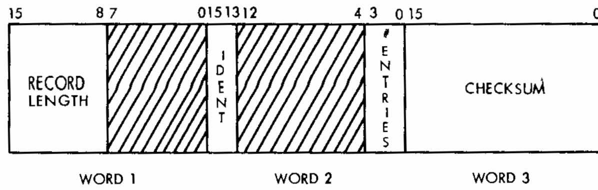
†Each word represents two frames arranged as follows:



ENT RECORD

CONTENT

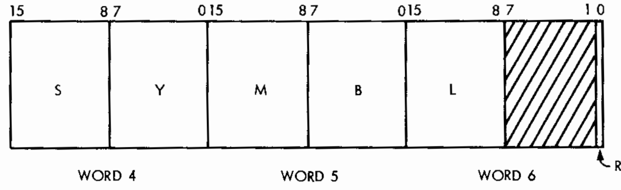
EXPLANATION



RECORD LENGTH = 7-59 WORDS

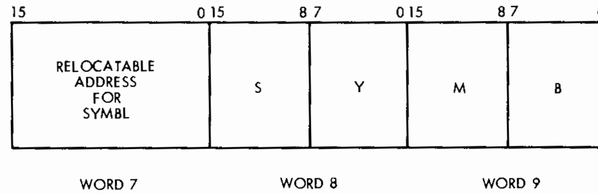
IDENT = 010

ENTRIES: 1 to 14 ENTRIES PER PROGRAM; EACH ENTRY IS FOUR WORDS LONG.

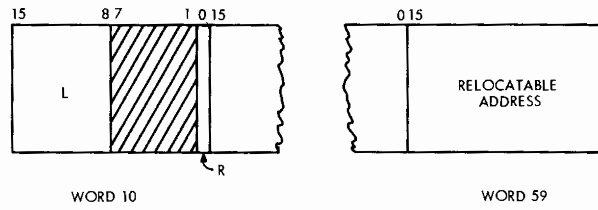


SYMBL: 5 CHARACTER ENTRY POINT SYMBOL

R: RELOCATION INDICATOR
= 0 IF PROGRAM RELOCATABLE
= 1 IF BASE PAGE RELOCATABLE

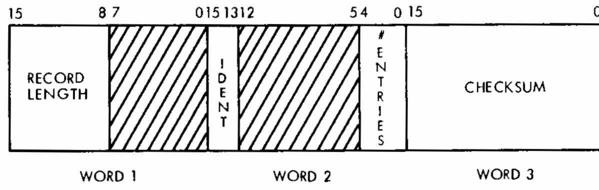


WORDS 4 THROUGH 7 ARE REPEATED FOR EACH ENTRY POINT SYMBOL.



EXT RECORD

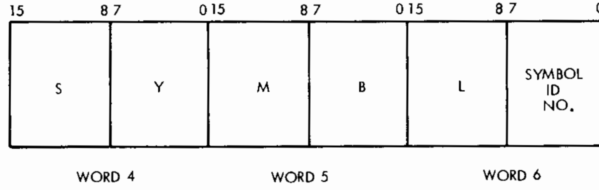
CONTENT | EXPLANATION



RECORD LENGTH = 6-60 WORDS

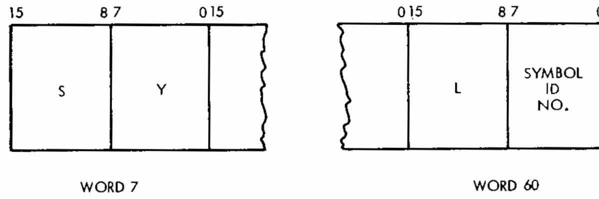
IDENT = 100

ENTRIES: 1 TO 19 PER RECORD; EACH ENTRY IS THREE WORDS LONG



SYMBL: 5 CHARACTER EXTERNAL SYMBOL

SYMBOL ID. NO.: NUMBER ASSIGNED TO SYMBL FOR USE IN LOCATING REFERENCE IN BODY OF PROGRAM.

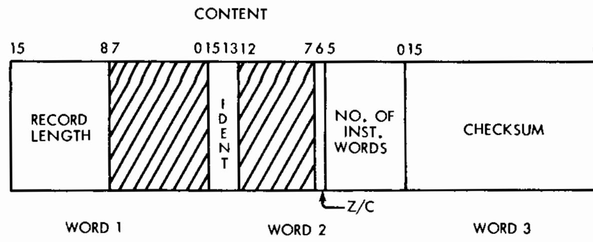


WORDS 4 THROUGH 6 REPEATED FOR EACH EXTERNAL SYMBOL (MAXIMUM OF 19 PER RECORD).

DBL RECORD

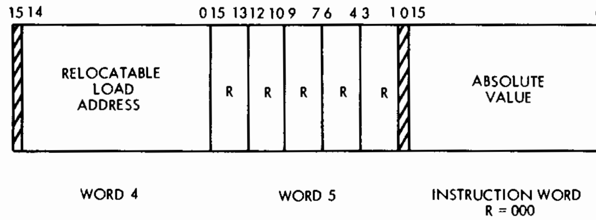
CONTENT

EXPLANATION



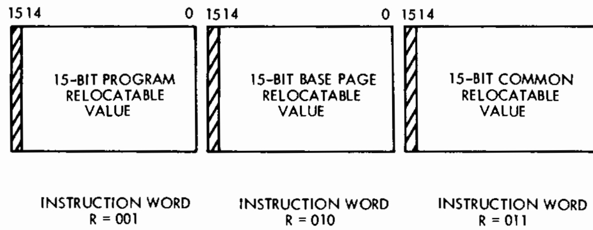
RECORD LENGTH = 5–60 WORDS
IDENT = 011
Z/C: BASE/CURRENT PAGE LOADING
= 0 FOR BASE PAGE
= 1 FOR CURRENT PAGE

NO. OF INST. WORDS: 1 TO 45 LOADABLE INSTRUCTION WORDS PER RECORD



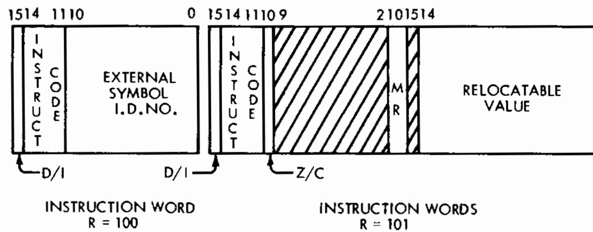
RELOCATABLE LOAD ADDRESS: STARTING ADDRESS FOR LOADING THE INSTRUCTIONS WHICH FOLLOW.

R's: RELOCATION INDICATORS:
000 = ABSOLUTE
001 = 15-BIT PROGRAM RELOCATABLE
010 = 15-BIT BASE PAGE RELOCATABLE
011 = 15-BIT COMMON RELOCATABLE
100 = EXTERNAL REFERENCE
101 = MEMORY REFERENCE



R_1 IS RELOCATION INDICATOR FOR INSTRUCTION $WORD_1$; R_2, FOR INSTRUCTION $WORD_2$; ETC–MEMORY REFERENCE INSTRUCTIONS USE TWO WORDS, WITHIN THE TWO-WORD GROUP, "MR" INDICATES RELOCATABILITY OF OPERAND SPECIFIED IN SECOND WORD:

00 = PROGRAM RELOCATABLE
01 = BASE PAGE RELOCATABLE
10 = COMMON RELOCATABLE



D/I: INDIRECT ADDRESSING

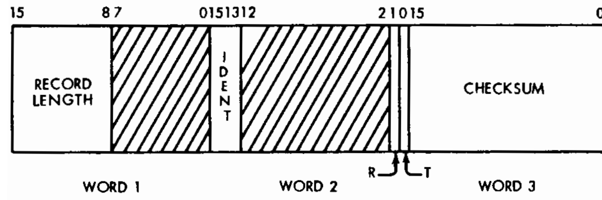
0 = DIRECT
1 = INDIRECT

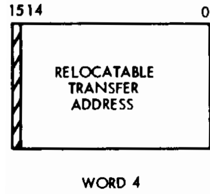
Z/C: BASE/CURRENT PAGE LOCATION OF OPERAND ADDRESS AS DETERMINED BY LOADER.

0 = BASE PAGE
1 - CURRENT PAGE

END RECORD

CONTENT





EXPLANATION

RECORD LENGTH = 4 WORDS

IDENT = 101

R: RELOCATION INDICATOR FOR TRANSFER ADDRESS

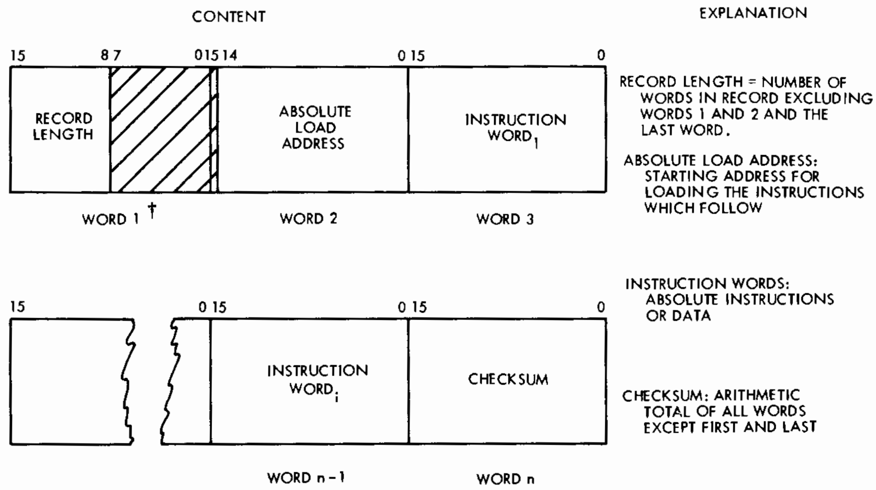
= 0 IF PROGRAM RELOCATABLE
= 1 IF BASE PAGE RELOCATABLE

T: TRANSFER ADDRESS INDICATOR

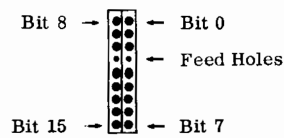
= 0 IF NO TRANSFER ADDRESS IN RECORD

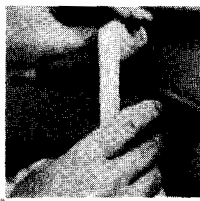
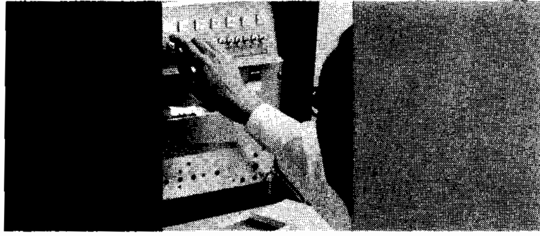
= 1 IF TRANSFER ADDRESS PRESENT

ABSOLUTE TAPE FORMAT



†Each word represents two frames arranged as follows:



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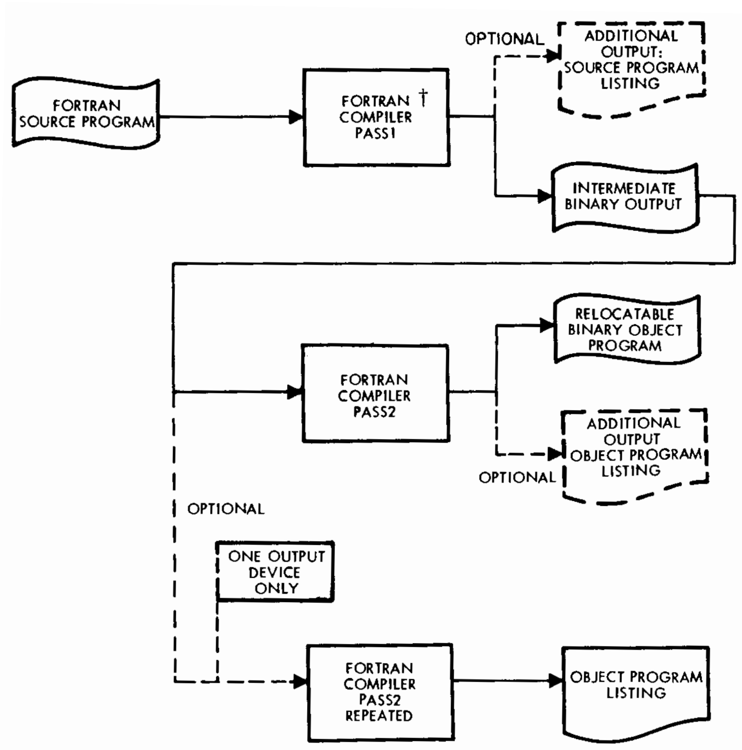
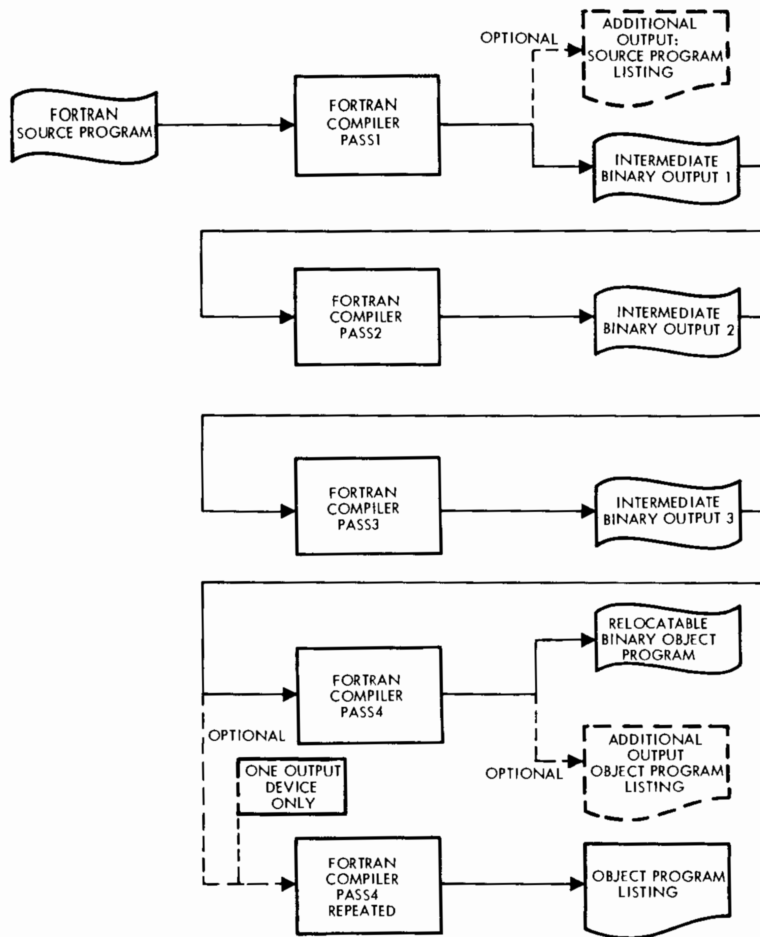


†When compiling with the magnetic tape system, operator intervention ceases after Pass 1 has been loaded.

8K MEMORY
FORTRAN COMPILATION PROCESS



4K MEMORY
FORTRAN COMPILATION PROCESS

INTRODUCTION

The FORTRAN compiler system accepts as input, a source program written according to American Standard Basic FORTRAN specifications; it produces as output, a relocatable binary object program which can be loaded and executed under control of the HP Basic Control System.

In addition to the ASA Basic FORTRAN language, HP FORTRAN provides a number of features which expand the flexibility of the system. Included are:

Free Field Input: Special characters included with ASCII input data direct its formatting; a FORMAT statement need not be specified in the source program.

Specification of heading and editing information in the FORMAT statement through use of the "..." notation; permits alphanumeric data to be read or written without giving the character count.

Array declaration within a COMMON statement.

Redefinition of its arguments and common areas by a function subprogram.

Interpretation of an END statement as a RETURN statement.

Basic External Functions which perform masking (Boolean) operations.

Two-branch IF statement.

Octal constants.

The paper tape version of the compiler operates in two or four passes depending on the size of memory. For an 8K system, the compiler produces a source listing and an intermediate binary tape in the first pass. This intermediate tape serves as input to the second pass. The second pass produces the relocatable object program tape and a listing of the program in assembly level language. If only one output device is available the last pass is repeated to produce the listing. For the 4K system, two additional passes are introduced before the pass producing the relocatable program tape. For these passes the intermediate binary output of the previous pass becomes the input for the current pass.

The magnetic tape version of the compiler uses the scratch area for storage of intermediate binary code. Pass 1 of FORTRAN writes the intermediate program. At the end of Pass 1, FORTRAN calls the Inter-Pass Loader; it searches for and loads Pass 2 of FORTRAN. Pass 2 spaces forward to the scratch area, processes the intermediate code and produces output on the punch and list devices as requested.

The minimum equipment configuration required to compile a program on the Computer is as follows:

2116B, 2115A, or 2114A Computer with 4K memory

2752A Teleprinter.

A FORTRAN program is constructed of characters grouped into lines and statements.

1.1 CHARACTER SET

The program is written using the following characters:

Alphabetic:	A through Z
Numeric:	0 through 9
Special:	
	Space
=	Equals
+	Plus
-	Minus
*	Asterisk
/	Slash
(	Left Parenthesis
)	Right Parenthesis
,	Comma
.	Decimal Point
$	Dollar Sign
"	Quotation mark

Spaces may be used anywhere in the program to improve appearance; they are significant only within heading data of FORMAT statements and, in lieu of other information, in the first six positions of a line.

In addition to the above set which is used to construct source language statements, certain characters have special significance when appearing with ASCII input data. They are the following:

space,	Data item delimiters
/	Record terminator
+ -	Sign of item
. E + -	Floating point number
@	Octal interger
"..."	Comments
←	Suppresses CR and LF

Details on the input data character set are given in Chapter 7.

1.2 LINES

A line is a string of up to 72 characters. On paper tape, each line is terminated by a return, (CR) , followed by a line feed, (LF) . This terminator may be in any position following the statement information or comment contained in the line.

Statements

A statement may be written in an initial line and up to five continuation lines. The statement may occupy positions 7 through 72 of these lines. The initial line contains a zero or blank in position 6. A continuation line contains any character other than zero or space in position 6 and may not contain a C in position 1.

Statement Labels

A statement may be labeled so that it may be referred to in other statements. A label consists of one to four numeric digits placed in any of the first five positions of a line. The number is unsigned and in the range of 1 through 9999. Imbedded spaces and leading zeros are ignored. If no label is used, the first five positions of the statement line must be blank. The statement label or blank follows the (CR) (LF) terminator of the previous line.

Comments

Lines containing comments may be included with the statement lines; the comments are printed along with the source program listing. A comment line requires a C in position 1 and may occupy positions 2 through 72. If more than one line is used, each line requires a C indicator. Each comment line is terminated with a (CR) and (LF) .

Control Statement

The first statement of a program is the control statement; it defines the output to be produced by the FORTRAN compiler. The following options are available:

> Relocatable binary – The program is to be loaded by the loader of the Basic Control System.
>
> Source Listing output – A listing of the source program is produced during the first pass of compiler operation.

Object Listing output – A list of the object program is produced during the last pass of compiler operation.

The control statement must be followed by the (CR) (LF) terminator.

End Line

Each subprogram is terminated with an end line which consists of blanks in positions 1 through 6 and the letters E, N, and D located in any of the positions 7 through 72. The special end line, END$, signifies the end of five or less programs being compiled at one time. The end line is terminated by (CR) (LF) .

1.3 CODING FORM

The FORTRAN coding form is shown below. Columns 73-80 may be used to indicate a sequence number for a line; they must not be punched on paper tape. All other columns of the form conform with line positions for paper tape.

HEWLETT-PACKARD FORTRAN CODING FORM

SAMPLE CODING FORM
(Actual Size 11 x 13-1/2)

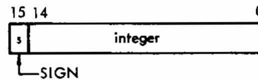
HP FORTRAN processes two types of data. They differ in mathematical significance, constant format, and symbolic representation. The two types are real and integer quantities.

2.1 DATA TYPE PROPERTIES

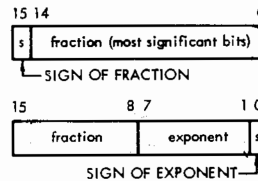
Integer and real data quantities have different ranges of values.

An integer quantity has an assumed fixed decimal point. It is represented by a 16-bit computer word with the most significant bit as the sign and the assumed decimal point on the right of the least significant bit.

An integer quantity has a range of -2^{15} to $2^{15}-1$.



A real quantity has a floating decimal point; it consists of a fractional part and an exponent part. It is represented by two 16-bit computer words; the exponent and its sign are eight bits; the fraction and its sign are twenty-four bits.



It has a range in magnitude of approximately 10^{-38} to 10^{38} and may assume positive, negative, or zero values. If the fraction is negative, the number is in two's complement form. A zero

value is stored as all zero bits. Precision is approximately seven decimal digits.

2.2 CONSTANTS

A constant is a value that is always defined during execution and may not be redefined. Three types of constants are used in HP FORTRAN: integer, octal (treated as integer), and real. The type of constant is determined by its form and content.

Integer

An integer constant consists of a string of up to five decimal digits. If the range -32768 to 32767 (-2^{15} to $2^{15}-1$) is exceeded, a diagnostic is provided by the compiler.

Examples:

```
8364    5932
1720    9
1872    31254
125     1
3653    30000
```

Octal

Octal constants consist of up to six octal digits followed by the letter B. The form is:

$n_1 n_2 n_3 n_4 n_5 n_6$ B

n_1 is 0 or 1

$n_2 - n_6$ are 0 through 7

If the constant exceeds six digits, or if a non-octal digit appears, the constant is treated as zero and a compiler diagnostic is provided.

Examples:

```
7677B    7631B
3270B    5B
3520B    75026B
175B     177776B
567B     177777B
```

Real

Real constants may be expressed as an integer part, a decimal point, and a decimal fraction part. The constant may include an exponent, representing a power of ten, to be applied to the preceding quantity. The forms of real constants are:

n.n   n.   .n   n.nE±e   n.E±e   .nE±e

n is the number and e is the exponent to the base ten. The plus sign may be omitted for a positive exponent. The range of e is 0 through 38. When the exponent indicator E is followed by a + or - sign, then all digits between the sign and the next operator or delimiter are assumed to be part of the exponent expression, e.

If the range of the real constant is exceeded, the constant is treated as zero and a compiler diagnostic message occurs.

Examples:

```
4.512      4.5E2
4.         .45E+3
.512       4.5E-5
4.0        0.5
4.E-10     .5E+37
1.         10000.0
```

2.3 VARIABLES

A variable is a quantity that may change during execution; it is identified by a symbolic name. Simple and subscripted variables are recognized. A simple variable represents a single quantity; a subscripted variable represents a single quantity (element) within an array of quantities. Variables are identified by one to five alphanumeric characters; the first character must be alphabetic.

The type of variable is determined by the first letter of the name. The letters I, J, K, L, M, and N, indicate an integer (fixed point) variable; any other letter indicates a real (floating point) variable. Spaces imbedded in variable names are ignored.

Simple Variable

A simple variable defines the location in which values can be stored. The value specified by the name is always the current value stored in that location.

Examples:

Integer	Real
I	ALPHA
JAIME	G13
K9	DOG
MIL	XP2
NIT	GAMMA

Subscripted Variable

A subscripted variable defines an element of an array; it consists of an alphanumeric identifier with one or two associated subscripts enclosed in parentheses. The identifier names the array; the subscripts point to the particular element. If more than two subscripts appear, a compiler diagnostic message is given.

Subscripts may be integer constants, variables, or expressions; they may have the form (exp_1, exp_2), where exp_i is one of the following:

c*v+k	v-k
c*v-k	v
c*v	k
v+k	

where c and k are integer constants and v is a simple integer variable.

Examples:

Integer	Real
I(J, K)	A(J)
LAD(3, 3)	BACK(M+5, 9)
MAJOR (24*K, I+5)	OP45(4*I)
NU (K+2)	RADI (IDEG)
NEXT (N*5)	VOLTI (I, J)

2.4 ARRAYS

An array is an ordered set of data of one or two dimensions; it occupies a block of successive memory locations. It is identified by a symbolic name which may be used to refer to the entire array. An array and its dimensions must be declared at the beginning of the program in a DIMENSION or COMMON statement. The type of an array is determined by the first letter of the array name. The letters I, J, K, L, M, and N, indicate an integer array; any other letter indicates a real array.

Each element of an array may be referred to by the array name and the subscript notation. Program execution errors may result if subscripts are larger than the dimensions initially declared for the array, however, no diagnostic messages are issued.

Array Structure

Elements of arrays are stored by columns in ascending order of storage locations. An array declared as SAM(3, 3), would be structured as:

Columns

	SAM(1, 1)	SAM(1, 2)	SAM(1, 3)
Rows	SAM(2, 1)	SAM(2, 2)	SAM(2, 3)
	SAM(3, 1)	SAM(3, 2)	SAM(3, 3)

and would be stored as:

m	SAM(1, 1)
m+1	SAM(2, 1)
m+2	SAM(3, 1)
m+3	SAM(1, 2)
m+4	SAM(2, 2)
m+5	SAM(3, 2)
m+6	SAM(1, 3)
m+7	SAM(2, 3)
m+8	SAM(3, 3)

The location of an array element with respect to the first element is a function of the subscripts, the first dimension, and the type of the array. Addresses are computed modulo 2^{15}.

Given DIMENSION A (L, M), the memory location of A (i, j) with respect to the first element, A, of the array, is given by the equation:

$$\ell = A + \{ i - 1 + L(j - 1) \} * s$$

The quantity in braces is the expanded subscript expression. The element size, s, is the number of storage words required for each element of the array: for integer arrays, s = 1 ; for real arrays, s = 2 .

Array Notation

The following subscript notations are permitted for array elements:

For a two-dimensional array, $A(d_1, d_2)$:

A(I, J)	implies A(I, J)
A(I)	implies A(I, 1)
A	implies A(1, 1)†

For a single-dimension array, A(d)

A(I)	implies A(I)
A	implies A(1)

The elements of a single-dimension array, A(d), however, may not be referred to as A(I, J). A diagnostic message is given by the compiler if this is attempted.

2.5 EXPRESSIONS

An expression is a constant, variable, function or a combination of these separated by operators and parentheses, written to comply with the rules for constructing the particular type of instruction. An arithmetic expression has numerical value; its type is determined by the type of the operands.

† In an Input/Output list, the name of a dimensioned array implies the entire array rather than the first element.

Examples:

```
A+B-C           .4+SIN(ALPHA)
X*COS(Y)        A/B+C-D*F
RALPH-ALPH      4+2*IABS(LITE)
```

2.6 STATEMENTS

Statements are the basic functional units of the language. Executable statements specify actions; non-executable statements describe the characteristics and arrangement of data, editing information, statement functions, and classification of program units.

A statement may be given a numeric label of up to four digits (1 to 9999); a label allows other statements to refer to a statement. Each statement label used must be unique within the program.

ARITHMETIC EXPRESSIONS AND ASSIGNMENT STATEMENTS 3

3.1 ARITHMETIC EXPRESSIONS

An arithmetic expression may be a constant, a simple or subscripted variable, or a function. Arithmetic expressions may be combined by arithmetic operators to form complex expressions.

Arithmetic operators are:

+	Addition
-	Subtraction
*	Multiplication
/	Division
**	Exponentiation

If α is an expression, (α) is an expression.
If α and β are arithmetic expressions, then the following are expressions:

$\alpha + \beta$	$\alpha - \beta$	α / β
$\alpha * \beta$	$+\alpha$	$-\alpha$
$\alpha ** \beta$		

An arithmetic expression may not contain adjoining arithmetic operators, α op op β.

Expressions of the form $\alpha ** \beta$ and $\alpha ** (-\beta)$ are valid; $\alpha ** \beta ** \gamma$ is not valid.

Examples:

PROGRAMMER | DATE | PROGRAM

C Label | CONT | STATEMENT

```
      Z
      L*533+2**15-I
      ABLE-3.14*HOUSE**32.E-2
      5*JACK(K,L+5)-LOUD
```

Order or Evaluation

In general, the hierachy of arithmetic operation is:

**	exponentiation	class 1
/	division	class 2
*	multiplication	
-	subtraction	class 3
+	addition	

In an expression with no parentheses or within a pair of parentheses, evaluation basically proceeds from left to right, or in the above order if adjacent operators are in a different class. †

Expressions enclosed in parentheses and function references are evaluated as they are encountered from left to right.

Examples:

In the examples below, s_1, $s_2, \ldots,$ s_n indicate intermediate results during the evaluation of the expression; the symbol $\rightarrow$ can be interpreted as "goes to".

a) Evaluation of class 1 precedes class 3

A+B**C-D
$B{**}C \rightarrow s_1$
$s_1 + A \rightarrow s_2$
$s_2 - D \rightarrow s_3$ $\quad s_3$ is the evaluated expression

b) Evaluation of class 2 precedes class 3

A*B*C/D+E*F-G/H
$A*B \rightarrow s_1$
$s_1 * C \rightarrow s_2$
$s_2 / D \rightarrow s_3$
$E*F \rightarrow s_4$
$s_4 + s_3 \rightarrow s_5$
$G/H \rightarrow s_6$
$-s_6 \rightarrow s_7$
$s_7 + s_5 \rightarrow s_8$ $\quad s_8$ is the evaluated expression

---

† When writing an integer expression it is important to remember not only the left to right scanning process, but also that dividing an integer quantity by an integer quantity yields a truncated result; thus 11/3 = 3 . The expression I*J/K may yield a different result than the expression J/K*I . For example, 4*3/2 = 6 ; but 3/2*4 = 4 .

c) Evaluation of an expression including a function is performed.

A+B**C+D+COS(E)
B**C $\rightarrow s_1$
A+$s_1 \rightarrow s_2$
s_2 + D $\rightarrow s_3$
COS(E) $\rightarrow s_4$
$s_4 + s_3 \rightarrow s_5$ s_5 is the evaluated expression

d) Parentheses can control the order of evaluation

A*B/C+D
A*B $\rightarrow s_1$
s_1 /C $\rightarrow s_2$
s_2 +D $\rightarrow s_3$ s_3 is the evaluated expression

A*B/(C+D)
A*B $\rightarrow s_1$
C+D $\rightarrow s_2$
$s_1 / s_2 \rightarrow s_3$ s_3 is the evaluated expression

e) If more than one pair of parentheses or if an exponential expression appears, evaluation is performed left to right.

A+B**C-(D*E+F)+(G-H*P)
B**C $\rightarrow s_1$
s_1 + A $\rightarrow s_2$
D*E $\rightarrow s_3$
s_3 +F $\rightarrow s_4$
$-s_4 \rightarrow s_5$
$s_5 + s_2 \rightarrow s_6$
H*P $\rightarrow s_7$
$-s_7 \rightarrow s_8$
s_8 + G $\rightarrow s_9$
$s_9 + s_6 \rightarrow s_{10}$ s_{10} is the evaluated expression

Type of Expression

With the exception of exponentiation and function arguments, all operands within an expression must be of the same type. An expression is either real or integer depending on the type of all of its constituent elements.

If either an integer or real operand is exponentiated by an integer operand, the resultant element is of the same type as that of the operand being exponentiated. If both operands are real, the resultant element is real.

Examples:

```
J**I     integer
A**I     real
A**B     real
```

An integer exponentiated by a real operand is not valid.

3.2 ASSIGNMENT STATEMENTS

An arithmetic assignment statement is of the form:

```
v = e
```

The variable, v , may be simple or subscripted; e is an expression. Execution of this statement causes the evaluation of the expression, e , and the assignment of the value to the variable.

Type of Statement

The processing of the evaluated expression is performed according to the following table:

Type of v	Type of e	Assignment rule
Integer	Integer	Transmit e to v without change.
Integer	Real	Truncate and transfer as integer to v.
Real	Integer	Transform integer form of e to floating decimal and transfer to v.
Real	Real	Transmit e to v without change.

Examples:

```
A=B**C+D+COS(E)
SAM(6)=R-S(6,2)*(T/U)
N=W+3.*(X**Y-Z)
BAKER=I*J+K*(L-M/N)
N=IZZY+LAKE/MOD
```

Transmit without change
Transmit without change
Truncate
Convert to real
Transmit without change

3.3 MASKING OPERATIONS

In HP FORTRAN, masking operations may be performed using the Basic External Functions IAND, IOR, and NOT (see Chapter 6). These functions are as follows:

IAND	Form the bit-by-bit logical product of two operands
IOR	Form the bit-by-bit logical sum of two operands
NOT	Complement the operand

The operations are described by the following table:

Value of Arguments		Value of Function		
a_1	a_2	IAND (a_1 , a_2)	IOR (a_1 , a_2)	NOT (a_1)
1	1	1	1	0
1	0	0	1	0
0	1	0	1	1
0	0	0	0	1

Examples:

```
IA = 72507B
IB = 71550B
```

IAND (IA, IB) is 70500B
IOR (IA, IB) is 73557B
NOT (IA) is 105270B

The Specifications statements, which include DIMENSION, COMMON, and EQUIVALENCE, define characteristics and arrangement of the data to be processed. These statements are non-executable; they do not produce machine instructions in the object program. The statements must all appear before the first executable statement in the following order: DIMENSION, COMMON, and EQUIVALENCE.

4.1 DIMENSION

The DIMENSION statement reserves storage for one or more arrays.

DIMENSION v_1 (i_1), v_2 (i_2), . . . , v_n (i_n)

An array declarator, $v_j(i_j)$; defines the name of an array, v_j , and its associated dimensions, (i_j) . The declarator subscript, i , may be an integer constant or two integer constants separated by a comma. The magnitude of the values given for the subscripts indicates the maximum value that the subscript may attain in any reference to the array.

The number of computer words reserved for a given array is determined by the product of the subscripts and the type of the array name. For integer arrays, the number of words equals the number of elements in the array. For real arrays, two words are used for each element; the storage area is twice the product of the subscripts.

A diagnostic message is printed if an array size exceeds 2^{15} -1 locations.

Examples:

DIMENSION SAM (5, 10), ROGER (10, 10), NILE (5, 20)

Area reserved for SAM	5*10*2 = 100 words
Area reserved for ROGER	10*10*2 = 200 words
Area reserved for NILE	5*20*1 = 100 words

4.2 COMMON

The COMMON statement reserves a block of storage that can be referenced by the main program and one or more subprograms. The areas of common information are specified by the statement form:

COMMON $a_1, a_2, \ldots, a_n$

Each area element, a_i , identifies a segment of the block for the subprogram in which the COMMON statement appears. The area elements may be simple variable identifiers, array names, or array declarators (dimensioned array names).

If dimensions for an array appear both in a COMMON statement and a DIMENSION statement, those in the DIMENSION statement will be used.

Any number of COMMON statements may appear in a subprogram section (preceding the first executable statement). The order of the arrays in common storage is determined by the order of the COMMON statements and the order of the area elements within the statements. All elements are stored contiguously in one block.

At the beginning of program execution, the contents of the common block are undefined; the data may be stored in the block by input/output or assignment statements.

Examples:

COMMON I (5), A (6), B (4)

Area reserved for I	=	5 words
Area reserved for A	=	12 words
Area reserved for B	=	8 words
Common area		25 words

	Common Block
Origin	I (1)
	I (2)
	I (3)
	I (4)
	I (5)
	A (1)
	A (1)

A (2)
A (2)
A (3)
A (3)
A (4)
A (4)
A (5)
A (5)
A (6)
A (6)
B (1)
B (1)
B (2)
B (2)
B (3)
B (3)
B (4)
B (4)

Correspondence of Common Blocks

Each subprogram that uses the common block must include a COMMON statement. Each subprogram may assign different variable and array names, and different array dimensions, however, if corresponding quantities are to agree, the types should be the same for corresponding positions in the block.

Examples:

```
MAIN PROG COMMON I (5), A (6), B (4)
        .
        .
        .
SUBPROG1 COMMON J (3), K (2), C (5), D (5)
```

MAIN PROG reference	Common Block	SUBPROG1 reference
I (1)	integer 1	J (1)
I (2)	integer 2	J (2)
I (3)	integer 3	J (3)
I (4)	integer 4	K (1)
I (5)	integer 5	K (2)
A (1)	real 1	C (1)
A (1)	real 1	C (1)

MAIN PROG reference	Common Block	SUBPROG1 reference
A (2)	real 2	C (2)
A (2)	real 2	C (2)
A (3)	real 3	C (3)
A (3)	real 3	C (3)
A (4)	real 4	C (4)
A (4)	real 4	C (4)
A (5)	real 5	C (5)
A (5)	real 5	C (5)
A (6)	real 6	D (1)
A (6)	real 6	D (1)
B (1)	real 7	D (2)
B (1)	real 7	D (2)
B (2)	real 8	D (3)
B (2)	real 8	D (3)
B (3)	real 9	D (4)
B (3)	real 9	D (4)
B (4)	real 10	D (5)
B (4)	real 10	D (5)

If portions of a common block are not referred to by a particular subprogram, dummy variables may be used to provide correspondence in reserved areas.

Examples:

```
MAIN PROG COMMON I (5), A (6), B (4)
      .
      .
      .
SUBPROG2 COMMON J (17), B (4)
```

MAIN PROG reference	Common Block	SUBPROG2 reference
I (1)	integer 1	J (1)
I (2)	integer 2	J (2)
I (3)	integer 3	J (3)
I (4)	integer 4	J (4)
I (5)	integer 5	J (5)

MAIN PROG reference	Common block	SUBPROG2 reference	
A (1)	real 1	J (6)	
A (1)	real 1	J (7)	J (17) is a dummy array. It is not referenced in SUBPROG 2 but provides proper correspondence in reserved areas so that SUBPROG 2 can refer to array B.
A (2)	real 2	J (8)	
A (2)	real 2	J (9)	
A (3)	real 3	J (10)	
A (3)	real 3	J (11)	
A (4)	real 4	J (12)	
A (4)	real 4	J (13)	
A (5)	real 5	J (14)	
A (5)	real 5	J (15)	
A (6)	real 6	J (16)	
A (6)	real 6	J (17)	
B (1)	real 7	B (1)	
B (1)	real 7	B (1)	
B (2)	real 8	B (2)	
B (2)	real 8	B (2)	
B (3)	real 9	B (3)	
B (3)	real 9	B (3)	
B (4)	real 10	B (4)	
B (4)	real 10	B (4)	

The length of the common block may differ in different subprograms, however, the subprogram (or main program) with the longest common block must be the first to be loaded at execution time.

4.3 EQUIVALENCE

The EQUIVALENCE statement permits sharing of storage by two or more entities. The statement has the form:

EQUIVALENCE (k_1), $(k_2), \ldots, (k_n)$

in which each k is a list of the form:

$a_1, a_2, \ldots, a_m$

Each a is either a variable name or a subscripted variable; the subscript of which contains only constants. The number of subscripts must correspond to the number of subscripts for the related array declarator.

All names in the list may be used to represent the same location. If an equivalence is established between elements of two or more arrays, there is a corresponding equivalence between other elements of the arrays; the arrays share some storage locations. The lengths may be different or equal.

Examples:

```
DIMENSION A (5), B (4)

EQUIVALENCE (A (4), B (2))
```

Array 1 Name	Array 2 Name	Quantity Element
A (1)		real 1
		real 1
A (2)		real 2
		real 2
A (3)	B (1)	real 3
		real 3
A (4)	B (2)	real 4
		real 4
A (5)	B (3)	real 5
		real 5
	B (4)	real 6
		real 6

The EQUIVALENCE statement establishes that the names A (4) and B (2) identify the fourth real quantity. The statements also establish a similar correspondence between A (3) and B (1), and A (5) and B (3).

An integer array or variable may be made equivalent to a real array or variable; equivalence may be established between different types. The variables may be with or without subscripts.

The effect of an EQUIVALENCE statement depends on whether or not the variables are assigned to the common block. When two variables or array elements share storage, the symbolic names of the variables or arrays may not both appear in COMMON statements in the same subprogram. The assignment of storage to variables and arrays declared in a COMMON statement is determined on the basis of their type and the array

declarator. Entities so declared are always contiguous according to the order in the COMMON statement. The EQUIVALENCE statement must not alter the origin of the common block, but arrays may be defined so that the length of the common block is increased.

Examples:

a) Effect of EQUIVALENCE, variables not in common block:

```
      DIMENSION I (4), J(2), K(5)
      EQUIVALENCE (I(3), K(2))
```

storage is assigned as follows:

Arrays		Quantities
I (1)		integer 1
I (2)	K (1)	integer 2
I (3)	K (2)	integer 3
I (4)	K (3)	integer 4
	K (4)	integer 5
	K (5)	integer 6
J (1)		integer 7
J (2)		integer 8

b) Effect of EQUIVALENCE, some variables in common block:

```
      DIMENSION K(5)
      COMMON I(4), J(2)
      EQUIVALENCE (I(3), K(2))
```

storage is assigned as follows:

Arrays		Quantities	
I (1)		integer 1	common block
I (2)	K (1)	integer 2	
I (3)	K (2)	integer 3	
I (4)	K (3)	integer 4	
J (1)	K (4)	integer 5	
J (2)	K (5)	integer 6	

c) Effect of EQUIVALENCE on the length of the common block:

```
DIMENSION K (7)
COMMON I (4), J(2)
EQUIVALENCE (J(1), K(4))
```

storage is assigned as follows:

Arrays		Quantities	
I (1)		integer 1	common block
I (2)	K (1)	integer 2	
I (3)	K (2)	integer 3	
I (4)	K (3)	integer 4	
J (1)	K (4)	integer 5	
J (2)	K (5)	integer 6	
	K (6)	integer 7	
	K (7)	integer 8	

The value of the subscripts for an array being made equivalent to another array should not be such that the origin of the common block is changed (for example, EQUIVALENCE (I (3), K(4)).

	Arrays			Quantities
		K (1)	← origin changed	integer 1
origin →	I (1)	K (2)		integer 2
	I (2)	K (3)		integer 3
	I (3)	K (4)		integer 4

Arrays		Quantities
I (4)	K (5)	integer 5
J (1)	K (6)	integer 6
J (2)	K (7)	integer 7

If contradictory EQUIVALENCE relationships are specified, a diagnostic message is printed.

Example:

a)

```
      EQUIVALENCE (A(2), B(2))
        .
        .
        .
      EQUIVALENCE (A(5), B(3))
```

b)

```
      EQUIVALENCE (A(2), B(2))
        .
        .
        .
      EQUIVALENCE (B(3), C(3))
        .
        .
        .
      EQUIVALENCE (A(5), C(2))
```

Program execution normally proceeds from statement to statement as they appear in the program. Control statements can be used to alter this sequence or cause a number of iterations of a program section. Control may be transferred to an executable statement only; a transfer to a non-executable statement will result in a program error which is usually recognized during compilation as a transfer to an undefined label.† With the DO statement, a predetermined sequence of instructions can be repeated a number of times with the stepping of a simple integer variable after each iteration.

Statements are labelled by unsigned numbers, 1 through 9999, which can be referred to from other sections of the program. A label up to four digits long precedes the FORTRAN statement and is separated from it by at least one blank or a zero. Imbedded blanks and leading zeros in the label are ignored: 1, 01, 0 1, 0001 are identical.

5.1 GO TO STATEMENTS

GO TO statements provide transfer of control.

GO TO k

This statement, an unconditional GO TO, causes the transfer of control to the statement labelled k .

GO TO $(k_1, k_2, \dots, k_n)$, i

This statement, a computed GO TO, acts as a many-branched transfer. The k's are statement labels and i is a simple integer variable. Execution of this statement causes the statement identified by the label k_j to be executed next, where j

† A transfer to a FORMAT statement is not detectable during compilation; if such an error occurs, no diagnostic message is produced.

is the value of i at the time of execution, and $1 \le j \le n$. If $i < 1$, a transfer to k_1 occurs; if $i > n$, a transfer to k_n occurs.

Examples:

```
   10 GO TO 500
      ISWCH = 2
   35 A = X*Y
      .
      .
   40 GO TO (5, 10, 15, 20), ISWCH
  500 JSWCH = ISWCH + 1
  540 GO TO (25, 30, 35, 40), JSWCH
```

At statement 40, control transfers to statement 10, which is an unconditional transfer to statement 500. At 540 control transfers to statement 35.

5.2 IF STATEMENTS

The arithmetic IF statement provides conditional transfer of control

$$\text{IF (e) } k_1, k_2, k_3$$

The e is an arithmetic expression and the k's are statement labels. The arithmetic IF is a three-way branch. Execution of this statement causes evaluation of the expression and transfer of control depending on the following conditions:

$e < 0$, go to k_1
$e = 0$, go to k_2
$e > 0$, go to k_3

Examples:

```
      IF (A)5, 10, 15
      IF (X**Y*COS(Z)+W)5,35, 15
```

The logical IF statement provides conditional transfer of control to either of two statements:

$$IF\ (e)\ k_1,\ k_2$$

The e is an arithmetic expression that may yield a negative or non-negative (positive or zero) value. Execution of this statement causes evaluation of the expression and transfer of control under the following conditions:

$e < 0$, go to k_1
$e \geq 0$, go to k_2

Examples:

PROGRAMMER | DATE | PROGRAM

STATEMENT

```
C Label  CONT
      IF (ISSW(N))5, 1Ø
      IF (A+B)2Ø, 25
      IF (LANI)3Ø, 4Ø
```

5.3 DO STATEMENTS

A DO statement makes it possible to repeat a group of statements.

$$DO\ n\ i = m_1,\ m_2,\ m_3$$

or

$$DO\ n\ i = m_1,\ m_2$$

The n is the label of an executable statement which ends the group of statements. The statement, called the terminal statement, must physically follow the DO statement in the source program. It may not be a GO TO of any form, IF, RETURN, STOP, PAUSE, or DO statement.

The i is the control variable; it may be a simple integer variable.

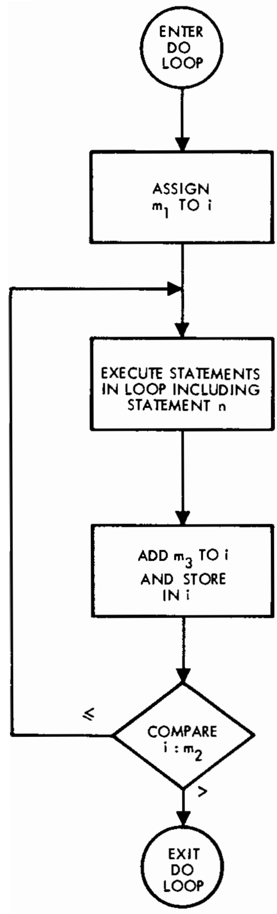
The m's are indexing parameters: m_1 is the initial parameter; m_2, the terminal parameter; and m_3, the incrementation parameter. They may be unsigned integer constants or

simple integer variables. At time of execution, they all must be greater than zero. If m_3 does not appear (second form), the incrementation value is assumed to be 1.

A DO statement defines a loop. Associated with each DO statemeant is a range that is defined to be those executable statements following the DO, to and including the terminal statement associated with the DO. At time of execution, the following steps occur:

1. The control variable is assigned the value of the initial parameter.
2. The range of the DO is executed.
3. The terminal statement is executed and the control variable is increased by the value of the incrementation parameter.
4. The control variable is compared with the terminal parameter. If less than or equal to the terminal parameter, the sequence is repeated starting at step 2. If the control variable exceeds the terminal parameter, the DO loop is satisfied and control transfers to the statement following n . The control variable becomes undefined.

Should m_1 exceed m_2 on the initial entry to the loop, the range of the DO is executed and control passes to the statement after n . If a transfer out of the DO loop occurs before the DO is satisfied, the current value of the control variable is preserved. The control variable, initial parameters, terminal parameter, and incrementation parameters may not be redefined during the execution of the range of the DO loop.

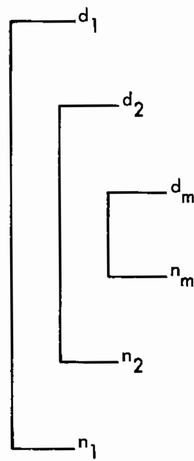


FORTRAN 5-5

DO Nests

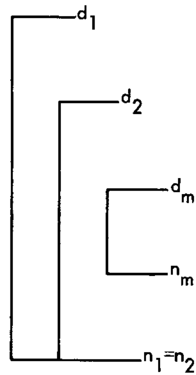
When the range of a DO loop contains another DO loop, the latter is said to be nested. DO loops may be nested 10 deep. The last statement of a nested DO loop must be the same as the last statement of the outer loop or occur before it. If $d_1, d_2, \ldots, d_n$ are DO statements, which appear in the order indicated by the subscripts; and if $n_1, n_2, \ldots, n_m$ are the respective terminal statements, then n_m must appear before or be the same as n_{m-1}, n_{m-1} must appear before or be the same as n_2, and n_2 must appear before or be the same as n_1.

Examples:

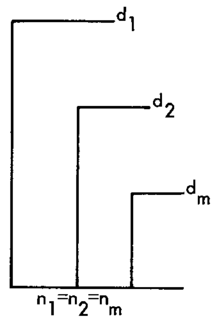


PROGRAMMER

```
    5 DO 1ØØ I = 1,1Ø,2
       .
       .
    7 DO 9Ø J = 1,1Ø,2
       .
       .
    9 DO 8Ø K = 1,1Ø,2
       .
       .
   8Ø CONTINUE
       .
       .
   9Ø CONTINUE
       .
       .
  1ØØ CONTINUE
```




```
PROGRAMMER
C  Label  CONT
    5  DO 1ØØ I = 1,2Ø
       .
       .
    8  DO 1ØØ J = 1,1Ø,3
       .
       .
   1Ø  DO 9Ø K = 1,2Ø,2
       .
       .
   9Ø  CONTINUE
       .
       .
  1ØØ  CONTINUE
```

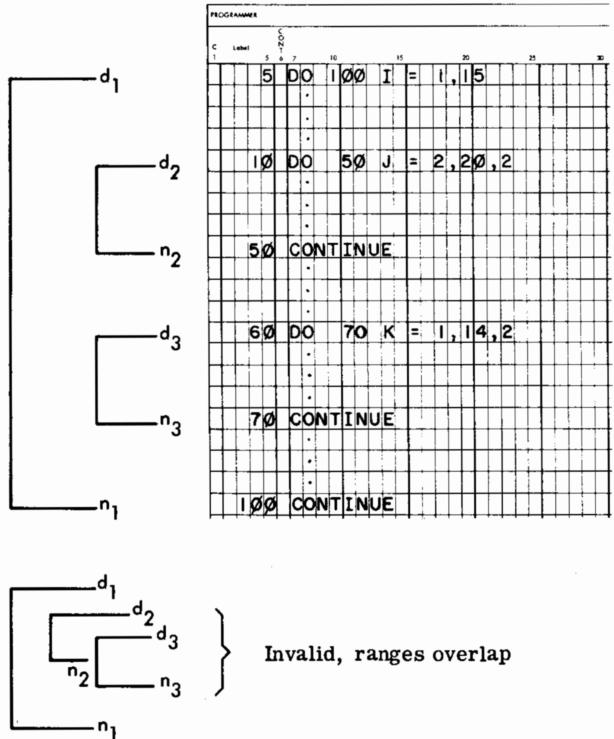



```
PROGRAMMER
C  Label  CONT
    5  DO 1ØØ I = 1,3Ø,5
       .
       .
   1Ø  DO 1ØØ J = 2,6
       .
       .
   2Ø  DO 1ØØ K = 5,5Ø,5
       .
       .
  1ØØ  CONTINUE
```

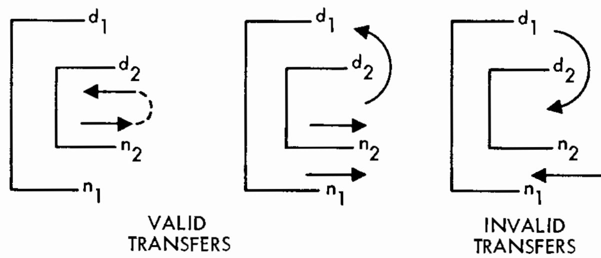
If one or more nested loops have the same terminal statement, when the inner DO is satisfied, the control variable for the next outer loop is incremented and tested against its associated terminal parameter. Control transfers to the statement following the terminal statement only when all related loops are satisfied.

DO loops may be nested in common with other loops as long as their ranges do not overlap.

Examples:



In a DO nest, a transfer may be made from an inner loop into an outer loop, and transfer is permissible outside of the loop. It is illegal, however, for a GO TO or IF to initiate a transfer of control from outside of the range of a DO into its range.



5.4 CONTINUE

This statement acts as no-operation instruction.

CONTINUE

The CONTINUE statement is most frequently used as the last statement of a DO loop to provide a loop termination when a GO TO or IF would normally be the last statement of the loop. If used elsewhere in the source program, it acts as a do-nothing instruction and control passes to the next sequential program statement.

5.5 PAUSE

This statement provides a temporary program halt.

PAUSE n
or
PAUSE

n may be up to four octal digits (without a B suffix) in the range 0 to 7777. This statement halts the execution of the program and types PAUSE on the Standard Teleprinter Output unit. The value of n , if given is displayed in the A-Register. When the RUN button is pressed, program execution resumes at the next statement.

5.6 STOP

The STOP statement terminates the execution of the program.

STOP n
or
STOP

n may be up to four octal digits (without a B suffix) in the range 0 to 7777. This statement halts the execution of the program and types STOP on the Standard Teleprinter Output unit. The value of n , if given, is displayed in the A-Register. If the RUN button is pressed, the halt operation is repeated.

5.7 END

The END statement indicates the physical end of a program or subprogram. It has the form:

END name

The END statement is required for every program or subprogram. The name of the program can be included, but it is ignored by the compiler. The END statement is executable in the sense that it will effect return from a subprogram in the absence of a RETURN statement. An END statement may be labeled and may serve as a junction point.

5.8 END$

The END$ statement indicates the physical end of five or less programs or subprograms that are to be compiled at one time. If there are four or less programs, the statement is printed on the source program listing. If there are exactly five, the statement is not printed. If more than five programs are on the same tape, the END$ may be omitted after the fifth program; the compiler stops accepting input after the fifth is processed.

MAIN PROGRAM, FUNCTIONS, AND SUBROUTINES 6

A FORTRAN program consists of a main program with or without subprograms. Subprograms, which are either functions or subroutines, are sets of statements that may be written and compiled separately from the main program.

The main program calls or references subprograms; and subprograms may call or reference other subprograms as long as the calls are non-recursive. That is, if program A calls subprogram B, subprogram B may not call program A. Furthermore, a program or subprogram may not call itself. A calling program is a main program or subprogram that refers to another subprogram.

In addition to multi-statement function subprograms, a function may be defined by a single statement in the program (statement function) or it may be defined as part of the FORTRAN Library (basic external function). A statement function definition may appear in a main program or subprogram body and is available only to the main program or subprogram containing it. A statement function may contain references to function subprograms, basic external functions, or other previously defined statement functions in the same subprogram. Basic external function references may appear in the main program, subprogram, and statement functions.

Main programs, subprograms, statement functions, and basic external functions communicate by means of arguments (parameters). The arguments appearing in a subroutine call or function reference are actual arguments. The corresponding entities appearing with the subprogram, statement function, or basic external function definition are the dummy arguments.

6.1 ARGUMENT CHARACTERISTICS

Actual and dummy arguments must agree in order, type, and number. If they do not agree in type, errors may result in the program execution, since no conversion takes place and no diagnostic messages are produced.

Within subprograms, dummy arguments may be array names or simple variables; for statement functions, they may be variables only. Dummy arguments are local to the subprogram or statement function containing them and, therefore, may be the same as names appearing elsewhere in the program. A maximum of 63 dummy arguments may be used in a function or subroutine.

No element of a dummy argument list may appear in a COMMON or EQUIVALENCE statement within the subprogram. If it does, a compiler diagnostic results. When a dummy argument represents an array, it should be declared in a DIMENSION statement within the subprogram. If it is not declared, only the first element of the array will be available to the subprogram and the array name must appear in the subprogram without subscripts.

Actual arguments appearing in subroutine calls and function references may be any of the following:

A constant
A variable name
An array element name
An array name
Any other arithmetic expression

6.2 MAIN PROGRAM

The first statement of a main program may be the following:

PROGRAM name

The name is an alphanumeric identifier of up to five characters. If the PROGRAM statement is omitted, the compiler assigns the name "FTN."

6.3 SUBROUTINE SUBPROGRAM

An external subroutine is a computational procedure which may return none, one, or more than one value through its arguments or through common storage. No value or type is associated with the name of a subroutine.

The first statement of a subroutine subprogram gives its name and, if relevant, its dummy arguments.

SUBROUTINE s (a_1, a_2, . . . , a_n)

or

SUBROUTINE s

The symbolic name, s, is an alphanumeric identifier of up to five characters by which the subroutine is called. If the subroutine is unnamed the compiler will assign the name of "." (period). The a's are the dummy arguments of the subroutine.

The name of the subroutine must not appear in any other statement within the subprogram.

The subroutine may define or redefine one or more of its arguments and areas in common so as to effectively return results. It may contain any statements except FUNCTION, another SUBROUTINE statement, or any statement that directly or indirectly references the subroutine being defined. It must have at least one RETURN or END statement which returns control to the calling program.

Examples:

```
      SUBROUTINE JIV(P,W,H)
      Z=5.*W+P**3
      H=Z-3.
      RETURN
      END
```

P, W and H are the dummy parameters. Actual values supplied by a calling program are to be substituted for P and W. The variable name supplied for H would contain the result on return to the calling program.

```
      SUBROUTINE MUL(K)
      COMMON MAT(10),PROD(10)
      DO 5 I=1,10
    5 PROD(I)=MAT(I)*K
      RETURN
      END
```

MUL multiplies the array supplied for MAT by the single value supplied for K to produce values to be stored in array PROD.

6.4 SUBROUTINE CALL

The executable statement in the calling program for referring to a subroutine is:

CALL s (a_1, a_2, ..., a_n)

or

CALL s

The symbolic name, s, identifies the subroutine being called; the a's define the actual arguments. The name may not appear in any specification statements in the calling program.

If an actual argument corresponds to a dummy argument that is defined or redefined in the called subprogram, the actual argument must be a variable name, an array element name, or an array name.

The CALL statement transfers control to the subroutine. Execution of the subroutine results in an association of actual arguments with all appearances of dummy arguments in executable statement and function definition statements. If the actual argument is an expression, the association is by value rather than by name. Following these associations, the statements of the subprogram are executed. When a RETURN or END statement is encountered, control is returned to the next executable statement following the CALL in the calling program. If the CALL statement is the last statement in a DO loop, looping continues until satisfied.

Examples:

```
      CALL JIV (15.,12.,ABLE)




      COMMON N(1Ø), Q(1Ø)
              .
              .
              .
      CALL MUL (I(5,3))
```

These calls provide actual arguments for the subroutines defined in the previous example. In subroutine JIV, 15. is substituted for P; 12., for W; and ABLE, for H.
For subroutine MUL, the data is passed via COMMON. The value supplied for the dummy argument K is element (5,3) of matrix I of the calling program.

6.5 FUNCTION SUBPROGRAM

A function subprogram is a computational procedure which returns a single value associated with the function name. The type of the function is determined by the name; an integer quantity is returned if the name begins with I, J, K, L, M, or N, otherwise it will be a real quantity.

The first statement of a function subprogram must have the following form:

FUNCTION f $(a_1, a_2, \ldots, a_n)$

The symbolic name, f, is an alphanumeric identifier of up to five characters by which the function is referenced. If the function is unnamed the compiler will assign the name of "." (period). The a's are the dummy arguments of the function.

The name of the function must not appear in any non-executable statement in the subprogram. It must be used in the subprogram, however, at least once as any of the following:

The left-hand identifier of an assignment statement
An element of an input list
An actual parameter of a subprogram reference

The value of name at the time of execution of a RETURN or END statement in the subprogram is called the value of the function.

The function subprogram may define or redefine one or more of its arguments and areas in common so as to effectively return results in addition to the value of the function. If the subprogram redefines variables contained in the same expression as the function reference, the evaluation sequence of the expression must be taken into account. Variables in the portion of the expression that is evaluated before the function reference is encountered and the values of variable subscripts are not affected by the execution of the function subprogram. Variables that appear following the function reference are modified according to the subprogram processing.

Examples:

a)

```
      FUNCTION IDIV(I,J)
      IDIV=I/J
      RETURN
      END
```

The function IDIV calculates the value of I divided by J. On return to the calling program the result provided is the value of IDIV.

b)

```
      FUNCTION IREAD (IUNT)
      .
      .
      .
      READ(IUNT,*)IREAD
      .
      .
      .
      RETURN
      END
```

The function IREAD reads a value from the unit IUNT (specified as an actual parameter in the calling program.) IREAD has this value on return to the calling program.

c)

```
      FUNCTION SCALL(A,B,C)
      .
      .
      .
      CALL SUBF(SCALL,A,B,C)
      .
      .
      .
      RETURN
      END
```

SCALL is both the function name and an actual parameter of a subroutine call. The value of SCALL is provided by SUBF and returned to the calling program.

d)

```
      FUNCTION ZETA(BETA,DELTA,GAMMA)
      A = BETA**2-DELTA**3
      GAMMA = A*5.2
      ZETA = GAMMA**2
      RETURN
      END
```

The function defines the value of GAMMA as well as finding the value of ZETA.

6.6 FUNCTION REFERENCE

A function subprogram is referenced by using the name and arguments in an arithmetic expression:

$$f\ (a_1,\ a_2, \ldots,\ a_n)$$

The type of function depends on the first letter of the name of the function referenced; the a's are the actual arguments. The reference may appear any place in an expression as an operand. The evaluated function will have a single value associated with the function name. When a function reference is encountered in an expression, control is transferred to the function indicated. Execution of the function results in an association of actual arguments with all appearances of dummy arguments in executable statements and function definition statements. If the actual argument is an expression, this association is by value rather than by name. Following these associations, the statements of the subprogram are executed. When a RETURN or END statement in the function subprogram is encountered, control returns to the statement containing the function reference. During execution the function also may define or redefine one or more of its arguments and areas in common.

Example:

```
a)      SANTU=K**IDIV(1Ø,5)+ICON

b)      SANDU=TAD+IREAD(1ØB)
```

The values of 10 and 5 are provided for I and J: The resulting value of IDIV would be 2. The function IREAD is called with 10B as the unit number. The value of IREAD would be the value of the item read from the device with unit reference number 10_8.

c)

```
ALPH=BETA*SCALL(1Ø.,9.,8.)
```

The actual parameters SCALL are 10., 9., and 8. The value of SCALL would depend on the value supplied by the subroutine SUBF.

d) The program,

```
GAMMB=5.Ø
RSLT=GAMMB+7.5+ZETA(.2,.3,GAMMB)
```

would result in the following calculation:

RSLT = 5.0 + 7.5 + ZETA

where ZETA would be determined as:

A = .2**2 - .3**3 = .04 - .027 = .013
GAMMA = .013*5.2 = .0676 (GAMMB is not altered)
ZETA = .0676**2 = .00456976

RSLT = 5.0 + 7.5 + .00456976
= 12.50456976

But, the program,

```
GAMMB=5.Ø
RSLT=ZETA(.2,.3,GAMMB)+7.5+GAMMB
```

would result in the following calculations for ZETA and GAMMB:

A = .2**2 - .3**3 = .04 - .027 = .013
GAMMA = .013*5.2 = .0676 = GAMMB
ZETA = .0676**2 = .00456976

RSLT = .00456976 + 7.5 + .0676
= 7.57216976

When referring to a function which redefines an argument which appears as a variable elsewhere in the same expression, the order of evaluation (i.e., the order in which the expression is stated) is significant.

6.7 STATEMENT FUNCTION

A statement function is defined internally to the program or subprogram in which it is referenced and must precede the first executable statement. The definition is a single statement similar in form to an arithmetic assignment statement.

$$f\ (a_1, a_2, \ldots, a_n) = e$$

The name of the statement function, f, is an alphanumeric identifier; a single value is associated with the name. The dummy arguments, a's, must be simple variables. One to ten arguments may be used. The expression, e, may be an arithmetic expression and may contain references to basic external functions, previously defined statement functions, or function subprograms. The dummy arguments must appear in the expression. Other variables appearing in the expression have the same values as they have outside the statement function.

The statement function name must not appear in any specification statements in the program or subprogram containing it.

Statement functions must precede the first executable statement of the program or subprogram, but they must follow all specification statements.

A statement function reference has the form:

$$f\ (a_1, a_2, \ldots, a_n)$$

f is the function name and the a's are the actual arguments. A function reference with its appropriate actual arguments may be used to define the value of an actual argument in a subroutine call or function subprogram reference.

Example:

```
INJR(M,N) = M*2+N**2+5
    .
    .
    .
CALL MATX (INJR(5,2),M)
    .
    .
    .
SUBROUTINE MATX (J,K)
    .
    .
    .
```

Statement function definition.

Subroutine call using statement function reference.

Execution of a statement function reference results in an association of actual argument values with the corresponding dummy arguments in the expression of the function definition, and evaluation of the expression. Following this, the resultant value is made available to the expression that contained the function reference and control is returned to that statement.

Example:

Statement function:

```
ABC(A,B)=A*(A**2-B**2)/(A**2+B**2)
```

Function reference:

```
CALC=RANM+ACES*ABC(7.,11.)
```

6.8 BASIC EXTERNAL FUNCTIONS

Certain basic functions are defined as part of the FORTRAN Library. When one of these appears as an operand in an expression, the compiler generates the appropriate calling sequence within the object program.

The types of these functions and their arguments are defined. The compiler recognizes the basic function and associates the type with the results. The actual arguments must correspond to the type required for the function; if not, a diagnostic message is issued. The functions available are shown below:

Function Name	Definition	Symbolic Name	No. of Arguments	Type of Argument	Type of Function
Absolute Value	$\|a\|$	ABS	1	Real	Real
		IABS	1	Integer	Integer
Float	Conversion from integer to real	FLOAT	1	Integer	Real
Fix	Conversion from real to integer	IFIX	1	Real	Integer
Transfer sign	Sign of a_2 times $\|a_1\|$	SIGN	2	Real	Real
		ISIGN	2	Integer	Integer
Exponential	e^a	EXP	1	Real	Real
Natural Logarithm	$\log_e$ (a)	ALOG	1	Real	Real
Trigonometric Sine	sine (a)†	SIN	1	Real	Real
Trigonometric Cosine	cos (a)†	COS	1	Real	Real
Trigonometric Tangent	tan (a)†	TAN	1	Real	Real
Hyperbolic Tangent	tanh (a)	TANH	1	Real	Real
Square Root	$(a)^{1/2}$	SQRT	1	Real	Real
Arctangent	arctan(a)	ATAN	1	Real	Real
And (Boolean)	$a_1 \wedge a_2$	IAND	2	Integer	Integer
Or (Boolean)	$a_1 \vee a_2$	IOR	2	Integer	Integer
Not (Boolean)	$\neg a$	NOT	1	Integer	Integer
Sense Switch	Sense Switch Register switch (n)	ISSW	1	Integer	Integer

†a is in radians

Examples:

PROGRAMMER | DATE | PROGRAM

C Label | CONT | STATEMENT

```
      SIGND=A+B*C/D-E
      SIGNN=ABS(SIGND)
      Y=FLOAT(NEWT)
      ISGND=I+J*K/L-M
      ISGNN=IABS(ISGND)
      IAL  =JACK*KEN*LARRY
      ISAL =ISIGN(IAL,ISGNN)
      POWR =EXP(X)
      ANTLG=ALOG(Y)
      OOHYP=SIN(AGL)
      AOHYP=COS(AGL)
      OOAH =TANH(AGLH)
      HFPR =SQRT(Z)
      ARC  =ATAN(S)
      LPROD=IAND(M,N)
      LSUM =IOR(M,N)
      LCLMT=NOT(M)
```

6.9 RETURN AND END

A subprogram normally contains a RETURN statement that indicates the end of logic flow within the subprogram and returns control to the calling program. It must always contain an END statement.

In function subprograms, control returns to the statement containing the function reference. In subroutine subprograms, control returns to the next executable statement following the CALL. A RETURN statement in the main program is interpreted as a STOP statement.

The END statement marks the physical end of a program, subroutine subprogram, or function subprogram. If the RETURN statement is omitted, END causes a return to the calling program. The END$ is required in addition to END statements when five or less subprograms are being compiled at one time.

INPUT/OUTPUT LISTS AND FORMAT CONTROL 7

Data transmission between internal storage and external equipment requires an input/output statement and, for ASCII character strings, either a FORMAT statement or format control symbols with the input data. The input/output statement specifies the input/output process, such as READ or WRITE; the unit of equipment on which the process is performed; and the list of data items to be moved. The FORMAT statements or control symbols provide conversion and editing information between the internal representation and the external character strings. If the data is in the form of strings of binary values, format control is unnecessary.

7.1 INPUT/OUTPUT LISTS

The input list specifies the names of the variables and array elements to which values are assigned on input. The output list specifies the references to the variables, array elements, and constants whose values are transmitted. The input and output lists are of the same form. The list elements consist of variable names, array elements, and array names separated by commas. The order in which the elements appear in the list is the sequence of transmission. If FORMAT statements are used, the order of the list elements must correspond to the order of the format descriptions for the data items. In array elements buffer length is limited to a maximum output of 60 computer words.

Subscripts in an input/output list may be of the form (exp_1, exp_2), where exp_i is one of the following:

```
c*v+k    v-k
c*v-k    v
c*v      k
v+k
```

where c and k are integer constants and v is a simple integer variable previously defined or defined within an implied DO loop.

DO-Implied Lists

A DO-implied list consists of one or more list elements and indexing parameters. The general form is

$$(\ldots(\text{list},\ i = m_1,\ m_2,\ m_3)\ldots)$$

list	Any series of arrays, array elements, or variables separated by commas
i	Control variable
m's	Index parameters in the form of unsigned integer constants or predefined integer variables

Data defined by the list elements is transmitted starting at the value of m_1 in increments of m_3 until m_2 is exceeded. If m_3 is omitted it is assumed to be one.

An implied DO loop may be used to transmit a simple variable or a sequence of variables more than one time.

Two-dimensional arrays may appear in the list with values specified for the range of the subscripts in an implied DO loop. The general form for an array is:

$$((a(d_1, d_2), i_1 = m_1,\ m_2,\ m_3),\ i_2 = n_1,\ n_2,\ n_3)$$

where,

a	An array name
d_1, d_2	Subscripts of the array in one of the preceding forms
i_1, i_2	Control variables representing either of the variable subscripts d_1 and d_2
m's, n's	Index parameters in the form of unsigned integer constants or predefined integer variables. If m_3 or n_3 is omitted, it is construed as 1.

The input/output list may contain nested implied DO loops. During execution, the control variables are assigned the values of the initial parameters ($i_1 = m_1$, $i_2 = n_1$). The first control variable defined in the list is incremented first. When the first control variable reaches the maximum value, it is reset; the next control variable to the right is incremented and the process is repeated until the last control variable has been incremented.

If the name of a dimensioned array appears in a list without subscripts, the entire array is transmitted.

Examples:

a) The DO-implied list:
```
   ((A(I,J), I=1, 20, 2), J=1, 50,5)
```
replaces the following:
```
   DO x J=1, 50, 5
   DO x I=1, 20, 2
   transmit A (I,J)
x  CONTINUE
```

b) Other implied DO loops might be:
```
   ((ABLE(5*KID-3, 100*LID), KID=1,100), LID=1,10)
   ((A(I,J), I=1,5),J=1,5)  Transmit elements by column
   ((A(I,J),J=1,5), I=1,5)  Transmit elements by row.
```

c) Nested implied DO loops:
```
   ((((A(I,J),B(K,L),K=1,10),L=1,15),I=1,20),J=1,25)
   (((A(I,J),B(K),K=1,10),I=20,100,10),K=9,90,10)
```

d) Simple variable transmission:
```
   (A, K=1, 10) Transmits 10 values of A.
```

e) Dimensioned array transmission:
```
   DIMENSION A(50,20)
         .
         .
         .
     ... A ...      list element
   is equivalent to:
   DO x I = 1,20
   DO x J = 1,50
   transmit A(J,I)
x  CONTINUE
```

7.2 FORMAT STATEMENT

ASCII input/output statements may refer to a FORMAT statement which contains the specifications relating to the internal-external structure of the corresponding input/output list elements.

FORMAT ($spec_1$, . . . , r($spec_m$, . . .), $spec_n$, . . .)

The spec's are format specifications and r is an optional repetition factor which must be an unsigned integer constant. FORMAT specifications may be nested to a depth of one level. The FORMAT statement is non-executable and may appear anywhere in the program.

7.3 FORMAT STATEMENT CONVERSION SPECIFICATIONS

The data elements in the input/output lists may be converted from external to internal and from internal to external representation according to FORMAT conversion specifications.† FORMAT statements may also contain editing codes.

Conversion Specifications

rEw.d	Real number with exponent
rFw.d	Real number without exponent
rIw	Decimal integer
rKw	Octal integer
rAw	Alphanumeric character

Editing Specification

nX	Blank field descriptor
nHh_1 h_2. . .h_n	Heading and labeling descriptors
r"h_1 h_2. . .h_n"	Heading and labeling descriptors
r/	Begin new record

† If the type of a variable in the input/output list does not correspond to the type specified in the FORMAT statement, the compiler insures that the proper conversion from one type to the other will take place.

Both w and n are nonzero integer constants representing the width of the field in the external character string; n may be omitted if the width is one. d is an integer constant representing the number of digits in the fractional part of the string. r , the repeat count, is an optional nonzero integer constant indicating the number of times to repeat the succeeding basic field descriptor. Each h is one character.

Ew.d Output

The E specification converts numbers in storage to character form for output. The field occupies w positions in the output record; the number appears in floating point form right justified in the field as:

$$\underline{\wedge}.x_1 \ldots x_d \ E{\pm}ee^{\dagger}$$

$x_1 \ldots x_d$ are the most significant digits of the value of the data to be output. ee are the digits in the exponent. Field w must be wide enough to contain significant digits, signs, decimal point, E , and exponent. Generally, w should be greater than or equal to d + 4.

If the field is not long enough to contain the output value, an attempt is made to adjust the value of d (i.e., truncating part or all of the fraction) so that a number is written in the field. If the remaining value is still to large for the field, dollar signs ($) are inserted in the entire field. If the field is longer than the output value, the quantity is right-justified with spaces to the left.

Examples:

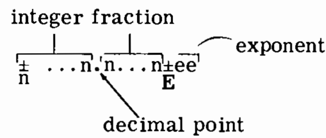
Label	Statement	
	WRITE(4,5)A	A contains +12.34 or -12.34
5	FORMAT(E10.3)	Result is ∧∧.123E+02 or ∧-.123E+02
	WRITE(4,5)A	A contains +12.34 or -12.34
5	FORMAT(E12.3)	Result is ∧∧∧∧.123E+02 or ∧∧∧-.123E+02
	WRITE(4,5)A	A contains +12.34 or -12.34
5	FORMAT(E7.3)	Result is .12E+02 or -.1E+02
	WRITE(4,5)A	A contains +12.34
5	FORMAT(E5.1)	Result is $$$$$

†The caret symbol, ∧ , indicates the presence of a space.

Ew.d Input

The E specification converts the number in the input field (specified by w) to a real number and stores it in the appropriate storage locations.

The input field may consist of integer, fraction, and exponent subfields:



The integer subfield begins with a + or - sign, or a digit and may contain a string of digits terminated by a decimal point, an E , + , - , or the end of the input field.

The fraction subfield begins with a decimal point and may contain a string of digits terminated by an E , + , - , or the end of the input field.

The exponent field may begin with a sign or an E and contains a string of digits. When it begins with E , the + is optional between E and the string. The value of the string of digits should not exceed 38. The number may appear in any positions within the field; spaces in the field are ignored.

Examples:

+1.2345E2
123.456+9
-0.1234-6
.12345E-3
1234
+12345
+1234E6

When no decimal point is present in the input quantity, d acts as a negative power of ten scaling factor. The internal representation of the input quantity will be:

(integer subfield) $x10^{-d}$ $x10^{(\text{exponent subfield})}$

Example:

```
FORMAT(E12.8)
```

Input quantity = ^^^1234+5^^

Conversion performed: $1234 \times 10^{-8} \times 10^{5}$

Result: 1.234

If a d value in the specification conflicts with the a decimal point appearing in an input field, the actual decimal point takes precedence.

Example:

```
FORMAT(E12.8)
```

Input quantity = ^^^^^1.234+5

Quantity stored: 1.234×10^{5}

The field width specified by w should always be the same as the width of the input field. When it is not, incorrect data may be read, converted and stored. The value of w should include positions for signs, the decimal point, the letter E , as well as the digits of the subfields:

Example:

```
      READ(5,1Ø)A,B,C
   1Ø FORMAT(E7.2,E5.3,E9.2)
```

Assuming input data in contiguous fields:

```
-12.3E1+1234123.46E-3
|← 7 →←5 ←— 9 —→|
```

The fields read would be:

-12.3E1
+1234
123.46E-3

and converted as:

-123.
1.234
.12346

However, if specifications were:

```
10 FORMAT(E7.2,E4.3,E7.2)
```

The fields read would be:

-12.3E1
+123
4123.46

and converted as:

-123
.123
4123.46

The effects of possible FORMAT specification errors such as the above may not be detected by the system.

Examples:

FORMAT Specification	Input Field	Converted Value
E9.2	+1.2345E2	123.45
E9.4	-0.1234-6	-.0000001234
E4.2	1234	12.34

Fw.d Output

The F specification converts real numbers in storage to character form for output. The field occupies w positions and will appear as a decimal number, right justified in the field.

△x...x.x...x

The x's are the most significant digits. The number of decimal places to the right of the decimal point is specified by d . If d is zero, no digits appear to the right of the decimal point. The field must be wide enough to contain the significant digits, sign, and decimal point. If the number is positive, the + sign is suppressed. If the field is not long enough to contain the output value, an attempt is made to adjust the value of d (i.e., truncating part or all of the fraction) so that a number is written in the field. If the remaining value is still too large for the field, dollar signs ($) are inserted in the entire field. If the field is longer than the output value, the number is right-justified with spaces occupying the excess positions on the left.

Examples:

Coding	Description
`WRITE(4,5)A` `5 FORMAT(F10.3)`	A contains +12.34 or -12.34 Result: ∧∧∧∧12.340 or ∧∧∧-12.340
`WRITE(4,5)A` `5 FORMAT(F12.3)`	A contains +12.34 or -12.34 Result: ∧∧∧∧∧∧12.340 or∧∧∧∧∧-12.340
`WRITE(4,5)A` `5 FORMAT(F4.3)`	A contains +12.34 Result: 12.3
`WRITE(4,5)A` `5 FORMAT(F4.3)`	A contains +12345.12 Result: $$$$

Fw.d Input

The F specification input is identical to the E specification input. Although the fields are generally assumed to contain only a sign, integer, decimal point, and fraction; they may also contain an exponent subfield. All restrictions for Ew.d input apply.

Iw

The Iw specification converts internal values to output character strings, or input character strings to internal numbers. The output external field occupies w record positions and appears right justified (spaces on left) as:

$\triangle x_1 \ldots x_d$

The x's represent the decimal digits (maximum of 5) of the integer. When the integer is positive on output, the sign is suppressed. If an output field is too short, dollar signs ($) will be placed in the output record.

The Iw specification, when used for input, is identical to an Fw.0 specification.

Examples:

```
      WRITE(6,1Ø)I,J,K,L
   1Ø FORMAT(I5,I5,I4,I6)
```

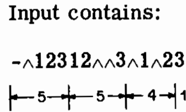
I contains -1234
J contains +12345
K contains +12345
L contains +12345

Result: -123412345$$$$^12345

```
      READ(5,1Ø)I,J,K,L
   1Ø FORMAT(I5,I5,I4,I1)
```

Input contains:

-^12312^^3^1^23



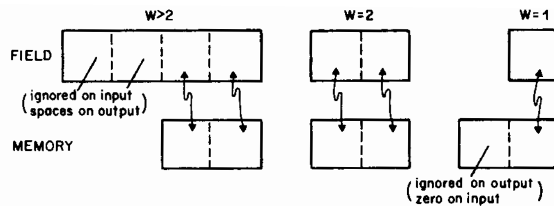
I contains -0123
J contains 12003
K contains 0102
L contains 3

Aw

This specification causes alphanumeric data on an external medium to be translated to or from ASCII form in memory. The associated list element must be of type integer.

On input, if the field, as indicated by w, is greater than 2, the first w-2 characters are ignored; only the last two characters are read. When w equals 2, the two characters are read. If w equals 1, one character is read and stored in the right half of a computer word; zero is entered in the left half.

On output, if the field is greater than 2, two characters are written with right justification in the field; the leading positions are filled with spaces. If w equals 2, the two characters are written. If w equals 1, the character in the right half of the computer word is written.



Example:

```
       Input data:  AZZ213-ABCXABC137 - ZZ9 (CR) (LF)

       DIMENSION ID (5)
       READ (5, 1Ø) 12, 11, ID
10     FORMAT (A1Ø, A1, 5A2)

       Result:  12  BC
                11  ØX
                ID  AB
                    C1
                    37
                    -Z
                    Z9
```

r@w   rKw

Octal integer values are converted under either the @ or the K specification. The field is w octal digits in length; the corresponding list element must be of type integer.

On input, if w is greater than or equal to 6, up to six octal digits are stored; non-octal digits appearing within the field are ignored. If the value of the octal digits within the field is greater than 177777, the results are unpredictable. If w is less than 6, or if less than six octal digits are encountered in the field, the number is right justified in the computer word with zero fill on the left.

On output, if the field is greater than 6, six octal digits are written with right justification in the field; the leading positions are filled with spaces. If w equals 6, the six octal digits are written. If w is less than 6, the w least significant octal digits are written.

Example:

```
       Input data:  123456-1234562342342342, 396E-Ø5   CR    L]

       DIMENSION ID(2), IE(2)
       READ (5, 10) IB, IC, ID, IE
10     FORMAT (@6, @7,  2@5,  2@4)
```

Result: IB 123456
IC 123456
ID Ø23423
Ø42342
IE ØØØØ36
ØØØØØ5

nX

The X specification may be used to include n blanks in an output record or to skip n characters on input to permit spacing of input/output quantities. In the specifications list, the comma following X is optional. ∧X is interpreted as 1X. 0X is not permitted.

Examples:

```
      WRITE(6,1Ø)A,B,I
   1Ø FORMAT(E8.3,5X,F6.2,5X,I4)
```

A contains +123.4
B contains -12.34
I contains -123

Result: ∧.1234E2∧∧∧∧∧-12.34∧∧∧∧∧-123

Input:

WEIGHT∧∧10∧∧PRICE∧∧$1.98∧∧TOTAL∧∧$19.80

```
      READ(5,1Ø)I,A,B
   1Ø FORMAT(8X,I2,1ØXF4.2,1ØXF5.2)
```

Result: I contains 10
A contains 1.98
B contains 19.80

$nHh_1h_2...h_n$

The H specification provides for the transfer of any combination of 8-bit ASCII characters, including blanks. n is an unsigned integer specifying the number of characters to the right of the H that are to be transmitted. The comma following the H specification is optional. ∧H is interpreted as 1H. 0H is not permitted.

On output, the ASCII data in the FORMAT statement is written on the unit in the form of comments, titles, and headings.

Example:

```
PROGRAMMER                                   DATE          PROGRAM
      WRITE(6,1Ø)
   1Ø FORMAT(20H THIS IS AN EXAMPLE )
```

Result: THIS IS AN EXAMPLE

```
      WRITE(6,1Ø)I,A,B
   1Ø FORMAT(8HWEIGHT  I2,1ØH  PRICE  $,F4.2,
     C1ØH  TOTAL  $,F5.2)
```

I contains 10
A contains 1.98
B contains 19.80

Result: WEIGHT 10 PRICE $1.98 TOTAL $19.80

On input, the data is transmitted from the unit to the FORMAT statement. A subsequent output statement transfers the new data to the output record.

Examples:

```
PROGRAMMER                                   DATE          PROGRAM
      READ(5,1Ø)
   1Ø FORMAT(31H^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^)
      WRITE(6,1Ø)
```

Input: H INPUT ALLOWS VARIABLE HEADERS

Result: H INPUT ALLOWS VARIABLE HEADERS

r"$h_1h_2 \ldots h_n$"

This specification also provides for the transfer of any combination of ASCII characters (except the quotation marks). The number of characters transmitted is the number of positions between the two quotation marks; field length is not specified. If r , an optional repeat count, is present, the character string within the quotation marks is repeated that number of times. Commas preceding the initial quotation mark and following the closing quotation are optional.

Examples:

```
      WRITE(6,1Ø)
   1Ø FORMAT("THIS ALSO IS AN EXAMPLE")
```

Result: THIS ALSO IS AN EXAMPLE

```
      WRITE(6,1Ø)
   1Ø FORMAT(3"ABC")
```

Result: ABCABCABC

On input, the number of characters within the quotation marks is skipped on the input field.

New Record

The slash, / , terminates the current record and signals the beginning of a new record of formatted data. It may occur anywhere in the specifications list and need not be separated from the other list elements by commas. Several records may be skipped by indicating consecutive slashes or by preceding the slash with a repetition factor; r-1 records are skipped for r/. On output the slash is used to skip lines, cards, or tape records; on input, it specifies that control passes to the next record or card.

Examples:

```
      WRITE(6,1Ø)
   1Ø FORMAT(22X,6HBUDGET///6HWEIGHT,6X,
     C5HPRICE,9X,5HTOTAL,8X)

              or

      WRITE(6,1Ø)
   1Ø FORMAT(22X,6HBUDGET,3/6HWEIGHT,6X,
     C5HPRICE,9X,5HTOTAL,8X)
```

Result:

line 1 ^^^^^^^^ ^^^^^ ^^^^^ ^^^^ BUDGET

line 2

line 3

line 4 WEIGHT^^^^^^ PRICE^^^^^^^^^ TOTAL^^^^^^^^

Repeat Specifications

Repetition of the field descriptors (except nH) is accomplished by preceding the descriptor with a repeat count, r . If the input/output list warrants, the conversion is interpreted repetitively up to the specified number of times.

Repetition of a group of field descriptors, including nH is accomplished by enclosing the group in parentheses and preceding the left parenthesis with a group repeat count. If no group repeat count is specified, a value of one is assumed. Grouped field descriptors may be nested to a depth of one level.

Examples:

```
      WRITE(4,10)I,J,K
   10 FORMAT(I5,I5,I5)
```

can be written as

```
      WRITE(4,10)I,J,K
   10 FORMAT(3I5)

      WRITE(4,10)A,B,I,C,D,J
   10 FORMAT(E8.3,5X,F6.2,5X,I4,E8.3,5X,
     CF6.2,5X,I4)
```

can be written as

```
      WRITE(4,10)A,B,I,C,D,J
   10 FORMAT(2(E8.3,5X,I4))
```

A nested repetition specification would be:

```
      FORMAT(E8.3,5X,5(F6.2,5X,I4))
```

The group F6.2, 5X, I4 would be written five times, and the entire group, once.

Unlimited Groups

FORMAT specifications may be repeated without use of the repetition factor. If list elements remain after all specifications in a FORMAT statement are processed, the rightmost group of repeated (enclosed in parentheses) specifications is used. If there is no repeated group, processing resumes with the first specification in the statement. On output, each time the rightmost parenthesis in the statement, or in the unlimited group, is reached, the current record is terminated.

7.4 FREE FIELD INPUT

By following certain conventions in the preparation of the input data, a 2116A FORTRAN program may be written without use of FORMAT statements. Special symbols included with the ASCII input data items direct the formatting:

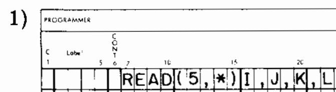
space or,	Data item delimiters
/	Record terminator
+ -	Sign of item
. E + -	Floating point number
@	Octal integer
"..."	Comments

All other ASCII non-numeric characters are treated as spaces (and delimiters). Free field input may be used for numeric data only. Free field input is indicated in the FORTRAN READ statement by using an asterisk rather than a number of a FORMAT statement.

Data Item Delimiters

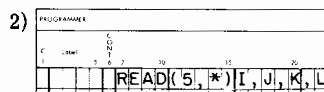
Any contiguous string of numeric and special formatting characters occurring between two commas, a comma and a space, or two spaces, is a data item whose value corresponds to a list element. A string of consecutive spaces is equivalent to one space. Two consecutive commas indicate that no data item is supplied for the corresponding list element; the current value of the list element is unchanged. An initial comma causes the first list element to be skipped.

Example:

1) 

Input data: 1720, 1966
1980 1492

Result: I contains 1720
J contains 1966
K contains 1980
L contains 1492

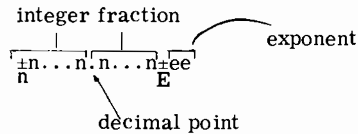
2) 

Input data: 1266,,1794,2000

Result: I contains 1266
J contains 1966
K contains 1794
L contains 2000

Floating Point Input

The symbols used to indicate a floating point data item are the same as those used in representing floating point data for FORMAT statement directed input:



If the decimal point is not present, it is assumed to follow the last digit.

Examples:

```
READ(5,*)A,B,C,D,E
```

Input Data: 3.14, 314E-2, 3140-3, .0314+2, .314E1

All are equivalent to 3.14

Octal Input

An octal input item has the following format:

$@\, x_1 \ldots x_d$

The symbol @ defines an octal integer. The x's are octal digits each in the range of 0 through 7. List elements corresponding to the octal data items must be type integer.

Record Terminator

A slash within a record causes the next record to be read immediately; the remainder of the current record is skipped.

Example:

```
READ(5,*)II,JJ,KK,LL,MM
```

Input data: 987, 654, 321, 123/DESCENDING (CR) (LF)
456

Result: II contains 987
JJ contains 654
KK contains 321
LL contains 123
MM contains 456

List Terminator

If a line terminates (with a (CR) (LF)) and a slash has not been encountered, the input operation terminates even though all list elements may not have been processed. The current values of remaining elements are unchanged.

Examples:

```
      READ(5,*)A,B,C,J,X,Y,Z
```

Input Data:

A=7.987 B=5E2 C=4.6859E-3 (CR) (LF)
J=3456 (CR) (LF)

Result: A contains 7.987
B contains 5E2
C contains 4.6859E-3

J, X, Y, Z are unchanged.

Comments

All characters appearing between a pair of quotation marks in the same line are considered to be comments and are ignored.

Examples:

"6.7321" is a comment and ignored
6.7321 is a real number

Input/output statements transfer information between memory and an external unit. The unit is specified as an integer variable that is defined elsewhere in the program or an integer constant.

Each statement may include a list of names of variables, arrays, and array elements. The named elements are assigned values on input and have their values transferred on output.

Records may be formatted or unformatted. A formatted record consists of a string of ASCII characters. The transfer of such a record requires the specification of a FORMAT statement or free field input data. An unformatted record consists of a string of binary values.

8.1 UNIT-REFERENCE

The integer specified for an input/output unit is a number which represents a Standard unit assignment or an installation unit assignment. The physical device referenced depends on tables established within the Basic Control System.

The Standard unit numbers are as follows:

Number	Name	Usual Equipment Type
1	Keyboard Input	2752A Teleprinter†
2	Teleprinter Output	2752A Teleprinter
3	Program Library	2737A Punched Tape Reader
4	Punch Output	2753A Tape Punch
5	Input	2737A Punched Tape Reader
6	List Output	2752A Teleprinter

†If data is to be printed on the Teleprinter as it is read, Unit-Reference number 1 must be used; printing occurs with no other number.

Installation unit numbers may be in the range $7\text{-}74_8$ with the largest value being determined by the number of units of equipment available at the installation. Each Standard unit may be a separate device, or a single device may be accessed by several Standard unit numbers as well as an installation unit number.†

8.2 FORMATTED READ, WRITE

A formatted READ statement is one of the forms:

```
READ (u, f)k
READ (u, *)k
READ (u, f)
```

Execution of this statement causes the input of the next ASCII records from unit u. The information is scanned and converted according to the FORMAT specification statement, f, and assigned to the elements of list k. If the input is free field, an asterisk is specified in the READ statement rather than the label of a FORMAT statement. If the list is absent, the FORMAT statement should contain editing specifications only.

A formatted WRITE statement may have one of the following forms:

```
WRITE (u, f)k
      or
WRITE (u, f)
```

This statement transfers ASCII information from locations given by names in the list k to output unit u. The values are converted and positioned as specified by the FORMAT statement f. If the list is absent, the FORMAT statement should contain editing specifications only.

---

†For complete details, see Basic Control System Programmer's Reference Manual.

8.3 UNFORMATTED READ, WRITE

An unformatted READ statement has one of the forms:

```
READ (u)k
     or
READ (u)
```

This statement transfers the next binary input record from the unit u to the elements of list k. The sequence of values required by the list may not exceed the sequence of values from the record. If no list is specified, READ (u) skips the next record.

An unformatted WRITE statement has the form:

```
WRITE (u)k
```

Execution of this statement creates the next record on unit u from the sequence of values represented by the list k.

8.4 AUXILIARY INPUT/OUTPUT STATEMENTS

There are three types of auxiliary input/output statements:

```
REWIND
BACKSPACE
ENDFILE
```

A REWIND statement has the form:

```
REWIND u
```

This statement causes the unit u to be positioned at its initial point. If the unit is currently at this position, the statement acts as a CONTINUE.

A BACKSPACE statement is as follows:

```
BACKSPACE u
```

BACKSPACE positions the unit u so that what had been the preceding record becomes the next record. If the unit is currently at its initial point, the statement acts as a CONTINUE.

An ENDFILE statement is of the form:

    ENDFILE u

Execution of this statement causes the recording of an end-of-file record on the output unit u. If given for an input unit, the statement acts as a CONTINUE.

In addition to the three auxiliary input output statements, a subroutine may be called to perform file and record spacing on magnetic tape. The subroutine call is as follows:

    CALL PTAPE (u, f, r)

u   Unit-Reference number of tape device

f   File spacing:

   A positive integer specifying the number of files to be spaced forward.

   A negative integer specifying the number of files to be backspaced.

r   Record spacing:

   A positive integer specifying the number of records to be spaced forward.

   A negative integer specifying the number of records to be backspaced.

Both file and record spacing may be specified in the same call (e.g., space forward 5 files, then backward 2 records). If file or record spacing is not to be performed, a zero is supplied as the parameter.

If backspacing would result in spacing beyond the Start-of-Tape mark, the spacing operation is terminated and program execution resumes. If forward spacing results in spacing beyond the End-of-Tape marker, the message "*EOT" is printed on the Standard Teleprinter Output unit. When the operator presses RUN, program execution resumes.

The FORTRAN Compiler accepts as input, paper tape containing a control statement and a source language program. The output produced by the Compiler may include a punched paper tape containing the object program; a listing of the source language program with diagnostic messages, if any; and a listing of the object program in assembly level language.

9.1 CONTROL STATEMENT

The control statement must be the first statement of the source program; it directs the compiler.

FTN, p_1, p_2, p_3

FTN is a free field control statement. Following the comma are one to three parameters, in any order, which define the output to be produced. The control statement must be terminated by an end-of-statement mark, (CR) (LF). Spaces embedded in the statement are ignored.

The parameters may be a combination of the following:

B Binary output: A program is to be punched in relocatable binary format suitable for loading by the Basic Control System loader.

L List output: A listing of the source language program is to be produced during Pass One.

A Assembly listing: A listing of the object program in assembly level language is to be produced in the last pass.

9.2 SOURCE PROGRAM

The source program follows the control statement. Each statement is followed by the end-of-statement mark, (CR) (LF). Specifications statements must precede executable statements. The last statement in each program submitted for compilation must be an END statement. Up to five source programs may be compiled at one time. The last program must be followed by and END$ statement, if less than six programs are to be compiled.

The control statement, each of the five programs, and the END$ terminator may be submitted on a single tape or on separate tapes. If more than five programs are contained on a tape, the compiler processes the first five and halts with the T-Register containing 102077 (end of Pass 1). The remaining programs must be compiled separately.

9.3 BINARY OUTPUT

The punch output produced by the compiler is a relocatable binary program. It does not include system subroutines introduced by the compiler, or library subroutines referred to in the program.

9.4 LIST OUTPUT

If the List Output parameter is specified, the first 72 characters of each line of the source program is printed on the List Output device. The END$ is the last statement printed. If exactly five programs are compiled, however, the END$ is omitted from the list.

If the Assembly listing parameter is specified, the program is printed in assembly level language on the List Output device. The program listing is followed by a Symbol Table for the assembly level program.

The format for the assembly level listing is as follows:

Columns	Content
1-5	Zero-relative location (octal) of the instruction
6-7	Blank

Columns	Content
8-13	Object code word in octal
14	Relocation or external symbol indicator
15	Blank
16-18	Mnemonic operation code
19	Blank
20-25	Operand address in octal or external symbol name.
26-27	The indicator ",I" if indirect addressing is used.

The Symbol Table listing has the following format:

Columns	Content
1-5	Symbol, statement label, or numeric symbol assigned by the compiler.
6	Blank
7	Relocation indicator
8	Blank
9-14	The zero-relative value of the symbol

The characters that designate an external symbol or type of relocation for the operand address or a symbol in the Symbol Table are:

Character	Relocation Base
Blank	Absolute
R	Program relocatable
X	External symbol
C	Common relocatable

9.5 OPERATING INSTRUCTIONS Paper Tape

The exact operating procedures for a compilation depend on the available hardware configuration.

One possible allocation of equipment might be as follows:

Compiler Input/Output	Standard Unit Designation	Physical Unit Assignment
Binary output	Punch Output	2753A Tape Punch
List output	Teleprinter Output	2752A Teleprinter
Assembly listing	Teleprinter Output	2752A Teleprinter
Source tape(s)	Input	2737A Punched Tape Reader

If there are two output devices as shown above, there are two passes (8K memory) or four passes (4K memory). The list output and an intermediate binary tape are both produced during the first pass; the assembly listing and the binary output are both produced during the last pass.

If one output device is available list output and intermediate binary output are written on the same tape during the first pass (the Compiler ignores the list output when reading the binary data during the second pass). The binary output is then produced in the next to the last pass; and the assembly listing, in the last pass.

The following procedures indicate the sequence of steps for compilation of a source program on paper tape:

A. Set Teleprinter to LINE and check that all equipment to be used is operable. If the Teleprinter is the only output device, turn ON punch unit.

B. Load FORTRAN Pass 1 using the Basic Binary Loader:

   1. Place FORTRAN binary tape in the device serving as the Standard Input unit (e.g., Punched Tape Reader).

   2. Set Switch Register to starting address of Basic Binary Loader (e.g., 007700 for 4K memory, 017700 for 8K memory).

3. Press LOAD ADDRESS.

4. Set Loader switch to ENABLED.

5. Press PRESET.

6. Press RUN.

7. When the computer halts and indicates that the FORTRAN tape is loaded (T-Register contains 102077), set Loader switch to PROTECTED.

C. If the System Input/Output (SIO) subroutines are on a tape which is separate from FORTRAN Pass 1, load the tape using the Basic Binary Loader as in Step B.

D. Set Switch Register to starting address of FORTRAN Pass 1: 000100

E. Press LOAD ADDRESS

F. Place source language tape in device serving as the Standard Input unit (e.g., Punched Tape Reader).

G. Press RUN.

H. If more than one source tape, repeat Steps F and G for each tape.

I. Perform either of the following depending on memory size:

4K Memory

1. At end of Pass 1 (T-Register contains 102077) load Pass 2 using the Basic Binary Loader as in Step B.

2. Remove binary output from Standard Punch device and place in device serving as the Standard Input unit. (If only one output device, both binary and list output are on the same tape.)

3. Set Switch Register to: 000100

4. Press LOAD ADDRESS

5. Press RUN

6. At end of Pass 2 (T-Register contains 102077), load Pass 3 using the Basic Binary Loader as in Step B.

7. Remove binary output from Standard Punch device and place in device serving as Standard Input unit.

8. Set Switch Register to: 000100

9. Press LOAD ADDRESS.

10. Press RUN.

11. At end of Pass 3 (T-Register contains 102077), load Pass 4 using the Basic Binary Loader as in Step B.

12. Remove binary output from Standard Punch device and place in device serving as Standard Input unit.

13. Set Switch Register to: 000100.

14. Press LOAD ADDRESS.

15. Press RUN.

16. At end of Pass 4, the relocatable binary object tape is on the Standard Punch unit. Either of the following conditions may exist:

    a. If the T-Register contains 102077, the compilation is complete. If an assembly listing was requested, it is on the List Output Device.

    b. If the T-Register contains 102001, an assembly listing pass is to be performed:

        (1) Place binary output from Pass 3 in device serving as Standard Input unit. (Turn off Teleprinter punch unit.)

        (2) Press RUN.

        (3) At end of listing pass, T-Register contains 102077.

8K Memory

1. At end of Pass 1 (T-Register contains 102077), load Pass 2 using the Basic Binary Loader as in Step B.

2. Remove binary output from Standard Punch device and place in device serving as the Standard Input Unit. (If only one output device, both binary and list output are on the same tape.)

3. Set Switch Register to: 000100

4. Press LOAD ADDRESS.

5. Press RUN.

6. At end of Pass 2, the relocatable binary object tape is on the Standard Punch unit. Either of the following conditions may exist:

   a. If the T-Register contains 102077, the compilation is complete. If an assembly listing was requested, it is on the List Output device.

   b. If the T-Register contains 102001, an assembly listing pass is to be performed:

      (1) Place binary output from Pass 1 in device serving as Standard Input unit. (Turn off Teleprinter punch unit.)

      (2) Press RUN.

      (3) At end of listing pass, T-Register contains 102077.

J. The Basic Control System Loader is used to load the object programs generated by FORTRAN and any referenced library routines. Listed below is a summary of procedures for normal loading of relocatable object programs and library routines (and for the printing of a Memory Allocation Listing): †

---

† See Section 9.8 for details and options.

1. Load the Basic Control System tape using the Basic Binary Loader as in Step B.

2. Set Switch Register to 000002, press LOAD ADDRESS, and set Switch Register to 000000.

3. Place FORTRAN or Assembler generated relocatable object tape in device serving as Standard Input unit.

4. Press RUN. The loader types "LOAD" when the tape is loaded.

5. If more than one relocatable object tape is to be loaded, repeat Steps J3 and J4 for each. Otherwise, set Switch Register to 000004 to load library routines.

6. Place FORTRAN library tape in device serving as Program Library unit.

7. Press RUN. When the loading operation is complete, the Loader types "*LST". Press RUN to print Loader Symbol Table. When the Loader types "*RUN", the program is ready for execution.

8. Press RUN to initiate execution.

During the operation of the Compiler, the following halts may occur:

T-Register	Explanation	Action
102000	Memory overflow: the program is too long	Irrecoverable error; program must be revised.
102001	End of binary object tape output, start of assembly listing.	If only one output device, place intermediate binary output from previous pass in Standard Input unit and press RUN.

T-Register	Explanation	Action
102007	For all passes except first, unrecognizable record on intermediate binary tape: 1) Punch error on previous pass. 2) Wrong tape supplied as input for pass.	If punch error, restart with Pass 1. If wrong tape, restart current pass: a) Load FORTRAN pass. b) Set Switch Register to 000100. c) Press LOAD ADDRESS. d) Place previous intermediate binary tape in input device. e) Press RUN.
102010	External symbol table overflow: the number of symbols exceeds 255.	Irrecoverable error; program must be revised.
102011	Checksum error on intermediate tape; indicates probable punch error.	Attempt to re-read record (binary records are separated by 4 feed frames). Otherwise, restart with Pass 1.
102066	Tape supply low on 2753A Tape Punch.	Load new tape and press RUN.
102077	Normal end of pass or compilation.	Proceed as indicated in above steps.

For diagnostic messages that might occur during loading see the Basic Control System Programmer's Reference Manual. Diagnostics are also issued by the input/output system provided by FORTRAN and by the FORTRAN library routines (Section 9. 9).

9.6 OPERATING INSTRUCTIONS Magnetic Tape

On larger machines with a minimum of 8K memory, the Magnetic Tape Unit may be used to compile FORTRAN programs.

The FORTRAN Compiler operating with magnetic tape uses the scratch area of the system tape for storage of intermediate binary code. Pass 1 writes the intermediate code. At the end of Pass 1, the Inter-Pass Loader is called. This loader searches for and loads Pass 2 of the Compiler. † Control is switched to Pass 2 which spaces forward to the scratch area, processes the intermediate code and produces output on the punch and list devices as requested.

The following procedures indicate the sequence of steps for compilation of a source program on magnetic tape:

A. Load system tape on Magnetic Tape Unit (See Magnetic Tape System, chapter 8, Operating Manual); check that all equipment to be used is operable.

B. Load Fortran Pass 1 using Magnetic Tape Binary Loader:

1) Set Switch Register to starting address of Magnetic Tape Binary Loader. For 8K configuration use 017700.

2) Press LOAD ADDRESS.

3) Set FORTRAN identification number in the Switch Register.

4) Press PRESET.

5) Set Loader switch to ENABLED.

6) Press RUN.

7) The computer halts at location 1 with 102077 in the T-Register. The FORTRAN binary tape has been located and loaded.

8) Set Loader switch to PROTECTED.

---

† The FORTRAN Compiler must be configured prior to use in the magnetic tape system. For complete details see the Standard Software Systems Operating Manual.

C. Place source language tape in device serving as the Standard Input unit.

D. Press RUN. †

E. At the end of compilation, the relocatable binary object tape is on the Standard Punch unit. Either of the following conditions may exist:

   1. If the T-Register contains 102077, the assembly listing was requested and is on the List Output device.

   2. If the T-Register contains 102001, an assembly listing pass is to be performed. Turn off Teleprinter punch unit. Press RUN.

During operation of the tape compiler, the following halts may occur:

T-Register	Explanation	Action
102017	A Write error has occurred during Pass 1.	Restart with beginning of Pass 1.
102027	A Read error has occurred during Pass 2.	Restart with beginning of Pass 1.

† To halt Pass 2 at any time, set Switch 1 up. To suppress leader and trailer on punch-out during Pass 2 of Mag. Tape FORTRAN, set switch Ø up.

9.7 DIAGNOSTIC MESSAGES

Errors detected in the source program are indicated by a numeric code inserted before or after the statement in the List Output.

The format is as follows:

E-eeee:	ssss + nnnn
eeee	The error diagnostic code shown below.
ssss	The statement label of the statement in which the error was detected. If unlabeled, 0000 is typed.
nnnn	Ordinal number of the erroneous statement following the last labeled statement. (Comment statements are not included in this count.)

Error Code	Description
0001	Statement label error:

a) The label is in positions other than 1-5.
b) A character in the label is not numeric.
c) The label is not in the range 1-9999.
d) The label is doubly defined.
e) The label indicated is used in a GO TO, DO, or IF statement or in an I/O operation to name a FORMAT statement, but it does not appear in the label field for any statement in the program (printed after END).

0002 Unrecognized Statement:

a) The statement being processed is not recognized as a valid statement.
b) A specifications statement follows an executable statement.
c) The specification statements are not in the following order:

DIMENSION
COMMON
EQUIVALENCE

d) A statement function precedes a specification statement, or a statement function follows an executable statement.

Error Code	Description
0003	Parenthesis error: There are an unequal number of left and right parentheses in a statement.
0004	Illegal character or format: a) A statement contains a character other than A through Z, 0 through 9, or space =+-/(),.$". b) A statement does not have the proper format. c) A control statement is missing, misspelled, or does not have the proper format.
0005	Adjacent operators: An arithmetic expression contains adjacent arithmetic operators.
0006	Illegal subscript: A variable name is used both as a simple variable and a subscripted variable.
0007	Doubly defined variable: a) A variable name appears more than once in a COMMON statement. b) A variable name appears more than once in a DIMENSION statement. c) A variable name appears more than once as a dummy argument in a statement function. d) A program, subroutine, or function name appears as a dummy parameter; in a specifications statement of the subroutine or function; or as a simple variable in a program or subroutine.
0008	Too many parameters: The dummy parameters for a subroutine or function exceed 63.
0009	Invalid arithmetic expression: a) Missing operator b) Illegal replacement
0010	Mixed mode expression: integer constants or variables appear in an arithmetic expression with real constants or variables.

Error Code	Description
0011	Invalid subscript:

a) Subscript is not an integer constant, integer variable, or legal subscript expression.
b) There are more than two subscripts (i.e., more than two dimensions.
c) Two subscripts appear for a variable which has been defined with one dimension only.

0012 Invalid constant

a) An integer constant is not in the range of -2^{15} to 2^{15} -1.
b) A real constant is not in the approximate range of 10^{38} to 10^{-38}.
c) A constant contains an illegal character.

0013 Invalid EQUIVALENCE statement:

a) Two or more of the variables appearing in an EQUIVALENCE statement are also defined in the COMMON block.
b) The variables contained in an EQUIVALENCE cause the origin of COMMON to be altered.
c) Contradictory equivalence; or equivalence between two or more arrays conflicts with a previously established equivalence.

0014 Table overflow: Too many variables and statement labels appear in the program.

0015 Invalid DO loop:

a) The terminal statement of a DO loop does not appear in the program or appears prior to the DO statement.
b) The terminal statement of a nested DO loop is not within the range of the outer DO loop.
c) DO loops are nested more than 10 deep.
d) Last statement in a loop is a GO TO, arithmetic IF, RETURN, STOP, PAUSE, or DO.
e) An indexing parameter is not an unsigned integer constant or simple integer variable or is specified as zero.

Error Code	Description
0016	Statement function name is doubly defined.
0017	A Write error has occurred while producing intermediate code output during Pass 1. (Magnetic tape only.)

9.8 OBJECT PROGRAM LOADING

If absolute binary output was specified, the Basic Binary Loader is used to load the object program tape.

If relocatable binary output was specified, the BCS Relocating Loader is used to load the object program tape. If the program refers to other Assembler or FORTRAN generated object programs, these tapes are loaded by the Relocating Loader at the same time. In general, the FORTRAN Library tape must be submitted for loading also.

Listed below are summaries of procedures for normal loading of object programs:

BASIC BINARY LOADER
OPERATING PROCEDURES SUMMARY

A. Place binary object tape in Standard Input unit.

B. Set Switch Register to starting address of Basic Binary Loader (e.g., 007700 for 4K memory, 017700 for 8K memory). 32K 077700

C. Press LOAD ADDRESS.

D. Set LOADER switch to ENABLED.

E. Press PRESET.

F. Press RUN.

G. When the computer halts with T-Register containing 102077, set LOADER switch to PROTECTED.

H. Set Switch Register to starting address of object program.

I. Press LOAD ADDRESS.

J. Check that all I/O devices are ready and loaded for operation of the program.

K. Press RUN.

BASIC CONTROL SYSTEM LOADER OPERATING PROCEDURES SUMMARY

A. Load the Basic Control System tape using the Basic Binary Loader.

B. Set Switch Register to 000002, press LOAD ADDRESS, and set Switch Register to 000000.

C. Place Assembler (or FORTRAN) generated relocatable object tape in Standard Input unit.

D. Press RUN. The loader types "LOAD" if it expects another relocatable or library program.

E. If more than one relocatable object tape is to be loaded, repeat Steps C and D for each. Otherwise, set Switch Register to 000004 to load library routines.

F. Place FORTRAN Library tape in device serving as Program Library unit.

G. Press RUN. When the loading operation is complete, the Loader types "*LST". Press RUN. The Loader types "*RUN" indicating the program is ready for execution. (See the Basic Control System Programmer's Reference manual for error message.)

H. Press RUN to initiate execution.

9.9 OBJECT PROGRAM DIAGNOSTIC MESSAGES

During execution of the object program, diagnostic messages may be printed on the Teleprinter Output unit by the input/output system supplied for FORTRAN programs. When a halt occurs, the A-Register contains a code which further defines the nature of the error:

Teleprinter Message	A-Register	Explanation	Action
*EQR	Unit Number	Equipment Error: End of input tape on 2752A Teleprinter or 2737A Punched Tape Reader; tape supply low on 2753A Tape Punch. B-Register contains status word of Equipment Table entry.	Place next tape in input device, or for Tape Punch, load new reel of tape. Press RUN.
*FMT	000001	FORMAT error: a) w or d field does not contain proper digits. b) No decimal point after w field c) w-d ≤ 4 for E specification.	Irrecoverable error; program must be recompiled.
*FMT	000002	a) FORMAT specifications are nested more than one level deep. b) A FORMAT statement contains more right parentheses than left parentheses.	Irrecoverable error; program must be recompiled.

Teleprinter Message	A-Register	Explanation	Action
*FMT	000003	a) Illegal character in FORMAT statement. b) Format repetition factor of zero. c) FORMAT statement defines more character POSITIONS than possible for device.	Irrecoverable error; program must be recompiled.
*FMT	000004	Illegal character in fixed field input item or number not right-justified in field.	Verify data.
*FMT	000005	A number has an illegal form (e.g., two E's, two decimal points, two signs, etc.)	Verify data.
*EOT		An attempt has been made to space beyond The End-of-Tape marker on magnetic tape.	Press RUN to resume program execution.

During the execution of an object program referring to the FORTRAN library routines, the following errors codes may be printed on the Teleprinter Output unit when error conditions are encountered by the specified subroutine:†

Error Code	Subroutine	Condition
02 UN	ALOG	$a \leq 0$
03 UN	SQRT	$a < 0$
04 UN	.RTOR	$x = 0,\ y \leq 0$
		$x < 0,\ y \neq 0$
05 OR	SIN, COS	$\lvert a\rvert > 2^{14}$
06 UN	.RTOI	$x = 0,\ i \leq 0$
07 OF	EXP	$\lvert a\rvert * \log_2 e \geq 124$
08 OF	.ITOI	i^j out of range
08 UN	.ITOI	$i = 0,\ j \leq 0$
09 OR	TAN	$\lvert a\rvert > 2^{14}$

UN = Floating point underflow

OF = Integer or floating point overflow

OR = Out of range

† For complete details, see FORTRAN Library Routines manual.

ASCII CHARACTER FORMAT

b_7				0	0	0	0	1	1	1	1
b_6				0	0	1	1	0	0	1	1
b_5				0	1	0	1	0	1	0	1
b_4	b_3	b_2	b_1								
0	0	0	0	NULL	DC_0	ƀ	0	@	P	UNASSIGNED	UNASSIGNED
0	0	0	1	SOM	DC_1	!	1	A	Q		
0	0	1	0	EOA	DC_2	"	2	B	R		
0	0	1	1	EOM	DC_3	#	3	C	S		
0	1	0	0	EOT	DC4 (STOP)	$	4	D	T		
0	1	0	1	WRU	ERR	%	5	E	U		
0	1	1	0	RU	SYNC	&	6	F	V		
0	1	1	1	BELL	LEM	' (APOS)	7	G	W		
1	0	0	0	FE_0	S_0	(	8	H	X		
1	0	0	1	HT / SK	S_1	)	9	I	Y		
1	0	1	0	LF	S_2	*	:	J	Z		
1	0	1	1	V_{TAB}	S_3	+	;	K	[		
1	1	0	0	FF	S_4	, (COMMA)	<	L	\		ACK
1	1	0	1	CR	S_5	—	=	M	]		①
1	1	1	0	SO	S_6	.	>	N	↑		ESC
1	1	1	1	SI	S_7	/	?	O	←		DEL

Standard 7-bit set code positional order and notation are shown below with b_7 the high-order and b_1 the low-order, bit position.

	b_7	b_6	b_5	b_4	b_3	b_2	b_1
EXAMPLE: The code for "R" is:	1	0	1	0	0	1	0

LEGEND

NULL	Null/Idle	DC_1-DC_3	Device Control
SOM	Start of message	DC_4(Stop)	Device control (stop)
EOA	End of address	ERR	Error
EOM	End of message	SYNC	Synchronous idle
EOT	End of transmission	LEM	Logical end of media
WRU	"Who are you?"	S_0-S_7	Separator (information)
RU	"Are you . . . ?"	ƀ	Word separator (space, normally non-printing)
BELL	Audible signal		
FE_0	Format effector	<	Less than
HT	Horizontal tabulation	>	Greater than
SK	Skip (punched card)	↑	Up arrow (Exponentiation)
LF	Line feed	←	Left arrow (Implies/Replaced by)
V_{TAB}	Vertical tabulation	\	Reverse slant
FF	Form feed	ACK	Acknowledge
CR	Carriage return	①	Unassigned control
SO	Shift out	ESC	Escape
SI	Shift in	DEL	Delete/Idle
DC_0	Device control reserved for data link escape		

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END$	5-10, 6-12
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Nonexecutable Statements

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Functions

Function Name	Definition	Symbolic Name	No. of Arguments	Type of Argument	Type of Function
Absolute Value	$\lvert a \rvert$	ABS	1	Real	Real
		IABS	1	Integer	Integer
Float	Conversion from integer to real	FLOAT	1	Integer	Real
Fix	Conversion from real to integer	IFIX	1	Real	Integer
Transfer sign	Sign of a_2 times $\lvert a_1 \rvert$	SIGN	2	Real	Real
		ISIGN	2	Integer	Integer
Exponential	e^a	EXP	1	Real	Real
Natural Logarithm	$\log_e (a)$	ALOG	1	Real	Real
Trigonometric Sine	sine (a)†	SIN	1	Real	Real
Trigonometric Cosine	cos (a)†	COS	1	Real	Real
Trigonometric Tangent	tan (a)†	TAN	1	Real	Real
Hyperbolic Tangent	tanh (a)	TANH	1	Real	Real
Square Root	$(a)^{1/2}$	SQRT	1	Real	Real
Arctangent	arctan (a)	ATAN	1	Real	Real
And (Boolean)	$a_1 \wedge a_2$	IAND	2	Integer	Integer
Or (Boolean)	$a_1 \vee a_2$	IOR	2	Integer	Integer
Not (Boolean)	$\neg a$	NOT	1	Integer	Integer
Sense Switch	Sense Switch Register Switch (n)	ISSW	1	Integer	Integer

† a is in radians

A FORTRAN program can refer to a subprogram that has been prepared using Assembler source language. The subprogram may be treated as a subroutine or as a function. The object code programs generated by FORTRAN and by the Assembler are then linked together by the Basic Control System Relocating Loader when the programs are loaded.

FORTRAN REFERENCE

In the FORTRAN program, a subroutine is called using the following statement:

CALL s $(a_1, a_2, \ldots, a_n)$

The symbolic name, s, identifies the subroutine and the a's are the actual arguments.

If the subprogram is a function, it is referenced by using the name and the actual arguments in an arithmetic expression:

$f(a_1, a_2, \ldots, a_n)$

As a result of either the call or the reference, FORTRAN generates the following coding sequence:

JSB s/f	Transfers control to subroutine or function
DEF*+n+1	Defines return location
DEF a_1	Defines address of a_1
DEF a_2	Defines address of a_2
⋮	
DEF a_n	Defines address of a_n

The words defining the addresses of the arguments may be direct or indirect depending on the actual arguments. For example, an integer constant as an actual argument would yield a direct reference; an integer variable might yield an indirect reference.

If the subprogram being referenced is a subroutine, it may return none, one, or more than one value through its arguments or through common storage. If the subprogram is a function, it is assumed to return a single value in the accumulators: a function of type integer returns a value in the A-Register; a function of type real returns a value in the A- and B-Registers.

The subprogram may transfer values directly by accessing the words in the calling sequence or it may make use of the FORTRAN library subroutine .ENTR to aid in the transfer.

DIRECT TRANSFER OF VALUES

Any suitable technique may be used to obtain or deliver values for the arguments and to return control to the calling program. If address arithmetic is used in conjunction with an argument (e.g., to process elements of an array), the base location must be a direct reference; the location given in the calling sequence must be checked to determine if it is a direct or indirect reference. If it is an indirect reference the location to which it points must also be checked, and so forth.

Example:

PROGRAMMER	DATE	PROGRAM

```
      NAM AMSUB
      ENT AMSUB
AMSUB NOP          AMSUB TO CONTAIN ADDR OF "*+N+1"
      LDA AMSUB,I  A CONTAINS VALUE OF "*+N+1".
      STA RETRN    RETRN CONTAINS VALUE OF "*+N+1".
NXTAG ISZ AMSUB    AMSUB CONTAINS ADDR OF LOCATION
      LDA AMSUB    OF ARGUMENT. TEST IF ALL ARGU-
      CPA RETRN    MENTS PROCESSED: COMPARE VALUE
      JMP RETRN,I  OF "*+N+1" WITH ADDR OF CURRENT
                   LOCATION OF ARGUMENT. IF EQUAL
PRSAG              RETURN TO CALLING PROGRAM, IF NOT,
       .           PROCESS ARGUMENT AS REQUIRED.
       .
       .
      LDA AMSUB,I  A CONTAINS LOCATION OF ARGUMENT.
      LDA Ø,I      LOAD ONE-WORD (FIXED POINT)
       .           VALUE INTO A.
       .
       .
      LCA AMSUB,I  LOAD TWO-WORD (FLOATING POINT)
```

```
          DLD  Ø,I       VALUE INTO A AND B.
            .
            .
            .
          LDA  AMSUB,I   STORE ONE-WORD VALUE IN ARGUMENT
          STA  OUTAD     LOCATION.
          LDA  W1VAL
          STA  OUTAD,I
            .
            .
            .
          LDA  AMSUB,I   STORE TWO-WORD IN ARGUMENT
          STA  OUTAD     LOCATIONS.
          DLD  W2VAL
          DST  OUTAD,I
            .
            .
            .
          LDA  AMSUB,I   A CONTAINS ADDR OF LOCATION OF
          SSA            ARGUMENT. TO DETERMINE IF REF IS
          JMP  *+2       INDIRECT, TEST BIT 15. IF ONE,
          JMP  *+5       SET TO ZERO WITH AND, THEN LOAD
          AND  ANMSK     A WITH REFERENCED LOCATION.
          LDA  Ø,I       REPEAT TEST WITH NEXT REF. WHEN
          JMP  *-5       DIRECT REF ENCOUNTERED, PROCEED
ANMSK     OCT  Ø77777    WITH PROCESSING.
            .
            .
            .
          JMP  NXTAG     RETURN THROUGH HERE WHEN NEXT
RETRN     BSS  1         ARGUMENT IS REQUIRED.
OUTAD     BSS  1
W1VAL     BSS  1
W2VAL     BSS  2
          END
```

The preceding example assumes that each argument is processed or partially processed before the next is obtained or delivered. Control returns to the calling program when all arguments have been picked up or delivered.

TRANSFER VIA .ENTR

The transfer of values to or from the locations listed in the calling sequence may be facilitated through use of the FORTRAN library subroutine .ENTR. This subroutine moves the addresses of the arguments into an area reserved within the Assembly language subroutine. The addresses stored in the reserved area are all direct references; .ENTR performs all the necessary direct/indirect testing, etc. It also sets the correct return address in the entry point location.

The general form of the subroutine is:

```
         NAM s                The subroutine name is s.
         ENT s
         EXT .ENTR            .ENTR must be declared as external.
a        BSS n                Reserves n words of storage for the
s        NOP                  addresses of the arguments; this pseudo
                              instruction must directly precede the
                              entry point location,  s .

         JSB .ENTR
         DEF a                Defines first location of area used to
  (First instruction)         store argument addresses.
             .
             .
             .
         JMP s, I
         END
```

Example:

```
      NAM AMSUB
      ENT AMSUB
      EXT .ENTR
AGMTS BSS 5
AMSUB NOP
      JSB .ENTR
      DEF AGMTS
PRSAG                  PROCESS ARGUMENTS AS REQUIRED
          .
          .
          .
      LDA AGMTS,I      PICK UP VALUE OF FIRST ARGUMENT
          .
          .
          .
      DLD AGMTS+1,I    PICK UP VALUE OF SECOND ARGUMENT
          .
          .
          .
      LDA W1VAL        STORE VALUE FOR THIRD ARGUMENT
      STA AGMTS+2,I
          .
          .
          .
      DLD W2VAL        STORE VALUE FOR FOURTH ARGUMENT
      DST AGMTS+3,I
          .
          .
          .
      LDA AGMTS+4      PICK UP ADDRESS OF FIFTH ARGUMENT
          .
          .
          .
      JMP AMSUB,I      RETURN TO CALLING PROGRAM
W1VAL BSS 1
W2VAL BSS 2
      END
```

It is possible to program and read data from instruments in a FORTRAN program. Pertinent instrument configurations are:

HP 2401C	Digital Voltmeter
HP 2401C	Digital Voltmeter with a Digital Voltmeter Programmer card.
HP 2401C	Digital Voltmeter, Digital Voltmeter Programmer Card, HP 2911A/B Scanner and Scanner Programmer Card.

A. DIGITAL VOLTMETER

In a configuration without a programmer card data can be read in from the voltmeter but it is not possible to program the voltmeter from the computer. Thus the range, function, and gate time must be set using the front panel switches on the instrument. The "SAMPLING RATE" knob must be set so that the internal "hold-off" is removed (max. sampling rate).

WRITE

The WRITE statement removes the "hold-off" on the voltmeter; the instrument is enabled to take a measurement using the range, function, and gate time set on the front panel.

WRITE (u) Where: u is variable name equal to the unit number assigned to the digital voltmeter when preparing the Basic Control System.

READ

The READ statement transfers the measurement result to the computer. Data may be read in as formatted ASCII or as thirty-two bits BCD.

BCD input:

READ (u) i, j or READ (u) x

Where:

- u as defined above.
- i,j Are integer variable names where the thirty-two bits of data will be stored.
- x is a floating point variable name where the thirty-two bits of data will be stored.

The digital voltmeter provides the computer with eight BCD digits (32 bits) as follows:

r	f	d_6	d_5
d_4	d_3	d_2	d_1

Where: R = Range
F = Function
D6-D1 = the six digit measurement

The range is a negative power of ten, and the six digits form a number in the range 000000 to 999999. For example, if the range were 4 and the function +DC, and D6-D1 = 163525, the data would be:

4	+DC	1	6
3	5	2	5

$+163525 \times 10^{-4}$ or 16.3525 Vdc

The following table shows the function codes for 8-4-2-1 HP 2401C Integrating Digital Voltmeters.

FUNCTION	8-4-2-1 CODE
PERIOD	0-0-0-0
+Vdc	0-0-0-1
-Vdc	0-0-1-0
kHz	0-0-1-1
k-Ω	0-1-0-0
m-Ω	0-1-0-1
Overload	1001
Vac	1011

ASCII input:

READ (u, f) x, i

Where:

- u — as defined above.
- f — label of FORMAT statement defining the format of the reading: (2X, E10.0, I4) or (2X, F10.0, I4).
- x — is the name of a floating point variable which will be set to the six digits of data times ten to negative range.
- i — (this conversion valid only for 8-4-2-1 digital voltmeters) is the name of an integer variable which is set to the function code.

The value of "i" for various function codes is:

I = 0 PERIOD	I = 4 kΩ
I = 1 + Vdc	I = 5 mΩ
I = 2 –Vdc	I = 9 OVERLOAD
I = 3 kHz	I = 11 Vac

The Formatter provides the computer with a string of characters as below:

$$\underbrace{r\ f\ d_6\ d_5\ d_4\ d_3\ d_2\ d_1\ E\text{-}\emptyset r}_{x}\ \underbrace{\wedge\wedge f_1\ f_2}_{i}$$

B. DIGITAL VOLTMETER AND A VOLTMETER PROGRAMMER CARD

With the programmer card the voltmeter can be directly programmed by the computer. (The instrument must be set for remote programming.)

WRITE

The following FORTRAN statements will (1) remove the computer "hold-off", (2) program the range, function, and gate time, and (3) send an "encode" command to the digital voltmeter which removes the internal instrument "hold-off".

WRITE (u_1)

WRITE (u_2) code

Where: u_1 — is an integer constant or variable name equal to the unit number of the digital voltmeter Data Source Interface card as assigned when the Basic Control System is prepared.

u_2 is an integer constant or variable name equal to the unit number of the digital voltmeter programmer card as assigned when the Basic Control System is prepared.

code is an integer variable name equal to the program code.

The digital voltmeter program code is a sixteen bit quantity. The sign bit (bit 15) will cause an "encode" if it is one, and will suppress the "encode" if it is zero. Bits 14-8 are ignored, and the function of bits 7-0 is illustrated in the table below.

Coding for Voltmeter Range, Function, and Sample Period

PROGRAM CODE BITS 7-Ø			
7-6	5-4-3	2-1-0	PROVIDES
		000	Autorange
		001	+ 10 Gain, 2411A
		010	0.1V Range
		211	1V Range
		100	10V Range
		101	100V Range
		110	1000V Range
		111	10 Megohm Range
	000		AC Normal
	001		AC Fast
	010		Frequency
	011		Period
	100		DC Volts
	101		Ohms
00			1 Sec. Sample Period
01			0.1 Sec. Sample Period
10			0.01 Sec. Sample Period

READ

The measurement result is transferred to the computer by the following statement.

READ (u), f) x, i

(as explained section A)

Example:

In the following example, assume that the digital voltmeter programmer card has been assigned unit number 1Ø during the preparation of the Basic Control System, and the DSI card on the corresponding digital voltmeter has been assigned the unit number 11. A measurement will be made using the AC/Ohms Converter:

Range:	10 volts
Function:	AC Normal
Gate Time:	1 second
Encode:	by the Digital Voltmeter Programmer Card

```
C
C    REMOVE THE HOLD-OFF ON THE VOLTMETER
C
     WRITE(11)
C
C    PROGRAM THE DIGITAL VOLTMETER AND CONVERTER ENCODE THEM
C
     NCODE = 1ØØØØ4B
     WRITE(1Ø), NCODE
C
C    READ THE DATA AND THE FUNCTION CODE
C
     READ(11,2Ø), DATA, IFUN
  2Ø FORMAT (2X, E1Ø.Ø, I4)
C
C    CHECK FOR OVERLOAD
C
     IF (IFUN-9) 5Ø, 4Ø, 5Ø
C
C    WRITE MEASSAGE IF OVERLOAD
C
  4Ø WRITE(2,41)
  41 FORMAT ("OVERLOAD ON UNIT #11")
C
C    CONTINUE
C
  5Ø CONTINUE
```

C. DIGITAL VOLTMETER, VOLTMETER PROGRAMMER CARD, SCANNER AND SCANNER PROGRAMMER CARD

When the HP 2401C Digital Voltmeter (and HP 2410B AC/Ohms Converter, and HP 2411A Guarded Data Amplifier) is used with the DSI card and the DVM Programmer Card, and the HP 2911A/B Scanner is used with the Scanner Programmer Card, it is possible to program the range, function, and gate time on the voltmeter (and converter and amplifier), and to program the scanner channel number and settling delay. (The instruments must be set for remote programming.)

WRITE

If the scanner is on the correct channel the following format is correct:

WRITE (u_1)

WRITE (u_2) code (as in section B; bit 15 = Ø)

If the scanner needs to be set to the correct channel the following FORTRAN statements will (1) remove the computer "hold-off", (2) program the range, function, and gate time on the digital voltmeter (and converter and amplifier), and (3) set the function, channel number, and scanner delay on the scanner, and (4) encode the voltmeter after the scanner delay:

WRITE (u_1)

WRITE (u_2) code

WRITE (u_3) chan, scan

Where:

- u_1 as defined above
- u_2 as defined above
- code as defined above
- u_3 is an integer constant or variable name equal to the unit number of the scanner programmer as assigned when the Basic Control System is prepared.
- chan is variable name equal to the channel number (0-999).
- scan is integer variable name equal to the scanner program code.

The scanner program code is a sixteen bit quantity. Only the last four bits are used. This code can be considered a two digit octal number, where the digits have the following significance:

scan = D1D2

D1 (Function)

- 0 = AC/DC Volts
- 1 = frequency period
- 2 = resistance

D2 (Scanner Delay)

Normal	High Voltage
0 = 15 ms	22 ms
1 = 17.5 ms	27 ms
2 = 22 ms	22 ms
3 = 27 ms	27 ms
4 = 42 ms	145 ms
5 = 62 ms	500 ms
6 = 145 ms	145 ms
7 = 500 ms	500 ms

READ

The measurement result is transferred to the computer by the following statement:

READ (u, f) x

(as explained in section A)

Using Simpson's rule, calculate the value of the integral:

$$\int_a^b \frac{\cos x}{x} dx$$

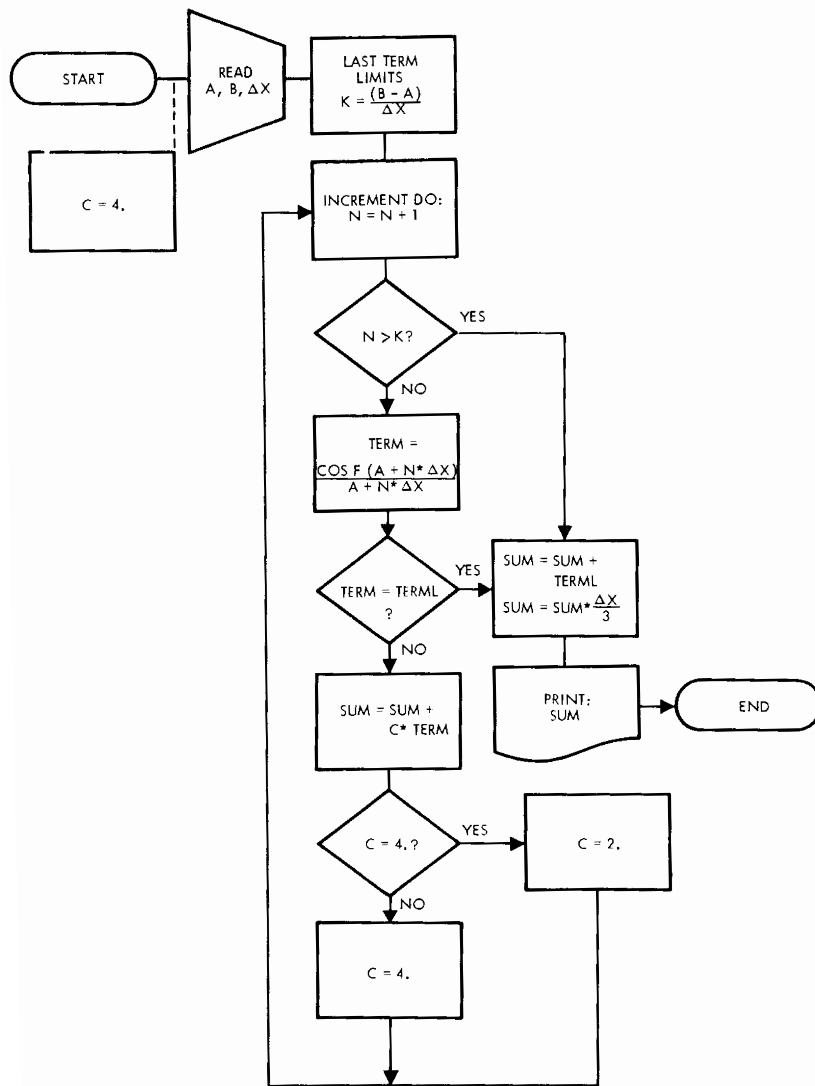
for the following possible values:

Variable	Range of Values
a	-6.99 to +6.99
b	-6.99 to +6.99
Δx	-.25 to +.25

Simpson's rule for approximating a definite integral is:

$$\int_a^b f(x)dx = \frac{\Delta x}{3}(f(a)+4f(a+\Delta x)+2f(a+2\Delta x)+4f(a+3\Delta x)+ \ldots +f(b)$$

The last term is reached when $(a+k\Delta x)=b$, and when neither a 2 nor a 4 appears in front of the first or last term.



SAMPLE PROGRAM FLOWCHART

PROGRAMMER | DATE | PROGRAM

C Label | CONT | STATEMENT

```
FTN,B,L,A
      PROGRAM SMPSN
      READ(1,1Ø) A,B,DELTX
   1Ø FORMAT(2E8.2,E7.2)
      TERML=COS(B)/B
      SUM=COS(A)/A
      K=(B-A)/DELTX
      C=4.
      I=K+1
      DO 6Ø N=1,I
      FN=N
      IF(N-K)2Ø,2Ø,7Ø
   2Ø TERM=COS(A+FN*DELTX)/(A+FN*DELTX)
      IF(TERM-TERML)3Ø,7Ø,3Ø
   3Ø SUM=SUM+C*TERM
      IF(C-4.)5Ø,4Ø,5Ø
   4Ø C=2.
      GO TO 6Ø
   5Ø C=4.
   6Ø CONTINUE
   7Ø SUM=SUM+TERML
   8Ø SUM=(SUM*DELTX)/3.
      WRITE(2,9Ø) SUM
   9Ø FORMAT("SUM=",E8.2)
      STOP
      END
      END$
```

M0251

Ø = ZERO   O = ALPHA O   I OR 1 = ONE   I = ALPHA I   LINE TERMINATED BY RETURN, LINE FEED (R LF)
2 = TWO   Z = ALPHA Z   LINE IS DELETED BY RUBOUT BEFORE R LF

```
FTN,B,L,A
      PROGRAM SMPSN
      READ(1,10) A,B,DELTX
   10 FORMAT(2E8.2,E7.2)
      TERML=COS(B)/B
      SUM=COS(A)/A
      K=(B-A)/DELTX
      C=4.
      I=K+1
      DO 60 N=1,I
      FN=N
      IF(N-K)20,20,70
   20 TERM=COS(A+FN*DELTX)/(A+FN*DELTX)
      IF(TERM-TERML)30,70,30
   30 SUM=SUM+C*TERM
      IF(C-4.)50,40,50
   40 C=2.
      GO TO 60
   50 C=4.
   60 CONTINUE
   70 SUM=SUM+TERML
   80 SUM=(SUM*DELTX)/3.
      WRITE(2,90) SUM
   90 FORMAT("SUM=",E8.2)
      STOP
      END
      END$
```

```
PAGE 0001   SMPSN

00000  000000  BSS 000000
00000  000000  OCT 000000
00001  062314R LDA 000314
00002  006404  OCT 006404
00003  016001X JSB .DIO.
00004  100277R DEF 000277,I
00005  100300R DEF 000300,I
00006  016002X JSB .IOR.
00007  016003X JSB .DST
00010  000246R DEF 000246
00011  016002X JSB .IOR.
00012  016003X JSB .DST
00013  000250R DEF 000250
00014  016002X JSB .IOR.
00015  016003X JSB .DST
00016  000252R DEF 000252
00017  126301R JMP 000301,I
00020  024040  OCT 024040
00021  031105  OCT 031105
00022  034056  OCT 034056
00023  031054  OCT 031054
00024  042467  OCT 042467
00025  027062  OCT 027062
00026  024400  OCT 024400
00027  016004X JSB .DLD
00030  000250R DEF 000250
00031  016005X JSB COS
00032  016006X JSB .FDV
00033  000250R DEF 000250
00034  016003X JSB .DST
00035  000254R DEF 000254
00036  016004X JSB .DLD
00037  000246R DEF 000246
00040  016005X JSB COS
00041  016006X JSB .FDV
00042  000246R DEF 000246
00043  016003X JSB .DST
00044  000256R DEF 000256
00045  016004X JSB .DLD
00046  000250R DEF 000250
00047  016007X JSB .FSB
00050  000246R DEF 000246
00051  016006X JSB .FDV
00052  000252R DEF 000252
```

```
00053   016010X JSB IFIX
00054   072260R STA 000260
00055   016004X JSB .DLD
00056   000315R DEF 000315
00057   016003X JSB .DST
00060   000261R DEF 000261
00061   062260R LDA 000260
00062   042314R ADA 000314
00063   072263R STA 000263
00064   062314R LDA 000314
00065   072264R STA 000264
00066   062264R LDA 000264
00067   016011X JSB FLOAT
00070   016003X JSB .DST
00071   000265R DEF 000265
00072   062264R LDA 000264
00073   003004  OCT 003004
00074   042260R ADA 000260
00075   003004  OCT 003004
00076   002020  OCT 002020
00077   126302R JMP 000302,I
00100   002002  OCT 002002
00101   126303R JMP 000303,I
00102   126302R JMP 000302,I
00103   016004X JSB .DLD
00104   000265R DEF 000265
00105   016012X JSB .FMP
00106   000252R DEF 000252
00107   016013X JSB .FAD
00110   000246R DEF 000246
00111   016003X JSB .DST
00112   000271R DEF 000271
00113   016005X JSB COS
00114   016003X JSB .DST
00115   000273R DEF 000273
00116   016004X JSB .DLD
00117   000265R DEF 000265
00120   016012X JSB .FMP
00121   000252R DEF 000252
00122   016013X JSB .FAD
00123   000246R DEF 000246
00124   016003X JSB .DST
00125   000275R DEF 000275
00126   016004X JSB .DLD
00127   000273R DEF 000273
00130   016006X JSB .FDV
00131   000275R DEF 000275
00132   016003X JSB .DST
00133   000267R DEF 000267
00134   016007X JSB .FSB
00135   000254R DEF 000254
00136   002020  OCT 002020
00137   126304R JMP 000304,I
00140   002002  OCT 002002
```

```
00141   126304R JMP 000304,I
00142   126303R JMP 000303,I
00143   016004X JSB .DLD
00144   000261R DEF 000261
00145   016012X JSB .FMP
00146   000267R DEF 000267
00147   016013X JSB .FAD
00150   000256R DEF 000256
00151   016003X JSB .DST
00152   000256R DEF 000256
00153   016004X JSB .DLD
00154   000261R DEF 000261
00155   016007X JSB .FSB
00156   000315R DEF 000315
00157   002020  OCT 002020
00160   126305R JMP 000305,I
00161   002002  OCT 002002
00162   126305R JMP 000305,I
00163   126306R JMP 000306,I
00164   016004X JSB .DLD
00165   000317R DEF 000317
00166   016003X JSB .DST
00167   000261R DEF 000261
00170   126307R JMP 000307,I
00171   016004X JSB .DLD
00172   000315R DEF 000315
00173   016003X JSB .DST
00174   000261R DEF 000261
00175   062264R LDA 000264
00176   002004  OCT 002004
00177   072264R STA 000264
00200   003004  OCT 003004
00201   042263R ADA 000263
00202   002021  OCT 002021
00203   026066R JMP 000066
00204   016004X JSB .DLD
00205   000256R DEF 000256
00206   016013X JSB .FAD
00207   000254R DEF 000254
00210   016003X JSB .DST
00211   000256R DEF 000256
00212   016004X JSB .DLD
00213   000256R DEF 000256
00214   016012X JSB .FMP
00215   000252R DEF 000252
00216   016006X JSB .FDV
00217   000321R DEF 000321
00220   016003X JSB .DST
00221   000256R DEF 000256
00222   062323R LDA 000323
00223   006400  OCT 006400
00224   016001X JSB .DIO.
00225   100311R DEF 000311,I
00226   100312R DEF 000312,I
```

```
00227  016004X JSB .DLD
00230  000256R DEF 000256
00231  016002X JSB .IOR.
00232  016014X JSB .DTA.
00233  126313R JMP 000313,I
00234  024040  OCT 024040
00235  021123  OCT 021123
00236  052515  OCT 052515
00237  036442  OCT 036442
00240  026105  OCT 026105
00241  034056  OCT 034056
00242  031051  OCT 031051
00243  002400  OCT 002400
00244  016015X JSB .STOP
00245  016015X JSB .STOP
00246  000000  BSS 000030
00276  000000  OCT 000000
00277  000020R DEF 000020
00300  000017R DEF 000017
00301  000027R DEF 000027
00302  000103R DEF 000103
00303  000204R DEF 000204
00304  000143R DEF 000143
00305  000171R DEF 000171
00306  000164R DEF 000164
00307  000175R DEF 000175
00310  000212R DEF 000212
00311  000234R DEF 000234
00312  000233R DEF 000233
00313  000243R DEF 000243
00314  000001  OCT 000001
00315  040000  OCT 040000
00316  000006  OCT 000006
00317  040000  OCT 040000
00320  000004  OCT 000004
00321  060000  OCT 060000
00322  000004  OCT 000004
00323  000002  OCT 000002
               TRA SMPSN
*** END
```

```
PAGE 0005   SMPSN


 SYMBOL  TABLE
SMPSN  R 000000
A      R 000246
B      R 000250
DELTX  R 000252
00010  R 000020
10000  R 000017
10001  R 000027
TERML  R 000254
SUM    R 000256
K      R 000260
C      R 000261
I      R 000263
N      R 000264
FN     R 000265
00020  R 000103
00070  R 000204
TERM   R 000267
00030  R 000143
00050  R 000171
00040  R 000164
00060  R 000175
00080  R 000212
00090  R 000234
10002  R 000233
10003  R 000243
```

```
SMPSN

 02000 02323

LOAD

FRMTR

 02324 04234
 00240 00730

COS

 04235 04244

SIN

 04245 04346

CHEBY

 04347 04437

..FCM

 04440 04447

..DLC

 04450 04461
```

FADSB

Ø4462 Ø4617

FDV

Ø4620 Ø4723

FMP

Ø4724 Ø5ØØ7

MPY

Ø5Ø1Ø Ø512Ø

.IENT

Ø5121 Ø5155

FLOAT

Ø5156 Ø5162

.PACK

Ø5163 Ø5267

DIV

Ø527Ø Ø5362

```
DLDST

 05363 05420

IFIX

 05421 05455

.STOP

 05456 05476

.ERRR

 05477 05517

PWR2

 05520 05543

.FLUN

 05544 05556
```

```
*LST

.IOC.  15434
.SQT.  15405
.MEM.  15400
.BUFR  15602
SMPSN  02000
.DIO.  03635
.IOR.  03505
.DST   05373
.DLD   05363
COS    04235
.FDV   04620
.FSB   04465
IFIX   05421
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.FMP   04724
.FAD   04462
.DTA.  03733
.STOP  05456
.BIO.  03710
.IOI.  03532
.IAR.  03571
.RAR.  03545
.FLUN  05544
.PACK  05163
.MPY   05010
SIN    04245
..FCM  04440
.ERRR  05477
.CHEB  04347
.IENT  05121
.PWR2  05520
..DLC  04450
.DIV   05270


*LINKS
 01723 01777


*RUN
```

Input and Output Data

```
    1.23     4.72     .25
SUM=-.63E+00
STOP
    1.23     2.01     .10
SUM=-.12E-01
STOP
    0.34     1.01     .02
SUM= .88E+00
STOP
    0.00     1.00     .01
SUM= .57E+36
STOP
    1.00     1.25     .05
SUM= .92E-01
STOP
```

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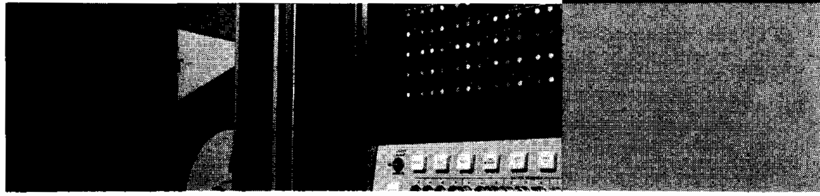

Program Library Reference Manual

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INTRODUCTION

This manual contains descriptions of the HP Computer Program library routines. These routines are grouped into five general categories: Math Routines, Arithmetic and Exponential Routines, Input/Output Service Routines, and Miscellaneous Routines.

Many of the routines including Input/Output Service Routines may be called from a FORTRAN or ALGOL program by specification of a function of the general form:

$$\text{function } (p_1, p_2, \ldots, p_n)$$

The Arithmetic and Exponential Routines are called from a program as a result of arithmetic expressions in the language. For example, I**K would generate a call to the .ITOI routine.

The Input/Output Service Routines are those which are called in FORTRAN and ALGOL programs. The Service Routines are those which are called by the other classes of Program library routines.

The Miscellaneous Routine performs various functions.

All classes of Program library routines may be called from an Assembly-language program. The Assembler calling sequence is listed with the description; routine names must be declared as EXTernal points in the program.

When a FORTRAN, ALGOL, or Assembly-language object program which references Program library routines is loaded for execution, Program library must also be loaded. The BCS Relocating Loader will load only those routines called by the user's object program.

The execution times listed in this manual are approximate. The i, j, x, y, and z notations indicate variable names or array element names to be provided by the user in the function or calling sequence. The variables i and j indicate integer, or fixed point, values; x and y indicate real, floating point, values. z is used to indicate that the value may be integer or real.

ABS

PURPOSE:	To calculate the absolute value of x, where x has a floating point value.
CALLING SEQUENCE:	DLD x JSB ABS
FORTRAN FUNCTION:	ABS(x)
NORMAL RETURN:	Floating point result is left in the A and B registers.
STORAGE:	5 words
EXECUTION TIME:	For $x \geq 0$, .006 ms For $x < 0$, 100 μs
ACCURACY:	23 bits

ALOG

PURPOSE:	To calculate the natural logarithm of x, where x has a floating point value.
CALLING SEQUENCE:	DLD x JSB ALOG
FORTRAN FUNCTION:	ALOG(x)
NORMAL RETURN:	Floating point result is left in the A and B registers. If error condition (below) occurs, the overflow bit is set.
STORAGE:	70 words (106_8)
EXECUTION TIME:	Minimum = 6.12 ms Average = 7.7 ms Maximum = 10.65 ms
ACCURACY:	22 bits

ERROR CONDITIONS:

Condition	Error Code
$x \leq 0$	Ø2 UN

ALGORITHM:

Let f = mantissa (x)

i = characteristic (x)

(that is, $x = 2^i \times f$)

Then answer = $(i + \log_2 f) \cdot (\log_e 2)$

$$= \log_e 2 \left(i + z \left[c_1 + \frac{c_2}{c_3 - z^2} \right] - 1/2 \right)$$

where

$$z = \frac{f - \sqrt{2}/2}{f + \sqrt{2}/2}$$

and

c_1 = 1.2920070987

c_2 = 2.6398577035

c_3 = 1.6567626301

PURPOSE:	To calculate the Arctangent of x, where x has a floating point value.
CALLING SEQUENCE:	DLD x JSB ATAN
FORTRAN FUNCTION:	ATAN(x)
NORMAL RETURN:	Result is in radians, in the range $-\pi/2$ to $\pi/2$. Floating point result is left in A and B registers.
STORAGE:	87 words (127_8)
EXECUTION TIME:	Minimum = 15.82 ms Average = 20.9 ms Maximum = 28.8 ms
ACCURACY:	21 bits
ALGORITHM:	if abs(X) >1 then U=1/X else U=X Y=U*Cheby(2*U*U -1) if abs(X) ≤ 1 then answer = Y else if X > 0 then answer = π/2-Y else answer = -π/2-Y

COS

PURPOSE:	To calculate the cosine of x, where x has a floating point value expressed in radians.
CALLING SEQUENCE:	DLD x JSB COS
FORTRAN FUNCTION:	COS(x)
NORMAL RETURN:	Floating point result is left in A and B registers. If error condition (below) occurs, the overflow bit is set.
STORAGE:	8 words (10_8)
EXECUTION TIME:	Minimum = 10.26 ms Average = 13.8 ms Maximum = 20.25 ms
ACCURACY:	See SIN.
ERROR CONDITIONS:	Condition: $ABS(x) > 2^{14}$ — Error Code: Ø5 OR
ALGORITHM:	$COS(x) = -SIN(x-\pi/2)$

PURPOSE: To calculate e^x, where x has a floating point value.

CALLING SEQUENCE:
```
DLD   x
JSB   EXP
```

FORTRAN FUNCTION: EXP(x)

NORMAL RETURN: Floating point result is left in the A and B registers. If error condition (below) occurs, the overflow bit is set.

STORAGE: 87 words (127_8)

EXECUTION TIME:
Minimum = 6.12 ms
Average = 7.7 ms
Maximum = 10.65 ms

ACCURACY: $e^{x+y} = e^x * e^y$

Hence, an absolute error of y in the representation of x introduces an error of $(e^{x+y} - e^x)$ into the value of EXP(x).

Thus for values of x with $|x| < 1$, 23 bits of accuracy can be expected, while for values of x with $|x|$ near 100, only 15 bits of accuracy can be expected.

ERROR CONDITIONS:

Condition	Error Code
$x * \log_2 e \geq 124$	Ø7 OF

ALGORITHM: Let i=ENTIER(x), and $f = x * \log_2 e - 1$ (See .IENT)

$$\text{Answer} = 2^i * \left[1 + \frac{2f}{c_4 + c_3 f^2 - f - c_2/(f^2 + c_1)} \right]$$

where

c_1 = 87.417497202
c_2 = 617.9722695
c_3 = 0.03465735903
c_4 = 9.9545957821

FLOAT

PURPOSE:	To convert the integer i to floating point format.
CALLING SEQUENCE:	LDA i JSB FLOAT
FORTRAN FUNCTION:	FLOAT(i)
NORMAL RETURN:	Floating point result is left in the A and B registers.
EXECUTION TIME:	Minimum = .1 ms Average = .2 ms Maximum = .3 ms
STORAGE:	10 words (12_8)

PURPOSE:	To calculate absolute value of i, where i has an integer value.
CALLING SEQUENCE:	LDA i JSB IABS
FORTRAN FUNCTION:	IABS (i)
NORMAL RETURN:	Integer result is left in A register.
EXECUTION TIME:	.0096 ms
STORAGE:	7 words
ACCURACY:	23 bits
ERROR CONDITIONS:	None

IFIX

PURPOSE:	To convert the floating point number x to integer format.
CALLING SEQUENCE:	DLD x JSB IFIX
FORTRAN FUNCTION:	IFIX(x)
NORMAL RETURN:	Integer result is left in A register. Any fractional portion is truncated. If the integer portion is greater than or equal to 2^{15}, the result is set to 32767.
STORAGE:	29 words (35_8)

ISIGN

PURPOSE:	To calculate sign of z times $\lvert i \rvert$ where z has an integer or floating point value and i has an integer value.
CALLING SEQUENCE:	JSB ISIGN DEF i DEF z
FORTRAN FUNCTION:	ISIGN (i, z)
NORMAL RETURN:	Integer result is left in A register.
STORAGE:	26 words (32_8)
EXECUTION TIME:	.05 ms
ACCURACY:	23 bits
ALGORITHM:	Same as SIGN.

SIGN

PURPOSE: To calculate sign of y times |x| , where x has a floating point and z has a floating point or integer value. In the case where z=0, the result of the SIGN function is 0, regardless of the value of |x| .

CALLING SEQUENCE:

```
JSB  SIGN
DEF  x
DEF  z
```

FORTRAN FUNCTION: SIGN (x, z)

NORMAL RETURN: Floating point result is left in A and B registers.

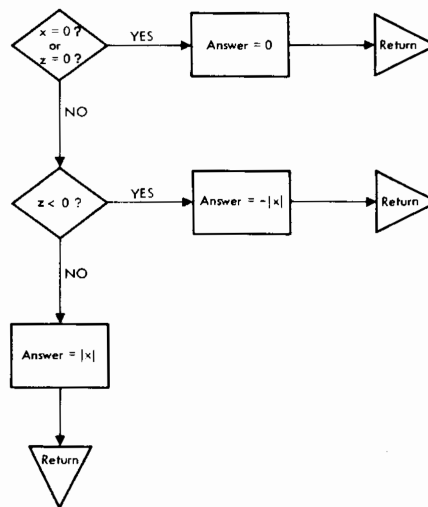
STORAGE: 30 words (36_8)

EXECUTION TIME:

Minimum = .3 ms
Average = .5 ms
Maximum = .9 ms

ACCURACY: 23 bits

ALGORITHM:



SIN

PURPOSE: To calculate sine of x, where x has a floating point value expressed in radians.

CALLING SEQUENCE:

```
DLD  x
JSB  SIN
```

FORTRAN FUNCTION: SIN(x)

NORMAL RETURN: Floating point result is left in the A and B registers. If error condition (below) occurs, the overflow bit is set.

STORAGE: 66 words (102_8)

EXECUTION TIME:

Minimum = 10.26 ms

Average = 13.8 ms

Maximum = 20.25 ms

ACCURACY: For small y, we have $\sin(n\pi + y) = \sin(y) \approx y$

That is, the accuracy of sin(x) for x near a non-zero integer multiple of π is limited by the accuracy of the subtraction $n\pi - x$.

For example, sin(3.14) would have approximately 4 decimal digits of accuracy (the possible 7 minus the 3-digit closeness to π).

ERROR CONDITIONS:

Condition	Error Code
ABS(x) > 2^{14}	Ø5 OR

ALGORITHM:

X=X*2/π

X=X-4*ENTIER((X+1)4) (See .IENT)

if X > 1 then X= 2-X

answer = X*Cheby (2*X*X-1)

SQRT

PURPOSE: To calculate the square root of x, where x has a floating point value.

CALLING SEQUENCE:

```
DLD   x
JSB SQRT
```

FORTRAN FUNCTION: SQRT(x)

NORMAL RETURN: Floating point result is left in A and B registers. If error condition (below) occurs, the overflow bit is set.

STORAGE: 77 words (115_8)

EXECUTION TIME:

Minimum = 3.94 ms

Average = 4.8 ms

Maximum = 6.45 ms

ACCURACY: 22 bits

ERROR CONDITIONS:

Condition	Error Code
$x < 0$	Ø3 UN

ALGORITHM:

Choose f such that $x=2^{2b}(f)$, $.25 \leq f < 1$

Then $\sqrt{x} = 2^b \sqrt{f}$

$\sqrt{f}$ is approximated by $p_1 = c_1 f + c_2$, where for

$.25 \leq f < .5$, $c_1 = .875$, $c_2 = .27863$

and for $.5 \leq f < 1$, $c_1 = .578125$, $c_2 = .421875$

This approximation is improved by two Newton iterations:

$p_2 = (p_1 + f/p_1)/2$

$p_3 = (p_2 + f/p_2)/2$

p_3 is the final result

TAN

PURPOSE:	To calculate tangent of x, where x has a floating point value expressed in radians.
CALLING SEQUENCE:	DLD x JSB TAN
FORTRAN FUNCTION:	TAN(x)
NORMAL RETURN:	Floating point result is left in the A and B registers. If error condition (below) occurs, the overflow bit is set.
STORAGE:	87 words (127_8)
EXECUTION TIME:	Minimum = 14.28 msec. Average ≈ 19.4 msec. Maximum ≈ 28.8 msec.
ACCURACY:	Approximately as accurate as SIN(x)/COS(x).

ERROR CONDITIONS:

Condition	Error Code
$x > 2^{14}$	Ø9 OR
$\tan(x) > 2^{128}$	(floating point overflow)

ALGORITHM:

X=4*X/π

X=X-4*ENTIER((X+1)/4) (See .IENT)

if X > 1 then Y=2-X else Y=X.

Y=Y*CHEBY (2*Y*Y-1)

if X > 1 then answer = 1/Y else answer = Y.

TANH

PURPOSE: To calculate hyperbolic tangent of x, where x has a floating point value.

CALLING SEQUENCE:

```
DLD   x
JSB   TANH
```

FORTRAN FUNCTION: TANH(x)

NORMAL RETURN: Floating point result is left in the A and B registers.

STORAGE: 99 words (143_8)

EXECUTION TIME: Depends on the range in which x lies. Always less than twice as long as EXP.

ACCURACY: At least 20 bits correct.

ALGORITHM:

1. $x \geq 0$
   a. $x \geq 16$

      TANH(x) = 1

   b. $.125 \leq x < 16$

      TANH(x) = (EXP(2*x) - 1)/(EXP(2*x) + 1)

   c. $.00005 \leq x < .125$

      $$\text{TANH}(x) = \left\{ c_1 + f^2 \left[c_2 + c_3 \left(c_4 + f^2 \right)^{-1} \right] \right\}^{-1}$$

      where:

      $f = 4*x*\log_2 e$

      $c_1 = 5.7707801636$

      $c_2 = .01732867951$

      $c_3 = 14.1384114018$

      $c_4 = 349.6699888$

   d. $x < .00005$

      TANH(x) = x

2. $x < 0$

   TANH(x) = -TANH(-x)

.DIV

PURPOSE:	To divide the two-word integer quantity i by the integer quantity j .
CALLING SEQUENCE:	JSB .DIV DEF j
ASSEMBLY LANGUAGE:	DIV j (i is a two-word quantity in the B and A registers)
NORMAL RETURN:	Result is left in the A and B registers; the quotient is left in A, the remainder in B.
STORAGE:	49 words (61_8)
EXECUTION TIME:	Minimum = .27 ms Average = .3 ms Maximum = .31 ms
ERROR CONDITIONS:	If the quotient is outside the range [-32768, 32767] , the overflow flag is set and the accumulator is set to 32767.

.DLD

PURPOSE:	To load x, a two-word quantity, into the A and B registers.
CALLING SEQUENCE:	JSB .DLD
	DEF x (x = address of the first word of the two-word quantity)
ASSEMBLY LANGUAGE:	DLD x (x = address of the first word of the two-word quantity)
NORMAL RETURN:	The quantity in locations x and x+1 will be loaded into the A and B registers.
STORAGE:	30 words (36_8)
EXECUTION TIME:	.06 ms

PURPOSE:	To store a two word quantity from the A and B registers to two consecutive locations in memory.
CALLING SEQUENCE:	JSB .DST DEF x
ASSEMBLY LANGUAGE:	DST x
NORMAL RETURN:	The quantity in the A and B registers will be stored in locations x and x+1 .
STORAGE:	30 words (36_8)
EXECUTION TIME:	.06 ms

.FAD

PURPOSE: To add two floating point numbers, x and y.

CALLING SEQUENCE:

```
JSB    .FAD
DEF    y     (x is assumed to be in A and B)
```

ASSEMBLY LANGUAGE:

```
FAD    y     (x is assumed to be in A and B)
```

NORMAL RETURN: The floating point sum is left in the A and B registers.

STORAGE: 94 words (136_8)

EXECUTION TIME:

Minimum = .3 ms

Average = .5 ms

Maximum = .9 ms

ERROR CONDITIONS:

If the result is outside the range of representable floating point numbers: $[-2^{127}, 2^{127}(1-2^{-23})]$ the overflow flag is set and the result $2^{128}(1-2^{-23})$ is returned. If an underflow occurs, (result within the range $(-2^{-129}(1+2^{-22}), 2^{-129})$) the overflow flag is set and the result 0 is returned.

PURPOSE:	To subtract the floating point number y from the floating point number x.
CALLING SEQUENCE:	JSB .FSB DEF y (x is assumed in A and B)
ASSEMBLY LANGUAGE:	FSB y (x is assumed in A and B)
NORMAL RETURN:	The floating point difference (x-y) is placed in the A and B registers.
STORAGE:	94 words (136_8)
EXECUTION TIME:	Minimum = .3 ms Average = .5 ms Maximum = .9 ms
ERROR CONDITIONS:	See FAD, page 2-4.

.FDV

PURPOSE:	To divide the floating point quantity x by the floating point quantity y .
CALLING SEQUENCE:	JSB .FDV DEF y (x is assumed in A and B)
ASSEMBLY LANGUAGE:	FDV y (x is assumed in A and B)
NORMAL RETURN:	The floating point quotient is left in the A and B registers.
STORAGE:	70 words (104_8)
EXECUTION TIME:	Minimum = 1.2 ms Average = 1.3 ms Maximum = 1.5 ms
ERROR CONDITIONS:	See FAD, page 2-4.

PURPOSE:	To multiply the two floating point numbers x and y.
CALLING SEQUENCE:	JSB .FMP
	DEF x (y is assumed in A and B)
ASSEMBLY LANGUAGE:	FMP x (y is assumed in A and B)
NORMAL RETURN:	The floating point product is returned in the A and B registers.
STORAGE:	51 words (63_8)
EXECUTION TIME:	Minimum = .64 ms
	Average = .7 ms
	Maximum = .75 ms
ERROR CONDITIONS:	See FAD, page 2-4.

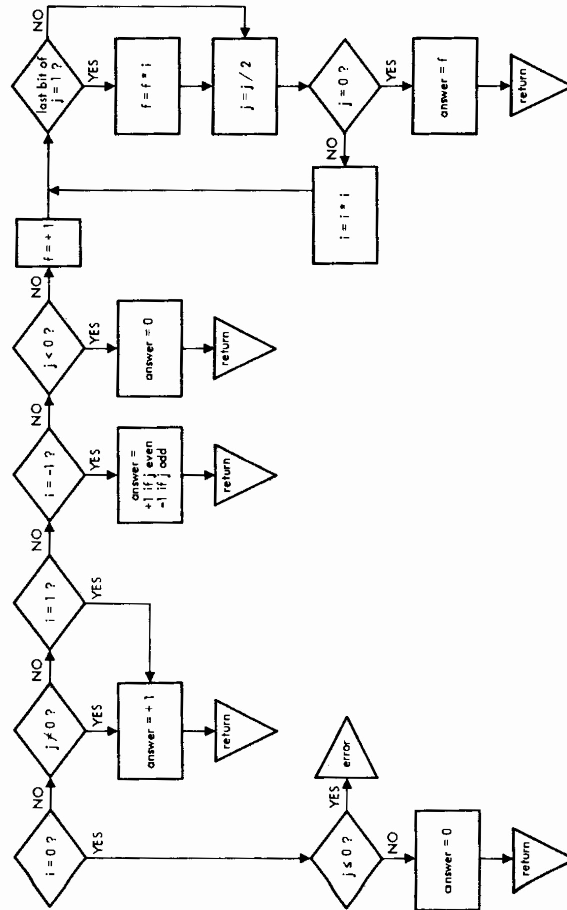
.ITOI

PURPOSE:	To calculate i^j, where i and j have integer values.
CALLING SEQUENCE:	JSB .ITOI DEF i DEF j
NORMAL RETURN:	Integer result is left in A register. If error condition (below) occurs, overflow bit is set.
STORAGE:	77 words (115_8)
EXECUTION TIME:	Minimum = (1.5) ($\log_2 j$) (.09) ms Average = (1.5) ($\log_2 j$) (.12) ms Maximum = (1.5) ($\log_2 j$) (.18) ms
ACCURACY:	23 bits

ERROR CONDITIONS:

Condition	Error Code
$i = 0,\ j \le 0$	Ø8 UN
$i^j \ge 2^{23}$	Ø8 OF

ALGORITHM:



.MPY

PURPOSE:	To multiply the two integer quantities i and j.
CALLING SEQUENCE:	JSB .MPY DEF i (j is assumed to be in the A register)
ASSEMBLY LANGUAGE:	MPY i (j is assumed to be in the A register)
NORMAL RETURN:	The result is left in the A and B registers: B containing most significant bits, A containing least significant bits.
STORAGE:	73 words (111_8)
EXECUTION TIME:	Minimum = .09 ms Average = .12 ms Maximum = .15 ms

PURPOSE: To calculate x^i, where x has a floating point and i an integer value.

CALLING SEQUENCE:

```
JSB   .RTOI
DEF   x
DEF   i
```

NORMAL RETURN: Floating point result is left in A and B registers. If error condition (below) occurs, overflow bit is set.

STORAGE: 78 words (116_8)

EXECUTION TIME: (Approximate)

Minimum = $(1.5)(\log_2 i)(.64)$ ms

Average = $(1.5)(\log_2 i)(.70)$ ms

Maximum = $(1.5)(\log_2 i)(.75)$ ms

ACCURACY: The only possibility of inaccuracy is that introduced by roundoff in the FMP or the FDV routine if $i < 0$.

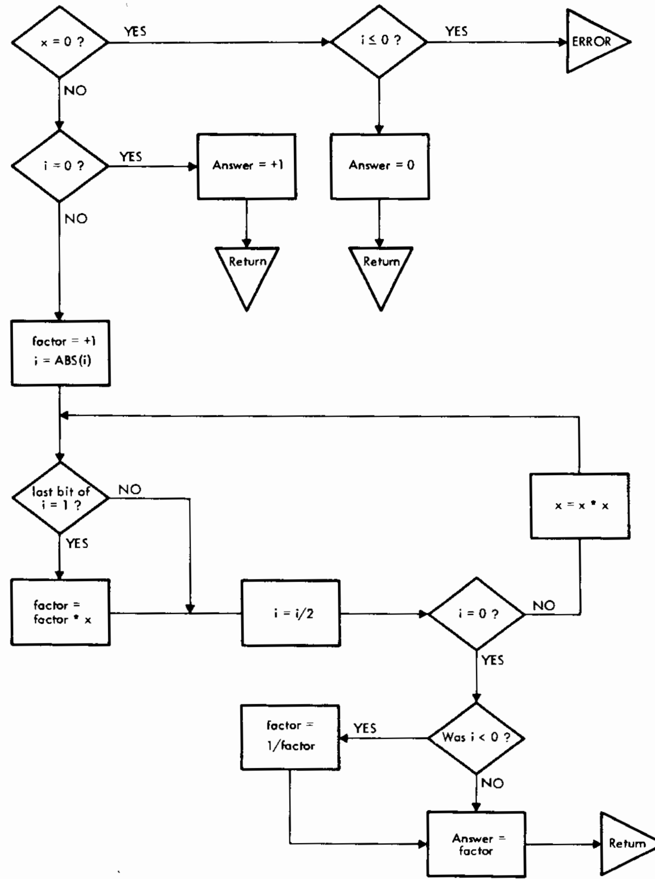
x^i gives the same result as the expression:

$$\underbrace{x*x*x*...*x}_{i\ \text{times}} \quad \text{or} \quad 1/\underbrace{x*x*x*....*x}_{i\ \text{times}}$$

ERROR CONDITIONS:

Condition	Error Code
$x=0,\ i \le 0$	Ø6 UN
$x^{\lvert i \rvert} > 2^{128}$	(floating point overflow)

ALGORITHM:



.RTOR

PURPOSE: To calculate x^y, where x and y have floating point values.

CALLING SEQUENCE:

```
JSB  .RTOR
DEF  x
DEF  y
```

NORMAL RETURN: Floating point result is left in A and B registers. If error condition (below) occurs, the overflow bit is set.

STORAGE: 46 words (56_8)

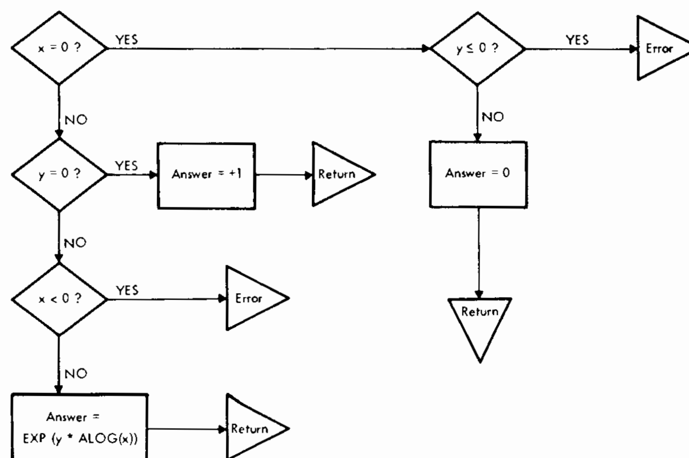
EXECUTION TIME:
Minimum = 12.24 ms
Average = 15.4 ms
Maximum = 21.3 ms

ACCURACY: 22 bits

ERROR CONDITIONS:

Condition	Error Code
$x < 0,\ y \leq 0$ $x = 0,\ y \neq 0$	Ø4 UN
$\lvert Y*ALOG(X)\rvert \geq 124$	Ø7 OF

ALGORITHM:



CLRIO

PURPOSE:	To perform a system clear request; makes all input/output devices available for the initiation of a new operation.
CALLING SEQUENCE:	JSB CLRIO DEF *+1
NORMAL RETURN:	All devices are available for new operations.
STORAGE:	5 words.

ENDIO

PURPOSE:	To delay further program execution until all current input/output operations are completed.
CALLING SEQUENCE:	JSB ENDIO DEF *+1
NORMAL RETURN:	All input/output operations are completed.
STORAGE:	7 words.

PURPOSE: To input or output data according to a specified format.

CALLING SEQUENCE: INPUT

Formatted	Internal (ASCII to binary conversion)	Binary
LDA <unit>	CLA	LDA <unit>
CLB, INB	CLB, INB	CLB, INB
JSB .DIO.	JSB .DIO.	JSB .BIO.
DEF <fmt> or OCT 0 (free field)	DEF <buffer address>	
DEF <end of list address> (first location following the calling sequence)	DEF <fmt>	
	DEF <end of list address>	

Real Variable	Integer Variable	Real Array	Integer Array
JSB .IOR.	JSB .IOI.	LDA <# of elements>	LDA <# of elements>
DST <variable name>	STA <variable name>	LDB <array address>	LDB <array address>
		JSB .RAR	JSB .IAR.

OUTPUT

Formatted	Internal (Binary to ASCII conversion)	Binary
LDA <unit>	CLA	LDA <unit>
CLB	CLB	CLB
JSB .DIO.	JSB .DIO.	JSB .BIO.
DEF <fmt>	DEF <buffer address>	
DEF <end of list address> (first location following the calling sequence)	DEF <fmt>	
	DEF <end of list address>	

Real Variable	Integer Variable	Real Array	Integer Array
DLD <variable name>	LDA <variable name>	LDA <# of elements>	LDA <# of elements>
JSB .IOR.	JSB .IOI	LDB <array address>	LDB <array address>
		JSB .RAR.	JSB .IAR.

JSB .DTA. <termination call> (output only)

INTERNAL CONVERSION: Data already in memory can be converted to or from ASCII using the following sequences.

To convert ASCII data to floating point or integer form:

```
CLA
CLB, INB
JSB  .DIO
DEF <buffer>        (buffer contains the ASCII infor-
                     mation to be converted)
DEF <fmt>
DEF <end-of-list>
```

The remainder of the calling sequence is the same as a normal input operation. The converted data will be stored as specified in the element description.

To convert floating point or integer data to ASCII form:

```
CLA
CLB
JSB  .DIO.
DEF <buffer>        (the converted data will be stored
                     at buffer)
DEF <fmt>
DEF <end-of-list>
```

The remainder of the calling sequence is the same as the normal output operation. The data which is to be converted is specified in the element description.

STORAGE: 1360 words (2520_8)

LEADR

PURPOSE: Produces consecutive feed frames (zeros) on punched tape to serve as leader.

CALLING SEQUENCE:

```
JSB LEADR
DEF *+3
DEF u
DEF n
```

The third word of the sequence defines the address of the memory location containing the unit-reference number of the punched tape unit on which the leader is to be punched.

The fourth word of the sequence defines the address of the memory location containing the number of inches, n, of leader which is to be punched on the tape.

NORMAL RETURN: The leader is punched as requested. (An attempt to perform this operation on other than a paper tape output device will result in an illegal request code error (a halt with zeros in A-Register) which is considered to be an irrecoverable error.)

STORAGE: 27 words (33_8)

PURPOSE: To position a magnetic tape by spacing forward or backward a number of files and records.

CALLING SEQUENCE:

```
JSB PTAPE
DEF *+4
DEF u
DEF file count
DEF record count
```

The third word of the sequence defines the address of the memory location containing the unit-reference number of the tape unit on which a reel is to be positioned.

The fourth word defines the address of the memory location containing the file spacing specification:

a) A positive integer for forward spacing.
b) A negative integer for backspacing.

The fifth word defines the address of the memory location containing the record spacing specification:

a) A positive integer for forward spacing.
b) A negative integer for backspacing.

When spacing by record, the file mark will be read as another record mark. Thus file marks must be considered in determining the correct spacing count. Both file and record spacing may be designated in the same call (e.g. Space backward 5 files, then forward 2 records).

NORMAL RETURN: On completion of the spacing operation, the tape is positioned ready for reading or writing (i. e., after a backspacing operation, the read head is positioned at the beginning of a file or record). If forward spacing positions the tape beyond the End-of-Tape marker, the operator presses RUN, execution resumes at the normal return location. If backward spacing would position the tape beyond the Start-of-Tape marker, the spacing operation is terminated and execution transfers to the normal return location.

ERROR CONDITION:

Condition	Message
An attempt to space beyond EOT	*EOT

STORAGE: 117 words (165_8)

CHEBY

PURPOSE: To evaluate the Chebyshev series represented by the table of coefficients at the argument x; where x has a floating point value.

CALLING SEQUENCE:

```
DLD  x
JSB  CHEBY
DEF  c    (c=starting address of table of floating
          point Chebyshev coefficients; the table
          is terminated by a zero word.)
```

NORMAL RETURN: Floating point result is left in A and B registers.

STORAGE: 57 words (71_8)

EXECUTION TIME: (where n=number of Chebyshev coefficients in table.)

Minimum = n(1.24) ms

Average = n(1.7) ms

Maximum = n(2.55) ms

ACCURACY: 22 bits

ERROR CONDITIONS: Possibility of floating point overflow in the case of TAN(x) when x is very close to a multiple of $\pi/2$.

..FCM

PURPOSE:	To complement the floating point number in the A- and B-Registers.
CALLING SEQUENCE:	DLD X (x = address of floating point value) JSB ..FCM
NORMAL RETURN:	The A and B-Register will contain the complemented floating point value.
STORAGE:	6 words

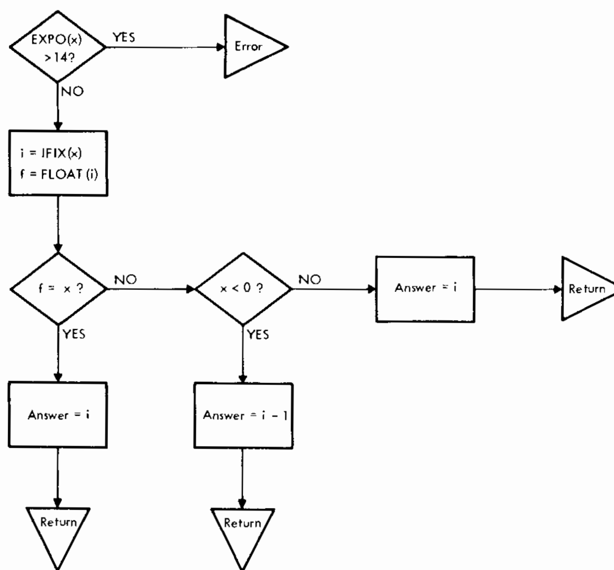
PURPOSE:	To write an error message, supplied by the calling routine, on the Standard Teleprinter Output device.		
CALLING SEQUENCE:	JSB	.ERRR	
	ASC	1,xx	(xx = 2 digit code identifying calling routine)
	ASC	1,yy	(yy = 2 letter code identifying type of error)
NORMAL RETURN:	Message is printed, A and B registers are destroyed.		
STORAGE:	17 words (21_8)		

.FLUN

PURPOSE:	To "unpack" a floating point number.
CALLING SEQUENCE:	JSB .FLUN
NORMAL RETURN:	Result is left with exponent in A register, and lower part of mantissa in B register.
STORAGE:	15 words (17_8)
EXECUTION TIME:	.03 ms

PURPOSE:	To calculate ENTIER(x); the greatest integer not algebraically exceeding x, where x has a floating point value.
CALLING SEQUENCE:	DLD x JSB .IENT JMP errtn (address of exit to be taken if EXPO(x) > 14)
NORMAL RETURN:	Integer result is left in A register.
EXECUTION TIME:	Minimum = .22 ms Average = .38 ms Maximum = .54 ms
STORAGE:	29 words (35_8)
ACCURACY:	Exact
ERROR CONDITIONS:	Condition: EXPO(x) > 14 — Error Code: (depends on error routine)

ALGORITHM:



ISSW

PURPOSE: Places the contents of switch n of the Switch Register into the sign position (bit 15) of the A-register. The A-Register can then be tested to determine the status of the switch (0 = off; 1 = on).

CALLING SEQUENCE:

```
LDA   n     (n is the number of the switch to be tested)
JSB   ISSW
```

NORMAL RETURN: The A-Register contains the image of the Switch Register which has been rotated until switch n occupies the sign bit position.

STORAGE: 7 words.

PURPOSE:	To extract mantissa part of x, where x has a floating point value. Thus x = MANT(x)*2**EXPO(x).
CALLING SEQUENCE:	DLD x JSB MANT
NORMAL RETURN:	Floating point result is left in A and B registers.
EXECUTION TIME:	.023 ms
STORAGE:	9 words (11_8)
ACCURACY:	23 bits

.PACK

PURPOSE: To transform the signed 31-bit mantissa contained in A and B registers to normalized floating point format.

CALLING SEQUENCE:

```
JSB   .PACK
BSS   1      (Contains exponent portion
              of floating point number)
```

NORMAL RETURN: Floating point result is left in A and B registers.

STORAGE: 69 words (105_8)

EXECUTION TIME: .1 to .15 ms

PURPOSE:	To calculate x (2^n), where x has a floating point value and n is an integer.
CALLING SEQUENCE:	DLD x JSB PWR2 DEC n
NORMAL RETURN:	Floating point result is left in A and B registers.
EXECUTION TIME:	.075 ms
STORAGE:	20 words (24_8)
ALGORITHM:	Exponent of x is increased by n.
ACCURACY:	23 bits
ERROR CONDITIONS:	None. Calling routine should check for possibility of overflow.

..DLC

PURPOSE: To load and complement a floating point quantity.

CALLING SEQUENCE:

```
JSB   ..DLC
DEF   X          (X = address of the two-word
                  quantity to be complemented)
```

NORMAL RETURN: The original contents of the A & B-Registers will be lost; the complemented quantity will be loaded into A & B-Registers.

STORAGE: 10 words (12_8)

ENTIE

PURPOSE: To calculate the greatest integer not algebraically exceeding a floating point value.

CALLING SEQUENCE:

```
DLD    X        (X = address of floating-point value)
JSB    ENTIE
```

NORMAL RETURN: The A-Register will contain the sign; the B-Register will contain the maximum integer.

STORAGE: 33 words (41_8)

PURPOSE:	To transfer the actual parameters of a FORTRAN function to the function or subroutine being entered.
CALLING SEQUENCE:	JSB .ENTR DEF a (a = First location of area used to store argument address)
NORMAL RETURN:	Stores parameters.
STORAGE:	38 words (46_8)

.GOTO

PURPOSE: To perform translation of a FORTRAN computed GO TO statement, GO TO ($k_1, k_2, \ldots k_n$), i.

CALLING SEQUENCE:

```
JSB   .GOTO
DEF   (return address)
DEF   (address of switch index j)
DEF   (address of label k1)
  .
  .
  .
DEF   (address of label kn)
```

NORMAL RETURN: Control will be switched to the correct statement. (See page 5-1 of FORTRAN Programmer's Reference Manual)

STORAGE: 19 words (28_8)

PURPOSE:	To take the logical product of i and j and store the result in the A-Register.
CALLING SEQUENCE:	JSB IAND DEF i (address of first argument) DEF j (address of second argument)
NORMAL RETURN:	The logical product will be left in the A-Register.
STORAGE:	8 words (10_8)

INDEX

PURPOSE:	To produce the absolute address of an array element where the array is described elsewhere in an array table.

CALLING SEQUENCE:

.INDA and .INDR are used by the ALGOL compiler in order to access array elements. .INDA produces the absolute address of an array element, whereas .INDR produces the value stored in that location. The calling sequence to this routine is:

```
JSB   .INDA or .INDR
DEF   array table
ABS   -number of indices
DEF   index 1
....
DEF   index n
```

The array table for a given array has the form:

```
TABLE ABS  number of indices (+= real, - = integer)
      ABS  size of 1st dim
      ABS  -lower bound of 1st dim
      ....
      ABS  size of last DIM
      ABS  -lower bound of last dim
```

NORMAL RETURN:

```
.INDA:   A = address of array element
.INDR:   A = value if integer
         A & B = value if real
```

ERROR RETURN:

Computer halts with A = address of JSB .INDA and prints INDEX? on teleprinter. When run is pushed, routine returns to the program with value = 0.

STORAGE: 81 words (121_8)

PURPOSE:	To take logical inclusive - or of i and j and return result in the A-Register.
CALLING SEQUENCE:	JSB IOR DEF i (i = address of first argument) DEF j (j = address of second argument)
NORMAL RETURN:	The A-Register contains the result.
STORAGE:	7 words

.MAP.

PURPOSE: This routine obtains the address of an element of a two dimensional array.

CALLING SEQUENCE:

```
JSB   .MAP.
DEF   (Base address of array)
DEF   (address of first dimension)
DEF   (address of second dimension)
OCT   (First dimension of array, two's
      complement if integer array)
```

NORMAL RETURN: The A-Register contains the address.

STORAGE: 31 words (37_8)

PURPOSE: Performs memory allocation for buffering. Requests may be made to allocate and release buffers from the memory available after loading.

Allocate
CALLING SEQUENCE:

```
JSB   .ALC.
DEC   X       (X = number of words needed)
```

NORMAL RETURN: In the A-Register is FWA buffer; in the B-Register, the number of words allocated.

Release Buffer
CALLING SEQUENCE:

```
JSB   .RTN.
DEF   (address of first word of buffer)
DEF   (number of words allocated)
```

NORMAL RETURN: Registers unchanged; buffers released.

NOTE: To release all storage allocated, insert the following before the release calling sequence.

```
CLA
STA   .CLR.
```

STORAGE: 214 words (326_8)

OVF

PURPOSE:	Returns true value (sign bit = 1) in the A-Register if overflow bit is set.
CALLING SEQUENCE:	(Number to be checked is in A-Register) JSB OVF
NORMAL RETURN:	A-Register is set to zero if no overflow has occurred; if an overflow condition is sensed the A-Register is set to 177777B.
STORAGE:	4 words

PURPOSE:	To print PAUSE on the Teleprinter and halt the computer with i in the A-Register.
CALLING SEQUENCE:	LDA i JSB .PAUS
NORMAL RETURN:	The A-Register will display i when the computer halts; PAUSE will be printed on the teleprinter.
STORAGE:	18 words (22_8)

.STOP

PURPOSE: To print STOP on the Teleprinter and halt the computer with i in the A-Register.

CALLING SEQUENCE:

```
LDA   i
JSB   .STOP
```

NORMAL RETURN: STOP will be printed on the teleprinter; the computer will halt and display i in the A-Register. The subroutine will repeat itself when the operator pushes RUN.

STORAGE: 17 words (21_8)

PURPOSE:	To switch control to one of a sequence of labels provided the sequence number of the label is in the A-Register.
CALLING SEQUENCE:	LDA i (i = value of switch) JSB .SWCH OCT (label count)
NORMAL RETURN:	The program will jump to the indicated label.
STORAGE:	15 words (17_8)

.TAPE

PURPOSE: To call .IOC. with parameters generated by FORTRAN auxiliary Input/Output statements.

CALLING SEQUENCE:

```
LDA   3Øxyy8
JSB   .TAPE
```

(The $3Øxyy_8$ is the .IOC. request code.

x = 4 for REWIND
x = 2 for BACKSPACE
x = 1 for END FILE
yy = logical unit number)

NORMAL RETURN: A tape operation for a FORTRAN compiled program will be initiated.

STORAGE: 5 words

SUMMARY OF ERROR CONDITIONS AND CODES A

Error codes are produced on the Standard Teleprinter Output device at object program execution time; the general format is:

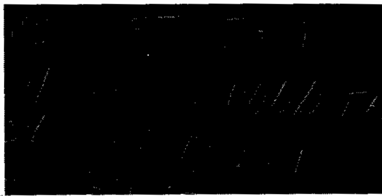
xx yy where xx is a two-digit code identifying the routine issuing the code, and yy is a two-letter mnemonic identifying the type of error. UN = underflow, OF = overflow, OR = out of range.

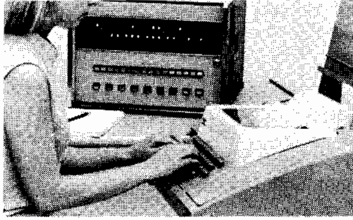
Error Code	Subroutine	Condition
02 UN	ALOG	$x \leq 0$
03 UN	SQRT	$x < 0$
04 UN	.RTOR	$x = 0, y \neq 0$
		$x < 0, y \leq 0$
05 OR	SIN COS	$ABS(x) > 2^{14}$
06 UN	.RTOI	$x = 0, i \leq 0$
07 OF	.RTOR	$x^{\|y\|}$ out of range
	EXP	$ABS(x)*\log_2 e > 124$
08 OF	.ITOI	i^j out of range
08 UN	.ITOI	$i = 0, j \leq 0$
09 OR	TAN	$x > 2^{14}$

Overflow may be caused in the TAN(x) routine when tan(x) is out of range; in the .RTOI routine when x**ABS(i) is out of range.

ALPHABETICAL LISTING OF SUBROUTINES ON THE 2018 LIBRARY TAPE B

ABS, 1-1
ALOG, 1-2
ATAN, 1-3
CHEBY, 4-1
CLR10, 3-1
COS, 1-4
DIV, 2-1
DLDST, 2-2
D.43
..DLC, 5-1
ENDIO, 3-2
ENTIE, 5-2
EXP, 1-5
.ENTR, 5-3
.ERRR, 4-3
FADSB, 2-4, 2-5
.FDV, 2-6
FLOAT, 1-6
.FMP, 2-7
FRMTR, 3-3
.FLUN, 4-4
..FCM, 4-2
GOTO, 5-4
IABS, 1-7
IAND, 5-5
IFIX, 1-8
INDEX, 5-6 (INDA, INDR)
ISIGN, 1-9
ISSW, 4-6
.IENT, 4-5
.IOR, 5-7
.ITOI, 2-10
LEADR, 3-6
MANT, 4-7
MEMRY, 5-9
.MPY, 2-9
.MAP., 5-8
OVF, 5-10
PTAPE, 3-7
PWR2, 4-9
.PACK, 4-8
.PAUS, 5-11
.PRAM, 5-12
.RND, 5-2
.RTOI, 2-10
.RTOR, 2-12
SIGN, 1-10
SIN, 1-11
SQRT, 1-12
.SCN
.STOP, 5-14
.SWCH, 5-15
TAN, 1-13
TANH, 1-14
.TAPE, 5-16
.2018





BASIC Language Reference Manual

The development of the BASIC Language and the original version of this manual on BASIC were supported in part by the National Science Foundation under terms of Grant NSF GE 3864 to Dartmouth College. Under this grant, Dartmouth College, under the direction of Professors John G. Kemeny and Thomas E. Kurtz, developed the BASIC Language and a compiler for operation under a time-sharing system in use at Dartmouth.

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INTRODUCTION

This publication is a reference manual for using the HP BASIC System with HP computers. It includes both the elements of the language and the information required to operate the system on the computer. The minimum configuration on which the HP BASIC Compiler will run is:

HP 2116B, 2115A, or 2114A Computer with 8196 words of memory

HP 2752A Teleprinter

WHAT IS A PROGRAM ?

A program is a set of directions, or a recipe, that is used to tell a computer how to provide an answer to some problem. It usually starts with the given data as the ingredients, contains a set of instructions to be performed or carried out in a certain order, and ends up with a set of answers as the cake. And, as with ordinary cakes, if you make a mistake in your program, you will end up with something else - perhaps hash!

Any program must fulfill two requirements before it can be carried out. The first is that it must be presented in a language that is understood by the "computer". If the program is a set of instructions for solving a system of linear equations and the "computer" is an English-speaking person, the program will be presented in some combination of mathematical notation and English. If the "computer" is a French-speaking person, the program must be in his language; and if the "computer" is a high-speed digital computer, the program must be presented in a language which the computer "understands".

The second requirement for all programs is that they must be completely and precisely stated. This requirement is crucial when dealing with a digital computer which has no ability to infer what you mean - it does what you tell it to do, not what you meant to tell it.

We are, of course, talking about programs which provide numerical answers to numerical problems. It is easy to program in the English language, but such a program poses great difficulties for the computer because English is rich with ambiguities and redundancies, those qualities which make poetry possible but computing impossible. Instead, you present your program in a language which resembles ordinary mathematical notation, which has a simple vocabulary and grammer, and which permits a complete and precise specification of your program. The language you will use is BASIC which is, at the same time, precise, simple and easy to understand.

A first introduction to writing a BASIC program is given in Chapter 1. This chapter includes all that you will need to know to write a wide variety of useful and interesting programs. Chapter 2 deals with more advanced computer techniques, and the Appendices contain a variety of reference materials.

1.1 AN EXAMPLE

The following example is a complete BASIC program for solving a system of two simultaneous linear equations in two variables:

$$ax + by = c$$

$$dx + ey = f$$

And then solving two different systems, each differing from this system only in the constants c and f.

You should be able to solve this system, if ae -bd is not equal to 0, to find that:

$$x = \frac{ce-bf}{ae-bd} \quad \text{and} \quad y = \frac{af-cd}{ae-bd}$$

If ae -bd = 0, there is either no solution or there are infinitely many, but there is no unique solution. If you are rusty on solving such systems, take our word for it that this is correct. For now, we want you to understand the BASIC program for solving this system.

Study this example carefully - in most cases the purpose of each line in the program is self-evident - and then read the commentary and explanation.

```
10    READ A, B, D, E
15    LET G = A * E-B * D
20    IF G = 0 THEN 65
30    READ C, F
37    LET X = (C*E - B*F)/G
42    LET Y = (A*F - C*D)/G
55    PRINT X, Y
60    GO TO 30
65    PRINT "NO UNIQUE SOLUTION"
70    DATA 1, 2, 4
80    DATA 2, -7, 5
85    DATA 1, 3, 4, -7
90    END
```

We immediately observe several things about this sample program. First, we see that the program uses only capital letters, since the teletypewriter has only capital letters.

A second observation is that each line of the program begins with a number. These numbers are called <u>line numbers</u> and serve to identify the lines, each of which is called a <u>statement</u>. Thus, a program is made up of statements, most of which are instructions to the computer. Line numbers also serve to specify the order in which the statements are to be performed by the computer. This means that you may type your program in any order. Before the program is run, the computer sorts out and edits the program, putting the statements into the order specified by their line numbers. (This editing process facilitates the correcting and changing of programs, as we shall explain later.)

A third observation is that each statement starts, after its line number, with an English word. This word denotes the type of the statement. There are several types of statements in BASIC, nine of which are discussed in this chapter. Seven of these nine appear in the sample program of this section.

A fourth observation, not at all obvious from the program, is that spaces have no significance in BASIC, except in messages enclosed in quotation marks which are to be printed out, as in line number 65 above. Thus, spaces may be used, or not used, at will to "pretty up" a program and make it more readable. Statement 10 could have been typed as 10READA, B, D, E and statement 15 as 15LETG=A*E-B*D.

With this preface, let us go through the example, step by step. The first statement, 10, is a READ statement. It must be accompanied by one or more DATA statements. When the computer encounters a READ statement while executing your program, it will cause the variables listed after the READ to be given values according to the next available numbers in the DATA statements. In the example, we read A in statement 10 and assign the value 1 to it from statement 70 and, similarly with B and 2, and with D and 4. At this point, we have exhausted the available data in statement 70, but there is more in statement 80, and we pick up from it the number 2 to be assigned to E.

We next go to statement 15, which is a LET statement, and first encounter a formula to be evaluated. (The asterisk "*" is obviously used to denote multiplication.) In this statement we direct the computer to compute the value of AE - BD, and to call the result G. In general, a LET statement directs the computer to set a variable equal to the formula on the right side of the equals sign. We know that if G is equal to zero, the system has no unique solution. Therefore, we next ask, in line 20, if G is equal to zero. If the computer discovers a "yes" answer to the question, it is directed to go to line 65, where it prints "NO UNIQUE SOLUTION". From this point, it would go to the next statement. But lines 70, 80, and 85 give it no instructions, since DATA statements are not "executed", and it then goes to line 90 which tells it to "END" the program.

If the answer to the question "Is G equal to zero?" is "no", as it is in this example, the computer goes on to the next statement, in this case 30. (Thus, an IF-THEN tells the computer where to go if the "IF" condition is met, but to go on to the next statement if it is not met.) The computer is now directed to read the next two entries from the DATA statements, -7 and 5, (both are in statement 80) and to assign them to C and F respectively. The computer is now ready to solve the system

$$x + 2y = -7$$

$$4x + 2y = 5.$$

In statements 37 and 42, we direct the computer to compute the value of X and Y according to the formulas provided. Note that we must use parentheses to indicate that CE - BF is divided by G; without parentheses, only BF would be divided by G and the computer would let $X = CE - \frac{BF}{G}$.

The computer is told to print the two values computed, that of X and that of Y, in line 55. Having done this, it moves on to line 60 where it is directed back to line 30. If there are additional numbers in the DATA statements, as there are here in 85, the computer is told in line 30 to take the next one and assign it to C, and the one after that to F. Thus, the computer is now ready to solve the system

$$x + 2y = 1$$

$$4x + 2y = 3.$$

As before, it finds the solution in 37 and 42 and prints them out in 55, and then is directed in 60 to go back to 30.

In line 30 the computer reads two more values, 4 and -7, which it finds in line 85. It then proceeds to solve the system

$$x + 2y = 4$$

$$4x + 2y = -7$$

and to print out the solutions. It is directed back again to 30, but there are no more pairs of numbers available for C and F in the DATA statements. The computer then informs you that it is out of data, printing on the paper in your teletypewriter "ERROR 56 IN LINE 30"

For a moment, let us look at the importance of the various statements. For example, what would have happened if we had omitted line number 55? The answer is simple: the computer would have solved the three systems and then told us when it was out of data. However, since it was not asked to tell us (PRINT) its answers, it would not do it, and the solutions would be the computer's secret. What would have happened if we had left out line 20? In this problem just solved nothing would have happened. But, if G were equal to zero, we would have set the computer the impossible task of dividing by zero, and it would tell us so, printing "ERROR 69 IN LINE 37". Had we left out statement 60, the computer would have solved the first system, printed out the values of X and Y, and then gone on to line 65 where it would be directed to print "NO UNIQUE SOLUTION". It would do this and then stop.

One very natural question arises from the seemingly arbitrary numbering of the statements: why this selection of line numbers? The answer is that the particular choice of line numbers is arbitrary, as long as the statements are numbered in the order which we want the machine to follow in executing the program. We could have numbered the statements 1, 2, 3, ..., 13, although we do not recommend this numbering. We would normally number the statements 10, 20, 30, ..., 130. We put the numbers such a distance apart so that we can later insert additional statements if we find that we have forgotten them in writing the program originally. Thus, if we find that we have left out two statements between those numbered 40 and 50, we can give them any two numbers between 40 and 50 - say 44 and 46; and in the editing and sorting process, the computer will put them in their proper place.

Another question arises from the seemingly arbitrary placing of the elements of data in the DATA statements: why place them as they have been in the sample program? Here again the choice is arbitrary and we need only put the numbers in the order that we want them read (the first for A, the second for B, the third for D, the fourth for E, the fifth for C, the sixth for F, the seventh for the next C, etc.) In place of the three statements numbered 70, 80, and 85, we could have put

```
75 DATA 1, 2, 4, 2, -7, 5, 1, 3, 4, -7
```

or we could have written, perhaps more naturally,

```
70 DATA 1, 2, 4, 2
75 DATA -7, 5
80 DATA 1, 3
85 DATA 4, -7
```

to indicate that the coefficients appear in the first data statement and the various pairs of right-hand constants appear in the subsequent statements.

The program and the resulting run is shown below exactly as it appears on the teletypewriter.

```
READY
10 READ A, B, D, E
15 LET G = A * E - B * D
20 IF G = 0 THEN 65
30 READ C, F
37 LET X = ( C * E - B * F ) / G
42 LET Y = ( A * F - C * D ) / G
55 PRINT X, Y
60 GO TO 30
65 PRINT "NO UNIQUE SOLUTION"
70 DATA 1, 2, 4
80 DATA 2, -7, 5
85 DATA 1, 3, 4, -7
90 END
RUN
 4              -5.5
 .666667         .166667
-3.66667         3.83333

ERROR 56 IN LINE  30
```

After typing the program, we type RUN followed by a CARRIAGE RETURN. Up to this point the computer stores the program and checks the form of the statements. It is this command which directs the computer to execute your program. The message out-of-data error code here may be ignored. However, in some cases it indicates an error in the program: for more details see Sec. 1.7.2.

1.2 FORMULAS

The computer can perform a great many operations; it can add, subtract, multiply, divide, extract square roots, raise a number to a power, and find the sine of a num-

ber (on an angle measured in radians), etc. - and we shall now learn how to tell the computer to perform these various operations and to perform them in the order that we want them done.

The computer performs its primary function (that of computation) by evaluating formulas which are supplied in a program. These formulas are very similar to those used in standard mathematical calculation, with the exception that all BASIC formulas must be written on a single line. Five arithmetic operations can be used to write a formula, and these are listed in the following table:

Symbol	Example	Meaning
+	A + B	Addition (add B to A)
-	A - B	Subtraction (subtract B from A)
*	A * B	Multiplication (multiply B by A)
/	A / B	Division (divide A by B)
↑	X ↑ 2	Raise to the power (find X^2)

We must be careful with parentheses to make sure that we group together those things which we want together. We must also understand the order in which the computer does its work. For example, if we type A + B * C ↑ D, the computer will first raise C to the power D, multiply this result by B, and then add A to the resulting product. This is the same convention as is usual for $A + B*C^D$. If this is not the order intended, then we must use parentheses to indicate a different order. For example, if it is the product of B and C that we want raised to the power D, we must write A + (B * C) ↑ D; or, if we want to multiply A + B by C to the power D, we write (A + B) * C ↑ D. We could even add A to B, multiply their sum by C, and raise the product to the power D by writing ((A + B) * C) ↑ D. The order of priorities is summarized in the following rules:

1. The formula inside parentheses is computed before the parenthesized quantity is used in further computations.

2. In the absence of parentheses in a formula involving addition, multiplication, and the raising of a number to the power, the computer first raises the number to the power, then performs the multiplication, and the addition comes last. Division has the same priority as multiplication, and subtraction the same as addition.

3. In the absence of parentheses in a formula involving operations of the same priority, the operations are performed from left to right.

These rules are illustrated in the previous example. The rules also tell us that the computer, faced with A - B - C, will (as usual) subtract B from A and then C from their difference; faced with A/B/C, it will divide A by B and that quotient by C. Given A ↑ B ↑ C, the computer will raise the number A to the power B and take the resulting number and raise it to the power C. If there is any question in your mind about the priority, put in more parentheses to eliminate possible ambiguities.

In addition to these five arithmetic operations, the computer can evaluate several mathematical functions. These functions are given special 3-letter English names, as the following list shows:

Functions	Interpretation	
SIN (X)	Find the sine of X	X interpreted as a number, or as an angle measured in radians
COS (X)	Find the cosine of X	
TAN (X)	Find the tangent of X	
ATN (X)	Find the arctangent of X	
EXP (X)	Find e^X	
LOG (X)	Find the natural logarithm of X (ln X)	
ABS (X)	Find the absolute value of X ($\|X\|$)	
SQR (X)	Find the square root of X ($\sqrt{X}$)	

Three other functions are also available in BASIC: INT, RND, and SGN; these are reserved for explanation in Chapter 2. In place of X, we may substitute any formula or any number in parentheses following any of these formulas. For example, we may ask the computer to find $\sqrt{4 + X^3}$ by writing SQR (4 + X↑3), or the arctangent of $3X - 2e^X + 8$ by writing ATN (3 * X - 2 * EXP (X) + 8).

If, sitting at the teletypwriter, you need the value of $(\frac{5}{6})^{17}$ you can write the two-line program

```
10    PRINT (5/6) ↑ 17
20    END
```

and the computer will find the decimal form of this number and print it out in less than it took you to type the program.

Since we have mentioned numbers and variables, we should be sure that we understand how to write numbers for the computer and what variables are allowed. A number may be positive or negative and it may contain up to approximately seven significant digits, but it must be expressed in decimal form. For example, all of the following are numbers in BASIC: 2, -3.675, 1234567, -.7654321, and 483.4156. The following are not numbers in BASIC: 14/3 and $\sqrt{7}$. We may ask the computer to find the decimal expansion of 14/3 or $\sqrt{7}$, and to do something with the resulting number, but we may not include either in a list of DATA. We gain further flexibility by use of the letter E, which stands for "times ten to the power". Thus, we may write .001234567 in a form acceptable to the computer in any of several forms: .1234567E-2 or 1234567E-9 or 1234.56789E-6. We may write ten million as 1E7 (or 1E + 7) and 1965 as 1.965E3 (or 1.965E + 3). We do not write E7 as a number, but must write 1E7 to indicate that it is 1 that is multiplied by 10^7. All numbers are represented in the computer by two 16-bit words. The exponent and its sign are eight bits; the fraction and its sign are twenty-four bits. They have a range in magnitude of approximately 10^{-38} to 10^{38} and may assume positive, negative or zero values. If a fraction is negative the number is stored in two's complement form. A zero value is stored as all zero bits. If a number is too large, the com-

puter prints "ERROR 65 IN LINE nn" and replaces it with the largest representable number of the same sign. If a number is too small, the computer prints "ERROR 66 IN LINE nn" and replaces it with zero.

A numerical variable in BASIC is denoted by any letter, or by any letter followed by a single digit. Thus, the computer will interpret E7 as a variable, along with A, X, N5, I0, and O1. A variable in BASIC stands for a number, usually one that is not known to the programmer at the time the program was written. Variables are given or assigned values by LET, READ, or INPUT statements. The value so assigned will not change until the next time a LET, READ, or INPUT statement is encountered with a value for that variable. However, all variables are set to "undefined" before a RUN. Thus, it is always necessary to assign a value to a variable before using the variable in a computation. Failure to do so will cause the computer to print "ERROR 50 IN LINE nn".

Six other mathematical symbols are provided for in BASIC, symbols of relation, and these are used in IF-THEN statements where it is necessary to compare values. An example of the use of these relation symbols was given in the sample program in Section 1.

Any of the following six standard relations may be used:

Symbol	Example	Meaning
=	A = B	Is equal to (A is equal to B)
<	A < B	Is less than (A is less than B)
<=	A <= B	Is less than or equal to (A is less than or equal to B)
>	A > B	Is greater than (A is greater than B)
>=	A >= B	Is greater than or equal to (A is greater than or equal to B)
#	A # B	Is not equal to (A is not equal to B)

1.3 LOOPS

We are frequently interested in writing a program in which one or more portions are performed not just once but a number of times, perhaps with slight changes each time. In order to write the simplest program, the one in which this portion to be repeated is written just once, we use the programming device known as a loop.

The programs which use loops can, perhaps, be best illustrated and explained by two programs for the simple task of printing out a table of the first 100 positive integers together with the square root of each. Without a loop, our program would be 101 lines long and read:

```
10      PRINT 1, SQR (1)
20      PRINT 2, SQR (2)
30      PRINT 3, SQR (3)
        . . . . . . .
```

```
990     PRINT 99, SQR (99)
1000    PRINT 100, SQR (100)
1010    END
```

With the following program, using one type of loop, we can obtain the same table with far fewer lines of instruction, 5 instead of 101:

```
10      LET X = 1
20      PRINT X, SQR (X)
30      LET X = X + 1
40      IF X < = 100 THEN 20
50      END
```

Statement 10 gives the value of 1 to X and "initializes" the loop. In line 20 both 1 and its square root are printed. Then, in line 30, X is increased by 1, to 2. Line 40 asks whether X is less than or equal to 100; an affirmative answer directs the computer back to line 20. Here it prints 2 and $\sqrt{2}$, and goes to 30. Again X is increased by 1, this time to 3, and at 40 it goes back to 20. This process is repeated line 20 (print 3 and $\sqrt{3}$), line 30 ($X = 4$), line 40 (since $4 \leq 100$ go back to line 20), etc - until the loop has been traversed 100 times. Then, after it has printed 100 and its square root, X becomes 101. The computer now receives a negative answer to the question in line 40 (X is greater than 100, not less than or equal to it), does not return to 20 but moves on to line 50, and ends the program. All loops contain four characteristics; initialization (line 10), the body (line 20), modification (line 30), and an exit test (line 40). Because loops are so important and because loops of the type just illustrated arise so often, BASIC provides two statements to specify a loop even more simply. They are the FOR and NEXT statements, and their use is illustrated in the program:

```
10      FOR X = 1 TO 100
20      PRINT X, SQR (X)
30      NEXT X
50      END
```

In line 10, X is set equal to 1, and a test is set up, like that of line 40 above. Line 30 carries out two tasks: X is increased by 1, and the test is carried out to determine whether to go back to 20 or go on. Thus lines 10 and 30 take the place of lines 10, 30, and 40 in the previous program - and they are easier to use.

Note that the value of X is increased by 1 each time we go through the loop. If we wanted a different increase, we could specify it by writing

```
10      FOR X = 1 TO 100 STEP 5
```

and the computer would assign 1 to X on the first time through the loop, 6 to X on the second time through, 11 on the third time, and 96 on the last time. Another step of 5 would take X beyond 100, so the program would proceed to the end after printing 96 and its square root. The STEP may be positive or negative, and we could have obtained the first table, printed in reverse order, by writing line 10 as

```
10      FOR X = 100 TO 1 STEP -1
```

In the absence of a STEP clause, a step size of + 1 is assumed.

More complicated FOR statements are allowed. The initial value, the final value, and the step size may all be formulas of any complexity. For example, if N and Z have been specified earlier in the program, we could write

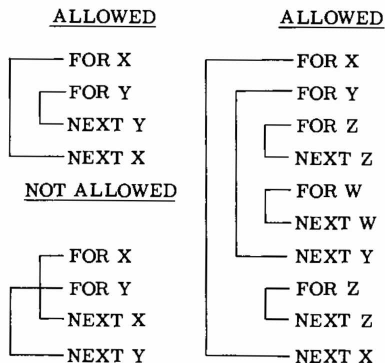
```
FOR X = N + 7 * Z TO (Z-N) /3 STEP (N-4 * Z) / 10
```

For a positive step-size, the loop continues as long as the control variable is algebraicly less than or equal to the final value. For a negative step-size, the loop continues as long as the control variable is greater than or equal to the final value.

If the initial value is greater than the final value (less than for negative step-size), then the body of the loop will not be performed at all, but the computer will immediately pass to the statement following the NEXT. As an example, the following program for adding up the first n integers will give the correct result 0 when n is 0.

```
10      READ N
20      LET S = 0
30      FOR K = 1 TO N
40      LET S = S + K
50      NEXT K
60      PRINT S
70      GO TO 10
90      DATA 3, 10, 0
99      END
```

It is often useful to have loops within loops. These are called nested loops and can be expressed with FOR and NEXT statements. However, they must actually be nested and must not cross, as the following skeleton examples illustrate:



1.4 ARRAYS

In addition to the ordinary variables used by BASIC, there are variables which can be used to designate the elements of an array. These are used where we might ordinarily use a subscript or a double subscript, for example the coefficients of a polynomial $[a_0, a_1, a_2, \ldots]$ or the elements of a matrix $[b_{i,j}]$. The variables which we use in BASIC consist of a single letter, which we call the name of the array, followed by the subscripts in brackets or parentheses. Thus, we might write A [1], A [2], A [3], etc., for the coefficients of the polynomial and B [1, 1], B [1, 2], etc., for the elements of the matrix.

We can enter the array A(1), A(2), A(3), . . . A(10) into a program very simply by the lines:

```
10    FOR I = 1 TO 10
20    READ A (I)
30    NEXT I
40    DATA 2, 3, -5, 5,2.2, 4, -9, 123, 4, -4
```

We need no special instruction to the computer if no subscript greater than 10 occurs. However, if we want larger subscripts, we must use a DIM statement, to indicate to the computer that it has to save extra space for the array. When in doubt, indicate a larger dimension than you expect to use. The maximum value for a dimension is 255. For example, if we want a list of 15 numbers entered, we might write:

```
10    DIM A (25)
20    READ N
30    FOR I = 1 TO N
40    READ A (I)
50    NEXT I
60    DATA 15
70    DATA 2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 37, 41, 43, 47
```

Statements 20 and 60 could have been eliminated by writing 30 as FOR I = 1 TO 15, but the form as typed would allow for the lengthening of the array by changing only statement 60, so long as it did not exceed 25.

We would enter a 3 × 5 array into a program by writing:

```
10    FOR I = 1 TO 3
20    FOR J = 1 TO 5
30    READ B (I, J)
40    NEXT J
50    NEXT I
60    DATA 2, 3, -5, -9, 2
```

```
70      DATA 4, -7, 3, 4, -2
80      DATA 3, -3, 5, 7, 8
```

Here again, we may enter an array with no dimension statement, and it will handle all the entries from B(1, 1) to B(10, 10). If you try to enter an array with a subscript greater than 10, without a DIM statement, you will get an error message telling you that you have a subscript error. This is easily rectified by entering the line:

```
5       DIM B (20, 30)
```

if, for instance, we need a 20-by-30 table.

The single letter denoting an array name may also be used to denote a simple variable without confusion. However, the same letter may not be used to denote both a singly subscripted and a doubly subscripted array in the same program. The form of the subscript is quite flexible, and you might have the array element B(I, K) or Q(A(3, 7), B - C).

Shown below is a list and run of a problem which uses both a singly and a doubly subscripted array. The program computes the total sales of each of five salesmen, all of whom sell the same three products. The array P gives the price/item of the three products and the array S tells how many items of each product each man sold. You can see from the program that product no. 1 sells for $1.25 per item, no. 2 for $4.30 per item, and no. 3 for $2.50 per item; and also that salesman no. 1 sold 40 items of the first product, 10 of the second, and 35 of the third, and so on. The program reads in the price array in lines 40-80, using data in lines 910-930. The same program could be used again, modifying only line 900 if the prices change, and only lines 910-930 to enter the sales in another month.

This sample program did not need a dimension statement, since the computer automatically saves enough space to allow all subscripts to run from 1 to 10. A DIM statement is normally used to save more space. But in a long program, requiring many small arrays, DIM may be used to save less space for arrays, in order to leave more for the program.

Since a DIM statement is not executed, it may be entered into the program on any line before END; it is convenient, however, to place DIM statements near the beginning of the program.

```
READY
10    FOR I = 1 TO 3
20       READ P(I)
30    NEXT I
40    FOR I = 1 TO 3
50       FOR J = 1 TO 5
60          READ S(I,J)
70       NEXT J
80    NEXT I
90    FOR J = 1 TO 5
100      LET S = 0
110      FOR I = 1 TO 3
120         LET S = S + P(I)*S(I,J)
130      NEXT I
140      PRINT "TOTAL SALES FOR SALESMAN "J, "$" S
```

```
150  NEXT J
900  DATA 1.25, 4.30, 2.50
910  DATA 40, 20, 37, 29, 42
920  DATA 10, 16, 3, 21, 8
930  DATA 35, 47, 29, 16, 33
999  END
RUN
TOTAL SALES FOR SALESMAN  1                    $ 180.5
TOTAL SALES FOR SALESMAN  2                    $ 211.3
TOTAL SALES FOR SALESMAN  3                    $ 131.65
TOTAL SALES FOR SALESMAN  4                    $ 166.55
TOTAL SALES FOR SALESMAN  5                    $ 169.4
```

1.5 USE OF THE SYSTEM

Now that we know something about writing a program in BASIC, how do we set about using a teletypewriter to type in our program and then to have the computer solve our problem?

First, load the BASIC system tape and initiate its execution. The computer then types READY and you should begin to type your program. Make sure that each line begins with a line number which contains no more than four digits and contains no non-digit characters. Be sure to press the CARRIAGE RETURN key at the completion of each line. Spaces may be inserted at any point in the line, including before the line numbers.

If, in the process of typing a statement, you make a typing error and notice it immediately, you can correct it by pressing the backward arrow (shift key above the letter "oh"). This will delete the character in the preceding space, and you can then type in the correct character. Pressing this key a number of times will erase from this line the characters in that number of preceding spaces. To delete all of the present line, press ALT MODE. † Programs or data may be annotated by typing the remark and then deleting the line (as far as the system is concerned) with an ALT MODE. BASIC types a slash to show that a line has been deleted.

After typing your complete program, you type RUN, press the CARRIAGE RETURN key, and hope. If the program is one which the computer can run, it will then run it and type out any results for which you have asked in your PRINT statements. This does not mean that your program is correct, but that it has no errors of the type known as "grammatical errors". If it had errors of this type, the computer would have typed an error code as soon as the error was detected during the typing of the program. Errors detected after RUN are structural (loop nesting, matching GOSUB and Return) or arithmetical errors. A list of the error codes is in Sect. 2.7 together with the interpretation of each.

If you are given an error message, you can correct the error by typing a new line with the correct statement. If you want to eliminate the statement on line 110 from your program, you can do this by typing 110 and then the CARRIAGE RETURN. If you want to insert a statement between those on lines 60 and 70, you can do this by giving it a line number between 60 and 70.

† Use ESC key if no ALT MODE key.

If it is obvious to you that you are getting the wrong answers to your problem, even while the computer is running, you can type STOP and the computation will cease. If the teletypewriter is actually typing, there is an express stop - just press any key. It will type STOP and then READY and you can start to make your corrections. If you are in serious trouble, use the express stop, and type SCRATCH. When the system is ready to accept a new program, READY will be typed.

A sample use of the system is shown below.

```
READY
10 FOR N = 1 TO 7
20 PRINT N, SQR(N)
30 NEXT N
40 PRINT "DONE"
50 END
RUN
 1             1
 2             1.41421
 3             1.73205
 4             2
 5             2.23607
 6             2.44949
 7             2.64575
DONE
```

1.6 ERRORS AND DEBUGGING

It may occasionally happen that the first run of a new problem will be free of errors and give the correct answers. But it is much more common that errors will be present and will have to be corrected. Errors are of two types: errors of form (or grammatical errors) which prevent the running of the program; and logical errors in the program which cause the computer to produce wrong answers or no answers at all.

Errors of form will cause error codes to be printed, and the various error codes are listed and explained in Sec. 2.7. Logical errors are often much harder to uncover, particularly when the program gives answers which seem to be nearly correct. In either case, after the errors are discovered, they can be corrected by changing lines, by inserting new lines, or by deleting lines from the program. As indicated in the last section, a line is changed by typing it correctly with the same line number; a line is inserted by typing it with a line number between those of two existing lines; and a line is deleted by typing its line number and pressing the CARRIAGE RETURN key. Notice that you can insert a line only if the original line numbers are not consecutive integers. For this reason, most programmers will start out using line numbers that are multiples of five or ten, but that is a matter of choice.

These corrections can be made at any time - whenever you notice them - either before or after a run. Since the computer sorts lines out and arranges them in order, a line may be retyped out of sequence. Simply retype the offending line with its original line number.

As with most problems in computing, we can best illustrate the process of finding the errors (or "bugs") in a program, and correcting (or "debugging") it, by an example. Let us consider the problem of finding that value of X between 0 and 3 for

which the sine of X is a maximum, and ask the machine to print out this value of X and the value of its sine. If you have studied trigonometry, you know that $\pi/2$ is the correct value; but we shall use the computer to test successive values of X from 0 to 3, first using intervals of .1, then of .01, and finally of .001. Thus, we shall ask the computer to find the sine of 0, of .1, of .2, of .3..., of 2.8, of 2.9, and of 3, and to determine which of these 31 values is the largest. It will do it by testing SIN(0) and SIN(.1) to see which is larger, and calling the larger of these two numbers M. Then it will pick the larger of M and SIN(.2) and call it M. This number will be checked against SIN(.3), and so on down the line. Each time a larger value of M is found, the value of X is "remembered" in X0. When it finishes, M will have been assigned to the largest value. It will then repeat the search, this time checking the 301 numbers 0, .01, .02, .03, ..., 2.98, 2.99, and 3, finding the sine of each and checking to see which has the largest sine. At the end of each of these three searches, we want the computer to print three numbers: the value X0 which has the largest sine, the sine of that number, and the interval of search.

Before going to the teletypewriter, we write a program and let us assume that it is the following:

```
 10    READ D
 20    LET X0 = 0
 30    FOR X = 0 TO 3 STEP D
 40    IF SIN (X) < = M THEN 100
 50    LET X0 = X
 60    LET M = SIN (X0)
 70    PRINT X0, X, D
 80    NEXT X0
 90    GO TO 20
100    DATA .1, .01..001
110    END
```

We shall list the entire sequence on the teletypewriter and make explanatory comments.

```
READY
1  REM PROGRAM NAME:  MAXSIN
10 READ D
20 LWR X0= 0
ERROR 4 IN LINE  20

20 LET X0= 0
30 FOR X = 0 TO 3 STEP D
40 IF SINE←(X) <= M THEN 100
50 LET X0=X
60 LET M = SIN(X)
70 PRINT XO, X, D
ERROR 21 IN LINE  70

70 PRINT X0, X, D
80 NEXT Z←X0
90 GO TO 20
100 DATA .1, .01, .001
```

```
110 END
RUN

ERROR 41 IN LINE  80
```

A message indicates that LET was mistyped in line 20, so we retype it, this time correctly.

Notice the use of the backwards arrow to erase a character in line 40, which should have started IF SIN (X) etc., and in line 80.

After receiving the second error message, we find that we used XO for a variable instead of X0 in line 70. The next error message indicates a FOR statement without a NEXT. Upon checking we see that the variable in the FOR and NEXT are different, so we correct statement 80. In looking over the program, we also notice that the IF-THEN statement in 40 directed the computer to a DATA statement and not to line 80 where it should go.

```
80 NEXT X
40 IF SIN(X) <= M THEN 80
RUN

ERROR 50 IN LINE  40
```

The message indicates that M has never been assigned an initial value. We decide to give it a value less than the maximum value of the sine, say -1.

```
20 LET M= -1
 RUN
 0              0              .1
 .1             .1             .1
 .2             .2             .1
 .3             .3             .1
 .4      STOP

READY
```

This is incorrect. We are having every value of X0, X, and the interval size printed, so we direct the machine to cease operations by typing S even while it is running. Note that the 'S' does not print, but the word STOP is printed.

We fix this by moving the PRINT statement outside the loop. Typing 70 deleted that line, and line 85 is outside of the loop. We also realize that we want M printed and not X.

```
70
85 PRINT X0, M, D
RUN
 1.6            .999574        .1
 1.6            .999574        .1
 1.6            .999574        .1
 1.6      STOP

READY
```

Of course, line 90 sent us back to line 20 to repeat the operation and not back to line 10 to pick up a new value for D. We also decide to put in headings for our columns by a PRINT statement.

```
90 GO TO 10
5  PRINT "X VALUE", "SIN", RESOLUTION"
ERROR 21 IN LINE  5
```

There is an error in our PRINT statement: no left quotation mark for the third item

Retype line 5, with all of the required quotation marks.

```
5  PRINT "X VALUE", "SIN", RESOLUT\
5  PRINT "X VALUE", "SIN", "RESOLUTION"
RUN
X VALUE         SIN             RESOLUTION
 1.6             .999574         .1
 1.57           1.               1.00000E-02
 1.57098        1                1.00000E-03

ERROR 56 IN LINE  10
```

Exactly the desired results. Of the 31 numbers (0, .1, .2, .3, . . . , 2.8, 2.9, 3) it is 1.6 which has the largest sine, namely .999574. Similarly for finer subdivisions.

Having changed so many parts of the program, we ask for a list of the corrected program. Listing the corrected program, from time to time, is an important part of debugging.

```
LIST
1  REM PROGRAM NAME:  MAXSIN
5  PRINT "X VALUE","SIN","RESOLUTION"
10  READ D
20  LET M=-1
30  FOR X= 0 TO  3 STEP D
40  IF SIN(X) <= M THEN 80
50  LET X0=X
60  LET M=SIN(X)
80  NEXT X
85  PRINT X0,M,D
90  GOTO 10
100  DATA  .1        , 1.00000E-02, 1.00000E-03
110  END

PLIST
```

The program is saved for later use by punching it on the Tape Punch.

In solving this problem, there is a common device which we did not use, namely the insertion of a PRINT statement when we wonder if the machine is computing what we think we asked it to compute. For example, if we wondered about M, we could have inserted 65 PRINT M, and we would have seen the values.

1.7 SUMMARY OF ELEMENTARY BASIC STATEMENTS

In this section we shall give a short and concise description of each of the types of BASIC statements discussed earlier in this chapter and add one statement to our list. In each form, we shall assume a line number, and shall use brackets to denote a general type. Thus, [variable] refers to any variable, which is a single letter, possibly followed by a single digit.

1.7.1 LET

This statement is not a statement of algebraic equality, but rather a command to the computer to perform certain computations and to assign the answer to a certain variable. Each LET statement is of the form: LET [variable] = [formula]. More generally several variables may be assigned the same value by a single LET statement.

Examples: (of the first type):

```
100 LET X = X + 1
259 LET W7 = (W-X4 ↑ 3)*(Z - A/(A -B)) -17
```

(of the second type):

```
 50 LET X = Y3 = A(3, 1) = 1
 90 LET W = Z = 3*X -4* X ↑ 2
```

1.7.2 READ and DATA

We use a READ statement to assign to the listed variables values obtained from a DATA statement. Neither statement is used without one of the other type. A READ statement causes the variables listed in it to be given, in order, the next available numbers in the collection of DATA statements. Before the program is run, the computer takes all of the DATA statements in the order in which they appear and creates a large data block. Each time a READ statement is encountered anywhere in the program, the data block supplies the next available number or numbers. If the data block runs out of data, with a READ statement still asking for more, the program is assumed to be done and we get an out-of-data error code.

Since we have to read in data before we can work with it, READ statements normally occur near the beginning of a program. The location of DATA statements is arbitrary, as long as they occur in the correct order. A common practice is to collect all DATA statements and place them just before the END statement.

Each READ statement is of the form:

READ [sequence of variables] and each DATA statement of the form:
DATA [sequence of numbers]

Examples:

```
150 READ X, Y, Z, X1, Y2, Q9
330 DATA 4, 2, 1.7
340 DATA 6.734E-3, -174.321, 3.14159265

234 READ B (K)
263 DATA 2, 3, 5, 7, 9, 11, 10, 8, 6, 4
```

```
10 READ R (I, J)
440 DATA -3, 5, -9, 2.37, 2.9876, -437.234E-5
450 DATA 2.765, 5.5576, 2.3789E2
```

Remember that only numbers are put in a DATA statement, and that 15/7 and $\sqrt{3}$ are formulas, not numbers.

1.7.3 PRINT

The PRINT statement has a number of different uses and is discussed in more detail in Chapter 2. The common uses are (a) to print out the result of some computations, (b) to print out verbatim a message included in the program, (c) a combination of the two, and (d) to skip a line. We have seen examples of only the first two in our sample programs. Each type is slightly different in form, but all start with PRINT after the line number.

Examples of type (a):

```
100 PRINT X, SQR (X)

135 PRINT X, Y, Z, B*B -4*A*C, EXP(A-B)
```

The first will print X and then, a few spaces to the right of that number, its square root. The second will print five different numbers:

X, Y, Z, B^2 -4AC, and e^{A-B}.

The computer will compute the two formulas and print them for you, as long as you have already given values to A, B, and C. It can print up to five numbers per line in this format.

Examples of type (b):

```
100 PRINT "NO UNIQUE SOLUTION"
430 PRINT "X VALUE","SINE","RESOLUTION"
```

Both have been encountered in the sample programs. The first prints that simple statement; the second prints the three labels with spaces between them. The labels in 430 automatically line up with three numbers called for in a PRINT statement (as long as the labels do not exceed 14 characters) as seen in MAXSIN.

Examples of type (c):

```
150 PRINT "THE VALUE OF X IS" X
 30 PRINT "THE SQUARE ROOT OF "X, "IS"
    SQR(X)
```

If the first has computed the value of X to be 3, it will print out: THE VALUE OF X is 3. If the second has computed the value of X to be 625, it will print out: THE SQUARE ROOT OF 625 IS 25.

Examples of type (d):

```
250 PRINT
```

The computer will advance the paper one line when it encounters this command.

1.7.4 GO TO

There are times in a program when you do not want all commands executed in the program. An example of this occurs in the MAXSIN problem where the computer has computed X0, M, and D and printed them out in line 85. We did not want the program to go to the END statement yet, but to go through the same process for a different value of D. So we directed the computer to go back to line 10 with a GO TO statement. Each is in the form of GO TO [line number]. (It is possible to go to a non-executable statement; control passes to the next sequential executable statement.)

Example: 150 GO TO 75

1.7.5 IF - THEN

There are times when we are interested in jumping the normal sequence of commands, if a certain relationship holds. For this we use an IF-THEN statement, sometimes called a conditional GO TO statement. Such a statement occurred at line 40 of MAXSIN. The more common form of the statement is:

IF [formula] [relation] [formula] THEN [line number]

Examples: 40 IF SIN (X) < = M THEN 80

20 IF G = 0 THEN 65

The first asks if the sine of X is less than or equal to M, and directs the computer to skip to line 80 if it is. The second asks if G is equal to 0, and directs the computer to skip to line 65 if it is. In each case, if the answer to the question is No, the computer will go to the next line of the program.

In the general sense, the IF-THEN statement may have the form:

IF [formula] THEN [line number]

Examples: 17 IF G = 0 THEN 77

35 IF A THEN 83

85 IF A + B - 5 THEN 302

90 IF -2 THEN 200

The formula is evaluated and the result interpreted as non-zero (true) or zero (false). Thus, in the first case, if G had a value of 2, the formula G = 0 is evaluated as zero or false. If A would have a value of 2 (in the second case), the formula is evaluated as non-zero or true. In the third case, if A equalled 2 and B equalled 3, the formula would yield a value of zero (false). The fourth example would always be true.

FOR [variable] = [formula] TO [formula] STEP [formula]

1.7.6 FOR and NEXT

We have already encountered the FOR and NEXT statements in our loops, and have seen that they go together, one at the entrance to the loop and one at the exit, directing the computer back to the entrance again. Every FOR statement is of the form

Any simple (not subscripted) variable may be used as the FOR variable. Most commonly, the expressions will be integers and the STEP omitted. In the latter case, a step size of one is assumed. The accompanying NEXT statement is simple in form, but the variable must be precisely the same one as that following FOR in the FOR statement. Its form is NEXT [variable].

Examples:

```
 30 FOR X = 0 TO 3 STEP D
 80 NEXT X
120 FOR X4 = (17 + COS(Z))/3 TO 3*SQR(10) STEP 1/4
235 NEXT X4
240 FOR X = 8 TO 3 STEP -1
456 FOR J = -3 TO 12 STEP 2
```

Notice that the step size may be a formula (1/4), a negative number (-1), or a positive number (2). In the example with lines 120 and 235, the successive values of X4 will be .25 apart, in increasing order. In the next example, the successive values of X will be 8, 7, 6, 5, 4, 3. In the last example, on successive trips through the loop, J will take on values -3, -1, 3, 5, 7, 9, and 11.

If the initial, final, or step-size values are given as formulas, these formulas are evaluated once and for all upon entering the FOR statement. The control variable can be changed in the body of the loop; of course, the exit test always uses the latest value of this variable.

If you write 50 FOR Z = 2 TO -2, without a negative step size, the body of the loop will not be performed and the computer will proceed to the statement immediately following the corresponding NEXT statement.

1.7.7 DIM

Whenever we want to enter an array with a subscript greater than 10, we must use a DIM statement to inform the computer to save us sufficient room.

Examples:

```
20 DIM H(35)
35 DIM Q(5, 25)
```

The first would enable us to enter an array of 35 items, and the latter a 5 × 25 array.

1.7.8 END

Every program must have an END statement, and it must be the statement with the highest line number in the program. Its form is simple: a line number with END.

Example:

```
999 END
```

2.1 MORE ABOUT PRINT

The uses of the PRINT statement were described in 1. 7. 3, but we shall give more detail here. Although the format of answers is automatically supplied for the beginner, the PRINT statement permits a greater flexibility for the more advanced programmer who wishes a different format for his output.

The teletypewriter line is divided into five zones starting at positions 0, 15, 30, 45, and 60. Control of the use of these comes from the use of the comma; a comma is a signal to move to the next print zone or, if the fifth print zone has just been filled, to move to the first print zone of the next line.

More compact output can be obtained by use of the semi-colon; it inhibits spacing between print zones on a line, acting only to separate quantities to be printed (e. g., A + B; C/D) or suppress a CARRIAGE RETURN at the end of a PRINT statement.

Spacing within a print zone depends on the value and type of the number being printed. A number is always printed in a zone larger than it needs and is left-justified in the zone. The size is determined as follows:

Value of Number	Type of Number	Format of Zone
$-999 \leq n \leq +999$	Integer	△xxx∧∧† only 6 long
$-32768 \leq n \leq -1000$ $+1000 \leq n \leq +32767$	Integer	△xxxxx∧∧∧
$.1 \leq n \leq 999999.5$	Large Integer or Real	△xxxxxxx∧∧∧∧ only 6 digits and decimal point. (Decimal point printed as one of x's; trailing zeros suppressed.)
$n < .1$ $999999.5 < n$	Large Integer or Real	△x. xxxxxE±ee∧∧∧

For Example, if you were to type the program

```
10 FOR I = 1 TO 15
20 PRINT I
30 NEXT I
40 END
RUN
```

†The carot symbol, ∧, represents a space typed on the teletypewriter.

the teletypewriter would print 1 at the beginning of a line, 2 at the beginning of the next line, and so on, finally printing 15 on the fifteenth line. But, by changing line 20 to read

```
20 PRINT I,
RUN
```

you would have the numbers printed in the zones, reading

```
1          2          3          4          5
6          7          8          9          10
11         12         13         14         15
```

If you wanted the numbers printed in this fashion, but more tightly packed, you would change line 20 to replace the comma by a semi-colon:

```
20 PRINT I;
RUN
```

and the result would be printed

```
1    2    3    4    5    6    7    8    9    10    11    12
13   14   15
```

You should remember that a label inside quotation marks is printed just as it appears and also that the end of a PRINT signals a new line, unless a comma or semicolon is the last symbol.

Thus, the instruction

50 PRINT X, Y

will result in the printing of two numbers and the return to the next line, while

50 PRINT X, Y,

will result in the printing of these two values and no return – the next number to be printed will occur in the third zone, after the values of X and Y in the first two.

Since the end of a PRINT statement signals a new line, you will remember that

250 PRINT

will cause the typewriter to advance the paper one line. It will put a blank line in line in your program, if you want to use it for vertical spacing of your results, or it causes the completion of partially filled line, as illustrated in the following fragment of a program:

```
50 FOR M = 1 to N
110 FOR J  = 1 to M
120 PRINT B (M, J);
130 NEXT J
140 PRINT
150 NEXT M
```

This program will print B(1, 1) and next to it B(1, 2). Without line 140, the teletypewriter would then go on printing B(2, 1), B(2, 2), and B(2, 3) on the same line, and then B(3, 1), B(3, 2) etc. Line 140 directs the teletypewriter, after printing the B(1, 2) value corresponding to M = 2, to start a new line and to do the same thing after printing the value of B(2, 3) corresponding to M = 3, etc.

The instructions

```
50 PRINT " HP BASIC ";
51 PRINT "LANGUAGE COMPILER"
90 END
RUN
```

will result in the printing of

```
HP BASIC LANGUAGE COMPILER
```

Formatting of output can be controlled even further by use of the function TAB.

Insertion of TAB(17) will cause the teletypewriter to move to column 17, just as if a tab had been set there. For this purpose the positions on a line are numbered from 0 through 71.

More precisely, TAB may contain any formula as its argument. The value of the formula is computed, and its integer part is taken. (If the result is greater than 71, the teletypewriter is moved to position zero of the next line.) The teletypewriter is then moved forward to this position – unless it has already passed this position, in which case the TAB is ignored.

For example, inserting the following line in a loop:

PRINT X; TAB(12); Y; TAB(27); Z

will cause the X-value to start in column 0, the Y-value in column 12 and the Z-value in column 27.

A comma following a TAB clause has no effect on positioning the teletypewriter. For example, the statement "PRINT TAB (7), A+B" causes the value of A+B to be printed starting at position 7, while the statement "PRINT Z, A+B" causes the value to be printed starting at position 15.

The following rules for the printing of numbers will help you in interpreting your printed results:

1. If a number is an integer with a value between -32768 and +32767, inclusive, the decimal point is not printed.

2. If the number is an integer out of the above range (see INT function), or if the number is real and has an absolute value between .1 and 999999.5, the number is rounded to six digits and printed with a decimal point. Zeros trailing the decimal point are suppressed.

3. If a number is either greater than 999999.5 or less than .1 in magnitude, it is rounded to six places; the teletypewriter then prints a space (if positive) or minus sign (if negative), the first digit, the decimal point, the next five digits, the letter E (indicating exponent), the sign of the exponent, and the exponent. For example, it will take 32, 437, 580, 259 and write it as 3.24376E + 10.

The following program, in which we print out powers of 2, shows how numbers are printed.

```
READY
10 FOR N = -5 TO 30
20 PRINT 2↑N;
30 NEXT N
40 END
RUN
 3.12500E-02    6.25000E-02    .125          .25           .5            1
 2     4     8      16     32     64     128    256    512    1024       2048
 4096      8192      16384     32768.        65536.        131072.       262144.
 524288.      1.04858E+06    2.09715E+06    4.19430E+06    8.38861E+06
 1.67772E+07    3.35544E+07    6.71089E+07    1.34218E+08    2.68435E+08
 5.36871E+08    1.07374E+09
```

2.2 FUNCTIONS AND DEF

Three functions were listed in Section 1.2 but not described: INT, RND and SGN.

2.2.1 INT

The INT function is the function which frequently appears in algebraic computation as [x], and it gives the greatest integer not greater than x for $-32768 \leq x < 32768$. Thus INT (2.35) = 2, INT (-2.35) = -3, and INT (12) = 12. INT (x) = 32767 for $x \geq 32768$ and INT (x) = -32768 for $x \leq -32768$.

One use of the INT function is to round numbers. We may use it to round to the nearest integer by asking for INT(X + .5). This will round 2.9, for example, to 3, by finding INT(2.9 + .5) = INT (3.4) = 3. You should convince yourself that this will indeed do the rounding guaranteed for it (it will round a number midway between two integers up to the larger of the integers).

It can also be used to round to any specific number of decimal places. For example, INT (10*X + .5)/10 rounds X correct to one decimal place, and INT (10↑D*X + .5)/10↑D rounds X correct to D decimal places.

2.2.2 RND

The function RND produces a random number between 0 and 1. The form of RND requires an argument although the argument has no significance, and so we write RND(X) or RND(Ø). (The argument may be a constant or a previously defined variable.)

If we want the first twenty random numbers, we write the program below and we get twenty six-digit decimals. This is illustrated in the following program.

```
READY
10 FOR L = 1 TO 20
20 PRINT RND(0),
30 NEXT L
40 END
RUN
 1.52602E-05     .500092          .500412          1.64799E-03      6.17992E-03
 .522248         .577867          .266971          .901025          .503415
 .411261         .436832          .419642          8.63642E-02      .241408
 .171168         .35434           8.55276E-02      .824103          .674869
READY
RUN
 1.52602E-05     .500092          .500412          1.64799E-03      6.17992E-03
 .522248
```

Note that the second RUN was giving exactly the same "random" numbers as the first RUN. This greatly facilitates the debugging of programs that use the random number generator.

On the other hand, if we want twenty random one-digit integers, we could change line 20 to read

```
20 PRINT INT(10*RND(0)),
```

and we would then obtain

```
0               5                5                0                0
5               5                2                9                5
4               4                4                0                2
1               3                0                8                6
```

We can vary the type of random numbers we want. For example, if we want 20 random numbers ranging from 1 to 9 inclusive, we could change line 20 as shown

```
20 PRINT INT(9*RND(0) + 1);
RUN
 1     5     5     1     1     5     6     3     9     5     4     4
 4     1     3     2     4     1     8     7
```

or we can obtain random numbers which are integers from 5 to 24 inclusive by changing line 20 as in the following example.

```
20 PRINT INT(20*RND(0) + 5);
RUN
 5     15    15    5     5     15    16    10    23    15    13    13
 13    6     9     8     12    6     21    18
```

In general, if we want our random numbers to be chosen from the A integers of which B is the smallest, we would call for INT(A*RND (0) + B).

2.2.3 SGN

The SGN function is one which assigns the value 1 to any positive number, 0 to zero, and -1 to any negative number. Thus SGN(7. 23) = 1, SGN(0) = 0, and SGN(-. 2387) = -1.

2.2.4 DEF

In addition to the standard functions, you can define any other function which you expect to use a number of times in your program by use of a DEF statement. The name of the defined function must be three letters, the first two of which are FN. Hence, you may define up to 26 functions, e. g., FNA, FNB, etc.

The handiness of such a function can be seen in a program where you frequently need the function $e^{-x^2} + 5$. You would introduce the function by the line

```
30 DEF FNE(X) = EXP(-X ↑ 2 + 5)
```

and later on call for various values of the function by FNE(. 1), FNE(3. 45), FNE (A+2), etc. Such definition can be a great time-saver when you want values of some function for a number of different values of the variable.

The DEF statement may occur anywhere in the program, and the expression to the right of the equal sign may be any formula which can be fitted onto one line. It may include any combination of other functions, including ones defined by different DEF statements, and it can involve other variables besides the ones denoting the argument of the function. Assuming FNR is defined by

```
70 DEF FNR(X) = SQR(2 + LOG(X) - EXP(Y*Z)*(X + SIN(2*Z)))
```

and you have previously assigned values to Y and Z, you can ask for FNR(2. 7). You can give new values to Y and Z before the next use of FNR.

The use of DEF is limited to those functions whose value may be computed within a single BASIC statement. However, there are often much more complicated functions or portions of a program which must be calculated at several points within the program. For these operations, the GOSUB statement may be used.

2.3 GOSUB AND RETURN

When a particular part of a program is to be performed more than one time, or possibly at several different places in the overall program, it is most efficiently programmed as a subroutine. The subroutine is entered with a GOSUB statement, where the number is the line number of the first statement in the subroutine. For example,

```
90 GOSUB 210
```

directs the computer to jump to line 210, the first line of the subroutine. The logical end of the subroutine should be a return command directing the computer to return to the earlier part of the program. For example,

```
350 RETURN
```

will tell the computer to go back to the first line numbered greater than 90, and to continue the program there.

The following example, a program for determining the greatest common divisor of three integers using the Euclidean Algorithm, illustrates the use of a subroutine. The first two numbers are selected in lines 30 and 40 and their GCD is determined in the subroutine, lines 200-310. The GCD just found is called X in line 60, the third number is called Y in line 70, and the subroutine is entered from line 80 to find the GCD of these two numbers. This number is, of course, the greatest common divisor of the three given numbers and is printed out with them in line 90.

You may use a GOSUB inside a subroutine to perform yet another subroutine. This would be called "nested GOSUBS". GOSUBS may be nested nine deep. In any case, it is absolutely necessary that a subroutine be left only with a RETURN statement, using a GOTO or an IF-THEN to get out if a subroutine will not work properly. You may have several RETURNs in the subroutine so long as exactly one of them will be used.

```
READY
10 PRINT " A", " B", " C", "GCD"
20 READ A, B, C
30 LET X = A
40 LET Y = B
50 GOSUB 200
60 LET X = G
70 LET Y = C
80 GOSUB 200
90 PRINT A, B, C, G
100 GO TO 20
110 DATA 60, 90, 120
120 DATA 38456, 64872, 98765
130 DATA 32, 384, 72
200 LET Q = INT(X/Y)
210 LET R = X - Q*Y
220 IF R = 0 THEN 300
230 LET X = Y
240 LET Y = R
250 GO TO 200
300 LET G = Y
310 RETURN
 320 END
RUN
 A               B               C               GCD
 60              90              120              30
 38456.          64872.          98765.           1
 32              384             72               8

ERROR 56 IN LINE  20
```

2.4 INPUT

There are times when it is desirable to have data entered during the running of a program. This is particularly true when one person writes the program and enters it into the machine's memory, and other persons are to supply the data. This may be done by an INPUT statement, which acts as a READ statement but does not draw numbers from a DATA statement. If, for example, you want the user to supply values for X and Y into a program, you will type

40 INPUT X, Y

before the first statement which is to use either of these numbers. When it encounters this statement, the computer will type a question mark and wait. The user types two numbers, separated by a comma, presses the CARRIAGE RETURN key and the computer goes on with the rest of the program.

Frequently an INPUT statement is combined with a PRINT statement to make sure that the user knows what the question mark is asking for. You might type

```
20 PRINT "YOUR VALUES OF X, Y, AND Z ARE";
30 INPUT X, Y, Z
```

and the machine will type out

```
YOUR VALUES OF X, Y, AND Z ARE?
```

Without the semicolon at the end of line 20, the question mark would have been printed on the next line.

Data entered via an INPUT statement is not saved with the program. Furthermore, it may take a long time to enter a large amount of data using INPUT. Therefore, INPUT should be used only when small amounts of data are to be entered, or when it is necessary to enter data during the running of the program such as with game-playing programs.

2.5 SOME MISCELLANEOUS STATEMENTS

Several other BASIC statements that may be useful from time to time are STOP, REM and RESTORE. The COM statement, a special feature of HP BASIC, permits transfer of data between programs.

2.5.1 STOP

STOP is entirely equivalent to GO TO xxxx, where xxxx is the line number of the END statement in the program. It is useful in programs having more than one natural finishing point. For example, the following two program portions are exactly equivalent.

```
250 GO TO 999      250 STOP
  .........          ....
340 GO TO 999      340 STOP
  .........          ....
999 END            999 END
```

2.5.2 REM

REM provides a means for inserting explanatory remarks in a program. The computer completely ignores the remainder of that line, allowing the programmer to follow the REM with directions for using the program, with identifications of the parts of a long program, or with anything else that he wants. Although what follows REM is ignored, its line number may be used in a GO TO or IF-THEN statement.

```
100 REM INSERT DATA IN LINES 900-998.  THE FIRST
110 REM NUMBER IS N, THE NUMBER OF POINTS. THEN
120 REM THE DATA POINTS THEMSELVES ARE ENTERED, BY

200 REM THIS IS A SUBROUTINE FOR SOLVING EQUATIONS
    .....
300 RETURN
    .....
520 GOSUB 200
```

2.5.3 RESTORE

Sometimes it is necessary to use the data in a program more than once. The RESTORE statement permits reading the data as many additional times as it is used. Whenever RESTORE is encountered in a program, the computer restores the data block pointer to the first number. A subsequent READ statement will then start reading the data all over again. A word of warning – if the desired data are preceded by code numbers or parameters, superfluous READ statements should be used to pass over these numbers. As an example, the following program portion reads the data, restores the data block to its original state, and reads the data again. Note the use of line 570 to "pass over" the value of N, which is already known.

```
100 READ N
110 FOR I = 1 TO N
120   READ X
    .....
200 NEXT I
    .....
560 RESTORE
570 READ X
580 FOR I = 1 TO N
590   READ X
    .....
```

2.5.4 COM

The COM statement allows one program to store information in memory for retrieval by a subsequent program (only one BASIC program can exist in the system at a given time). The form of the statement is the same as for the DIM statement with the word COM replacing DIM, thus the common area information is accessible only as an array. Care must be taken not to dimension the same array in both a COM and DIM statement. The COM statement must be the first entered and lowest numbered statement of the program.

The common area is a block of contiguous storage elements; two computer words per element. The elements are allotted in the order that the arrays appear in the COM statement; the elements within an array are stored row by row. It is the programmer's responsibility to see that the portions of the common area are accessed properly. Assuming that one program starts with the statement "1 COM A(10), B(3,3)" and another with "1 COM C(5), D(5), F(3,3)", the common area storage elements would be assigned as follows:

Element Position	First Program Reference	Second Program Reference
1	A(1)	C(1)
2	A(2)	C(2)
3	A(3)	C(3)
4	A(4)	C(4)
5	A(5)	C(5)
6	A(6)	D(1)
7	A(7)	D(2)
8	A(8)	D(3)
9	A(9)	D(4)
10	A(10)	D(5)
11	B(1, 1)	F(1, 1)
12	B(1, 2)	F(1, 2)
13	B(1, 3)	F(1, 3)
14	B(2, 1)	F(2, 1)
15	B(2, 2)	F(2, 2)
16	B(2, 3)	F(2, 3)
17	B(3, 1)	F(3, 1)
18	B(3, 2)	F(3, 2)
19	B(3, 3)	F(3, 3)

A reference in the first program to B(1, 1) would access the same element as a reference to F(1, 1) in the second program. If A contained only 9 elements, however, the B(1, 1) and F(1, 1) references would access different elements.

The length of the common area may vary between programs, but for any two programs, information may be transferred only via the portion which is common to both.

If the first program declares "1 COM A(10), B(5, 5)" and the succeeding program contains "1 COM D(10), E(5, 5), F(10)", the values of F would be unpredictable. If the second program contained "1 COM D(10)" only, the contents of B would be destroyed.

2.6 MATRICES

A common and convenient interpretation of doubly subscripted arrays is as matrices. Although you can work out for yourself programs which involve matrix computations, there is a special set of twelve instructions for such computations. They are identified by the fact that each instruction must start with the word 'MAT'. They are

MAT READ A, B, C	Read the three matrices, their dimensions having been previously specified. Data is stored in the matrix row by row.
MAT C = ZER	Fill out C with zeros.
MAT C = CON	Fill out C with ones.
MAT C = IDN	Set up C as an identity matrix.
MAT PRINT A, B;C	Print the three matrices, with A and C in the regular format, but B closely packed.
MAT B = A	Set the matrix B equal to the matrix A.
MAT C = A + B	Add the two matrices A and B.
MAT C = A - B	Subtract the matrix B from the matrix A.
MAT C = A*B	Multiply the matrix A by the matrix B.
MAT C = TRN(A)	Transpose the matrix A.
MAT C = (K)*A	Multiply the matrix A by K. K, which must be in parentheses, may be a formula.
MAT C = INV(A)	Invert the matrix A.

These twelve statements, with the addition of DIM, make matrix computations easier, and in combination with the ordinary BASIC instructions make the language much more powerful. However, the user has to be careful to keep (and to understand) the conventions "built into" the language. We will discuss, below, the individual MAT statements.

The following convention has been adopted for MAT: If in a MAT instruction we have a matrix of dimension M-by-N, the rows are numbered 1, 2, . . . , M, and the columns 1, 2, . . . , N.

The DIM statement may simply indicate what the maximum dimension is to be. Thus, if we write

```
DIM M(20, 35)
```

then M may have up to 20 rows and up to 35 columns. This statement is to save enough space for the matrix, and hence, the only care at this point is that the dimensions declared are large enough to accommodate the matrix. (The assumed dimensions of 10 rows by 10 columns do not apply for a matrix involved in matrix computations.)

The actual dimensions of a matrix are established either when it is set up (by a DIM statement) or when they are defined in one of four MAT statements: MAT READ, MAT – ZER, MAT – CON, or MAT – IDN.
Thus,

```
10 DIM M(20, 7)
----
50 MAT READ M
```

will read a 20-by-7 matrix for M, while

```
50 MAT READ M(17, 30)
```

will read 17-by-30 matrix for M, provided sufficient space has been saved for it by writing, for example,

```
10 DIM M(20, 35).
```

The elements of a matrix are stored by row in ascending locations in memory; two computer words are used for each element. A matrix declared as DIM A(3, 3) will be structured as:

	Columns		
Rows	A(1, 1)	A(1, 2)	A(1, 3)
	A(2, 1)	A(2, 2)	A(2, 3)
	A(3, 1)	A(3, 2)	A(3, 3)

The elements would be stored in the following order:

Element Position	Memory Location	Element
1	m	A(1, 1)
2	m+2	A(1, 2)
3	m+4	A(1, 3)
4	m+6	A(2, 1)
5	m+8	A(2, 2)
6	m+10	A(2, 3)
7	m+12	A(3, 1)
8	m+14	A(3, 2)
9	m+16	A(3, 3)

Given a statement DIM A(M, N), the location of element A(i, j) with respect to the first element, A(1, 1), of the matrix is given by the equation:

$$\text{location } A(1, 1) + 2(M(i-1) + (j-1))$$

The three instructions:

```
MAT M = ZER
MAT M = CON
MAT M = IDN
```

which set up a matrix M with all components zero, all components equal to one, and as an identity matrix, respectively, act like MAT READ as far as the dimension of the resulting matrix is concerned. For example,

```
MAT M = CON(7, 3)
```

sets up a 7-by-3 matrix with 1 in every component, while

```
MAT M = CON
```

sets up a matrix, with ones in every component, according to previously specified dimensions. Thus,

```
10 DIM M(20, 7)
20 MAT READ M(7, 3)
.......
35 MAT M = CON
.......
70 MAT M = ZER(15, 7)
.......
90 MAT M = ZER(16, 10)
```

will first read in a 7-by-3 matrix for M. Then it will set up a 7-by-3 matrix of all ones for M (the actual dimension having been set up as 7-by-3 in line 20.) Next it will set up M as a 15-by-7 all zero matrix. (Note that although this is larger than the previous M, it is within the limits set in 10.) But it will result in an error code in line 90. The limit set in line 10 is 140 components, and in 90 we are calling for 160 components. The original dimensions may be exceeded, providing the total number of components is within the proper limit;

```
90 MAT M = ZER(25, 5)
```

would not yield an error message.

The MAT PRINT statement causes the array elements to be printed row by row across the page. The spacing between row elements is controlled by the use of , and ; in the same manner as for the PRINT statement. Rows containing more elements than can be printed on a line are continued on consecutive lines. Each row is started on a new line and is spearated from the previous row by a blank line. Thus the instruction

```
MAT PRINT A, B; C
```

will cause the three matrices to be printed A and C with five components to a line and B with up to twelve.

Singly subscripted arrays may be interpreted as column nestors. Vectors may be used in place of matrices, as long as the above rules are observed. Since a vector like V(I) is treated as a column vector by BASIC, a row vector has to be introduced as a matrix that has only one row, namely row 1. Thus

```
DIM X(7), Y (1, 5)
```

introduces a 7-component column vector and a 5-component row vector.

A column vector will be printed one element to the line with double spacing between lines. A row vector will be printed in the manner indicated by the form of the statement. For example: if V is a row vector then, "MAT PRINT V" will print the vector V a single element to the line; "MAT PRINT V, " will print V as a row vector, five numbers to the line, while

MAT PRINT V;

will print V as a row vector with up to twelve numbers to the line

MAT B = A

This sets B up to be the same as A provided the dimensions previously assigned to B are the same as those of A.

MAT C = A + B, MAT C = A - B

For these to be legal A, B, and C must have the same dimensions. Instructions MAT A = A±B are legal – the indicated operation is performed and the answer stored in A. Only a single arithmetic operation is allowed so MAT D = A + B - C is illegal but may be achieved with two MAT instructions.

MAT C = A * B

For this to be legal it is necessary that the number of columns in A be equal to the number of rows in B, the number of rows in C be equal to the number of rows in A, and the number of columns in C be equal to the number of columns in B. For example, if A has dimension L-by-M and B has dimension M-by-N then C = A * B must have dimension L-by-N. It should be noted that while MAT A = A + B may be legal, MAT A = A * B will result in nonsense. There is good reason for this. In adding two matrices we may immediately store the answer in one of the matrices; but if we attempt to do this in multiplying two matrices, we will destroy components which would be needed to complete the computation. MAT B = A * A is, of course, legal provided A is a 'square' matrix.

MAT C = TRN(A)

This lets C be the transpose of the matrix A. If A is an M-by-N matrix C must be an N-by-M matrix.

MAT C = (K) * A

The matrix C is the matrix A multiplied by the value of K (i.e., each component of A is multiplied by K to form the components of C). K, which must be in parentheses, may be a number or a formula. MAT A = (K) * A is legal.

MAT C = INV(A)

The number C is the inverse of A. (A must, of course, be a 'square' matrix.) A matrix must not be inverted or transposed into itself.

We close this section with two illustrations of matrix programs. The first one reads in A and B in line 30 and in so doing sets up the correct dimensions. Dimensions

for C are set up in line 35. Then, in line 40, A + A is computed and the answer is called C. Note that the data in line 90 results in A being 2-by-3 and B being 3-by-3. Both MAT PRINT formats are illustrated, and one method of labeling a matrix print is shown.

```
READY
10 DIM A(15,15), B(15,15), C(15,15)
20 READ M,N
30 MAT READ A(M,N), B(N,N)
35 MAT C = ZER(M,N)
40 MAT C = A + A
50 MAT PRINT C;
60 MAT C = A*B
70 PRINT
75 PRINT "A*B ="
80 MAT PRINT C,
90 DATA 2, 3
91 DATA 1, 2, 3
92 DATA 4, 5, 6
93 DATA 1, 0, -1
94 DATA 0, -1, -1
95 DATA -1, 0, 0
99 END
RUN
 2      4      6

 8      10     12


A*B =
-2                -2                -3

-2                -5                -9
```

The second example inverts an N-by-N Hilbert Matrix

```
1       1/2       1/3  .  .  .  1/N
1/2     1/3       1/4  .  .  .  1/N+1
1/3     1/4       1/5  .  .  .  1/N+2
 .       .         .   .  .  .
 .       .         .   .  .  .
 .       .         .   .  .  .
1/N     1/N+1     1/N+2         1/2N-1
```

Ordinary BASIC instructions are used to set up the matrix in lines 50 to 90. Note that this occurs after correct dimensions have been declared. Then a single instruction results in the computation of the inverse, and one more instruction prints it. In this example we have supplied 4 for N in the DATA statement and have made a run for this case.

```
READY
5   REM THIS PROGRAM INVERTS AN N-BY-N MATRIX
10  DIM A(20,20), B(20,20)
20  READ N
30  MAT A = CON(N,N)
40  MAT B = CON(N,N)
50  FOR I = 1 TO N
60  FOR J = 1 TO N
70  LET A(I,J) = 1/(I+J-1)
80  NEXT J
90  NEXT I
100 MAT B = INV(A)
110 PRINT
115 PRINT "INV(A) ="
120 PRINT
125 MAT PRINT B;
190 DATA 4
199 END
RUN

INV(A) =

 16.0019     -120.021      240.049     -140.031

-120.02       1200.22     -2700.52      1680.33

 240.048     -2700.51      6481.2      -4200.77

-140.03       1680.33     -4200.77      2800.49
```

The reader is warned that beyond N = 7 the Hilbert matrix cannot be inverted because of severe round-off errors.

2.7 ERROR CODES

An error message is printed as soon as the error condition is detected. The format is as follows:

ERROR xx IN LINE nn

Error Code	Meaning
1	Statement ends unexpectedly.
2	Input exceeds 71 characters.
3	System command not recognized. (May be missing statement number.)
4	Missing or incorrect statement type.
5	Exponent of number is missing power.
6	Symbol following MAT not recognized.
7	LET statement has no store.
8	Multiple or misplaced COM statement.

9	Missing or incorrect function identifier in DEF.
10	Missing parameter in DEF statement.
11	Missing assignment operator.
12	Missing THEN.
13	Missing or incorrect for-variable.
14	Missing TO.
15	Incorrect STEP in FOR statement.
16	Called routine does not exist.
17	Wrong number of parameters in CALL statement.
18	Missing or incorrect constant in DATA statement.
19	Missing or incorrect variable in READ statement.
20	No closing quote for PRINT string.
21	Missing print delimiter or bad PRINT quantity.
22	Illegal word follows MAT.
23	Missing delimiter.
24	Improper matrix function.
25	No subscript where expected.
26	May not invert or transpose matrix into self.
27	Missing multiplication operator.
28	Improper matrix operator.
29	Matrix may not be both operand and result of matrix multiplication.
30	Missing left parenthesis.
31	Missing right parenthesis.
32	Operand not recognized.
33	Defined array missing subscript part.
34	Missing array identifier.
35	Missing or bad integer.
36	Non -blank characters following statement's logical end.
37	Out of storage during syntax phase.
38	Punched Tape Reader not ready.
39	Doubly defined function.
40	FOR statement has no matching NEXT statement.
41	NEXT statement has no matching FOR statement.
42	Out of storage for symbol table.
43	Array appears with inconsistent dimensions.

44	Last statement is not END.
45	Array doubly dimensioned.
46	Number of dimensions not obvious.
47	Array too large.
48	Out of storage during array allocation.
49	Subscript exceeds bound.
50	Accessed operand has undefined value.
51	Non-integer power of negative number.
52	Zero to zero power.
53	Missing statement.
54	Gosubs nested 1Ø deep.
55	RETURN finds no address.
56	Out of data.
57	Out of storage during execution.
58	Dynamic array exceeds allocated storage.
59	Dimensions not compatible.
60	Matrix operand contains undefined element.
61	Singular or nearly singular matrix.
62	Trigonometric function argument is too large.
63	Attempted square root of negative argument.
64	Attempted log of negative argument.

The following errors are warning only, execution continues.

65	Numerical overflow, result taken to be + or -infinity.
66	Numerical underflow, result taken to be zero.
67	Log of zero taken to be -infinity.
68	EXP overflows, result taken to be +infinity.
69.	Division by zero, result taken to be + or -infinity.
7Ø	Zero raised to negative power, result taken to be +infinity.

To use the BASIC system, you load the tape into the computer, start execution of the system, and begin typing your program when the system types "READY." If desired, the program may also be entered from the Punched Tape Reader.

OPERATING INSTRUCTIONS

Load BASIC using the Basic Binary Loader.

1. Place BASIC binary tape in the Standard Input Unit (e. g., Punched Tape Reader).
2. Set Switch Register to starting address of Basic Binary Loader: 017700
3. Press LOAD ADDRESS.
4. Set Loader switch to ENABLED. (On 2114A: LOADER ENABLE to ON.)
5. Press PRESET.
6. Press RUN.
7. When the computer halts with T-Register containing 102077, the BASIC tape is loaded. Set Loader switch to PROTECTED. (2114A: LOADER ENABLE to NORMAL.)

Set Switch Register to starting address of BASIC:

000100

Press LOAD ADDRESS and Run.

When the system types READY, begin typing program. Terminate each line with a CARRIAGE RETURN. (When the system is ready to accept a new line, it issues a LINE FEED.)

If errors are made while typing the program, they can be corrected by one of the following:

1. To delete one or more characters that have just been typed, press ← for each character, then type in the correct characters.
2. To delete the current line, press ALT MODE or ESC, and type the correct line.
3. To correct a previously typed line, retype the entire line starting with the line number.
4. To delete a previously typed line, type the line number followed by a CARRIAGE RETURN.

CONTROL COMMANDS

There are several commands that may be given to the computer by typing the command at the start of a new line (no line number) and following the command with a CARRIAGE RETURN.

STOP — Stops all operations at once. When the teletypewriter is typing, depressing any key will execute the STOP command. When the system is ready to accept further input, it types "READY".

RUN — Begins the computation of a program.

SCRATCH — Destroys the problem currently being worked on; it gives the user a "clean sheet" to work on. When the system is ready to accept a new program, it types "READY."

LIST — Causes an up-to-date listing of the program to be typed out. †

LIST XXXX — Causes an up-to-date listing of the program to be typed out beginning at line number XXXX and continuing to the end. †

TAPE — Informs the system that the program will be entered through the teletype reader. As the program tape will have line feeds following carriage returns, the feedback of a line feed after each statement will be suppressed to avoid double spacing between lines of the program.

PLIST — Causes an up-to-date copy of the program with leader, trailer to be punched on the High Speed Tape Punch. This tape may be saved and reloaded to execute the program at a later date. ①

PTAPE — Causes the system to read in the program from the Punched Tape Photoreader. ②

① If this command is given to a system which does not have a High Speed Tape Punch, the program is listed on the teletype preceded and followed by blank characters. Therefore to obtain a listing for debugging purposes type LIST, to obtain a copy of the program on paper tape for future use turn on the punch device appropriate to the system and type PLIST.

② If this command is given to a system which does not have a Photoreader, the system will type STOP READY and await further input from the teletype.

† The last few characters of statements whose listing exceeds 72 characters may not show on the listing but they are not lost internally.

HP BASIC provides two additional statements for use in a program.

WAIT

The WAIT statement extends BASIC to allow the introduction of delays into a program. Execution of WAIT (formula) causes the program to wait for the number of milliseconds, up to 32767, specified by the value of the formula. This is not precise because it does not take into account the time required to evaluate the formula.

CALL

The CALL statement is a provision of HP BASIC for interfacing absolute assembly language subroutines, typically input-output drivers, which can be added to the standard system to create specialized configurations. When executing a CALL statement, BASIC transfers control to an absolute assembly language subroutine which has been appended to the standard system. Once this transfer has taken place, the subroutine is in complete control of the computer and is at liberty to alter any part of core including the system itself. To minimize the danger of destroying the system by such an alteration, only those programmers who are proficient in absolute assembly language programming should attempt to append CALL statement subroutines to the standard system.

Subroutines which have been appended to BASIC can be accessed in a BASIC program through a statement of the form:

CALL (<subroutine number>, <parameter list>).

The subroutine number is a positive integer specifying the desired subroutine, if no such numbered subroutine exists the statement will be rejected by the syntax analyzer. The parameters, separated by commas, may be any formulas and their number is dependent upon the subroutine called. As an example, suppose that a subroutine designated by 5 has been appended to the system. Its function is to take readings from an A to D subsystem and store them in an array. The parameters specify the array into which the values are to be inserted, the channel number of the first point to be measured, the setup for the A to D converter and the number of points to be measured. A representative call might be as follows:

```
20 CALL (5,  A[1],  1,  1188,  10)
         ↑   ↑      ↑   ↑      ↑
         |   |      |   |      Number of points
         |   |      |   A to D setup
         |   |      Starting channel number
         |   First element of data array
         Subroutine number
```

In using such statements, it is very important that correct parameters be supplied. Interchanging the first and second parameters could result in the destruction of the core-resident BASIC system, unless special precautions have been taken by the writer of the called subroutine.

PREPARATION OF SPECIAL SYSTEMS

Since subroutines accessed by CALL statements are a part of the BASIC system rather than a part of the user's BASIC program, they may be included on the composite tape produced by PBS. This can be accomplished by following the instructions given in Appendix E except that the absolute assembly binary tape of the subroutines is loaded between steps 2. and 3. The binary tape from step 8. replaces the normal BASIC system tape.

BASIC accesses called subroutines through a table containing linkage information. Entries in the table, one per subroutine, are two words in length. Bits 5-0 of the first word contain the number identifying the subroutine (chosen freely from 1 to 77_8 inclusive) and bits 15-8 contain the number of parameters passed to the subroutine (CALL statements with an incorrect number of parameters will be rejected by the syntax analyzer). The second word contains the absolute address of the entry point of the subroutine (control is transferred via a JSB). Although subroutine numbers need not be assigned in any particular order, all entries in the table must be contiguous. An acceptable auxiliary tape contains the following:

1) An ORG statement to origin the program at an address greater than that of the last word of the BASIC system. The address of this last word + 1 is contained in location 110_8 of the standard BASIC system. Hence, a suitable lower limit for the origin address can be determined by loading BASIC and examining location 110_8.

2) The subroutine linkage table described above.

3) The assembly language subroutines.

4) Code to set the following linkage addresses:

   a) In location 110_8 put the address of the last word + 1 used in the auxiliary tape.

   b) In location 121_8 put the address of the first word of the subroutine linkage table.

   c) In location 122_8 put the address of the last word + 1 of the subroutine linkage table.

Assume that location 110_8 of the standard BASIC system contains 13405_8. An acceptable auxiliary tape could be assembled from the following code:

```
         ORG 13405B
SBTBL    OCT 2406    Subroutine 6 has 5 parameters
         DEF SB6
         OCT 1421    Subroutine 17 has 3 parameters
         DEF SB17
```

```
ENDTB    EQU * + 1
SB6      NOP
         .
         .              Subroutine #6 body
         .
         JMP SB6, I
SB17     NOP
         .
         .              Subroutine #17 body
         .
         JMP SB17, I
LSTWD    EQU * + 1
         ORG 110B
         DEF LSTWD
         ORG 121B
         DEF SBTBL
         DEF ENDTB
         END
```

Acceptable calls to subroutines SB6 and SB17 might be

```
CALL (6, A, B, 1, N*3, SIN(X + Y))
CALL (17, A[1], 5, N)
```

WARNING

Location 111_8 of the standard BASIC system contains the address of the last word of available memory. It is not possible to create a system which requires more space than that existing between the addresses in locations 110_8 and 111_8. Systems using all or most of this space leave very little space for the user of the system.

INTERNAL DESIGN CONSIDERATIONS FOR CALL SUBROUTINES

The parameters of a CALL statement provide the dynamic link between BASIC and the called subroutine. Prior to transferring control to the subroutine, BASIC evaluates the parameters and stacks the addresses of the results. Upon entering the subroutine, the A-register contains the address of this stack (i. e., the address of the addresses of the values of the parameters). The A-register initially points to the address of the first parameter; successively decrementing the A-register causes it to point to successive parameter addresses. A typical situation follows:

17300	3rd parameter address		17302	A-register upon entry to called subroutine.
17301	2nd parameter address	Parameter address list		
17302	1st parameter address			

The parameter addresses passed by BASIC give the subroutine access to values in the BASIC program. The only way a called subroutine can transmit its results to a BASIC program is to store through the address of a parameter.

Transmittal of quantities of data between a BASIC program and a called subroutine is most conveniently handled through arrays. Since only addresses are passed to a subroutine, an array parameter must be an element of the array (in general this would be the first element of the array). When using arrays in this manner, it is important to remember that arrays are stored by rows, and that each element is a floating point number occupying two words. Hence, if an array A has M columns per row, the address of A[I , J] is (address A[1,1] + 2(M(I-1) + (J-1)).

It may be necessary or desirable for a called subroutine to output on the teletype. This may be done by loading a buffer address into the B-register, a character count into the A-register, and executing a JSB 102B, I. The referenced block of core will be interpreted as an ASCII string and output accordingly, followed by a carriage return and line feed.

SYSTEM PROTECTION

Whenever data is transferred from a called subroutine through the address of a parameter, there is a danger that the BASIC system or users program might be destroyed. This situation can arise when parameters are specified incorrectly or insufficient space is allocated in a data array. For example, constants (e.g. 2 or -1.1) in a BASIC program are stored in the program as they appear, therefore storing through the address of a constant parameter will change the actual constant in the CALL statement. A subsequent execution of that statement may lead to strange results. A parameter that is an expression (e.g. A & B or NOT A AND B) will be evaluated and the result placed in a temporary location. Since the parameter address references this temporary, storing into it will not harm the BASIC system or program. However, the value stored there is lost to the BASIC program. If a called subroutine stores more values in an array than the array can hold, the resulting overflow of data may destroy the BASIC system or program. To provide some protection against these dangers, users of CALL statements should be cautioned against the danger of using unsuitable parameters in CALL statements (especially against using a simple variable or a constant where an array element is expected). Also, when using arrays as parameters it is good practice to include the dimensions of the array as additional parameters to allow a means of checking within the subroutine.

A really effective measure of protection is available at the cost of additional programming effort. BASIC contains sets of pointers delimiting the areas of memory within which different types of parameters exist. By checking parameter addresses against these bounds, the subroutine can verify that they are of the expected type. If X represents the parameter address, the following applies:

a) Constant parameter (112B) < X < (113B)

b) Simple variable parameter (116B) < X < (117B)

c) Array parameter 1) In common storage (110B) < X < (112B)
2) Not in common storage (113B) < X < (115B)

d) Expression parameter (115B) < X < (1120B)

where (112B) etc. means the contents of location number octal 112.

HP BASIC extends the concept of the formula to include logical operators. Included are the familiar relational operators =, # (not equal), <, >, <= (less than or equal), and >= (greater than or equal) and the Boolean operators AND, OR, and NOT. With the exception of NOT, which takes the following operand as its single argument, all of these are binary operators. In a formula the binary operators have a lower priority than any of the arithmetic operators ↑, *, /, +, and -. Among the binary operators the priority in ascending order is OR, AND, and the relational operators (all of equal priority). NOT has the same priority as the unary + and unary -. Thus

```
NOT A + B = C OR SGN(K) AND SGN(J)
```

is equivalent to

```
(((NOT A) + B) = C) OR (SGN(K) AND SGN(J)).
```

The relational operators take algebraic numbers as arguments and return 0 (false) or 1 (true) according to the relationship existing between their arguments. Thus 3 < 2 evaluates to 0 and A # 0 evaluates to 1 if A has a non-zero value. The Boolean operators consider their arguments as zero (false) or non-zero (true) and return 0 or 1 as follows:

AND			OR			NOT	
Arg 1	Arg 2	Result	Arg 1	Arg 2	Result	Arg	Result
non-zero	non-zero	1	non-zero	non-zero	1	non-zero	0
non-zero	zero	0	non-zero	zero	1	zero	1
zero	non-zero	0	zero	non-zero	1		
zero	zero	0	zero	zero	0		

Thus 3 and 1 evaluates to 1 while NOT -3 AND 0 evaluates to 0. It is important to realize that A < B < C is not equivalent to A < B AND B < C. If A = -3, B = -2, and C = 1/2 the former evaluates as (-3 < -2) < 1/2 or 0 (false) whereas the latter evaluates as (-3 < -2) AND (-2 < 1/2) or 1 (true).

The syntax of HP BASIC is described in Backus Normal Form through the use of several metalinguistic symbols. Quantities within < and > are metalinguistic variables representing a syntactic class. The symbol "::" means "is defined as" and connects the metalinguistic variable on the left with its definition on the right. Multiple definitions of a metalinguistic variable are separated by the symbol "|", meaning "or". All capital letters and symbols not enclosed in < and > are actual characters as they appear in the language (e. g., RESTORE or <integer>.<integer>). Uncapitalized letters represent English language expositions such as carriage return. Juxtaposition of quantities in a definition implies juxtaposition in the language; all BASIC punctuation appears explicitly.

Example: <integer>::=<digit> | <integer><digit> explains that an <integer> is either a <digit> or an <integer> immediately followed by a <digit>. (Remember that blanks in BASIC only count within a character string, so that 1 23 is the same as 123.) It is easy to see that an integer begins with a digit and absorbs digits to its right one by one until it finds a non-digit character.

<basic program>::= <program statement> | <basic program> <program statement>[1]

<program statement>::= <sequence number> <basic statement> carriage return

<sequence number>::= <integer>[2]

<basic statement>::= <let statement> | <dim statement> | <com statement> |
<def statement> | <rem statement> | <go to statement> |
<if statement> | <for statement> | <next statement> | <gosub statement> |
<return statement> | <end statement> | <stop statement> |
<wait statement> | <call statement> | <data statement> |
<read statement> | <restore statement> | <input statement> |
<print statement> | <mat statement>

<let statement>::= <let head> <formula>

<let head>::= LET <variable> = | <let head> <variable> =

<formula>::= <conjunction> | <formula> OR <conjunction>

<conjunction>::= <boolean primary> | <conjunction> AND <boolean primary>

<boolean primary>::= <arithmetic expression> |
<boolean primary> <relational operator> <arithmetic expression>

```
<arithmetic expression>::= <term>|<arithmetic expression> + <term>|
            <arithmetic expression> - <term>
<term>::= <factor>|<term> * <factor>|<term>/<factor>
<factor>::= <primary>|<sign><primary>|NOT <primary>
<primary>::= <operand>|<primary>    <operands>
<relational operator>::= >|<|>=|<=|=|#
<operand>::= < variable>|<unsigned number>|<system function>|
            <function>|<formula operand>
<variable>::= <simple variable>|<subscripted variable>
<simple variable>::= <letter>|<letter><digit>
<subscripted variable>::= <array identifier><subscript head>
            <subscript><right bracket>
<array identifier>::= <letter>
<subscript head>::= <left bracket>|<left bracket><subscript>,
<subscript>::= <formula>
<letter>::= A|B|C|D|E|F|G|H|I|J|K|L|M|N|O|P|Q|R|S|T|U|V|W|X|Y|Z
<digit>::= 0|1|2|3|4|5|6|7|8|9
<left bracket>::= (|[
<right bracket>::= )|]
<sign>::= +|-
<unsigned number>::= <decimal part>|<decimal part><exponent>
<decimal part>::= <integer>|<integer>.|<integer>.<integer>|. <integer>
<integer>::= <digit>|<integer><digit>
<exponent>::= E<integer>|E<sign><integer>
<system function>::= <system function name><parameter part>
<system function name>::= SIN|COS|TAN|ATN|EXP|LOG|ABS|SQR|INT|RND|SGN
<parameter part>::= <left bracket><actual parameter><right bracket>
<actual parameter>::= <formula>
<function>::= FN<letter><parameter part>
<formula operand>::= <left bracket><formula><right bracket>
<dim statement>::= DIM <formal array list>
<formal array list>::= <formal array>|<formal array list>, <formal array>
<formal array>::= <array identifier><formal bound head><formal bound>
            <right bracket>
<formal bound head>::= <left bracket>|<left bracket><formal bound>,
```

<formal bound>::= <integer>[3]

<com statement>::= COM <formal array list>

<def statement>::= DEF FN<letter> <left bracket> <formal parameter>
<right bracket>= <formula>

<formal parameter>::= <simple variable>

<rem statement>::= REM<character string>

<character string>::= <character> | <character string> <character>

<character>::= any teletype character except carriage return, alt mode, escape,
rubout, or line feed

<go to statement>::= GO TO<sequence number>

<if statement>::= IF<formula> THEN <sequence number>

<for statement>::= <for head> | <for head> STEP <step size>

<for head>::= FOR <for variable>= <initial value>TO<limit value>

<for variable>::= <simple variable>

<initial value>::= <formula>

<limit value>::= <formula>

<step size>::= <formula>

<next statement>::= NEXT <for variable>

<gosub statement>::= GOSUB <sequence number>

<return statement>::= RETURN

<end statement>::= END

<stop statement>::= STOP

<wait statement>::= WAIT <parameter part>

<call statement>::= CALL<call head> <right bracket>

<call head>::= <left bracket> <driver number> | <call head>, <actual parameter>

<data statement>::= DATA <constant> | <data statement>, <constant>

<constant>::= <unsigned number> | <sign> <unsigned number>

<read statement>::= READ <variable list>

<variable list>::= <variable> | <variable list>, <variable>

<restore statement>::= RESTORE

<input statement>::= INPUT <variable list>

<print statement>::= <print head> | <print head> <print formula>

<print head>::= PRINT | <print head> <print part>

<print part>::= <string> | <string> <delimiter> | <print formula> <delimiter> |
<print formula> <string> | <print formula><string> <delimiter>

<string>::= "<character string>"[4]

<delimiter>::= , | ;

<print formula>::= <formula> | TAB <parameter part>

<mat statement>::= MAT <mat body>

<mat body>::= <mat read> | <mat print> | <mat replacement>

<mat read>::= READ <actual array> | <mat read>, <actual array>

<actual array>::= <array identifier> | <array identifier><bound part>

<bound part>::= <actual bound head> <actual bound> <right bracket>

<actual bound head>::= <left bracket> | <left bracket> <actual bound>,

<actual bound>::= <formula>

<mat print>::= PRINT <mat print part> | PRINT <mat print part> <delimiter>

<mat print part>::= <array identifier> | <mat print part> <delimiter> <array identifier

<mat replacement>::= <array identifier>= <mat formula>

<mat formula>::= <array identifier> | <mat function> | <array identifier> <mat operato
<array identifier> | <formula operand>* <array identifier>

<mat function>::= <mat initialization> | <mat initialization> <bound part> |
INV <array parameter> | TRN <array parameter>

<mat initialization>::= ZER | CON | IDN [5]

<array parameter>::= <left bracket> <array identifier> <right bracket>[6]

<mat operator>::= + | - | * [7]

(1) The <com statement>, if any exists, must be the first statement presented and have the lowest sequence number.
(2) A sequence number may not exceed 9999 and must be non-zero.
(3) A formal bound may not exceed 255 and must be non-zero.
(4) Strings may not contain the quote character (").
(5) A <bound part> for an IDN must be doubly subscripted.
(6) An array may not be inverted or transposed into itself.
(7) An array may not be replaced by itself multiplied by another array.

The Prepare BASIC System Program prepares a composite binary tape containing configured system input/output drivers, the significant locations in the system linkage area and, optionally, the BASIC compiler.

PBS is an absolute program containing unconfigured teletype, photo reader and punch drivers. The BASIC compiler will be included on the composite tape if it is loaded along with PBS by the Binary Loader.

When initiated, PBS requests I/O assignments for the teletype, photo reader and punch, configures the drivers in accordance with these assignments, and punches a binary tape containing the configured drivers and the BASIC compiler, if loaded. Multiple copies of this tape may be obtained.

OPERATING PROCEDURES FOR PBS

The system on which the composite tape is prepared must have a teletype ASR 33 or 35 in the same I/O channels as that of the system on which the compiler is to run. The tape is prepared in the following manner:

1. Load PBS using the Binary Loader.
2. Load the BASIC compiler, if desired.
3. Set the switch register to 000002. Press Load Address.
4. Set switches 5-0 of the switch register to the lower numbered channel assigned to the teletype.
5. Press Run.
6. PBS outputs the following request on the teletype:

   PHOTO READER I/O ADDRESS?

   Respond by inputting via the teletype keyboard the I/O channel number assigned to the photoreader followed by a carriage return (CR) . If there is no photo-reader, type a (CR) only.
7. PBS outputs the following request on the teletype:

   PUNCH I/O ADDRESS?

   Respond by inputting via the teletype keyboard the I/O channel number assigned to the punch followed by a (CR) . If there is no punch, type a (CR) only.

8. Preparatory to punching the composite tape, PBS inquires if there is a high speed punch on the system, which is being used to prepare the tape, by outputting the request:

   SYSTEM DUMP I/O ADDRESS?

   a) If there is a high speed punch on the system, input its I/O channel number on the keyboard following by a (CR) . PBS then proceeds to punch the composite tape on the high speed punch.

      [Note if the preparation is performed on the computer on which BASIC is to run, the punch address given in 8 will be the same as that given in 7.]

   b) If there is no high speed punch on the system, input a (CR) only. PBS prints:

      TURN ON TTY PUNCH, PRESS RUN

      and halts the computer with 102011 showing on the T-register.

   Turn on the TTY punch as instructed. When Run is pressed, PBS will proceed to punch the composite tape on the TTY punch.

9. When punching is complete, PBS will halt the computer with 102077 showing on the T-register. Further copies of the tape may be obtained by pressing Run after such a halt.

   The following error conditions are detected by PBS:

   1. If, in step 4, switches 5-0 of the switch register are set to a value less than 10_8, PSB will halt the computer with 102055 showing on the T-register. To recover, set the switch register to the correct number and press Run.

   2. If in steps 6, 7, 8 a number less than 10_8 or greater than 77_8 is input PSB will output the message:

      INVALID I/O ADDRESS

      To recover, input the correct number via the keyboard.

   3. A channel number may consist only of two digits, no preceding or trailing blanks or other characters.

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