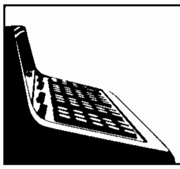
MODEL

30

HEWLETT-PACKARD CALCULATOR

BAMP 30 PAC
VOLUME NO. 1

HEWLETT hp PACKARD



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Chapter Titles

Introduction

This manual explains how to use Bamp '30, a software package for frequency-domain analysis of linear electronic circuits. Bamp is a broad-band simulator that uses two-ports for basic building blocks. To analyze a circuit, you must decompose it into a collection of interconnected two-ports and then describe this circuit decomposition to Bamp. The reader, impatient to see how this is done, should turn immediately to Chapter 6, which contains a number of examples worked out in complete detail.

A convention used throughout this manual is that quantities in square brackets [ ] are optional inputs. This convention is consistent with the Hewlett-Packard 9830A Calculator Operating and Programming Manual, HP part number 09830-90001.

Chuck Holmes
Hewlett-Packard

Model 30 System Configuration

MODEL 30 CALCULATOR

☐ 1760 Words RWM, Basic Calculator
☐ 3808 Words RWM, Option 275
☒ 7904 Words RWM, Option 276

ROMS

Plotter Control ______
String Variables ______
Advanced Programming 1 ______
______ ______

PERIPHERALS	SELECT CODE
☐ 9860A Card Reader	______
☐ 9861A Typewriter	______
☒ 9862A Plotter	______
☐ 9863A Paper Tape Reader	______
☐ 9864A Digitizer	______
☐ 9865A Cassette Memory	______
☒ 9866A Thermal Page Printer	______
☐ 9867 Mass Memory Drive (Unit No.)	______
☐ ______	______
☐ ______	______
☐ ______	______
☐ ______	______
☐ ______	______

Software Configuration

Description	Part Number	Revision
Complete Pac	09830-71103	A
Manual	09830-71102	A
Program Cassette	09839-71102	A
BAMPDF Cassette	09839-71103	A
DEV Data Cassette	09839-71104	A

BAMP 30 Basic Analysis and Mapping Program

DESCRIPTION:

Bamp '30 is a collection of programs for obtaining the frequency-domain response of linear electronic circuits that can be built up by interconnecting two-ports. (Suffix '30 distinguishes the 9830A implementation from other implementations or closely related programs that run on time-sharing computer systems and other calculators.) It is also correct to think of Bamp as a broad-band circuit simulator.

Bamp is a two-port program. This means

1. elementary two-ports are used as basic building blocks, and
2. the overall or composite circuit built up by Bamp is in turn a two-port.

The scattering or S-matrix for the overall circuit is the first result of any analysis performed by Bamp. This scattering matrix is stored in the 9830A memory as a function of frequency and can be used to compute, print, and plot numerous additional outputs including

1. G-, H-, Y-, and Z- matrices for the overall circuit.
2. Stability factor, maximum available gain, and source and load reflections for achieving maximum available gain.
3. Delay.
4. Transducer gain for arbitrary source and load reflection coefficients.
5. Mapping of load impedance onto the plane of the input reflection coefficient and of the source impedance onto the plane of the output reflection coefficient.

In addition to mapping load and source impedances onto input and output reflection coefficient planes, Bamp can also be used to map an internal impedance onto the plane of any one of the overall S-parameters.

The inputs to Bamp are:

1. Circuit description consisting of
    - component two-ports, parameter values, and interconnections
    - one explicit output request (optional) (the computed S-matrix is the default output)
    - optional units and program parameters (default units are Gigahertz for frequency, ohms for resistance, nanohenrys for inductance, picofarods for for capacitance, and centimeters for length)
2. Frequencies

Elementary two-ports available for building up a composite circuit include resistances; inductances; capacitances; combinations of R, L, and C; transformers; gyrators; ideal linear amplifiers; a TEM transmission line; and a simple wave guide model. In addition to these standard elements, it is possible to include any linear element or component for which you have one- or two-port data, either measured, calculated, or hypothetical.

The size circuit that Bamp '30 can handle is determined by the following constraints:

1. There can be at most 60 component two-ports.
2. The total number of two-port parameters cannot exceed 150.

A circuit using nothing but single-parameter two-ports can include the maximum of 60 two-ports. At the other extreme, a circuit containing nothing but TEM lines is limited to a maximum of 25 two-ports, since each transmission line has six parameters.

The maximum number of frequencies allowed in any one run is twenty (20). However, a succession of analyses can be performed using different frequencies in different runs. Negative frequencies are acceptable.

The topological constraints are those imposed by Bamp's two-port nature. To use Bamp to analyze a circuit it must be possible to build up that circuit by interconnecting two-ports.

Full-precision accuracy is used in all calculations required to build up the overall circuit. However, split-precision accuracy is used for parameter values.

METHODS:

Appendix A describes the method of analysis using references listed below.

ACKNOWLEDGEMENTS:

Bamp '30 as well as the original version for time-sharing computers were developed by Chuck Holmes, formerly of the Hewlett-Packard Microwave Division. Initial discussions with Nick Kuhn, under whose supervision the work was started, were valuable. Extensive technical discussions with Luiz Peregrino were important throughout the development of Bamp and are gratefully acknowledged.

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Chapter I

USER INSTRUCTIONS

CHAPTER 1
USER INSTRUCTIONS

1.1 Introduction

Bamp is a two-port program. This means

- Bamp builds up an overall or composite circuit by combining elementary two-ports
- The composite circuit built up by Bamp is in turn a two-port.

Your task as a user is to describe your circuit to Bamp as an interconnection of two-ports, to specify the frequencies at which analysis is to be performed, and to request the outputs you desire.

The functions performed by Bamp are suggested by the block diagram in Fig 1.1.1. Different sub-programs are required to perform each of these functions. The entry program, the one that accepts the circuit description is on file 0 of the Bamp cassette. All other programs are loaded and run under program control.

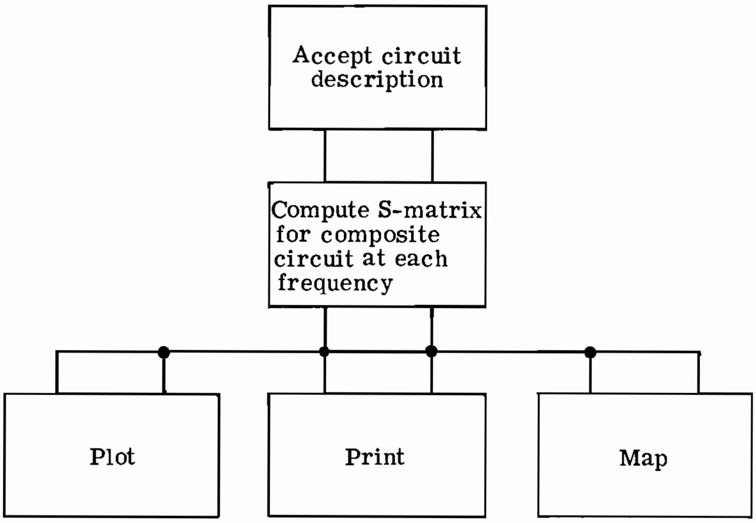


Fig 1.1.1 Block diagram showing functions performed by Bamp.

The circuit description consists of the following:

- names of component two-ports selected from Bamp's catalog of two-ports, parameter values, and connections
- auxiliary operations that expand the catalog of two-ports, if these operations are used
- optional units and program parameters, if any
- initial output request.

The following features simplify the task of supplying a circuit description.

- free format input
- self-contained editing capability
- provision for loading from a circuit cassette once the circuit has been typed in and stored on a cassette

The remainder of this chapter tells how to prepare a circuit description and contains detailed instructions for using Bamp. Sections 1.2 and 1.3 present Bamp's catalog of two-ports and describe two-port connections. Auxiliary operations are discussed in section 1.4. Default and optional units are tabulated in section 1.5. There are three program parameters. One of these, the reference impedance, is discussed to some extent in section 1.6 and in greater detail in Appendix A. The other two program parameters relate to mapping and are discussed in Chapter 2, which is devoted to mapping. Available outputs are listed in section 1.7. The procedure for specifying frequencies is outlined in section 1.8. After these preliminaries come what are perhaps the two most important sections in this chapter. Section 1.9 uses a number of circuits to illustrate circuit decomposition into component two-ports and preparation of the circuit description. Many of these circuits appear as completely worked out examples in Chapter 6, and appropriate references to these examples are given in section 1.9. Section 1.10 provides detailed, step-by-step instructions for using Bamp. Section 1.11 explains how to store a circuit on a circuit cassette.

1.2 Catalog of Two-ports

There are two types of two-ports in Bamp's catalog of two-ports. The first type, hereafter referred to as Type I, consists of two-ports for which Bamp computes a matrix representation. Common electric circuit elements such as resistances, inductances, capacitances, transformers, transmission lines, ideal linear amplifiers, etc. are Type I two-ports. Each of these is identified by a unique name and most require a parameter value or values for complete specification. Type II two-ports differ in that a matrix representation, which can be either an S-, G-, H-, Y-, or Z- matrix, is supplied to Bamp; Bamp does not compute the matrix representation. The name applied to all Type II two-ports is DEV k, $k = 1, 2, 3$. The identifying number k is necessary to distinguish between two or more different Type II two-ports in the same circuit. The matrix representation supplied to Bamp can be measured, computed, or hypothetical, and the actual two-port represented by DEV k can be active or passive. DEV k is commonly used to represent a microwave transistor in which case the matrix representation usually consists of measured S-parameters. At lower frequencies a transistor might be represented by means of measured Y-parameters, for example.

Table 1, which is a fold-out at the end of this chapter lists all of Bamp's two-ports. Brief discussions of these two-ports are presented below. It is understood that port 1 is to the left and port 2 is to the right (see Appendix A.1).

1.2.1 Type I Two-ports

Except for the two-port DEV k, all of the two-ports in Table 1 are Type I two-ports. Most of the Type I two-ports require one or more parameter values for a complete specification. The exceptions are the fixed two-ports and the two-ports used for mapping. The general form for including any Type I two-port in a circuit description is

name *parameter value(s)* *connection*

where *connection* specifies the interconnection with the remainder of the circuit and is discussed in section 1.3.

The following comments apply to all Type I two-ports:

1. *Connection* is an optional input. The cascade connection is assumed if no other is specified (see section 1.3).
2. In a circuit description, the order of *parameter value(s)* and *connection* can be reversed.
3. The final P in the names RP, LP, CP, PTCP, STCP indicates that the element (resistance, inductance, capacitance, or RLC combination) is in parallel with the ports. The element is a shunt element.

4. The final S in the names RS, LS, CS, PTCS, STCS indicates that the element (resistance, inductance, capacitance, or RLC) is a series element.

5. The parameter for the ideal transformer can be supplied as a single member, which is interpreted as the ratio of port 2 to port 1 turns, or alternatively as two numbers which are interpreted as real impedance levels at ports 1 and 2. For example, two equivalent ways of specifying the same transformer are

   TF 2   TF 50 200

   Negating the turns ratio reverses the polarity.

6. The gyrator parameter is R where

$$V_1 = RI_2$$
$$V_2 = -RI_1$$

   (Voltage and current definitions are standard, but are shown in Appendix A.1.)

7. The parameters for the RLC circuits must be in the order *r l c*.

8. The names of the controlled sources mean

   Voltage Dependent Voltage Source
   Voltage Dependent Current Source
   Current Dependent Voltage Source
   Current Dependent Current Source

   Two numbers, *re gain* and *im gain*, are normally supplied as parameters. However, only one number is acceptable, in which case the second parameter *im gain* is set equal to zero.

9. The two-port TL is a TEM (transverse electro-magnetic wave) model of a transmission line. The parameters are

$$\sqrt{L/C} \qquad \text{LEN} \qquad V_r \qquad R \qquad G$$

   where

   L = series inductance/unit length
   C = shunt capacitance/unit length
   R = series resistance/unit length
   G = shunt conductance/unit length
   V_r = relative phase velocity

   The first parameter, $\sqrt{L/C}$ is the characteristic impedance, if the line is lossless ($R = G = 0$). In this manual the symbol Z_0 is often used for $\sqrt{L/C}$ for a lossless line.

   If the line is lossless, then R and G can be omitted as inputs. Conversely, Bamp assumes a lossless line if R and G are omitted. If a non-zero value is given for R, then Bamp prompts for a reference frequency, the frequency at which R has the specified value. Here you have an option. You can enter the reference frequency f_{REF}, or you can enter 0. If you enter non-zero f_{REF}, then at the computation frequency f Bamp accounts for skin effect according to

$$R \longleftarrow R\sqrt{f/f_{REF}}$$

If you enter 0 for the reference frequency, then R is treated as a constant and skin effect is ignored.

10. The two-port WG is a simple model for a wave guide. The parameters are

$$f_c \qquad \text{LEN}$$

where f_c is the cut-off frequency. The model is a single-mode model, and the wave guide is assumed to be air-filled, lossless, and matched at all frequencies.

11. TEL can replace any parameter value. This tells Bamp that you want to supply the parameter value from the keyboard just prior to analysis and is useful for manually changing a parameter from run to run in a sequence of analyses. A circuit can contain any number of TELS. TEL's are used in several of the examples in Chapter 6.

12. OPE and SHO are ideal open and short circuits, and THRU is an ideal thru section.

13. MAPP and MAPS are used for mapping and are discussed in Chapter 2.

1.2.2 Type II Two-ports (DEV 1, DEV 2, DEV 3)

A Type II two-port is a two-port for which a matrix representation either S, G, H, Y, or Z is supplied to Bamp. There are two ways in which this can be done.

1. The S-, G-, H-, Y-, or Z- matrix can be typed in when requested by Bamp.
2. The matrix representation can be supplied from a DEV data cassette previously set up by the program Bampdf (see Chapter 4).

Which method is used is determined by information supplied in the circuit description. The general form of the input for a Type II two-port is

DEV *k* [*DEV data file name*] *connection*
k = 1, 2, 3

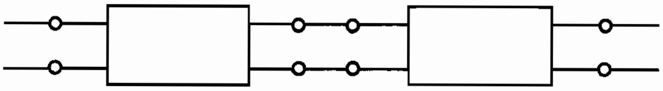
If the name of a DEV data file is included, then Bamp expects to read the matrix representation from a DEV data cassette, and you are directed to insert the cassette when it is needed (see Example 6.4.1 in Chapter 6). If the name of a DEV data file is not included, then Bamp asks you to type in the matrix representation when it is needed (see Example 6.4.4 of Chapter 6).

As is true for Type I two-ports, so also for Type II two-ports, *connection* is an optional input. If *connection* is included, then the order of DEV *data file name* and *connection* can be reversed.

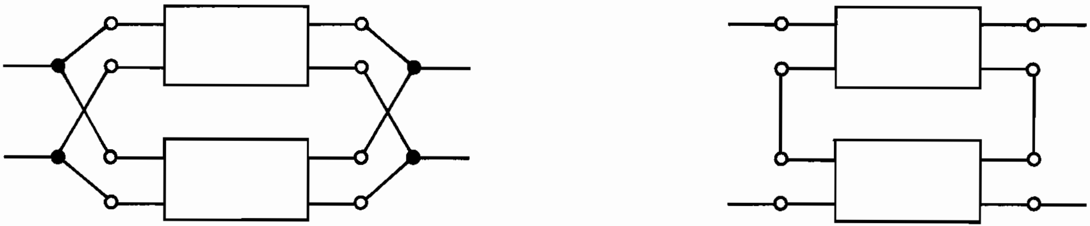
It is not necessary to supply DEV data at each analysis frequency, since Bamp interpolates if necessary, assuming that it is possible to do so. Interpolation is parabolic, if the analysis frequency is surrounded by three data points, but linear if surrounded by only two. DEV data are not extrapolated. A message is printed if interpolation is not possible (section Chapter 3, section 3.3.1).

1.3 Two-port Connections

There are five ways in which two two-ports can be connected, and these are shown in Fig 1.3.1. Bamp mnemonics are in parenthesis.



cascade (CAS)



parallel (PAR)

series (SER)

paralled-series (PARSER)

series-parallel (SERPAR)

Fig 1.3.1 Two-port connections

The following notes are applicable.

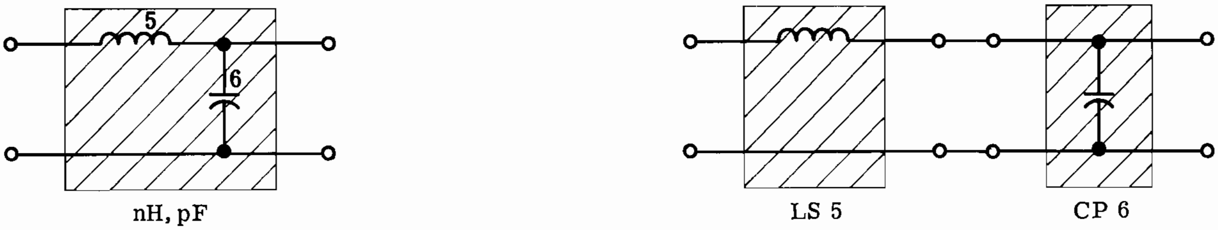
1. Detailed mathematical analyses of these connections are provided in Ref 1, pp. 145-151. A less detailed discussion is provided in Appendix A.2.
2. In a circuit description *connection* is one of the mnemonics

   CAS PAR SER PARSER SERPAR

3. Fig 1.3.2 provides a simple example of the CAS connection of two two-ports.
   The circuit description is

   LS 5 CP 6 CAS

   However, CAS can be omitted, since Bamp uses CAS as a default connection.



a) circuit

b) CAS connection of component two-ports

Fig 1.3.2 CAS connection of two-ports

4. As suggested by the circuit in Fig 1.3.2, the order of two-ports in a circuit description implies the sequence in which the two-ports are combined. Bamp builds up a cascade chain from left to right.

1.4 Auxiliary Operations

There are a total of five auxiliary operations. They are:

- HOLD *k*
- SER *k*
- SHU *k*
- CIR ± *k*
- USE ± *k*

where *k* is a reference number between 1 and 5. *k* can also be thought of as identifying a storage location. There are a total of five storage locations for those operations. The operations HOLD *k*, SER *k* , SHU *k* , and CIR ± *k* cause a two-port to be built up and to be transferred to the storage location *k* . USE ± *k* fetches the two-port from storage location *k* for use just as any other two-port is used. (Here the terminology is not precise. It would be more accurate to say that the action of HOLD *k* , SER *k* , SHU *k* , and CIR ± *k* is to form an S-matrix representation of a certain two-port and to transfer this matrix to array *k* .)

The following terminology is useful for explaining the auxiliary operations

- two-port in working space
- two-port in storage location *k*

In the beginning, the working space and the five storage locations are all empty. Bamp then builds up a composite two-port in working space. If HOLD *k* , SER *k* , SHU *k* , or CIR ± *k* is encountered, then operations are performed as explained below, and the result is transferred to storage location *k* . Working space is then cleared and a new composite two-port is built up as Bamp continues to execute.

1.4.1 HOLD *k*

The result is that shown in Fig 1.4.1.

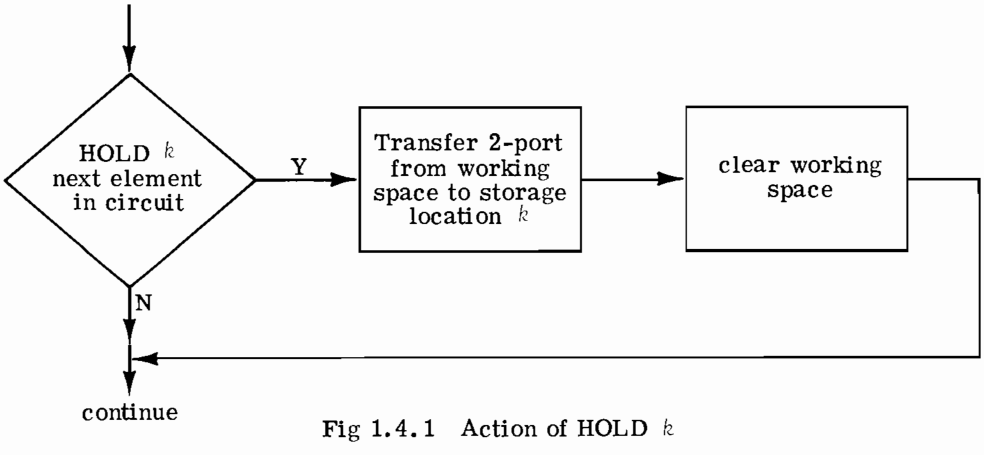


Fig 1.4.1 Action of HOLD *k*

1.4.2 SER *k*

Figure 1.4.2 shows what SER *k* does

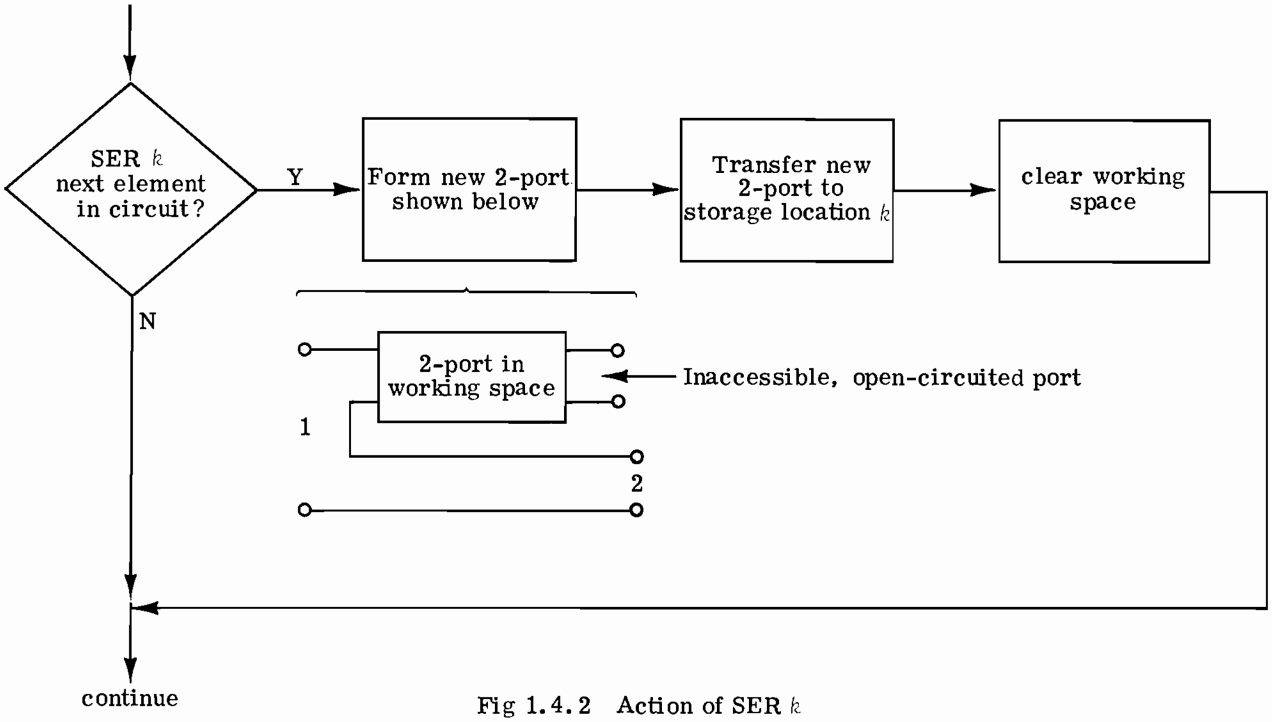


Fig 1.4.2 Action of SER *k*

In words, SER *k* causes three things to happen.

1. A new two-port is formed. This new two-port consists of an impedance in series with the ports. This series impedance is equal to the input impedance of the two-port in working space with the output port open-circuited.
2. The new two-port is transferred to storage location *k*.
3. Working space is cleared.

1.4.3 SHU *k*

Figure 1.4.3.1 depicts the action of SHU *k* .

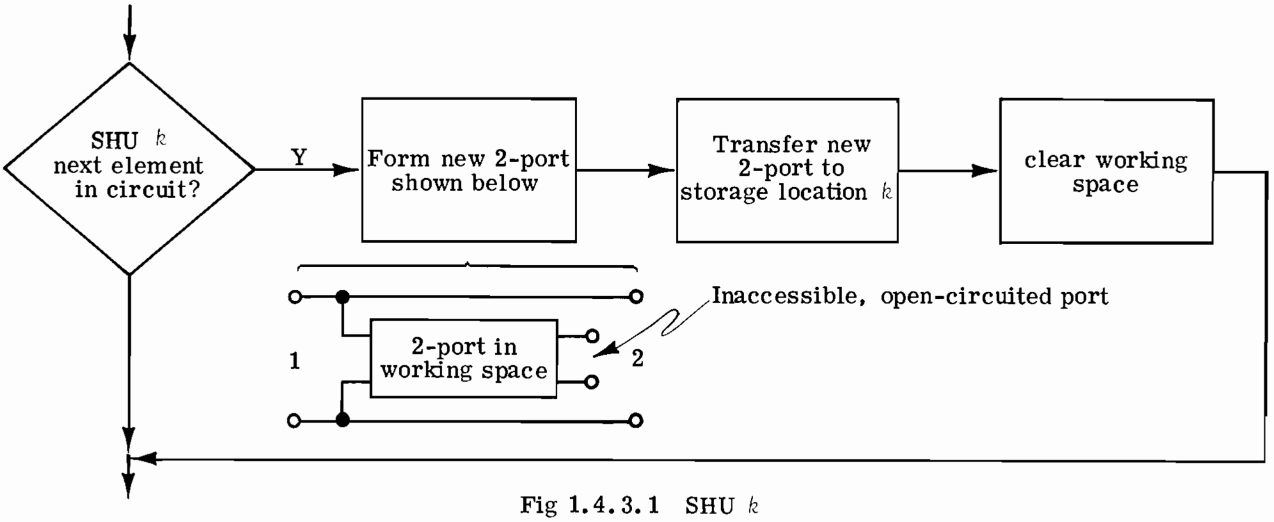


Fig 1.4.3.1 SHU *k*

SHU *k* is very much like SER *k*. The only difference is that the new two-port formed by SHU *k* has a shunt impedance rather than a series impedance.

SHU *k* is commonly used to model bias stubs for microwave transistor amplifiers. An example is given in section 1.4.6.1.

1.4.4 CIR ± *k*

CIR ± *k* connects port 1 of the two-port in working space to port 3 of an ideal, three-port circulator as shown in Fig 1.4.4. CIR - *k* differs from CIR *k* only in that the direction of transmission is reversed.

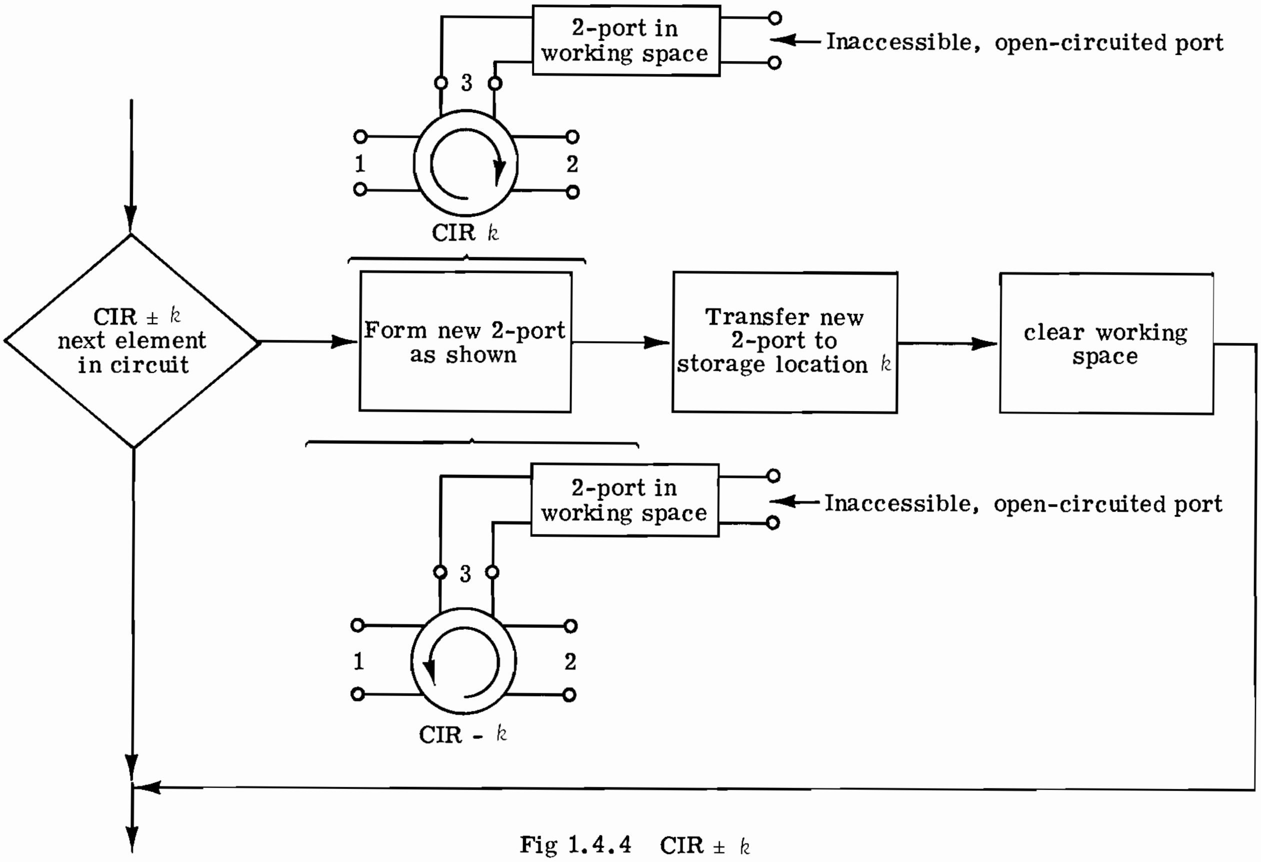


Fig 1.4.4 CIR ± *k*

CIR ± *k* can be used to model an isolator as shown in section 1.4.6.3. Another use is in modeling reflection type, non-reciprocal amplifiers as illustrated in section 1.9.5.

1.4.5 USE ± *k*

USE *k* fetches the two-port in storage location *k* and builds it into the composite two-port in working space. USE - *k* does the same, except that ports 1 and 2 of the stored two-port are interchanged before it is built into the composite circuit. That is USE - *k* causes the stored two-port to be turned end-for-end before it is brought into the composite circuit (see section 1.9.6 for an example of USE - *k*).

Both USE *k* and USE - *k* leave the stored two-port unaffected. Let us say that a two-port is built up and stored by HOLD 2. This two-port can be brought back into the composite two-port any number of times, either as USE 2 or as USE -2, unless the stored two-port is replaced by a subsequent SER 2, SHU 2, or CIR ± 2.

All storage locations as well as the working space are cleared prior to building up a composite circuit whether it is a completely new circuit or the same circuit at a different frequency.

Strictly speaking, USE ± *k* requires a connection for complete specification and the form is

USE ± *k* *connection*

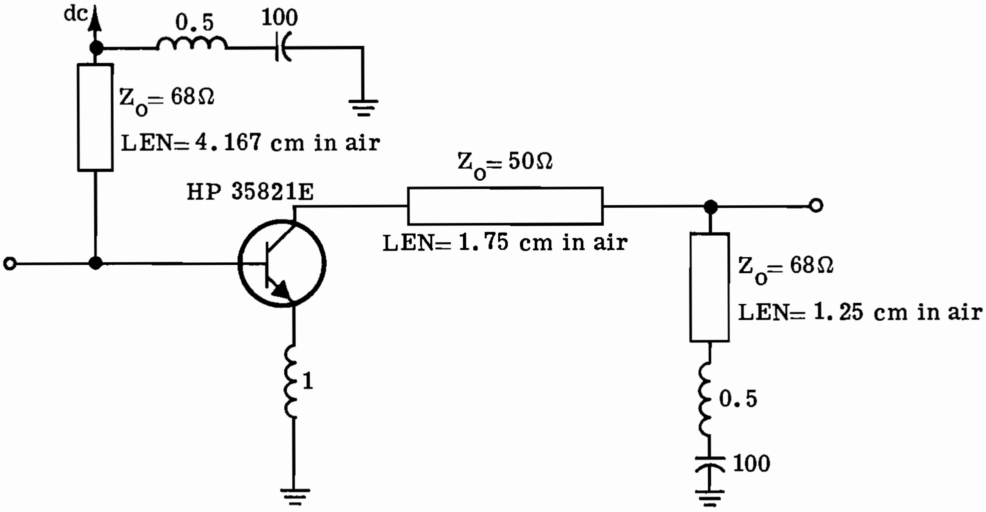
where *connection* is one of CAS, PAR, SER, PARSER, or SERPAR. However, just as for any two-port *connection* can be omitted. CAS is assumed, if *connection* is omitted.

1.4.6 Examples

This section contains three examples in which the auxiliary operations are required. The first of these employs both HOLD *k* and SHU *k* in a microwave amplifier. In the second example SER *k* is used to build up a two-port from empirical impedance values for a one-port. The final example, which is in section 1.4.6.3, shows how to use CIR ± *k* to model an isolator.

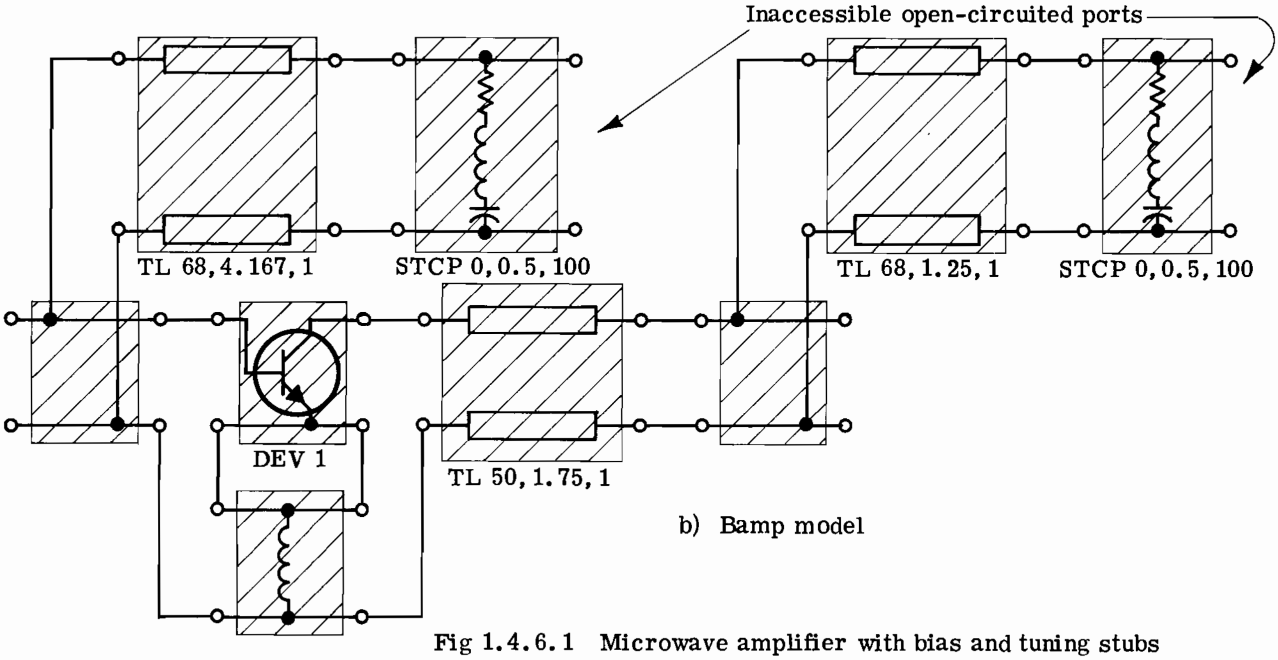
1.4.6.1 Microwave amplifier with bias and tuning stubs

The circuit in Fig 1.4.6.1 is an output stage. The 100 pF capacitances provide rf by-pass to ground, and the 0.5 nH inductances model the capacitor lead inductance.



pF, nH, ZR= 50Ω, f_o= 1.8GHz

a) Circuit



b) Bamp model

Fig 1.4.6.1 Microwave amplifier with bias and tuning stubs

A description for the Bamp model is

```
DEV 1  LP 1  SER  HOLD 1
TL 68  4.167  1 STCP  0  0.5  100  [CAS]  SHU 2
TL 68  1.25   1 STCP  0  0.5  100  [CAS]  SHU 3
USE 2  USE 1  [CAS]  TL  50  1.75  1  [CAS]  USE 3  [CAS]
```

Note the following

- HOLD 1 builds up a composite two-port and places it in storage location 1. This composite two-port consists of the transistor represented by DEV 1 together with a 1-nH inductance between the emitter and rf ground.
- The storage location number 1 in HOLD 1 has no relationship whatsoever to the reference number 1 in DEV 1.
- The effect of SHU 2 and SHU 3 is to expand the catalog of two-ports to include bias and tuning stubs, just as HOLD 1 expands the catalog of two-ports to include a transistor with an emitter inductance.
- The final composite circuit is built up by the last line in the circuit description, namely

```
USE  2  USE  1 [CAS] TL  50  1.75  1 [CAS] USE  3 [CAS]
```

- The two-ports in storage locations 1-3 are built up anew for each frequency at which the circuit is run.

See Example 6.4.3 in Chapter 6 for an actual run.

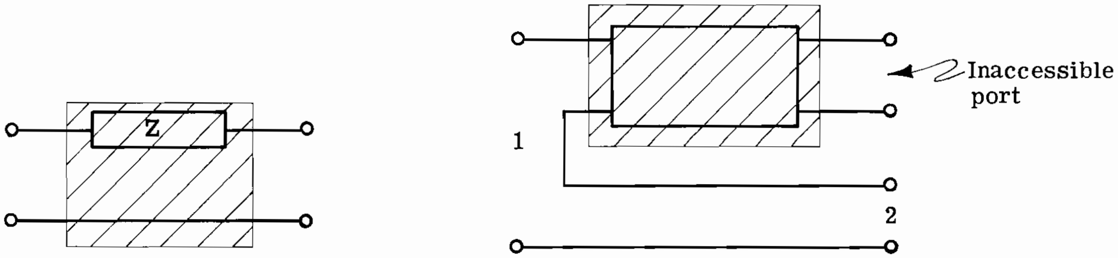
Here is an alternative circuit description that uses only two storage locations. Note

```
DEV  1  LP  1  SER  HOLD  1
TL  68  4.167  1  STCP  0  0.5  100 [CAS] SHU 2
USE  2  USE  1 [CAS] HOLD  1
TL  68  1.25  1  STCP  0  0.5  100 [CAS] SHU 2
USE  1  TL  50  1.75  1 [CAS] USE  2
```

that each of the storage locations 1 and 2 sequentially store two different two-ports. In large problems it is often necessary to economize the use of storage locations in this way.

1.4.6.2 Modeling an empirically known series impedance

Let Z be an impedance for which empirical values are available over some range of frequencies. Suppose that you want to include this impedance in a Bamp model as in Fig 1.4.6.2a. In considering Fig 1.4.6.2 it is important to keep in mind that you start with actual values of Z, but do not have in



a) two-port desired for Bamp model

b) Bamp implementation using SER

Fig 1.4.6.2 Developing a series two-port using empirical impedance values hand a matrix representation for the two-port in Fig 1.4.6.2a. The circuit description is simply

DEV 1 SER *k*

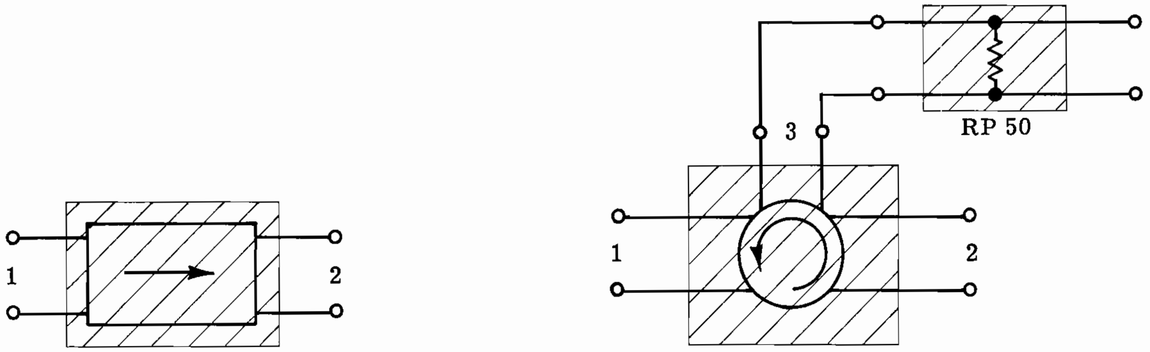
When Bamp requests data for DEV 1, then you type in the empirical data for Z_{11} and supply dummy numbers, zeros, for example, for Z_{12}, Z_{21}, and Z_{22}.

SHU *k* can be used in an analogous way to model an empirically known shunt impedance.

USE ± *k* is necessary to bring the two-port back into a composite circuit.

1.4.6.3 Modeling an isolator

Suppose you want to model an ideal isolator that provides perfect transmission from port 1 to port 2, but prevents transmission from port 2 to port 1. This can be done as shown in Fig 1.4.6.3.



a) Isolator

b) Bamp model using CIR - *k*

Fig 1.4.6.3 Bamp model for ideal isolator

The reference impedance (see section 1.6 and Appendix A.1) is assumed to be 50-ohms. If some other value *zr* were used, then the two-port RP 50 would be replaced by RP *zr* . The circuit description is

RP 50 CIR - *k*

Energy is transmitted from port 1 to port 2 as shown by the arrow. Energy incident on port 2 from outside is transmitted out of port 3 where it is totally absorbed, since the two-port RP provides a perfect match. Thus, there is no energy reflected back into port 3 and therefore no energy for transmission out of port 1.

The circuit described by

RP 50 CIR *k*

provides transmission from port 2 to port 1, but not from 1 to 2, in a 50-ohm system.

CIR ± *k* builds and stores the isolator. USE ± *k* is necessary to bring the isolator back into a composite circuit.

1.5 Default and optional units

Table 1.5.1 lists default and optional units. For each quantity, the first unit listed is the default unit and is underlined.

Quantity	Unit	Code
Frequency	Gigahertz	GHZ
	Hertz	HZ
	Kilohertz	KHZ
	Megahertz	MHZ
Resistance	Ohm	OH
	Kilohm	KO
	Megaohm	MO
Inductance	Nanohenry	NH
	Henry	H
	Millihenry	MH
	Microhenry	UH
Capacitance	Picofarad	PF
	Farad	F
	Millifarad	MF
	Microfarad	UF
	Nanofarad	NF
Length	Centimeter	CM
	Meter	M
	Inch	IN

Table 1.5.1 Default (underlined) and optional units

Code for optional units can be entered at any point in the circuit description, as illustrated in the examples in section 1.9. The editor can also be used to change units as explained in subset 7 of the detailed user instructions in section 1.10.

A given unit, be it default or optional, applies throughout a circuit. For example, if the microhenry is specified as the unit of inductance, then all inductances are assumed to be expressed in microhenrys. It is not possible to express some inductances in nanohenrys.

1.6 Reference impedance

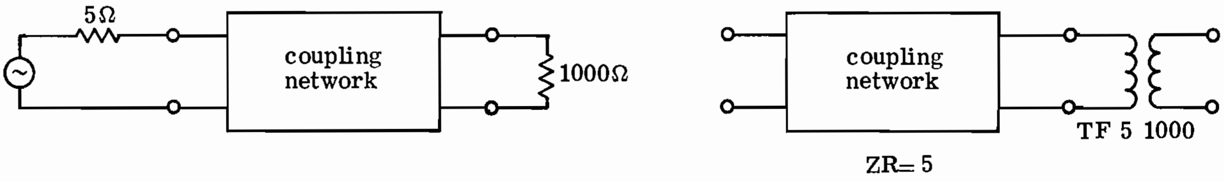
In some circuits it is convenient to think of the reference impedance as being the source and also the load resistance. At microwave frequencies the reference impedance is thought of as the system impedance and commonly is 50-ohms or 75-ohms. Another interpretation, which encompasses the first two, is that the reference impedance is simply a parameter in the transformation to S-parameters as discussed in Appendix A.1.

Bamp normally uses 50-ohms as the reference impedance, but any other non-zero, real value can be specified. To use a reference impedance of 75-ohms, for example, simply include

ZR = 75

in the circuit description. Example 1.9.1 in section 1.9 uses 1-ohm for the reference impedance.

With regard to source and load resistances, a natural question is how to handle unequal source and load resistances. One way is to use either source or load resistance for the reference impedance and use a transformer to achieve the unequal impedance. For example, suppose a 5-ohm source is to supply a 1000-ohm load through a network that reduces to a two-port as shown in Fig 1.6.1.



a) circuit

b) Bamp implementation

Fig 1.6.1 Unequal source and load resistances

The reference impedance is declared to be 5-ohms, the coupling network is built up in the usual way, and a transformer is added in cascade at the output.

A word of caution is needed. Whenever a set of DEV S-parameters is supplied, Bamp treats the S-parameters as if they were measured, or computed, using the value of reference impedance in the circuit description. If this is not the case, then erroneous results are obtained. For example suppose 75-ohms has been specified as the reference impedance. It would be incorrect to use DEV S-parameters measured in a 50-ohm, system unless the 50-ohm S-parameters are transformed to a 75-ohm reference. Appendix B illustrates how to use Bamp to carry out this transformation.

1.7 Outputs

There are three types of outputs. These are:

- printed
- plotted
- mapped

Mapped outputs are discussed in Chapter 2.

The outputs that can be printed are listed in Table 1.7.1 together with the code for requesting each of them. With one exception the output is printed as a tabulation versus frequency. The exception is transducer gain (GT). This output is more user interactive. You specify frequency and also source and load reflection coefficients. Bamp then computes and prints the input and output reflection coefficients as well as the transducer gain. Details are given in subset 5 of the detailed user instructions in section 1.10.

The quantities in the AMP output are:

K = Rollett stability factor = reciprocal of Linvill stability factor
$G_{A\ MAX}$ = maximum available gain
$G_{U\ MAX}$ = maximum unilateral gain
Γ_{MS} = source reflection coefficient for $G_{A\ MAX}$
Γ_{ML} = load reflection coefficient for $G_{A\ MAX}$

There are two types of plots. In subset 4 of the detailed user instructions of section 1.10 these are referred to as

- R-I for real-imaginary or polar plots
- F-Y for rectangular plots versus frequency.

The variables that can be plotted and the code for requesting each of these is given in Table 1.7.2. In Table 1.7.2, i, j = 1, 2. For example, S22 requests a polar plot (R-I plot) of S_{22}, whereas SDB21 requests an F-Y plot of $20 \log_{10} |S_{21}|$.

One, but only one, of the following can be included in the circuit description.

- SRI
- SMP
- SDB
- PLOT
- PRINT

Code	Output
SRI	S-matrix for overall circuit in real-imaginary form
SMP	S-matrix for overall circuit in magnitude-phase
SDB	Same as SMP except $\|S_{12}\|$ and $\|S_{21}\|$ in dB
GRI	G-matrix for overall circuit in real-imaginary form
GMP	G-matrix for overall circuit in magnitude-phase
GDB	Same as GMP except $\|G_{12}\|$ and $\|G_{21}\|$ in dB
HRI	H-matrix for over circuit in real-imaginary form
HMP	H-matrix for overall circuit in magnitude-phase
HDB	Same as HMP except $\|H_{12}\|$ and $\|H_{21}\|$ in dB
YRI	Y-matrix for overall circuit in real-imaginary form
YMP	Y-matrix for overall circuit in magnitude-phase
ZRI	Z-matrix for overall circuit in real-imaginary form
ZMP	Z-matrix for overall circuit in magnitude-phase
AMP	$K, G_{A\ MAX}, G_{U\ MAX}, \Gamma_{MS}, \Gamma_{ML}$
FIL	Loss, return loss, and delay in forward direction
IVSWR	Input VSWR
OVSWR	Output VSWR
GT	Transducer gain

Table 1.7.1. Printed Outputs

- MAPLOAD
- MAPSOURCE

If any one of SRI, SMP, or SDB is included, then that output is printed as the S-matrix is computed for the overall circuit. After the S-matrix has been computed at all frequencies, then it is possible to go to the plot, print, and map programs for additional outputs. If one of PLOT, PRINT, MAPLOAD, or MAPSOURCE is included with the circuit description, then the appropriate program is loaded and run after the S-matrix for the overall circuit has been computed at all frequencies. (See subset 3 of detailed user instructions in section 1.10.)

The output request included in the circuit description is only the initial output request. Any number of additional outputs (plotted, printed, or mapped) can be obtained unless the circuit contains MAPP or MAPS (see Chapter 2).

Type of Plot	Code				
	S	G	H	Y	Z
R-I plot of S, G, H, Y, or Z parameter	Sij	Gij	Hij	Yij	Zij
R-I plot of reciprocal of S, G, H, Y, or Z parameter	1/Sij	1/Gij	1/Hij	1/Yij	1/Zij
F-Y plot of magnitude of S, G, H, Y, or Z parameter	SMij	GMij	HMij	YMij	ZMij
F-Y plot of reciprocal of magnitude of S, G, H, Y, or Z parameter	1/SMij	1/GMij	1/HMij	1/YMij	1/ZMij
F-Y plot of magnitude in dB	SDBij	GDBij	HDBij	-	-
F-Y plot of reciprocal of magnitude in dB	1/SDBij	1/GDBij	1/HDBij	-	-
F-Y plot of phase of S, G, H, Y, or Z parameter	SPij	GPij	HPij	YPij	ZPij
R-I plot of Γ_{MS}	GMS				
R-I plot of Γ_{ML}	GML				
F-Y plot of K	K				
F-Y plot of $G_{A\ MAX}$	GAMAX				
F-Y plot of $G_{U\ MAX}$	GUMAX				
F-Y plot of delay	DELAY				
F-Y plot of input VSWR	IVSWR				
F-Y plot of output VSWR	OVSWR				

Table 1.7.2. Plotted Outputs

NOTE: Units of DELAY are determined by frequency units as follows:

HERTZ	SECONDS
KILOHERTZ	MILLISECONDS
MEGAHERTZ	MICROSECONDS
GIGAHERTZ	NANOSECONDS

1.8 Frequencies

There are three ways to specify frequencies. These are:

- set of discrete frequencies; F1, F2, F3, ---
- linearly stepped range; STEP F1, F2, ΔF
- exponentially stepped range; ESTEP F1, F2, N

For the linearly stepped range

- F1 = start frequency
- F2 = stop frequency
- ΔF = frequency step

For the exponentially stepped range

- F1 = start frequency
- F2 = stop frequency
- N = number of frequencies

More precisely, the exponentially stepped range is the set of frequencies

$$\{F1, rF1, r^2F1, ---, r^{N-1}F1\}$$

where r is a number, computed by Bamp, such that

$$r^{N-1}F1 = F2$$

The three methods of specifying frequencies can be intermixed in any way, but all must be in a single line of input. For example,

```
ESTEP 0.08 1.5 10 2 3.5 STEP 5 6 .2
```

specifies the following

- 10 exponentially spaced frequencies covering the range $0.08 \leq F \leq 1.5$
- a set of two discrete frequencies consisting of F= 2 and F= 3.5
- a linearly stepped set covering the range $5 \leq F \leq 6$ in steps $\Delta F = 0.2$

Bamp can accept at most 20 frequencies in any one run. The editor can be used to change frequencies in a subsequent run as explained in subset 7 of the detailed user instructions in section 1.10.

Whenever a set of frequencies is specified Bamp does two things

- eliminates duplicate entries, if any
- arranges remaining frequencies in ascending order

Analysis is always performed in the order of increasing frequency.

1.9 Circuit decomposition into two-ports

The purpose of this section is to show by means of several examples how to decompose a circuit into an interconnection of two-ports and to write down the circuit description. Many of these circuits have been run on Bamp, and the actual runs have been collected together in Chapter 6 of this manual.

1.9.1 Low-pass filter

Consider first the complete circuit shown in Fig 1.9.1.1 in which a 1-ohm source supplies a 1-ohm load through a simple low-pass filter.

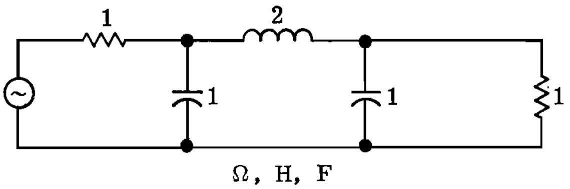
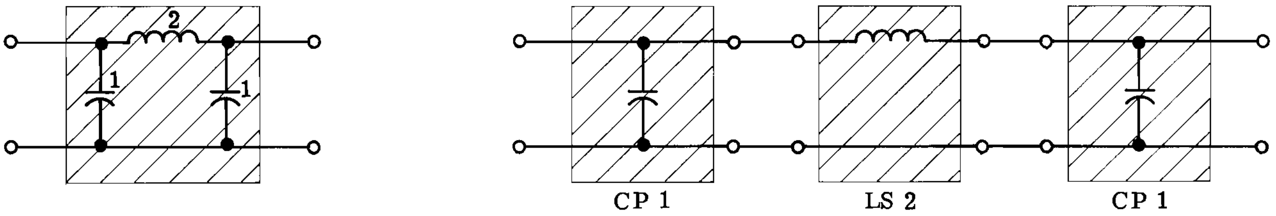


Fig 1.9.1.1 Low-pass filter

The reference impedance is set equal to 1 ohm to account for the source and load resistances (see section 1.6). The remainder of the circuit is built up as shown in Fig 1.9.1.2.



a) Filter section

b) CAS connection of component two-ports

Fig 1.9.1.2 Decomposition of filter section into component two-ports

The interconnection of two-ports in Fig 1.9.1.2 is described by

```
CP 1 LS 2 [CAS] CP 1 [CAS]
```

in which CAS in square brackets indicates that the connection is optional, since CAS is the default connection. The complete circuit description must include the value of ZR as well as optional units for inductance and capacitance (see section 1.5). Also, since the 3 dB point is $f = 1/2\pi \approx 0.159$ Hz, it is convenient to specify Hz as the unit of frequency. A complete circuit description is

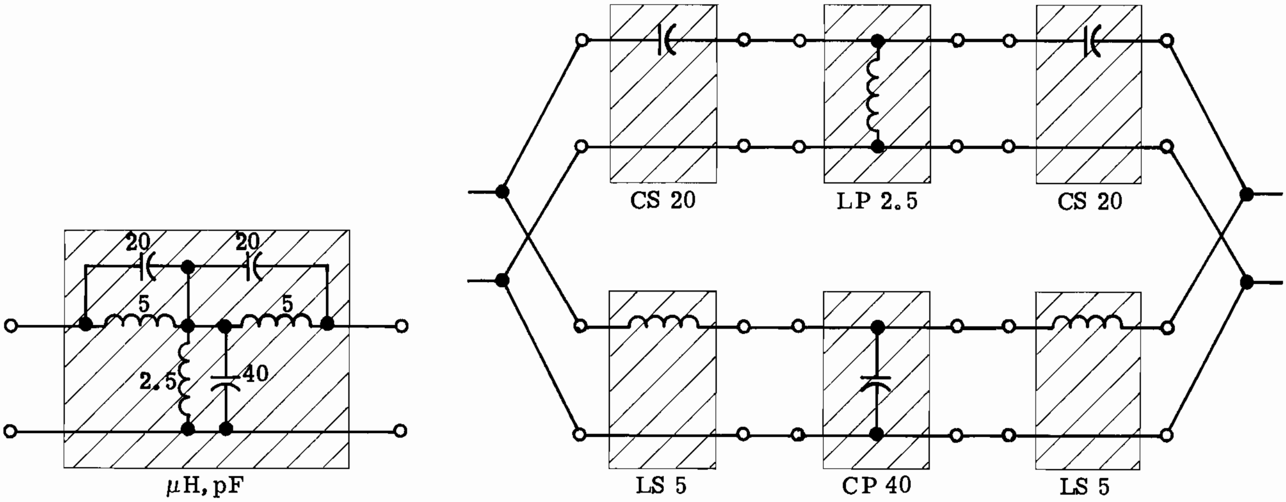
```
ZR= 50 H F HZ
CP 1 LS 2 [CAS] CP 1 [CAS]
```

Refer to section 6.1 of Chapter 6 for actual runs.

Code for the optional unit and and the value of ZR can appear in any order at any point in the circuit description. They are not required to appear together in the first line as shown.

1.9.2 Twin-T filter

The twin-T filter shown in Fig 1.9.2 introduces the parallel connection and also the auxiliary operations HOLD and USE (see section 1.4). Because the filter has unity transmission at $50/\pi \approx 15.91$ MHz, it is convenient to use MHz as the unit of frequency.



a) Filter section

b) Interconnection of component two-ports

Fig 1.9.2 Twin-T filter

The complete circuit description can be written

```
UH MHZ
CS 20 LP 2.5 [CAS] CS 20 [CAS] HOLD 1
LS 5 CP 40 [CAS] LS 5 [CAS] USE 1 PAR
```

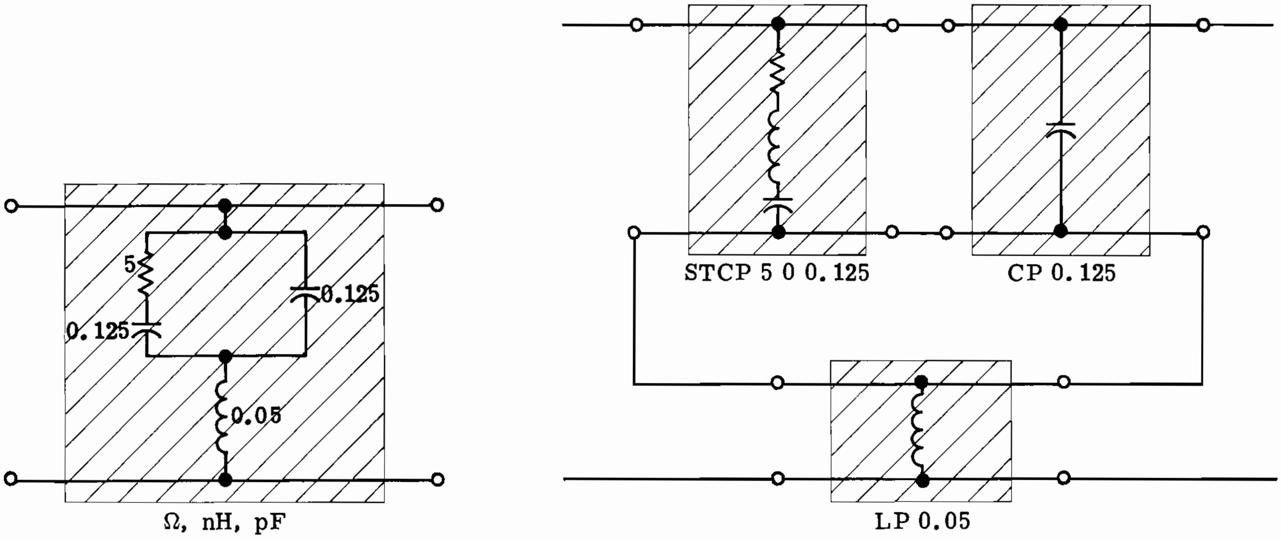
HOLD 1 can be thought of as expanding the catalog of two-ports to include the upper T-section (CS 20 LP 2.5 CS 20) for use in this specific problem. This special two-port is brought back into the circuit by USE 1.

In this problem the source and load resistances have the default value ZR = 50 ohms.

See example 6.2 in Chapter 6 for an actual run.

1.9.3 Lumped model of hot-carrier diode

The circuit in Fig 1.9.3.1 can be used to model a hot-carrier diode at microwave frequencies. One purpose of this example is to illustrate the SER connection. Another is to point out alternative ways of building up the same circuit.



a) circuit model

b) Bamp model

Fig 1.9.3.1 Lumped circuit model of hot-carrier diode

The circuit description is

```
STCP 5 0 0.125 CP 0.125 [CAS] LP 0.05 SER
```

Fig 1.9.3.2 shows another way to build up the circuit

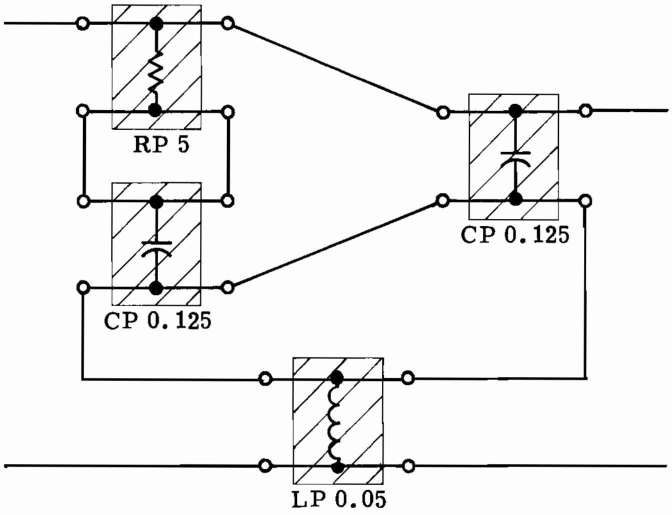


Fig 1.9.3.2 Alternative circuit decomposition for hot-carrier diode

The circuit description for Fig 1.9.3.2 is

```
RP 5 CP 0.125 SER CP 0.125 [CAS] LP 0.05 [SER]
```

Although the two ways of using Bamp to model the hot-carrier diode produce identical results, the circuit of Fig 1.9.3.2 takes an appreciably longer time to run. This is because of the two SER connections. The SER connection is time-consuming (roughly four seconds).

Example 6.3 of Chapter 6 is an actual run for the circuit of Fig 1.9.3.1.

1.9.4 Microwave transistor amplifier

A single-stage amplifier using an HP 35821E transistor is shown in Fig 1.9.4.

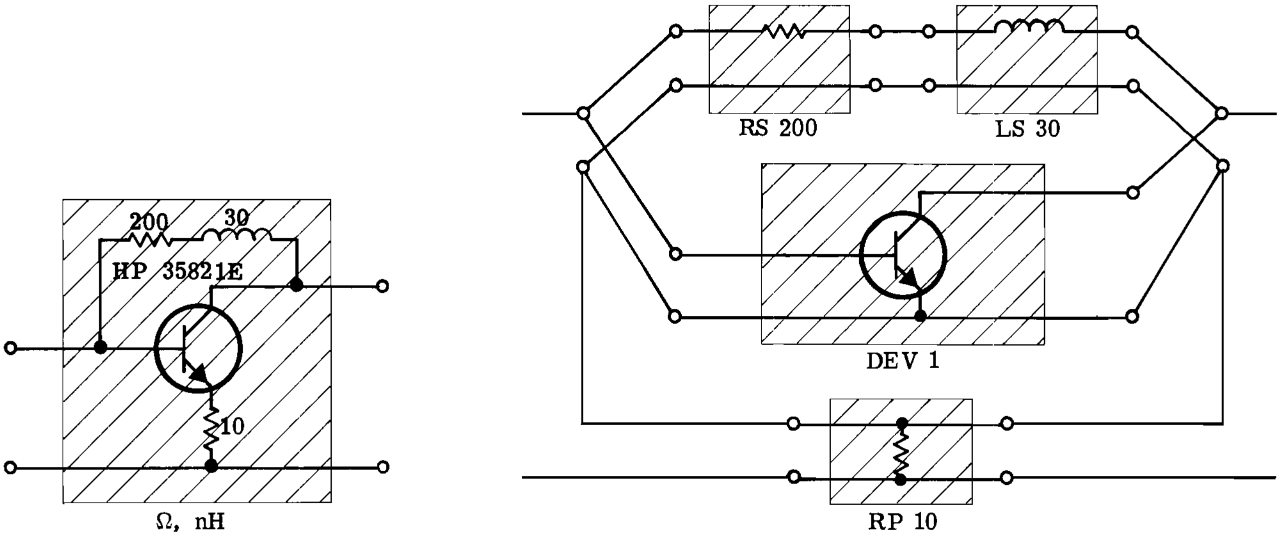


Fig 1.9.4 Single-stage microwave transistor amplifier

This circuit requires all three of the connections CAS, PAR, and SER. The circuit description is

```
RS 200 LS 30 [CAS] DEV 1 HP35821E PAR RP 10 SER
```

The name HP35821E instructs Bamp to access data for the transistor from a cassette DEV data file identified by the name HP35821E.

The circuit of Fig 1.9.4 is analyzed in section 6.4 of Chapter 6.

Example 6.4.4 in Chapter 6 is a two-stage microwave amplifier including bias stubs. In this example DEV data are typed in from the keyboard; they are not read from a DEV data cassette.

1.9.5 Negative resistance, non-reciprocal amplifier

The circuit in Fig 1.9.5 is a negative resistance, non-reciprocal amplifier. The source and load resistances are accounted for by setting ZR = 100 ohms. In using Bamp to analyze this circuit the arm consisting of the negative resistance with matching network is first built up and then connected to the third arm of the circulator by means of the operation CIR *k* .

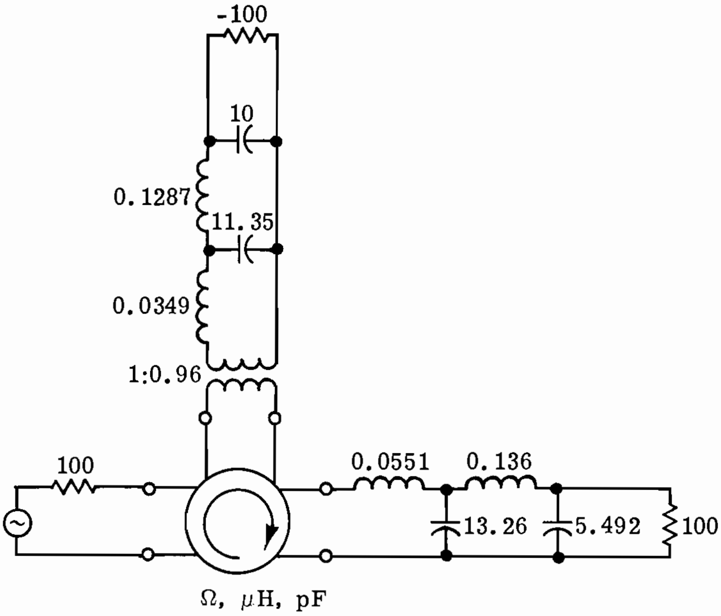


Fig 1.9.5 Negative resistance, reflection amplifier

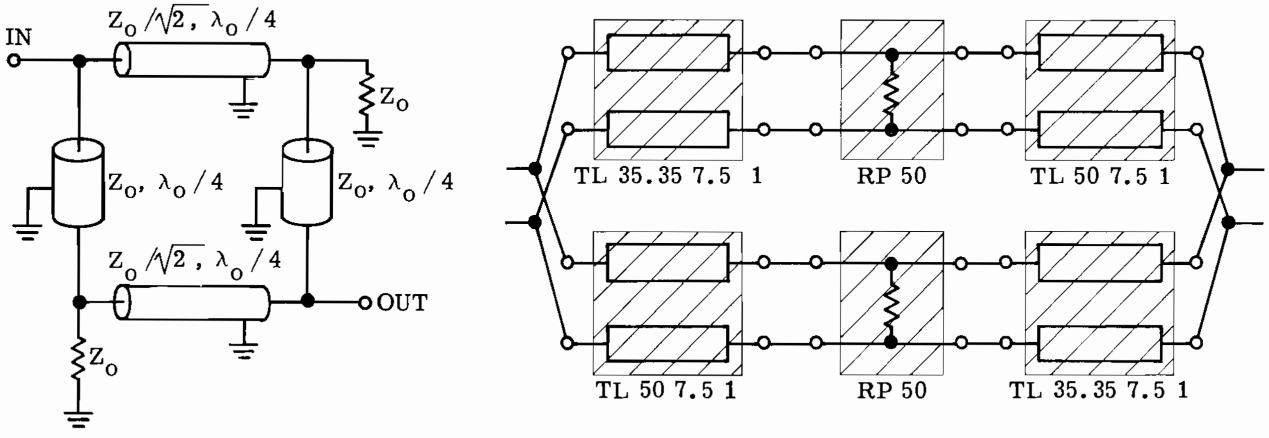
The circuit description is

```
ZR =  100  UH   MHZ
TF  0.96  LS  0.0349  [CAS]  CP  11.35  [CAS]  LS  0.1287  [CAS]
CP  10   [CAS]  RP  -100  CIR  1
USE  1  LS  0.0551  [CAS]  CP  13.26  [CAS] LS  0.136  [CAS]
CP  5.492  [CAS]
```

See example 6.5 in Chapter 6 for an actual run.

1.9.6 3-dB branch-line coupler

Fig 1.9.6 shows a 3-dB branch line coupler.



a) coupler

b) Bamp model for Z_o = 50 ohms and λ_o = 30 cm (f_o = 1 GHz)

Fig 1.9.6 3-dB branch-line coupler

By noting that the lower branch is just the upper branch turned end for end, it is possible to reduce the computational effort. The circuit description is

```
TL 35.35 7.5 1 RP 50 TL 50 7.5 1 HOLD 1
USE 1 USE -1 PAR
```

See example 6.6 in Chapter 6 for an actual run.

1.10 Detailed instructions

The previous sections provide background information for using Bamp. This section outlines step-by-step the actual procedure for running Bamp '30. These instructions comprise seven subsets.

There are three different cassettes referenced in the instructions. These are

- Bamp cassette
- DEV data cassette
- Circuit cassette

The Bamp cassette is essential. The other two cassettes may or may not be used. The DEV data cassette contains two-port data. The circuit cassette can be used to store a complete circuit for convenient re-run at a later time. The procedure for storing a circuit is given in section 1.11.

The Bamp cassette contains a total of six programs. The entry program is on file 0. Except under special circumstances as explained in Chapter 5, section 5.2, you must start with the program on file 0. An error message and wasted time are the inevitable result of the sequence

Press: SCRATCH
Press: EXECUTE
Insert: Bamp cassette
Press: LOAD
Enter: 1 (or 2 or 3 or 4 or 5)
Press: EXECUTE
When "├—" appears in the display
Press: RUN
Press: EXECUTE

Except as explained in Chapter 5, you must follow steps 101 and 102 of subset 1 exactly.

In typing in a circuit from the keyboard you first provide the circuit description and then specify frequencies. The circuit description comprises

- two-ports and auxiliary operations together with parameter values and connections
- optional units and program parameters
- a single output request which can be any one of
  - SRI
  - SMP
  - SDB
  - PLOT

PRINT
MAPLOAD
MAPSOURCE

The order in which two-ports and auxiliary operations appear in a circuit description determines the sequence in which the overall circuit is built up. Sequence numbers in multiples of 10 starting at 10 are assigned automatically. These sequence numbers appear as line numbers in a listing of the circuit. The editor is used to obtain a listing. The editor can also be used to insert intermediate lines or delete existing lines.

Code for optional units, program parameters, and the single output request can appear in any order at any point in the circuit description. It is not essential that an output request be included. SDB is the default output. Although the circuit description can contain only one output request, additional outputs can be obtained once the overall S-parameters have been computed (see steps 309-322 of subset 3).

When the circuit description is completely typed in, then starting a new line you specify all frequencies as a single line of input.

If you make an error and are aware of the error what you should do is to continue until you have specified the frequencies and then call the editor. You can use the editor to correct the error or otherwise modify the circuit (see steps 106, 107, 111, and 112 of subset 1).

Step 113 in subset 1 and step 722 in subset 7 require some clarification. These steps are reproduced here for ready reference.

113. If DEV data are required; go to step 114
If DEV data are not required; go to step 116

722. If DEV data are required; go to step 723
If DEV data are not required; go to step 725

First of all, you the user do not decide whether or not DEV data are required. Bamp knows and does what is required. However, you should know whether or not DEV data are required. These are the conditions under which DEV data are required.

- The circuit has been entered, but not run, and contains one or more of DEV 1, DEV 2, or DEV 3.
- The circuit has been run, but a new two-port DEV 1, DEV 2, or DEV 3 has been inserted using the editor.
- The circuit has been run, but the frequencies have been changed, again using the editor.

USER INSTRUCTIONS

Subset 1. Input Circuit Description

101. Press: SCRATCH
Press: EXECUTE
Insert: Bamp cassette
Press: LOAD
Press: EXECUTE

102. When "├—" appears in the display
Press: RUN
Press: EXECUTE

103. When "KEYB'D OR C'SETTE INPUT(K OR C)?" appears in the display
Type : K
or
Type : C
Press: EXECUTE

104. If you typed K; go to step 105
If you typed C; go to step 108

105. When "BEGIN?" appears in the display
Type : A line consisting of part or all of the circuit description, but containing no more than 72 characters. Individual items must be separated by spaces or commas.
Press: EXECUTE

106. When "?" appears in the display
Type : Continuation of circuit description, if not complete
or
Enter: All frequencies as a single line of input of no more than 72 characters. This line can contain any mixture of discrete frequencies or stepped ranges up to a limit of 20 frequencies.
Press: EXECUTE

107. If you typed a continuation of the circuit description; go to step 106.
If you entered frequencies; go to step 111.

108. When "FILE NUMBER?" appears in the display
Enter: number of file containing circuit
Press: EXECUTE

109. When "1. INSERT CKT C'SETTE 2. TYPE GO?" appears in the display
Remove: Bamp cassette (after rewind)
Insert: circuit cassette
Type : GO
Press: EXECUTE

110. When "1.INSERT BAMP C'SETTE 2.TYPE GO?" appears in the display

Remove: circuit cassette (after rewind)
Insert: Bamp cassette
Type : GO
Press: EXECUTE

111. When "EDIT, RUN, OR STOP (E, R, S)?" appears in the display

Type : E [DIT]
or
Type : R [UN]
or
Type : S [TOP]
Press: EXECUTE

112. If you typed E; go to step 701 (subset 7)
If you typed R; go to step 113
If you typed S; Bamp is terminated and the cassette is rewound

113. If DEV data are required; go to step 114
If DEV data are not required; go to step 116

114. REMARK The program on file 1 is loaded. Approximately 40 seconds are required.

115. Go to step 201 (subset 2)

116. REMARK The program on file 2 is loaded. Approximately 85 seconds are required.

117. Go to step 301 (subset 3)

Subset 2. DEV Data Acquisition

201. REMARK The circuit is scanned for the 2-ports DEV 1, DEV 2, and DEV 3.

202. If "DATA(F, 11, 12, 21, 22) FOR DEV *k* ?" is printed; go to step 203
If "1. INSERT DATA C'SETTE 2. TYPE GO?" appears in the display; go to step 214

203. Enter: A line of data consisting of frequency as the first item followed by two numbers for each of the matrix elements 11, 12, 21, and 22 in that order. Individual items must be separated by spaces or commas.
Press: EXECUTE

204. When "?" appears in the display
Enter: A line of data as in step 203
or
Type : /
or
Type : C value_1
Press: EXECUTE

205. REMARK In step 204 any typed input having / as the leading character is equivalent to / and likewise for C. For example, /XYZ is equivalent to / and CHANGE value_1 is equivalent to C value_1.

206. If you entered a line of data; go to step 204
If you typed / or equivalent; go to step 211
If you typed C value_1 or equivalent; go to step 207

207. You can check or change a previously entered line of data for DEV *k* . Starting with frequency equal to value_1, each separate item in that line of data is displayed. In step 208 *n* is any one of the date items as they are displayed in succession.

208. When " *n* ?" appears in the display
Enter: value
or
Type : space
or
Type : S [TOP]
Press: EXECUTE

209. REMARK Entering a new value replaces the displayed value. Typing space retains the displayed value.

210. If you typed S or equivalent; go to step 204
If not all nine data items have been displayed; go to step 208
If all data items have been displayed; go to step 204

211. When "S, G, H, Y, OR Z?" appears in the display

Type : S
or
Type : G
or
Type : H
or
Type : Y
or
Type : Z
Press: EXECUTE

212. When "RI, MP, OR DB?" appears in the display
Type : RI
or
Type : MP
or
Type : DB
Press: EXECUTE

213. Go to step 218

214. Remove: Bamp cassette (after rewind)
Insert: data cassette
Type : GO
Press: EXECUTE

215. If " *name* NOT ON CASSETTE" is printed; go to step 216
Go to step 218

216. When "1.INSERT DATA C'SETTE 2.TYPE GO?" appears in the display
Remove: data cassette (after rewind)
Insert: data cassette
Type : GO
Press: EXECUTE

217. Go to step 215

218. If the circuit contains another 2-port DEV *k* for which data have not been accessed; go to step 202

219. If a data cassette has not been inserted; go to step 223

220. When "1.INSERT BAMP C'SETTE 2.TYPE GO?" appears in the display
Remove: data cassette (after rewind)
Insert: Bamp cassette
Type : GO
Press: EXECUTE

221. REMARK The program on file 2 is loaded. Approximately 85 seconds are required.

222. Go to step 301 (subset 3)

223. REMARK The program on file 2 is loaded. Approximately 45 seconds are required.

224. Go to step 301 (subset 3)

Subset 3. Compute S-matrix for Overall Circuit

301. REMARK The circuit is scanned for TEL inputs.

302. If there are TEL inputs; go to step 303
If there are no TEL inputs; go to step 309

303. (Assume, for example, that the first TEL input is in line 30, which contains a transmission line, the 2-port TL, for which $\sqrt{L/C}$ and LEN are TEL inputs.)
When "30 SQR(L/C)= ?" appears in the display
Enter: value of $\sqrt{L/C}$
or
Type : space (or any non-numeric)
Press: EXECUTE
When " LEN= ?" appears in the display
Enter: value of LEN
or
Type : space (or any non-numeric)
Press: EXECUTE

304. REMARK Typing space or any non-numeric retains the previous value. All TEL inputs are set equal to zero when the circuit is first input. After EXECUTE is pressed the value of the TEL parameter is printed.

305. If there are no more TEL's; go to step 309

306. REMARK Parameter values are requested as in step 303; that is, the circuit line number and an appropriate mnemonic are displayed.

307. Enter: value
or
Type : space (or any non-numeric)
Press: EXECUTE

308. Go to step 305

309. If SRI, SMP, or SDB has been requested as an output; go to step 310
If neither SRI, SMP, nor SDB is the requested output; go to step 311

310. REMARK An appropriate caption is printed.

311. REMARK The S-matrix for the overall circuit is computed at the first frequency. This result is stored in memory and also printed, if SRI, SMP, or SDB is the requested output.

312. If there are additional frequencies; go to step 313
If there are no additional frequencies; go to step 315

313. REMARK The S-matrix for the overall circuit is computed at the next frequency. This result is stored in memory and is also printed, if the requested output is SRI, SMP, or SDB.

314. Go to step 312

315. If SRI, SMP, or SDB was printed; go to step 316
If the requested output is PLOT; go to step 318
If the requested output is PRINT; go to step 320
If the requested output is MAPLOAD or MAPSOURCE; go to step 322
If the circuit contains MAPP or MAPS; go to step 322

316. When "NEXT?" appears in the display
Type : PLOT
or
Type : PRINT
or
Type : MAPLOAD
or
Type : MAPSOURCE
or
Type : E [DIT]
or
Type : R [UN]
or
Type : W [RITE]
or
Type : S [TOP]
Press: EXECUTE

317. If you typed PLOT; go to step 318
If you typed PRINT; go to step 320
If you typed MAPLOAD or MAPSOURCE; go to step 322
If you typed E; go to step 324
If you typed R; go to step 301
If you typed W; go to step 326
If you typed S; Bamp is terminated and the cassette is rewound

318. REMARK The program on file 3 is loaded. Approximately 60 seconds are required.

319. Go to step 401 (subset 4)

320. REMARK The program on file 4 is loaded. Approximately 115 seconds are required.

321. Go to step 501 (subset 5)

322. REMARK The program on file 5 is loaded. Approximately 135 seconds are required.

323. Go to step 601 (subset 6)

324. REMARK The program on file 0 is loaded. Approximately 90 seconds are required.

325. Go to step 701 (subset 7)

326. REMARK The program on file 0 is loaded. Approximately 90 seconds are required.

327. Go to step 101 (subset 1)

Subset 4. Plot

401. When "VARIABLE?" appears in the display

Type : any one of the following

For real-imaginary (R-I) plots:

Sij, 1/Sij, Yij, 1/Yij, Zij, 1/Zij, Gij, 1/Gij, Hij, 1/Hij, GML, GMS

$i, j = 1, 2$

For rectangular (F-Y) plots:

SMij, 1/SMij, SDBij, 1/SDBij, SPij
YMij, 1/YMij, YPij
ZMij, 1/ZMij, ZPij
GMij, 1/GMij, GDBij, 1/GDBij, GPij
HMij, 1/HMij, HDBij, 1/HDBij, HPij
DELAY, K, GAMAX, GUMAX
IVSWR, OVSWR

$i, j = 1, 2$

or

Type : space
Press: EXECUTE

402. If you typed space; go to step 430
If you typed an element of the admittance Y or the impedance Z matrix, for example YM11 or Z22; go to step 403
Go to step 404

403. When "NORMALIZED (Y OR N)?" appears in the display

Type : Y [ES]

or

Type : N [O]
Press: EXECUTE

404. If you requested an R-I plot, for example S11; go to step 405
If you requested an F-Y plot, for example SM11; go to step 413

405. REMARK The maximum magnitude of the quantity to be plotted is printed, for example max $|S_{11}|$.

406. REMARK You next specify the values of the variables at the graph limits. Let (R0, R9) be the values of the real part at the (left, right) graph limits and let (I0, I9) be the values of the imaginary part at the (bottom, top) graph limits. The values of (R0, R9) and (I0, I9) are entered in step 407.

407. When "SCALE?" appears in the display

Type : value$_1$ [value$_2$ [value$_3$ value$_4$]] [ADJUST PLOTTER]

or

Type : ADJUST PLOTTER

or

Type : space
Press: EXECUTE

408. REMARKS

If the input is value$_1$ alone, then R0= I0= -ABS(value$_1$) and R9= I9= ABS(value$_1$).

If the input consists of value$_1$ and value$_2$, then R0= -ABS(value$_1$), R9= ABS(value$_1$), I0= -ABS(value$_2$), and I9= ABS(value$_2$).

If the inputs consists of value$_1$, value$_2$, value$_3$, and value$_4$, then R0= min(value$_1$, value$_2$), R9= max(value$_1$, value$_2$), I0= min(value$_3$, value$_4$), and I9= max(value$_3$, value$_4$).

Typing space retains previous values, or sets R0= I0= -1, and R9= I9= 1, if there are no previous values.

ADJUST PLOTTER (or any non-numeric in the position indicated for ADJUST PLOTTER) causes a sequence of numbers to be transmitted to the plotter, which is adjusted by you as follows:

(R0, 0)	use POS controls
(R9, 0)	use SIZE controls
(0, I0)	use VER POS only
(0, I9)	use VER SIZE only

409. If you did not type ADJUST PLOTTER (or equivalent); go to step 420

410. When "HOR POS?" appears in the display
Adjust: POS controls
Type : space
Press: EXECUTE
When "HOR SIZE?" appears in the display
Adjust: SIZE controls
Type : space
Press: EXECUTE
When "VER POS?" appears in the display
Adjust: VER POS only
Type : space
Press: EXECUTE
When "VER SIZE?" appears in the display
Adjust: VER SIZE only
Type : space
Press: EXECUTE

411. When "REPEAT ADJUSTMENT(Y OR N)?" appears in the display
Type : Y [ES]
or
Type : N [O]
Press: EXECUTE

412. If you typed Y; go to step 410
Go to step 420

413. REMARK The max and min values of the Y-variable are printed, for example, max $|S_{11}|$ and min $|S_{11}|$.

414. REMARK You next specify values at the graph limits. Let (F0, F9) be the values of frequency at the (left, right) of the graph, and let (Y0, Y9) be the values of the Y-variable at the (bottom, top) of the graph.

415. When "FREQ SCALE?" appears in the display

Enter: $value_1$ $value_2$ [LOG]

Press: EXECUTE

416. When "VER SCALE?" appears in the display

Enter: $value_1$ $value_2$ [LOG]

Press: EXECUTE

417. REMARKS

The optional input LOG specifies a logarithmic scale. In step 415 the smaller of ($value_1$, $value_2$) is assigned to F0; the larger of ($value_1$, $value_2$) is assigned to F9. ($value_1$= $value_2$ is rejected as an input)

In step 416 the smaller of ($value_1$, $value_2$) is assigned to Y0; the larger of ($value_1$$value_2$) is assigned to Y9. ($value_1$= $value_2$ is rejected as an input)

418. REMARK Once the frequency and vertical scales have been set, they can be retained in a subsequent F-Y plot by typing space rather than $value_1$ value $_2$ in step 415 or step 416. "Subsequent" here refers only to plots made prior to reloading the program in memory. Once the plot program is replaced in memory, the graph limits are lost.

419. When "ADJUST PLOTTER(LL, UR)?" appears in the display

Adjust: plotter

Type : space (or any character(s))

Press: EXECUTE

420. REMARK The requested variable is plotted.

421. When "AGAIN?" appears in the display

Type : Y [ES]

or

Type : N [O]

or

Type : MF $value_1$

or

Type : LETTER

Press: EXECUTE

422. If you typed Y; go to step 423

If you typed N; go to step 401

If you typed MF $value_1$; go to step 425

If you typed LETTER; go to step 427

423. REMARK You have directed that your plot be repeated.

424. If your plot is R-I; go to step 405

If your plot is F-Y; go to step 413

425. REMARKS

A marker is placed on the graph at the frequency closest to $value_1$. The frequency marked, either $value_1$ or the frequency closest to $value_1$, is printed.

426. Go to step 421

427. REMARK The system is now in the "typewriter" mode. You can label your plot.

428. To return control to the program

Press: STOP

429. Go to step 421

430. When "NEXT?" appears in the display

Type : PLOT
or
Type : PRINT
or
Type : MAPLOAD
or
Type : MAPSOURCE
or
Type : E [DIT]
or
Type : R [UN]
or
Type : W [RITE]
or
Type : S [TOP]
Press: EXECUTE

431. If you typed PLOT; go to step 401
If you typed PRINT; go to step 432
If you typed MAPLOAD or MAPSOURCE; go to step 434
If you typed E; go to step 436
If you typed R; go to step 438
If you typed W; go to step 440
If you typed S; Bamp is terminated and the cassette is rewound

432. REMARK The program on file 4 is loaded. Approximately 60 seconds are required.

433. Go to step 501 (subset 5)

434. REMARK The program on file 5 is loaded. Approximately 115 seconds are required.

435. Go to step 601 (subset 6)

436. REMARK The program on file 0 is loaded. Approximately 110 seconds are required.

437. Go to step 701 (subset 7)

438. REMARK The program on file 2 is loaded. Approximately 90 seconds are required.

439. Go to step 301 (subset 3)

440. REMARK The program on file 0 is loaded. Approximately 110 seconds are required.

441. Go to step 101 (subset 1)

Subset 5. Print

501. When "OUTPUT?" appears in the display

Type : any one of the following:

SRI, SMP, SDB
YRI, YMP
ZRI, ZMP
GRI, GMP, GDB
HRI, HMP, HDB
AMP, FIL, IVSWR, OVSWR, GT

or

Type : space
Press: EXECUTE

502. If you typed YRI, YMP, ZRI, or ZMP; go to step 503
If you typed GT; go to step 506
If you typed space; go to step 519
Go to step 504

503. When "NORMALIZED(Y OR N)?" appears in the display

Type : Y [ES]

or

Type : N [O]
Press: EXECUTE

504. REMARK The specified output is computed and printed.

505. Go to step 501

506. When "F= ?" appears in the display

Enter : value_1

or

Type : space
Press: EXECUTE

507. If you typed space; go to step 501

508. When "SOURCE REFL COEFF (MAG, ANG)?" appears in the display

Enter : value_1 [value_2]

or

Type : *

or

Type : space
Press: EXECUTE

509. If you typed value_1 [value_2] ; go to step 510

If you typed *; go to step 512
If you typed space; go to step 514

510. REMARK The phase is set equal to zero, if $value_2$ is omitted.

511. Go to step 515

512. REMARK The source reflection coefficient is set equal to the conjugate of the input reflection coefficient when the input reflection coefficient is computed.

513. Go to step 515

514. REMARK The source reflection coefficient is set equal to zero.

515. When "LOAD REFL COEFF (MAG, ANG)?" appears in the display

Enter: $value_1$ [$value_2$]
or
Type : *
or
Type : space
Press: EXECUTE

516. REMARK Remarks 510, 512, and 514 apply with obvious modifications with this one exception. If the source is to be matched, then a value of Γ_L must be entered, or the previous value must be retained. That is, * is not acceptable in step 515, if * is typed in step 508.

517. REMARK Frequency, Γ_{source}, Γ_{in}, Γ_{load}, Γ_{out}, and transducer gain are printed.

518. Go to step 506

519. When "NEXT?" appears in the display

Type : PRINT
or
Type : PLOT
or
Type : MAPLOAD
or
Type : MAPSOURCE
or
Type : E [DIT]
or
Type : R [UN]
or
Type : W [RITE]
or
Type : S [TOP]
Press: EXECUTE

520. If you typed PRINT; go to step 501
If you typed PLOT; go to step 521
If you typed MAPLOAD or MAPSOURCE; go to step 523
If you typed E; go to step 525
If you typed R; go to step 527
If you typed W; go to step 529
If you typed S; Bamp is terminated and the cassette is rewound

521. REMARK The program on file 3 is loaded. Approximately 55 seconds are required.

522. Go to step 401 (subset 4)

523. REMARK The program on file 5 is loaded. Approximately 55 seconds are required.

524. Go to step 601 (subset 6)

525. REMARK The program on file 0 is loaded. Approximately 130 seconds are required.

526. Go to step 701 (subset 7)

527. REMARK The program on file 2 is loaded. Approximately 110 seconds are required.

528. Go to step 301 (subset 3)

529. REMARK The program on file 0 is loaded. Approximately 130 seconds are required.

530. Go to step 101 (subset 1)

Subset 6. Mapping

601. If load impedance is the mapped element (MAPLOAD); go to step 602
If source impedance is the mapped element (MAPSOURCE); go to step 604
If an internal impedance (MAPP or MAPS) is the mapped element; go to step 612

602. REMARK "Z-LOAD ONTO INPUT REFLECTION COEFFICIENT PLANE" is printed.

603. Go to step 605

604. REMARK "Z-SOURCE ONTO OUTPUT REFLECTION COEFFICIENT PLANE" is printed.

605. When "VARIABLE (GAMMA OR 1/GAMMA)?" appears in the display
Type : GAMMA
or
Type : 1/GAMMA
Press: EXECUTE

606. If "FREQ?" appears in the display; go to step 607
Go to step 610

607. When "FREQ?" appears in the display
Enter: value_1
Press: EXECUTE

608. If the S-matrix for the overall circuit has been computed at the frequency value_1; go to step 609

If the S-matrix for the overall circuit has not been computed at the frequency value_1; go to step 607

609. REMARKS
value_1 is the frequency at which the mapping is carried out. If the S-matrix for the overall circuit has been computed at only one frequency; then that frequency is the frequency at which the mapping is carried out. Steps 607 and 608 are skipped.

610. REMARK "F= δ" is printed, where δ is the frequency at which the mapping is performed.

611. Go to step 613

612. When "VARIABLE?" appears in the display
Type : S11
or
Type : S12
or
Type : S21
or
Type : S22
or
Type : 1/S11
or

Type : 1/S12

or

Type : 1/S21

or

Type : 1/S22

Press: EXECUTE

613. REMARK The form of the mapping is

$S = T + R(Z - N^*) / (Z + N)$

$S = \Gamma_{in}, 1/\Gamma_{in}, \Gamma_{out}, 1/\Gamma_{out}, S\,ij$, or $1/S\,ij$; i , $j = 1, 2$

Z = load, source, or internal impedance, that is, the impedance being mapped

T, R, N are complex numbers that are computed and printed

614. If AIF > 1000; go to step 618

615. When "SCALE?" appears in the display

Enter : value$_1$ [value$_2$ [value$_3$ value$_4$]] [ADJUST PLOTTER]

or

Type : ADJUST PLOTTER

or

Type : space

Press: EXECUTE

616. REMARK See steps 406 through 412 of subset 4 for a complete explanation of the inputs in step 615.

617. REMARK The specified variable (Γ_{in}, $1/\Gamma_{in}$, Γ_{out}, $1/\Gamma_{out}$, $S\,ij$, or $1/S\,ij$; i, $j = 1, 2$) is plotted.

618. When "NEXT?" appears in the display

Type : RP value$_1$

or

Type : XP value$_1$

or

Type : LP value$_1$

or

Type : CP value$_1$

or

Type : ZP value$_1$ value$_2$

or

Type : RLP value$_1$ value$_2$

or

Type : RCP value$_1$ value$_2$

or

Type : RS value$_1$

or

Type : XS value$_1$

or

Type : LS value$_1$

or

Type : CS value$_1$

or

Type : ZS value$_1$ value$_2$

or
Type : RLS value$_1$ value$_2$
or
Type : RCS value$_1$ value$_2$
or
Type : MAPLOAD
or
Type : MAPSOURCE
or
Type : any one of S11, 1/S11, S12, 1/S12, S21, 1/S21, S22, 1/S22
or
Type : LETTER
or
Type : PLOT
or
Type : PRINT
or
Type : E [DIT]
or
Type : R [UN]
or
Type : W [RITE]
or
Type : S [TOP]
Press: EXECUTE

619. If you typed RP, XP, LP, CP, RS, XS, LS, or CS followed by value$_1$; go to step 620
If you typed ZP, RLP, RCP, ZS, RLS, or RCS followed by value$_1$ value$_2$; go to step 623
If you typed MAPLOAD; go to step 625
If you typed MAPSOURCE; go to step 626
If you typed S11, 1/S11, S12, 1/S12, S21, 1/S21, S22, or 1/S22; go to step 627
If you typed LETTER; go to step 628
If you typed PLOT; go to step 631
If you typed PRINT; go to step 634
If you typed E; go to step 637
If you typed R; go to step 639
If you typed W; go to step 641
If you typed S; Bamp is terminated and the cassette is rewound

620. If AIF < 1000; go to step 621
If AIF $\geq$ 1000; go to step 618

621. REMARKS
A parallel or series connection of R and X is mapped onto the S plane where S is any one of Γ_{in}; $1/\Gamma_{in}$, Γ_{out}, $1/\Gamma_{out}$, S_{ij}, or $1/S_{ij}$ with $i, j = 1, 2$.
The connection is parallel R and parallel X, if the second character is P, for example RP.
The connection is series R and series X, if the second character is S, for example RS.
If you typed RP value$_1$ or RS value$_1$, the result is a plot for R fixed at value$_1$ and X variable, $-\infty < X < \infty$.
If you typed XP, XS, LP, LS, CP, or CS followed by value$_1$, the plot is for X, L, or C fixed at value$_1$ and R variable, $0 \leq R < \infty$. (The complete image circle corresponding to $-\infty < R < \infty$ can

be obtained by selecting the proper program parameter.)

622. Go to step 618

623. REMARKS

The value of S $(S = \Gamma_{in}, 1/\Gamma_{in}, \Gamma_{out}, 1/\Gamma_{out}, S_{ij}$, or $1/S_{ij}$; $i, j = 1, 2)$ is computed and printed. This value is also plotted, if AIF $\leq$ 1000.

ZP, RLP, and RCP all imply a parallel connection of R and X.

ZS, RLS, and RCS all imply a series connection of R and X.

624. Go to step 618

625. If the circuit does not contain MAPP or MAPS; go to step 602
If the circuit contains MAPP or MAPS; go to step 618

626. If the circuit does not contain MAPP or MAPS; go to step 604
If the circuit contains MAPP or MAPS; go to step 618

627. If the circuit contains MAPP or MAPS; go to step 612
If the circuit does not contain MAPP or MAPS; go to step 618

628. REMARK The system is now in the "typewriter" mode.

629. To return to Bamp
Press: STOP

630. Go to step 618

631. If the circuit does not contain MAPP or MAPS; go to step 632
If the circuit contains MAPP or MAPS; go to step 618

632. REMARK The program on file 3 is loaded. Approximately 100 seconds are required.

633. Go to step 401 (subset 4)

634. If the circuit does not contain MAPP or MAPS; go to step 635
If the circuit contains MAPP or MAPS; go to step 618

635. REMARK The program on file 4 is loaded. Approximately 105 seconds are required.

636. Go to step 501 (subset 5)

637. REMARK The program on file 0 is loaded. Approximately 155 seconds are required.

638. Go to step 701 (subset 7)

639. REMARK The program on file 2 is loaded. Approximately 135 seconds are required.

640. Go to step 301 (subset 3)

641. REMARK The program on file 0 is loaded. Approximately 155 seconds are required.

642. Go to step 101 (subset 1)

Subset 7. Editing

701. When "EDITOR?" appears in the display

Type : LIST [value$_1$ [value$_2$]]

or

Type : LOAD value$_1$

or

Type : a line of input with a reference line number as the first item followed by a circuit element

or

Type : value$_1$

or

Type : REN

or

Type : FREQ value$_1$ value$_2$ value$_3$ . . .

or

Type : STEP value$_1$ value$_2$ value$_3$

or

Type : ESTEP value$_1$ value$_2$ value$_3$

or

Type : a line containing any combination of units, program parameters, and an output request

or

Type : R [UN]

or

Type : W [RITE]

or

Type : S [TOP]

Press: EXECUTE

702. If you typed LIST; go to step 703
If you typed LOAD; go to step 705
If you typed a line containing a circuit element; go to step 708
If you typed value$_1$; go to step 713
If you typed REN; go to step 716
If you typed FREQ value$_1$ value$_2$ value$_3$ . . .; go to step 718
If you typed STEP value$_1$ value$_2$ value$_3$; go to step 718
If you typed ESTEP value$_1$ value$_2$ value$_3$; go to step 718
If you typed units, program parameters, or output request; go to step 720
If you typed R; go to step 722
If you typed W; go to step 101 (Subset 1)
If you typed S; Bamp is terminated and the cassette is rewound

703. REMARKS

The circuit is listed.

If both optional inputs $value_1$ and $value_2$ are included; then lines between $value_1$ and $value_2$ are listed.

If only $value_1$ is included, the listing starts at the line numbered $value_1$.

If $value_1 = 0$, the listing includes units, program parameters, and the output request.

LIST0, 0 lists only units, program parameters, and the output request.

704. Go to step 701

705. When "1.INSERT CKT C'SETTE 2.TYPE GO?" appears in the display

Remove: Bamp cassette (after rewind)
Insert: circuit cassette
Type : GO
Press: EXECUTE

706. When "1.INSERT BAMP C'SETTE 2.TYPE GO?" appears in the display

Remove: circuit cassette (after rewind)
Insert: Bamp cassette
Type : GO
Press: EXECUTE

707. Go to step 111 (subset 1)

708. If the reference line number is already in the circuit; go to step 709
If the reference line number is not in the circuit; go to step 711

709. REMARK The circuit element contained in the line of input replaces the existing circuit element.

710. Go to step 701

711. REMARK The circuit element in the line of input is inserted. The line number is the line reference number contained in the line of input.

712. Go to step 701

713. If the circuit contains a line numbered $value_1$; go to step 714.
If the circuit does not contain a line numbered $value_1$; go to step 701.

714. REMARK The line numbered $value_1$ is deleted from the circuit

715. Go to step 701

716. REMARKS

The circuit is renumbered in multiples of 10 starting at 10.

Renumbering is for convenience only and is not required.

717. Go to step 701

718. REMARKS

The frequencies in the line of input replace all existing frequencies.

The line of input can actually contain any combination of discrete frequencies or stepped ranges, but no more than 20 frequencies can be accepted. Here is an example,

```
FREQ .5 STEP 1  9  1  ESTEP 10 100 10
```

719. Go to step 701

720. REMARK Units, program parameters, and the output request contained in the line of input replace existing quantities.

721. Go to step 701

722. If DEV data are required; go to step 723
If DEV data are not required; go to step 725

723. REMARK The program on file 1 is loaded. Approximately 40 seconds are required.

724. Go to step 201 (subset 2)

725. REMARK The program on file 2 is loaded. Approximately 85 seconds are required.

726. Go to step 301 (subset 3)

1.11 Storing a Circuit

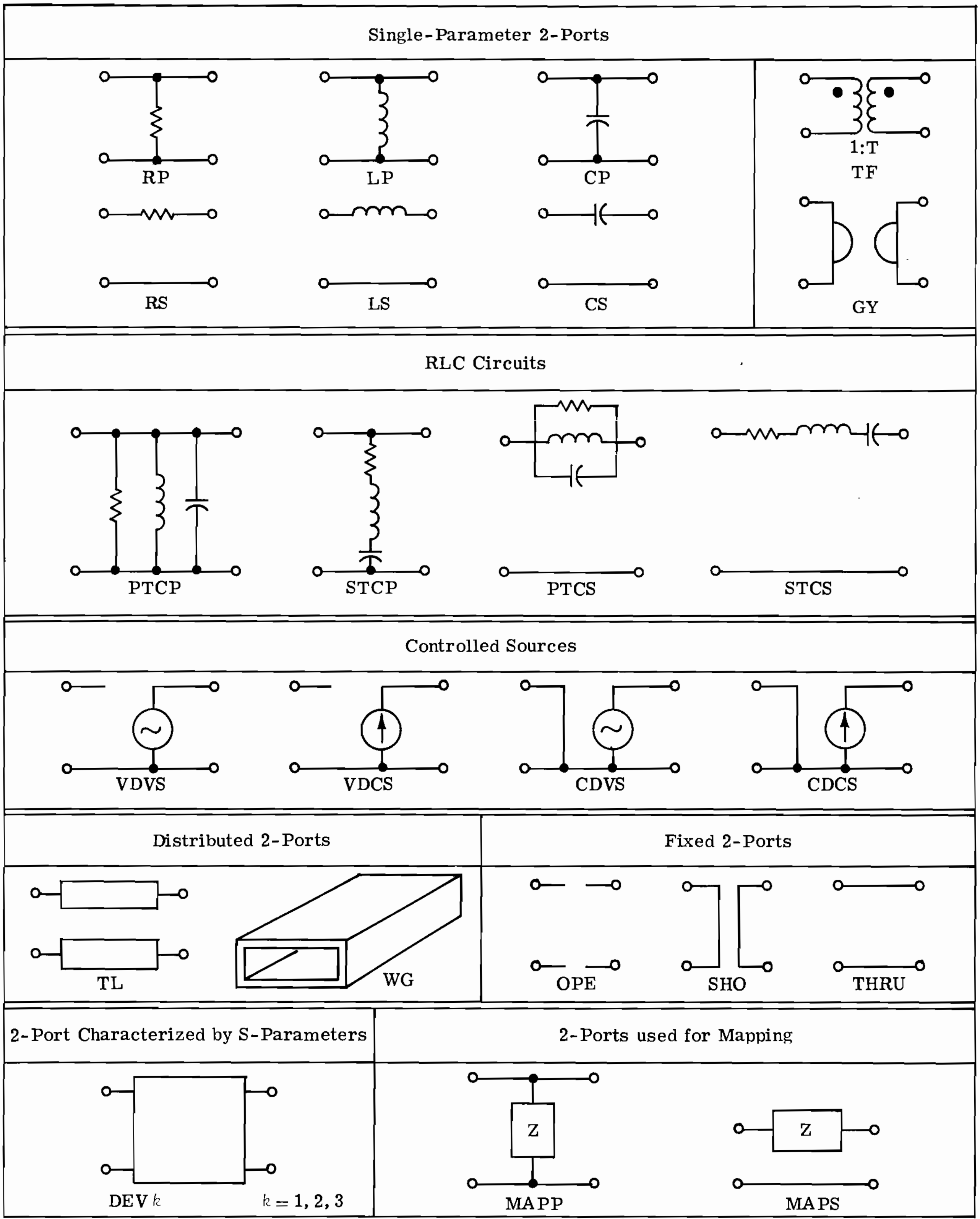
Once a circuit has been accepted by Bamp then it can be stored on a circuit cassette and later loaded in memory for re-run according to steps 103, 104, 108-111 of subset 1 in section 1.10. The file used to store the circuit must be at least 2100 words long. In the following, it is assumed that you have prepared a cassette by marking files that have a capacity of at least 2100 words.

When the circuit has been accepted and run, or when it has been accepted and you have typed S [TOP] in step 111 of subset 1 in section 1.10, then you do the following:

001 Remove: Bamp cassette
Insert: circuit cassette
Type : STORE DATA value$_1$
Press: EXECUTE
002 REMARK value$_1$ is the number of the file on which the circuit is stored. You must keep a record of which circuit is stored on which file.
003 When "├—" appears in the display
Press: REWIND
Remove: circuit cassette

If analysis is performed prior to storing the circuit, then the stored circuit contains the computed S-parameters as well as DEV data, if the circuit contains DEV 1, DEV 2, or DEV 3. If the circuit has only been accepted but not run before it is stored, then the stored circuit obviously does not contain S-parameters. Neither does it contain DEV data.

Table 1. 2-Ports
(See Section 1.2 for Detail)



Chapter II
MAPPING

CHAPTER 2
MAPPING

2.1 Introduction

As used in this manual, mapping can be thought of as a way to display graphically how an impedance affects a two-port characteristic. Mapping is therefore useful for studying network sensitivity to variations in a single impedance and also for stability investigations.

As one example of mapping, the output MAPLOAD routinely maps the entire right-half of the load impedance plane onto the plane of the input reflection coefficient. If any part of the map lies outside the unit circle in the Γ_{in}-plane, then there is a load impedance with positive real part for which $|\Gamma_{in}| > 1$. This is equivalent to saying that the two-port is unstable for some load impedance with positive real part. Further it is possible to identify those impedances that cause the instability and to find circuit modifications that make the two-port absolutely stable. For a specific example, see Chapter 6, Example 6.4.2.

For conciseness of notation, the pair (Z, S) will denote a mapping throughout the remainder of this manual. Z is the variable impedance and S is the two-port characteristic into which Z is mapped. Available pairs are listed below.

Z	S
Load impedance, Z_L	Γ_{in} or $1/\Gamma_{in}$
Source impedance, Z_S	Γ_{out} or $1/\Gamma_{out}$
Internal impedance, Z	S_{ij} or $1/S_{ij}$, $i, j = 1, 2$

where

Γ_{in} = input reflection coefficient

Γ_{out} = output reflection coefficient

S_{ij} = ijth element of overall two-port S-matrix

The output request MAPLOAD instructs Bamp to map Z_L onto the Γ_{in} or $1/\Gamma_{in}$ plane. You make the choice Γ_{in} or $1/\Gamma_{in}$ later in the program. The source impedance Z_S is mapped onto the Γ_{out} or $1/\Gamma_{out}$ plane as a result of the output request MAPSOURCE. An internal impedance is mapped by including one of the two-ports MAPP or MAPS in the circuit as explained in section 2.3.

The equation on which mapping is based can be written as

$$S = T + R(Z - N^*)/(Z + N) \tag{2.1.1}$$

where T, R, and N are complex numbers that are computed by Bamp. (N* is the complex conjugate of N.) Bamp '30 always prints T and R in polar form and N in real-imaginary form.

Equation (2.1.1) is one form of the bilinear transformation, as is obvious when it is rewritten in the equivalent form

$$S = \frac{(T+R)Z + TN - RN^*}{Z + N} \tag{2.1.2}$$

Bode, Ref 5, proved that the bilinear transformation applies between an impedance and the network admittance and impedance matrices. The underlying transformation from impedances to S-parameters means that the bilinear relationship applies to S-parameters as well. Kuhn, Ref. 6, has proven the validity of Eq. (2.1.1) working entirely with S-parameters.

Two points should be emphasized

1. In general, T, R, and N in Eq. (2.1.1) are frequency dependent. This means that a mapping at one frequency is not necessarily valid at another.
2. Mapping applies to one impedance only. Equation (2.1.1) is not valid, if there are two or more variable impedances.

Some additional discussion of Eq. (2.1.1) is useful as background for interpreting and understanding the mapped outputs. The imaginary axis divides the impedance plane into right-half and left-half planes. The real part is positive in the right-half plane. The image in the complex S-plane of the imaginary axis is a circle, which divides the S-plane into an inside and an outside. There are two possibilities: 1. The right-half plane maps inside, 2. The left-half plane maps outside. Which of these occurs is determined by the algebraic sign of ReN. Specifically,

1. $\mathrm{ReN} > 0 \Longrightarrow$ right half of impedance plane maps inside the image of the imaginary axis
   left-half plane maps outside
2. $\mathrm{ReN} < 0 \Longrightarrow$ right-half of impedance plane maps outside the image of the imaginary axis
   left-half plane maps inside

If the right-half plane maps inside, that is, if ReN > 0, then for any Z in the right-half plane

$$|S| \leq |S|_{\max} = |T| + |R| \tag{2.1.3}$$

The printed values of $|T|$ and $|R|$ along with Eq. (2.1.3) are useful in selecting the scale in step 615 of the user instructions in section 1.10. Choosing a scale factor greater than $|S|_{\max}$ assures you of obtaining the full image of the right-half plane. If the right-half plane maps outside, then $|S|$ is unbounded for some Z in the right-half plane. Equation (2.1.3) is not valid, therefore, for ReN < 0.

There are two singularities for Eq. (2.1.1). These are

$$\mathrm{Re}Z = -\mathrm{ReN}$$

and

$$\mathrm{Im}Z = -\mathrm{ImN}$$

The images of these two lines are mutually perpendicular straight lines in the S-plane. For example T=0, R=1, and N=1 reduce Eq. (2.1.1) to the equation of a standard Smith chart in normalized form, namely

$$S = \frac{Z - 1}{Z + 1}$$

The singularities are

$$R = \mathrm{Re}Z = -1$$
$$X = \mathrm{Im}Z = 0$$

The image of $X = 0$ is of course just the horizontal axis of the standard Smith chart. The image of $R = -1$ is the line

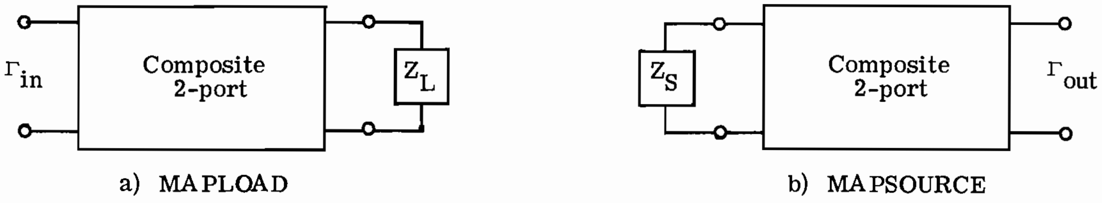
$$S = 1 + j(2/X)$$

which is a vertical line through the open-circuit position on the Smith chart.

2.2 MAPLOAD and MAPSOURCE (mapping a terminal impedance)

See Example 6.4.2 in Chapter 6 for an example of MAPLOAD.

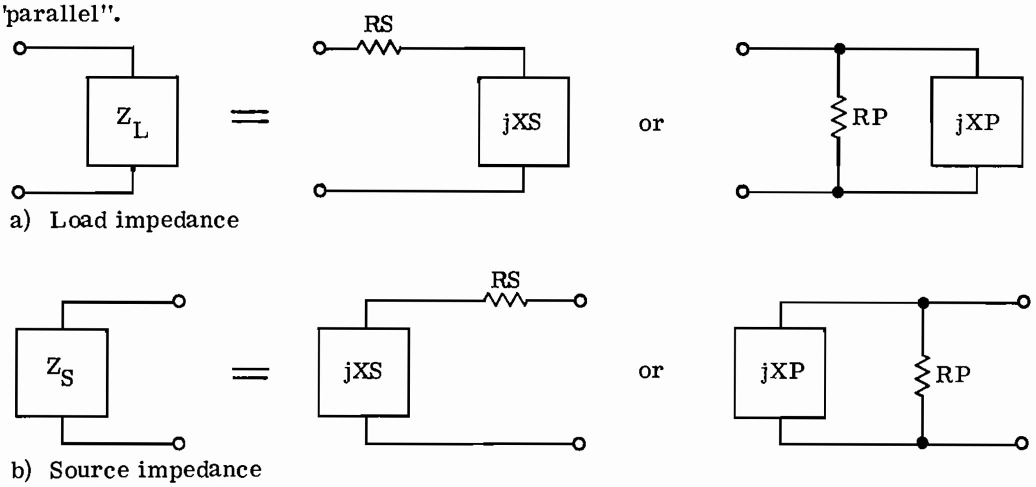
Figure 2.2.1 shows the circuit configuration for MAPLOAD and MAPSOURCE. The load and source impedances can be either series R and series X or parallel R and parallel X as shown in Fig. 2.2.2. In Fig 2.2.2 and throughout this chapter, S in RS and XS means "series"; P in RP and XP means "parallel".



a) MAPLOAD

b) MAPSOURCE

Fig 2.2.1 Circuit configuration for MAPLOAD and MAPSOURCE



a) Load impedance

b) Source impedance

Fig 2.2.2 Possible forms of load and source impedances for MAPLOAD and MAPSOURCE

MAPLOAD and MAPSOURCE are output requests for a fixed composite two-port. Either MAPLOAD or MAPSOURCE can be the single output request allowed in the original circuit description, or either can be typed in response to the prompt NEXT? whenever this prompt is displayed (see steps 316, 430, 519, and 618 of detailed user instructions in section 1.10). It is in step 605 of the user instructions that you select Γ or $1/\Gamma$ where Γ is Γ_{in} for MAPLOAD, but Γ_{out} for MAPSOURCE.

Except as noted in section 2.4.1, two plots are produced routinely. The first of these is

$$S(XS)\,\Big|_{RS=0} \quad = \quad S(XP)\,\Big|_{RP=\infty}, \; -\infty < XS,\ XP < \infty$$

and the second is

$$S(RS)\,\Big|_{XS=0} \quad = \quad S(RP)\,\Big|_{XP=\infty}, \; 0 \leq RS,\ RP < \infty$$

where S is Γ_{in}, $1/\Gamma_{in}$, Γ_{out}, or $1/\Gamma_{out}$ according to your previous choice of MAPLOAD or MAPSOURCE and of GAMMA or 1/GAMMA. The first plot, a mapping of the imaginary axis in the Z-plane onto the complex S-plane, is a full circle. The second plot, a mapping of positive resistance onto the S-plane is an arc of a circle.

After the two routine plots have been completed, then the prompt NEXT? appears in the display (see step 618 of user instructions in section 1.10). You then have the option of adding any one of the plots:

1. Resistance, constant at positive, negative, or zero value

$$S(XS)\,\Big|_{RS\,=\,\text{constant}} \qquad\qquad S(XP)\,\Big|_{RP\,=\,\text{constant}}$$
$$-\infty < XS,\ XP < \infty$$

2. Reactance constant at positive, negative, or zero value

$$S(RS)\,\Big|_{XS\,=\,\text{constant}} \qquad\qquad S(RP)\,\Big|_{XP\,=\,\text{constant}}$$

or one of the image points

3. S(ZS) S(ZP)

To select a plot of the type 1 above you type

Series connection		Parallel connection
RS value_1	or	RP value_1

where value_1 is the constant value of resistance either RS or RP.

To obtain a plot of the type 2 above you type

Series connection		Parallel connection
XS value_1		XP value_1
or		or
LS value_1	or	LP value_1
or		or
CS value_1		CP value_1

where value_1 is the constant value of X or alternatively of L or C. If X is specified, then Bamp computes and prints the corresponding value of L or C. On the other hand, if L or C is specified, then Bamp computes and prints the corresponding value of X.

To obtain an image point as in 3 above you type

Series connection	Parallel connection
ZS value_1 value_2	ZP value_1 value_2
or	or
RLS value_1 value_2	RLP value_1 value_2
or	or
RCS value_1 value_2	RCP value_1 value_2

where value_1 is the fixed value of resistance, which can be positive negative or zero; and value_2 is X, L, or C. If X is specified, then L or C is computed and printed. If L or C is specified, then X is computed and printed. In addition to plotting the image point, Bamp prints the magnitude and phase of S.

MAPLOAD and MAPSOURCE are also acceptable responses to NEXT? If you have completed a mapping of load impedance onto the input reflection coefficient plane and want to map source impedance onto the output reflection coefficient plane, then you type MAPSOURCE. By typing MAPLOAD or MAPSOURCE you can obtain a mapping at a different frequency, if the composite two-port has been built up at more than one frequency.

Other acceptable responses to NEXT? are

LETTER
PLOT
PRINT
E [DIT]
R [UN]
W [RITE]
S [TOP]

LETTER allows you to type captions from the keyboard. PLOT and PRINT load and run programs that allow you to obtain additional graphical or tabular outputs. E [DIT] calls the editor; R [UN] calls for another analysis, which you might want if the circuit has TEL inputs for parameter values; W [RITE] loads and runs the input program; and S [TOP] terminates the program and rewinds the Bamp cassette.

2.3 MAPP and MAPS (mapping an internal impedance)

MAPP and MAPS are illustrated as Examples 6.8 and 6.9 in Chapter 6.

MAPP and MAPS are special two-ports. As shown in Fig. 2.3.1, MAPP consists of an impedance Z in parallel with the ports, and this impedance can be a series connection of R and X or, alternatively, a parallel connection of R and X. MAPS differs from MAPP in that impedance Z is in series with the ports. In common with MAPP, Z can be either a series or parallel connection of R and X as shown in Fig 2.3.2.

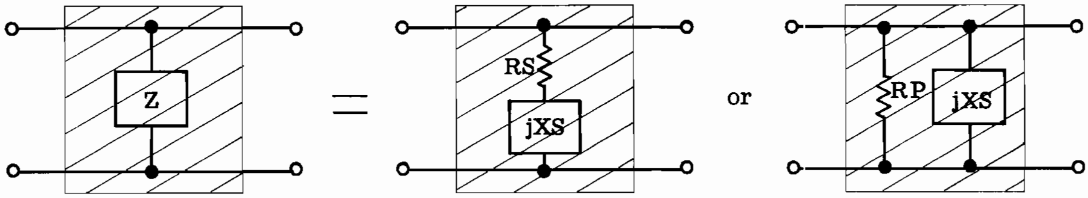


Fig 2.3.1 The two-port MAPP

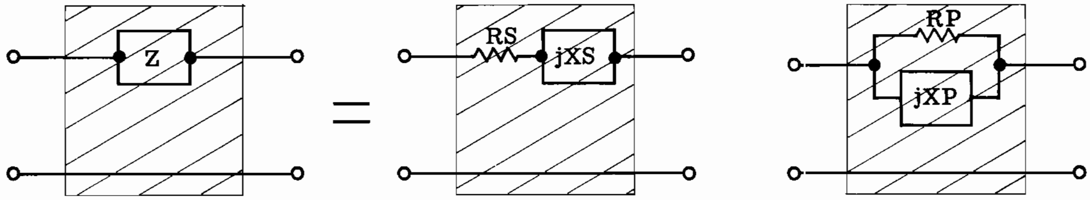


Fig 2.3.2 The two-port MAPS

One of MAPP or MAPS can be included in a circuit at any point where a shunt or series element is acceptable. The Z associated with the two-port MAPP or MAPS is then the impedance that is later mapped onto the plane of one or more of the S-parameters of the composite two-port.

MAPP and MAPS can also be thought of as implicit output requests. If MAPP or MAPS is included in a circuit description, then the mapped output is the only available output. It is not possible to plot or print any other output and MAPLOAD and MAPSOURCE are not possible. (There is a program idiosyncrasy you should know about. Suppose you enter a circuit including MAPP or MAPS and then use editor to obtain a listing including line 0 as in step 703 of the user instructions in section 1.10. SDB is listed as the output request. However, this request is ignored when the circuit is run.)

The impedance Z performs two functions. First of all, in three preliminary analyses Bamp sequentially assigns to Z the values jZR, ZR, and -jZR where ZR is the real reference impedance. The overall S-parameters are computed and stored. Bamp then has available three sets of S-parameters corresponding to three known impedances. These S-parameters are used to compute T, R, and N in the mapping equation (2.1.1). Secondly, the forms of Z, series and parallel R and X, allow you to select specific plots and image points exactly as described in section 2.2 for MAPLOAD and MAPSOURCE. For an internal mapping as well as for MAPLOAD and MAPSOURCE, the two automatic plots are

$$S(XS)\,\big|_{RS=0} = S(XP)\,\big|_{RP=\infty},\ -\infty < XS,\ XP < \infty$$

and

$$S(RS)\,\big|_{XS=0} = S(RP)\,\big|_{XP=\infty},\ 0 \leq RS,\ RP < \infty$$

After the three preliminary analyses mentioned above have been completed, then the mapping program, which is on file 5, is loaded and run. After the mapping program starts to run, the first user input responds to the prompt VARIABLE? in step 612 of the user instructions in section 1.10. Here you select S_{ij} or $1/S_{ij}$, i, j = 1, 2. The constants T, R, and N are computed and printed, and the two automatic plots are produced after the scale is specified as in step 615 of the user instructions. The prompt NEXT? then appears in the display. You can select any one of the three types of plots in section 2.2, or you can type any one of the following

Sij or 1/Sij, i,j = 1, 2
LETTER
E [DIT]
R [UN]
W[RITE]
S [TOP]

Sij or 1/Sij call for another mapping. LETTER allows you to label your graph from the keyboard; and E [DIT],R [UN],W[RITE],S[TOP]call the editor, call for another circuit analysis, call the input program, and terminate Bamp and rewind the Bamp cassette. Any of the responses MAPLOAD, MAPSOURCE, PLOT, and PRINT are ignored without comment.

Examples 6.8 and 6.9 in Chapter 6 show how to use MAPP and MAPS and illustrate the mapping procedure. These are simple, but interesting illustrative circuits. Larger networks with many more component two-ports and with MAPP or MAPS embedded deep within the network could be used.

There are two concluding points to keep in mind

1. In mapping an internal impedance, you should specify only one frequency. All frequencies except the first are ignored, if more than one is specified. To obtain a mapping at a different frequency, you should use the editor to change the frequency.
2. Do not include more than one impedance to be mapped. This means that only one of MAPP or MAPS should appear in the circuit and this only one time. Bamp will not reject a circuit that has more than one impedance to be mapped. Rather, a mapped output will be obtained, but that output will most likely be meaningless, since Eq. (2.1.1) is not valid for more than one impedance.

2.4 Program parameters for mapping

2.4.1 Angular Increment Factor

Almost all of Bamp's mapped outputs are circles or arcs of circles. These are plotted by computing the center and radius of the circle and then drawing chords for equi-angular displacements through an appropriate range of angles. The angular step is inversely proportional to the square root of the radius and is given by

$$\Delta\theta = \frac{AIF}{\sqrt{\rho}} \qquad (2.4.1.1)$$

where

ρ = radius of circle
AIF = angular increment factor

The default value of AIF is five, but any value greater than zero can be used. A value greater than five provides a cruder approximation to a circle, but requires fewer points, and therefore less time, to plot.

To change the angular increment factor to 7.5, for example, type

AIF [=] 7.5

as a part of the circuit description. Or, use the editor as follows

when "EDITOR?" appears in the display
Type : AIF [=] 7.5
Press: EXECUTE

If AIF > 1000, the plot routine is disabled. In this case T, R, and N are printed and the value of S for specified impedances ZS and ZP are printed, but circles are not plotted. If AIF = 1000 circles are not plotted, but images of specified impedances are plotted.

2.4.2 Domain of resistance

In plots of the form

$$S(RS)\big|_{XS=\text{constant}} \qquad S(RP)\big|_{XP=\text{constant}}$$

values of RS and RP are normally restricted to

$$0 \leq RS,\ RP < \infty$$

and the plot is an arc of a circle. The restriction to non-negative resistance can be removed by typing

(minus sign) as a part of the circuit description. This same thing can be done using the editor as follows

When "EDITOR?" appears in the display
Type : -
Press: EXECUTE

The restriction to non-negative resistance is restored using the editor as follows

When "EDITOR?" appears in the display
Type : +
Press: EXECUTE

Plots of the form

$$S(RS)\,\big|_{XS=\text{constant}} \qquad S(RP)\,\big|_{XP=\text{constant}}$$

$$-\infty < RS, RP < \infty$$

are full circles.

Chapter III

DIAGNOSTIC MESSAGES

CHAPTER 3
DIAGNOSTIC MESSAGES

One of the goals in developing Bamp '30 has been to build-in safeguards against all calculator run errors. This goal has not been achieved, entirely, but a calculator error message should be a rare event.

Many Bamp safeguards have the effect of insisting that all inputs be intelligble. If a user input is unintelligble or is not acceptable, then Bamp will often repeat the prompt without comment. In other cases Bamp will print or display a disgnostic message. This chapter lists some of the disgnostic messages and suggests actions you should take. These messages are collected together in sections corresponding to the Bamp sub-program that prints them. Messages are printed, unless there is an explicit statement to the contrary.

3.1 Input-Edit program (file 0)

3.1.1 REPLACE THIS ITEM:

The printed text contains a substring from a line of input that is being processed. This substring cannot be recognized, possibly because of a typing error or failure to include a delimiter (space or comma). Re-type the substring and press EXECUTE. The line of input is reconstructed from the replaced item, the reconstructed line is printed, and processing continues.

3.1.2 (mnemonic(s) for parameter value(s)) = ?

This message appears in the display and follows an audible "BEEP". Your circuit description contains a two-port with less than the required number of parameters. Enter these parameter values, or TEL's, or mixtures, but only these parameter values.

3.1.3 REF NUMBER?

This message appears in the display and follows an audible "BEEP". The problem is that your circuit description contains a two-port DEV without an accompanying reference number or an auxiliary operation (HOLD, SER, SHU, CIR, or USE) without a reference number. For a two-port DEV, you should enter 1, 2, or 3. For an auxiliary operation you should enter a number between 1 and 5. In both cases you must be careful not to duplicate a reference number intended for a different two-port DEV, or a different or unrelated auxiliary operation.

3.1.4 REF NUMBER OUT OF BOUNDS

This message also appears in the display. The reference number for a DEV is not 1, 2, or 3, or the reference number for an auxiliary operation is not 1, 2, 3, 4, or 5. After a pause message 3.1.3 appears also.

3.1.5 (DEV data file name) CHANGED TO DEV (k)

This message is for information only and requires no action. For the first parenthesis there is the name of a DEV data file, and for the second there is an integer 1, 2, or 3. Your circuit description contained two type II two-ports DEV k using the same reference numbers but different DEV data file names. Bamp found an unused number and assigned it to one of the two-ports.

3.1.6 (DEV data file name) EXCEEDS LIMIT OF 3 DEV

This is what happens as a result of the situation in 3.1.5, if the circuit already contains three different type II two-ports.

3.1.7 ERROR--REPEAT STEPPED RANGE

Your frequency specification contains a linearly stepped range with one or more of start, stop, or step frequency missing. Re-enter not only this range but all subsequent frequencies, if any, as a single line.

3.1.8 START, STOP FOR ESTEP MUST HAVE SAME SIGN

Your frequency specification contains an exponentially stepped range for which $(F1)(F2) \leq 0$ where F1 and F2 are start and stop frequencies. It is necessary that $(F1)(F2) > 0$, so re-enter this range as well as all subsequent frequencies, if any, as a single line of input.

3.1.9 LIMIT OF 20 FREQS--FIRST 20 ACCEPTED

You have entered more than 20 frequencies. All above 20 have been discarded. You will actually have less than 20, if your first 20 contained duplicates. This is because duplicates are thrown out, but only after all in excess of 20 have been discarded.

3.2 DEV data acquisition (file 1)

3.2.1 ERROR--REPEAT ENTIRE LINE?

This message appears in the display following an audible "BEEP". Your line of data contains less than nine items that have numeric values. Simply re-enter a correct line of data containing nine numbers.

3.2.2 (DEV data file name) NOT ON CASSETTE

The DEV data cassette does not have a file identified by the name in your circuit description. Your only alternatives are to replace the data cassette with one that does have the required file, or to terminate the run.

3.3 Analysis (file 2)

3.3.1 (FREQ) INSUFFICIENT DATA FOR DEV (k)

This message is for information only. No action is required. You have requested analysis at a frequency for which DEV data are not available and cannot be obtained by interpolation. Recall that Bamp does not extrapolate DEV data.

3.3.2 STORAGE LOCATION ( ) IS EMPTY

The parenthesis represents a storage location k . This storage location is empty, but USE $\pm k$ is attempting to fetch a two-port from it. The editor is called automatically. Edit the circuit supplying the required HOLD k , SER k , SHU k, or CIR $\pm k$.

3.3.3 PROB--CONN OR 2-PORT

This message immediately precedes a program STOP to prevent a divide-by-zero. Review your circuit to be sure it is correct physically. You can continue by doing the following

Press: CONTINUE
Press: EXECUTE

but you will get divide-by-zero messages.

3.4 Plot (file 3)

3.4.1 MATRIX DOES NOT EXIST

You have requested a plot of some G-, H-, Y-, or Z- parameter, but a finite G-, H-, Y-, or Z-matrix does not exist at one or more analysis frequencies. Bamp makes no further effort to plot this variable, but does give you an opportunity to plot a different variable.

3.4.2 (variable) NOT RECOGNIZED

Your response to the prompt VARIABLE? is the quantity represented by the parenthesis. Perhaps a typographical error has been made. Try again.

3.5 Mapping (file 5)

3.5.1 SINGULARITY

The equations for mapping an internal impedance cannot be solved for T, R, and N.

Chapter IV
BAMPDF

CHAPTER 4
BAMPDF

4.1 Purpose

Bampdf is a stand-alone program on file 0 of the Bampdf cassette. It is used to create a DEV data file for use by Bamp. There are three ways in which this can be done.

1. Type in a set of two-port S-, G-, H-, Y-, or Z-parameters from the 9830A keyboard.
2. Transfer S-parameters computed by Bamp from the 9830A memory to a DEV data cassette.
3. Transform a set of S-parameters in an existing DEV data file from either the common-emitter (CE), common-collecter (CC), or common-base (CB) configuration to a different configuration (CE, CC, or CB) and store as a different DEV data file.

In addition to creating a DEV data file, Bampdf can be used to do the following

- correct or change data in an existing DEV data file,
- list all or part of an existing DEV data file, and
- print an index for a DEV data cassette.

In summary, the tasks that Bampdf can perform are

- WRITE, that is, create a DEV data file using data typed from the keyboard or S-parameters read from the 9830A memory after a run by Bamp.
- CORRECT data in an existing DEV data file.
- LIST all or part of an existing DEV data file.
- INDEX a DEV data cassette
- TRANSFORM data from CE, CC, or CB to a different configuration either CE, CC, or CB.

4.2 Preparing a DEV data cassette

You are supplied a DEV data cassette that has nine (9) DEV data files. An index for this cassette as well as listings of these files are included in this manual as Appendix C. You can add up to 21 additional files to this cassette by following the step-by-step user instructions in section 4.4. The only preliminary not specifically included in the user instructions is that you must enable the cassette for writing. There is, however, a most important precaution. *In step 805 of the user instructions in section 4.4 you must type O [LD]. Existing files are lost, if you type N [EW].*

If you use a different cassette, then as a preliminary you must mark appropriate files (see pages 5-6 and 5-7 of the Hewlett-Packard 9830A Calculator operating and programming manual, HP part number 09830-90001). The correct way to mark a data cassette is

```
MARK 1, 500
MARK 30, 1000
```

File 0, the file marked for 500 words, is used to store an index for the entire cassette. The index file is created by Bampdf and is used by both Bampdf and by Bamp. The remaining files are used as DEV data files.

Once a cassette has been marked and has at least one DEV data file stored, it then becomes an OLD data cassette. Additional data files can be added up to a limit of 30 files, but the precaution mentioned above applies. If you say that the cassette is a NEW cassette in step 805, then all existing files are lost.

4.3 Naming a DEV data file

You supply names for the DEV data files you create using Bampdf. The following restrictions apply

- The name must not contain more than 10 characters.
- Do not use DEV or any other Bamp term. DEV will be rejected, without comment, as a name, but other Bamp terms will not. The forbidden names are

DEV
RP
LP
CP
RS
LS
CS
TF
GY
PTCP
PTCS
STCP
STCS
VDVS
VDCS
CDVS
CDCS
TL
WG
OPE
SHO
THRU
MAPP
MAPS

HOLD
CIR
SER
SHU
USE

SRI
SMP
SDB
PLOT
PRINT
MAPLOAD
MAPSOURCE

CAS
PAR
SER
PARSER
SERPAR

STEP
ESTEP

HZ
KHZ
MHZ
GHZ
OH
KO
MO
H
MH
UH
NH
F
MF
UF
NF
PF
M
CM
IN
AIF
-
+
ZR

- Do not use a numeric as the leading character.

4.4 Capacity of DEV data files

Each DEV data file can contain up to 25 frequency points. No more than 25 frequency points are allowed in any one file.

4.5 User instructions

This section contains detailed user instructions. Example 6.10 in Chapter 6 is an actual run that illustrates how to use Bamdf to create a DEV data file and to transform from one configuration to another (CB to CE in Example 6.10). Another example using Bampdf appears in Appendix B where a DEV data file is created from computed S-parameters stored in the 9830A memory.

Subset 8. Bampdf

801. REMARK Bampdf is used to create a DEV data file for use by Bamp. There are two different ways to do so. These are:

    1. Enter data from the keyboard. These data can be S-, G-, H-, Y-, or Z-parameters, and the format can be RI (real-imaginary), MP (magnitude-phase), or DB (magnitude-phase with 12 and 21 magnitudes in dB, that is, 20xlog$_{10}$magnitude).
    2. Transfer data directly from the 9830 memory immediately after Bamp has been run. The DEV data file created in this way contains S-parameters computed by Bamp, and the format is RI. One reason for creating a DEV data file in this way is to reduce a large sub-block of a larger circuit to a single 2-port for use in the larger circuit. An example is one stage of a multi-stage amplifier. The steps that must be followed are:
        - i. run Bamp
        - ii. remove the Bamp cassette
        - iii. go immediately to step 802. *Do not* press SCRATCH.

802.
Insert: Bampdf cassette
Press: LOAD
Press: EXECUTE

803. When "⊢" appears in the display
Press: RUN
Press: EXECUTE

804. When "1.INSERT DATA C'SETTE 2.TYPE GO?" appears in the display
Remove: Bampdf cassette
Insert: data cassette
Type : GO
Press: EXECUTE

805. When "NEW OR OLD?" appears in the display
Type : N[EW]
or
Type : O [LD]
Press: EXECUTE

806. If you typed N; go to step 807
If you typed O; go to step 825

807. REMARK You have told Bampdf that the data cassette is empty, or that you want to replace all existing data files starting from file 1, the first data file on the cassette.

808. When "NAME OF DATA FILE?" appears in the display
Type : name consisting of no more than 10 characters--do not use DEV or the name of any other Bamp 2-port or term such as STEP, PLOT, etc.
or

Type : space
Press: EXECUTE

809. If you typed the name of a DEV data file; go to step 810
If you typed space; go to step 825

810. When "ARE DATA IN MEMORY(Y OR N)?" appears in the display
Type : Y [ES]
or
Type : N [O]
Press: EXECUTE

811. If you typed Y; go to step 812
If you typed N; go to step 814

812. REMARK The DEV data file is created automatically from S-parameters previously computed by Bamp and currently stored in the 9830 memory.

813. Go to step 808

814. When "G, H, S, Y, OR Z?" appears in the display
Type : G
or
Type : H
or
Type : S
or
Type : Y
or
Type : Z
Press: EXECUTE

815. When "RI, MP, OR DB?" appears in the display
Type : RI
or
Type : MP
or
Type : DB
Press: EXECUTE

816. When "FREQ UNITS (GHZ, MHZ, KHZ, OR HZ)?" appears in the display
Type : GHZ
or
Type : MHZ
or
Type : KHZ
or
Type : HZ
Press: EXECUTE

817. When "BIAS(V, MA)?" appears in the display
Enter: value_1 value_2
Press: EXECUTE

818. When "DATA(FREQ, 11, 12, 21, 22)?" appears in the display
Enter : a line of data consisting of frequency as the first item followed by two

numbers for each of the matrix elements 11, 12, 21, and 22 in that order
Press: EXECUTE

819. When "?" appears in the display
Enter : a line of data as in step 818
or
Type : C value_1
or
Type : space
or
Type : /
Press: EXECUTE

820. If you entered a line of data; go to step 819
If you typed C value_1; go to step 821
If you typed space or if you typed /; go to step 808

821. REMARK Data at the frequency f = value_1 are displayed item-by-item starting with f. You can change or retain any item. In step 822 *n* is any one of the data items as they are displayed successively.

822. When " *n* ?" appears in the display
Enter: value
or
Type : space
or
Type : S [TOP]
Press: EXECUTE

823. REMARKS
Entering value replaces *n*
Typing space retains *n*

824. If you typed S, or if all data have been displayed; go to step 819
If not all data have been displayed; go to step 822

825. When "TASK?" appears in the display
Type : W [RITE]
or
Type : C [ORRECT]
or
Type : L [IST]
or
Type : I[NDEX]
or
Type : T [RANSFORM]
or
Type : S [TOP]
Press: EXECUTE

826. If you typed W; go to step 808
If you typed C; go to step 827
If you typed L; go to step 827
If you typed I; go to step 841
If you typed T; go to step 843

If you typed S; Bampdf is terminated and the data cassette is rewound

827. When "NAME OF DATA FILE?" appears in the display
Type : name of DEV data file
Press: EXECUTE

828. If the typed C in step 825; go to step 829
If you typed L in step 825; go to step 835

829. When "FREQ?" appears in the display
Enter: value$_1$
or
Type : space
Press: EXECUTE

830. If you entered value$_1$; go to step 831
If you typed space; go to step 825

831. REMARK Data at the frequency f = value$_1$ are displayed item-by-item starting with f. You can change or retain any item. In step 832 n is any one of the data items as they are displayed in succession.

832. When "n?" appears in the display
Enter: value
or
Type : space
or
Type : S [TOP]
Press: EXECUTE

833. REMARKS
Entering value replaces n
Typing space retains n

834. If you typed S, or if all data have been displayed; go to step 829
If not all data have been displayed; go to step 832

835. When "FREQ RANGE?" appears in the display
Enter: value$_1$ [value$_2$]
or
Type : space
Press: EXECUTE

836. REMARKS
Let f_l = min(value$_1$, value$_2$), if both value$_1$ and value$_2$ are entered
f_l = value$_1$, if value$_2$ is omitted
$f_l = -\infty$, if space is typed

Let f_u = max(value$_1$, value$_2$), if both value$_1$ and value$_2$ are entered
$f_u = +\infty$, if value$_2$ is omitted

837. When "RI, MP, OR DB?" appears in the display
Type : RI
or
Type : MP
or
Type : DB
Press: EXECUTE

838. REMARKS
The listing consists of data at all frequencies f such that
$f_l \le f \le f_u$, if f_Z and f_u are both finite.
The listing consists of data at all frequencies f such that
$f_l \le f$, if $f_u = + \infty$.
The entire file is listed if $f_l = - \infty$ and $f_u = + \infty$

839. When "AGAIN?" appears in the display
Type : Y [ES]
or
Type : N [O]
Press: EXECUTE

840. If you typed Y; go to step 835
If you typed N; go to step 825

841. REMARK An index for the entire data cassette is printed. The following information is included:

- file number and name of DEV data file
- type of data (S-, G-, H-, Y-, or Z-parameters)
- data format (RI, MP, or DB)
- bias conditions
- list of frequencies

842. Go to step 825

843. When "SOURCE FILE?" appears in the display
Type : name of source DEV data file
Press: EXECUTE

844. When "DESTINATION FILE?" appears in the display
Type : name of DEV data file for transformed data
Press: EXECUTE

845. When "ORIGINAL (CE, CB, OR CC)?" appears in the display
Type : CE
or
Type : CB
or
Type : CC
Press: EXECUTE

846. When "DESIRED (CE, CB, OR CC)?" appears in the display
Type : CE
or
Type : CB
or
Type : CC
Press: EXECUTE

847. REMARK Data are transformed as requested and stored in the DEV data file whose name was typed in step 844.

848. Go to step 825

4.6 Bampdf diagnostics

Bampdf diagostics are grouped together in this section according to the tasks WRITE, CORRECT, etc. All of these messages are printed, unless there is an explicit statement to the contrary.

4.6.1 WRITE task

The WRITE task is the task that creates a new DEV data file. This file can be an addition to an old data cassette, or the first file on a new data cassette. Among the inputs you supply are

- name for the data file
- type data, frequency units, and bias conditions
- lines of data with each line containing nine data elements (frequency and two numbers for each of the 11, 12, 21, and 22 matrix elements at that frequency)

The possible diagnostic messages are

4.6.1.1 DUPLICATE ENTRY--DO YOU WANT TO REPLACE EXISTING FILE (Y OR N)

The name you have typed for the DEV data file you are creating is already being used on the data cassette. You replace, and therefore loose, the existing file by responding Y [ES]. If you respond N [O], then you can type in a different name.

4.6.1.2 CASSETTE FILLED

All 30 DEV data files have been used. You must use a new cassette, or replace an existing file by using a duplicate name

4.6.1.3 NOT ENOUGH DATA--REPEAT ENTIRE LINE

This message appears in the display, but is not printed. The last line of data you entered does not contain nine valid data items. You must re-enter the entire line.

4.6.2 CORRECT task

You use this task to correct or change one or more lines of data in a DEV data file;your inputs are

- name of DEV data file
- frequency at which data are to be corrected

There are two possible diagnostic messages

4.6.2.1 (name of DEV data file) NOT ON CASSETTE

The cassette does not contain a file identified by the name you have typed. You may have made a typographical error. If not, check the cassette index using the INDEX task.

4.6.2.2 (frequency) NOT IN FILE

The frequency you have specified cannot be found in the file.

4.6.3 LIST task

This task allows you to list all or part of an existing file. Your inputs are

- name of DEV data file
- range of frequencies to be listed.

There is one possible diagnostic message

4.6.3.1 (name of DEV data file) NOT ON CASSETTE

This is the same message as 4.6.2.1, and the comments there apply here as well.

4.6.4 TRANSFORM task

TRANSFORM reads a set of S-parameters from a source DEV data file; computes S-parameters for a specified configuration, either CE, CB, or CC; and stores the computed S-parameters in a specified destination file. Your inputs include

- name of source file
- name of destination file
- desired configuration

The possible diagnostic messages are

4.6.4.1 (name of DEV data file) NOT ON CASSETTE

The name you have given for the source file cannot be found on the cassette.

4.6.4.2 (name of DEV data file) DOES NOT CONTAIN S-PARAMETERS

The source file contains G-, H-, Y-, or Z-parameters. Bampdf is programmed to carry out the transformation for S-parameters only.

4.6.4.3 (name of DEV data file) IS SOURCE--OVERWRITE (Y OR N)

The name you have given for the destination file is the same as the name of the source file. If you respond Y [ES],then the transformed data replace the source data, and the original data are lost. If you respond N [O],you can then supply a different name for the destination file.

4.6.4.4 DUPLICATE ENTRY--OVERWRITE (Y OR N)

The name you have given for the destination file is not the same as the name of the source file, but does duplicate another name on the cassette. The response Y [ES] causes the existing file to be replaced. N [O] gives you an opportunity to supply an alternate name.

4.6.4.5 CASSETTE FILLED

There is no room on the data cassette, since all 30 files have been used.

4.6.4.6 SINGULARITY AT F = (frequency)

Bampdf cannot carry out the transformation at the specified frequency. This frequency does not appear in the destination file.

Chapter V

ESOTERICA

CHAPTER 5
ESOTERICA

This chapter contains information that is somewhat peripheral to the main goal of this manual, that is to tell you how to run Bamp '30, but nevertheless is useful for obtaining a better understanding of Bamp '30 and how to use it most effectively.

5.1 The COMMON statement

The first statement in every Bamp program including Bampdf is

```
1 COM CS [180],Z8,DS [60,9], AI [252], BS [150], EI [3,6], S [8], 0, Z
```

The purpose of these arrays and variables are

variable or array	function
AI (252)	A( ) is an integer array that stores code for two-ports and auxiliary operations. Each two-port or auxiliary operation requires four positions. (You therefore see that A( ) will store up to 63 two-ports or auxiliary operations despite the conservative claim that the limit is 60 two-ports or auxiliary operations.) The first four positions are used as follows. A(1) contains the sequence or line number. This number is supplied by Bamp when the circuit is first written, but is supplied by you when editing. A(2) contains a combination code for the two-port or auxiliary operation and the connection. A(3) is used for one of two purposes: 1. For two-ports with parameters, A(3) contains a code for TEL or no TEL. 2. A(3) contains the reference number for the two-port DEV *k* and for the auxiliary operations HOLD *k* , SER *k* , USE *k* , CIR I *k* , and USE ± *k* . A(4) contains zero or a pointer into array B( ). The pointer identifies the position in B( ) that contains the two-port parameter or the first parameter of multiple-parameter two-port. For two-ports that do not have parameters, for a two-port DEV *k* , and for auxiliary operations, A(4) = 0. This pattern is repeated for each set of four positions. The end of a circuit contains 9999. If there are a total of say 11 two-ports and auxiliary operations, then Bamp writes 9999 into A(45).
BS(150)	B( ) is a split-precision array for storing two-port parameters. The end of this array is marked by Z8 (see below).
CS(180)	C( ) is a split-precision array that stores frequency and computed

	S-parameters for the overall circuit built up by Bamp. The pattern is C(1) = frequency C(2) = Re S_{11} C(3) = Im S_{11} C(4) = Re S_{12} C(5) = Im S_{12} C(6) = Re S_{21} C(7) = Im S_{21} C(8) = Re S_{22} C(9) = Im S_{22} and this pattern can be repeated a maximum of 20 times. The end of this array is also marked by Z8, if it is not completely filled.
DS(60, 9)	D( ) is a split-precision array for storing DEV S-parameters. Twenty (20) rows are allowed for each of DEV 1, DEV 2, and DEV 3. Regardless of the type of data supplied, either from a data cassette or from the keyboard, the program on file 1 of the Bamp cassette converts these data to S-parameters in real-imaginary form before storing in D( ). In each row of D( ) the order of data is always frequency, Re S_{11}, Im S_{11}, Re S_{12}, Im S_{12}, Re S_{21}, Im S_{21}, Re S_{22}, and Im S_{22}.
EI(3, 6)	E( ) is an integer array for storing the numeric equivalent of the names of data files for DEV 1, DEV 2, and DEV 3. Row 1 is used for DEV 1, 2 for DEV 2, and 3 for DEV 3.
S(8)	S is a full-precision array that stores code for units and program parameters as follows. S(1) unit of frequency S(2) unit of resistance S(3) unit of inductance S(4) unit of capacitance S(5) unit of length S(6) angular increment factor for mapping S(7) domain of resistance for mapping The eighth position is used to maintain a permanent record of the initial output request as follows S(8) = 1 => SRI S(8) = 2 => SMP S(8) = 3 => SDB S(8) = 4 => PLOT S(8) = 5 => PRINT S(8) = 6 => MAPLOAD S(8) = 7 => MAPSOURCE
O	The variable O contains code for the immediate output request. For example if the initial output request is SDB, then S(8) = 3. If a plot is then requested, O is assigned the value 4, but S(8) is not changed.
Z	Z stores the value of reference impedance.

Z8	Z8 is used to mark the end of arrays B( ), C( ), and D( ), if these arrays are not filled. Z8 = -3.84211E+20

One reason for knowing about the COM statement is that you can write and store your own program containing this COM statement, load the program after Bamp has run, and use the S-parameters computed by Bamp. If you use only the computed S-parameters, then your COM statement can be simply

```
1 COM CS[180], Z8
```

In fact, this is the reason for placing C( ) first in the statement.

When a circuit is stored on a circuit cassette as explained in section 1.11 of Chapter 1, it is the arrays and variables in COM that are stored.

5.2 Short cuts for using Bamp files 2-5

By way of review, files 2-5 perform the functions indicated below.

file	function
2	compute S-matrix for composite circuit
3	Plot
4	Print
5	Map

If a circuit has been run by Bamp '30 and stored on a circuit cassette as explained in section 1.11 of Chapter 1, then that circuit can be loaded to and used by files 2-5 as outlined below.

5.2.1 Press: SCRATCH
Press: EXECUTE
Insert: Bamp cassette
Press: LOAD
Enter: 2
or
Enter: 3
or
Enter: 4
or
Enter: 5
Press: EXECUTE

5.2.2 When "⊢" appears in the display
Press: REWIND
Press: INIT

5.2.3 When "⊢" appears in the display
Remove: Bamp cassette (after rewind)
Insert: circuit cassette
Type : LOAD DATA value$_1$
Press: EXECUTE

5.2.4 REMARK value$_1$ is the number of the file containing your circuit.

5.2.5 When "⊢" appears in the display
Press: REWIND
Remove: circuit cassette (after rewind)
Insert: Bamp cassette

5.2.6 If you entered 2, 3, or 4 in step 5.2.1; go to step 5.2.13
If you entered 5 in step 5.2.1 (if you loaded the Map program); go to step 5.2.7

5.2.7 If your circuit contains MAPP or MAPS; go to step 5.2.8
If you want MAPLOAD; go to step 5.2.10

If you want MAPSOURCE; go to step 5.2.12

5.2.8 Type : O= 0
Press: EXECUTE

5.2.9 Go to step 5.2.13

5.2.10 Type : O = 6
Press: EXECUTE

5.2.11 Go to step 5.2.13

5.2.12 Type : O = 7
Press: EXECUTE

5.2.13 Press: RUN
Press: EXECUTE

5.2.14 REMARK Now revert to user instructions in section 1.10 of Chapter 1 as follows
Subset 3, if you loaded Bamp file 2
Subset 4, if you loaded Bamp file 3
Subset 5, if you loaded Bamp file 4
Subset 6, if you loaded Bamp file 5

Now comes the question: Why would I ever want to follow this procedure? Several answers are given below, but the underlying reason for all is that you save steps and therefore time.

- If your stored circuit contains TEL inputs, and you want a re-run with some of all of the TEL's assigned different values, then you would load the analysis program (file 2 on the Bamp cassette).
- If you want additional plotted or printed outputs, then you would load files 3 or 4. As an example, suppose you want a plot of $|S_{21}|$ as a function of frequency. If your circuit has been run and stored, then you can load file 3, which contains the plot program, type SDB21, and then press EXECUTE when the prompt VARIABLE? appears in the display. This occurs after step 5.2.13 has been completed. Suppose you want to look at transducer gain. Load Bamp file 4. After step 5.2.13 the prompt OUTPUT? appears. Then you type GT and press EXECUTE.
- If you want MAPLOAD or MAPSOURCE, or if you want additional internal mappings, assuming your stored circuit has MAPP or MAPS and has been run previously, then you load the program on file 5.

5.3 Saving REWIND time

Let us say you are using the mapping program and know that you next want to edit your circuit, perhaps to change the frequency. You can save more than 90 seconds of rewind time by pressing REWIND while the map program is executing. Likewise, you can save significant amounts of time from plot-to-edit, plot-to-run, print-to-edit, print-to-run, and map-to-run by pressing REWIND while the plot, print, and map programs are executing.

Obviously, time is saved primarily by rewind while a program is executing. There is a slight additional saving in that the system does not have to find the end of the current file, as it normally does.

5.4 Supplying Frequencies

In Chapter 1, you are told that frequencies must be entered as a separate line following the complete circuit description. However, frequencies can be entered as the last item(s) in the final line of the circuit description. For example,

```
LS 5 CP 6 1
```

calls for analysis at the single frequency 1 GHz, and

```
LS 5 CP 6 1 STEP 2 10 2
```

calls for analysis at 1, 2, 4, 6, 8, and 10 GHz.

Chapter VI

EXAMPLES

CHAPTER 6
EXAMPLES

This chapter consists of a collection of actual runs using Bamp '30. Most of these examples are also discussed in Chapter 1, but there the emphasis is on decomposition into elementary two-ports and preparation of the circuit description rather than on the mechanics of using Bamp '30.

In the first of these examples, Example 6.1.1, the Print-All key is ON so that you see all inputs as well as those that are normally printed back by Bamp '30. The Print-All key is OFF in all subsequent examples. (See page 2-13 of Hewlett-Packard 9830A Calculator Operating and Programming Manual, HP Part No. 09830-90001 for more information about the Print-All key.)

User input is underlined in all examples.

Some of these examples contain operator errors. All errors are corrected, and note that the errors as well as the corrective actions are annotated. You should know that the errors were not staged. They occurred through operator carelessness and were left in to show some of the things that can go wrong and what can be done to compensate. See particularly Examples 6.4.2, 6.4.4, and 6.6.

6.1 Low-pass filter (Butterworth)

This circuit is discussed in section 1.9.1 of Chapter 1. In Example 6.1.1 SDB is printed over the frequency interval 0.05 to 1 Hz. The same circuit is re-run as Example 6.1.2, but here the initial output request is changed to PLOT. The plotted outputs, which are shown as Fig 6.1.1, are S_{21} in dB and delay.

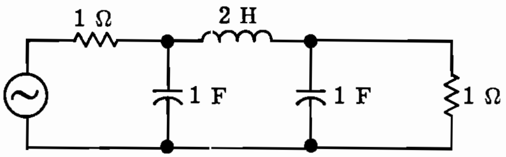
Note the following:

- Optional units are used for inductance (Henrys), capacitance (Farads), and frequency (Hertz); and the reference impedance is set equal to 1 ohm.
- In Example 6.1.1 SDB is printed as a default output, since the circuit description does not contain an explicit output request.
- Total elapsed time for running Example 6.1.1 from initial LOAD to complete rewind after final STOP was 5 min 45 sec. The actual compute and print time was 100 sec or 5 seconds, per frequency.
- The circuit description in Example 6.1.2 contains the explicit output request PLOT.

EXAMPLE

Note: User responses
underlined

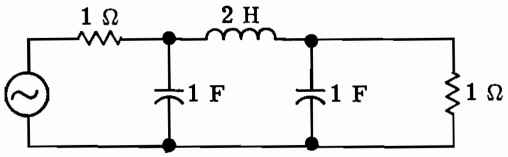
```
                    EXAMPLE 6.1.1  BUTTERWORTH FILTER

NOTE: PRT ALL ON AFTER THIS LINE
LOAD
RUN


BAMP CASSETTE #1, PN 09839-71102 REVA


KEYB'D OR C'SETTE INPUT(K OR C)?K
K
BEGIN?H F HZ ZR=1 ←—— Actual input
H F HZ ZR=1 ←—— Print-back

?CP 1 LS 2 CP 1
CP 1 LS 2 CP 1

?ESTEP .05 1 20
ESTEP .05 1 20

EDIT,RUN,OR STOP(E,R,S)?R
```



$f_{3\ dB} = 1/2\pi \approx 0.159$ Hz

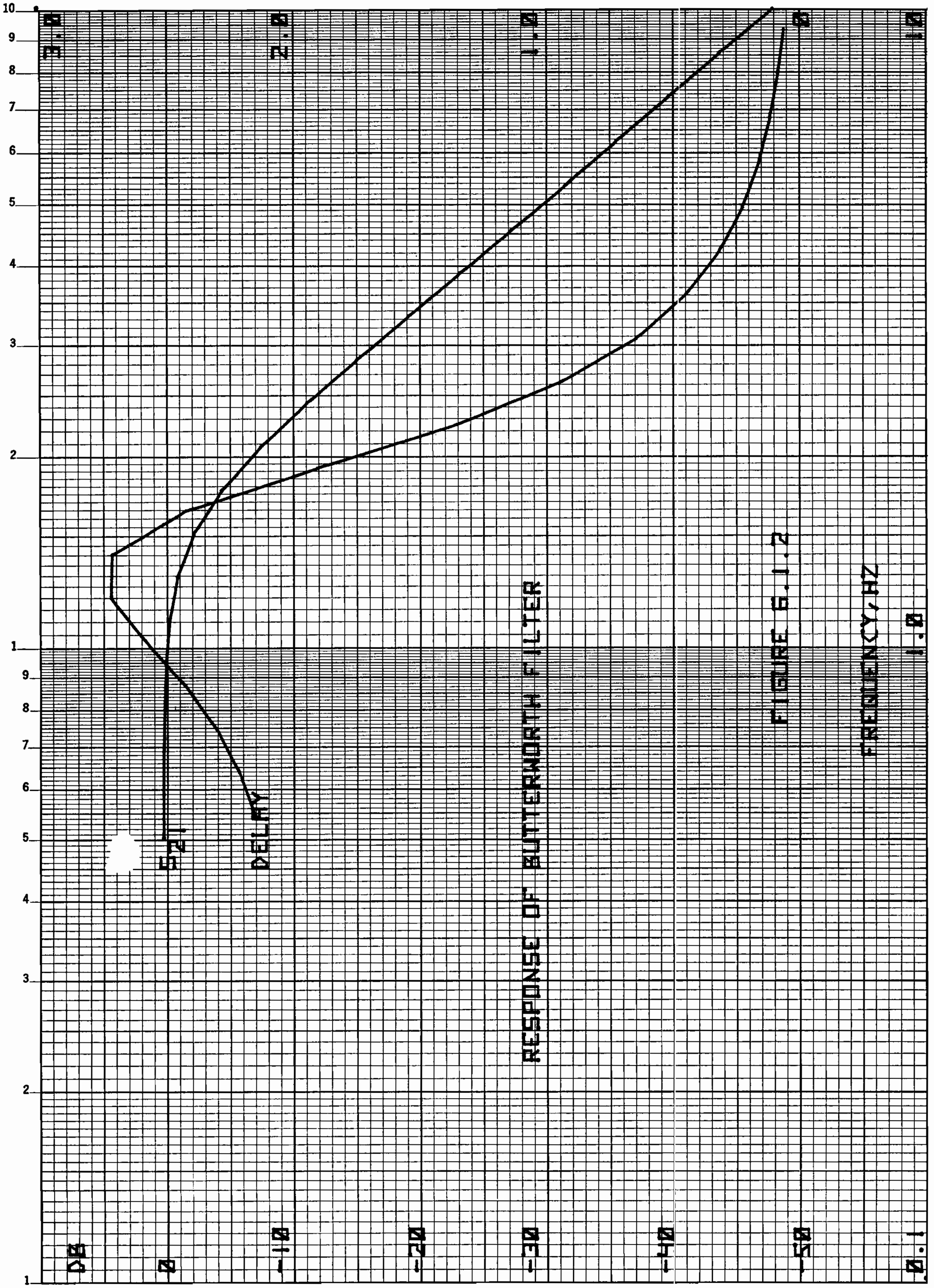
```
                          S-MATRIX IN MAGNITUDE AND PHASE
                 11                    12                     21                     22
FREQ       MAG      ANG         DB     ANG         DB     ANG          MAG       ANG
 0.050    0.031     53.3      -0.00   -36.7      -0.00   -36.7       0.031      53.3
 0.059    0.050     46.8      -0.01   -43.2      -0.01   -43.2       0.050      46.8
 0.069    0.080     38.8      -0.03   -51.2      -0.03   -51.2       0.080      38.8
 0.080    0.127     29.2      -0.07   -60.8      -0.07   -60.8       0.127      29.2
 0.094    0.201     17.3      -0.18   -72.7      -0.18   -72.7       0.201      17.3
 0.110    0.313      2.4      -0.45   -87.6      -0.45   -87.6       0.313       2.4
 0.129    0.468    -15.9      -1.07  -105.9      -1.07  -105.9       0.468     -15.9
 0.151    0.648    -37.3      -2.36  -127.3      -2.36  -127.3       0.648     -37.3
 0.177    0.807    -59.7      -4.56  -149.7      -4.56  -149.7       0.807     -59.7
 0.207    0.910    -80.2      -7.63  -170.2      -7.63  -170.2       0.910     -80.2
 0.242    0.962    -97.4     -11.25   172.6     -11.25   172.6       0.962     -97.4
 0.283    0.985   -111.3     -15.16   158.7     -15.16   158.7       0.985    -111.3
 0.332    0.994   -122.4     -19.18   147.6     -19.18   147.6       0.994    -122.4
 0.388    0.998   -131.5     -23.26   138.5     -23.26   138.5       0.998    -131.5
 0.455    0.999   -139.0     -27.36   131.0     -27.36   131.0       0.999    -139.0
 0.532    1.000   -145.2     -31.46   124.8     -31.46   124.8       1.000    -145.2
 0.623    1.000   -150.4     -35.57   119.6     -35.57   119.6       1.000    -150.4
 0.730    1.000   -154.8     -39.67   115.2     -39.67   115.2       1.000    -154.8
 0.854    1.000   -158.5     -43.78   111.5     -43.78   111.5       1.000    -158.5
 1.000    1.000   -161.7     -47.89   108.3     -47.89   108.3       1.000    -161.7
NEXT?STOP

STOP
```

```
             EXAMPLE 6.1.2 BUTTERWORTH FILTER

NOTE: PRT ALL OFF IN THIS AND SUBSEQUENT EXAMPLES

BAMP CASSETTE #1, PN 09839-71102 REVA
```



$f_{3\ dB} = 1/2\pi \approx 0.159$

```
K
H F HZ ZR=1

CP 1 LS 2 CP 1

PLOT

ESTEP .05 1 20

SDB21
MIN=-47.89087479    MAX=-4.17638E-03
FREQ SCALE
.01 1 LOG
VER SCALE
10 -60
ADJUST PLOTTER(LL,UR) ←— Space EXECUTE required (after adjusting plotter)
N ←— Do not repeat plot of  S21
DELAY
MIN= 0.060251072    MAX= 2.706376867
FREQ SCALE
               ←— Space EXECUTE retains frequency limits
VER SCALE
-.5 3
ADJUST PLOTTER(LL,UR) ←— Space EXECUTE
LETTER
  ←— Type captions and then press STOP
N ←— Response to AGAIN?

S ←— Response to VARIABLE? (Space EXECUTE)
  ←— Response to NEXT?
```



RESPONSE OF BUTTERWORTH FILTER

FIGURE 6.1.2

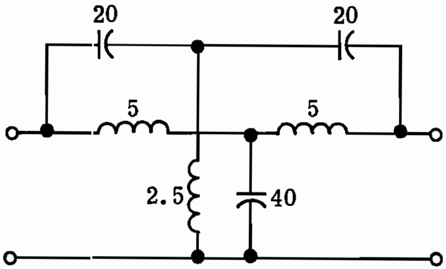
6.2 Twin-T filter

The Twin-T filter run as Example 6.2 is discussed in in section 1.9.2 of Chapter 1. Note the following:

- The auxiliary operations HOLD k and USE k are required. In this example $k = 1$.
- Three frequency ranges are specified. All of these frequencies are in a single line that follows the circuit description.
- The S-matrix is printed as a default output, since the circuit description does not contain an explicit output request. The S-matrix is printed as it is computed.
- After analysis has been completed at all frequencies, then the PRINT program is called and the FIL output is requested.

The total elapsed time for completing Example 6.2 was 12 minutes from the initial LOAD.

```
                        EXAMPLE 6.2  TWIN-T FILTER

BAMP CASSETTE #1, PN 09839-71102 REVA
```



μH, pF, ZR = 50Ω

```
K
UH MHZ CS 20 LP 2.5 CS 20 HOLD 1

LS 5 CP 40 LS 5 USE 1 PAR

STEP 11 15 1 STEP 15.1 16.9 .2 STEP 17 20 1


                          S-MATRIX IN MAGNITUDE AND PHASE
                    11                   12                   21                   22
FREQ          MAG      ANG        DB     ANG        DB     ANG        MAG      ANG
 11.00       0.945    -10.5     -9.68  -100.5     -9.68  -100.5     0.945    -10.5
 12.00       0.924    -16.0     -8.33  -106.0     -8.33  -106.0     0.924    -16.0
 13.00       0.879    -23.8     -6.43  -113.8     -6.43  -113.8     0.879    -23.8
 14.00       0.773    -36.4     -3.96  -126.4     -3.96  -126.4     0.773    -36.4
 15.00       0.500    -58.7     -1.25  -148.7     -1.25  -148.7     0.500    -58.7
 15.10       0.456    -61.6     -1.01  -151.6     -1.01  -151.6     0.456    -61.6
 15.30       0.360    -68.0     -0.60  -158.0     -0.60  -158.0     0.360    -68.0
 15.50       0.251    -74.9     -0.28  -164.9     -0.28  -164.9     0.251    -74.9
 15.70       0.132    -82.1     -0.08  -172.1     -0.08  -172.1     0.132    -82.1
 15.90       0.010    -89.4     -0.00  -179.4     -0.00  -179.4     0.010    -89.4
 16.10       0.112     83.3     -0.06   173.3     -0.06   173.3     0.112     83.3
 16.30       0.228     76.3     -0.23   166.3     -0.23   166.3     0.228     76.3
 16.50       0.333     69.7     -0.51   159.7     -0.51   159.7     0.333     69.7
 16.70       0.425     63.7     -0.87   153.7     -0.87   153.7     0.425     63.7
 16.90       0.505     58.3     -1.28   148.3     -1.28   148.3     0.505     58.3
 17.00       0.540     55.8     -1.49   145.8     -1.49   145.8     0.540     55.8
 18.00       0.761     37.6     -3.76   127.6     -3.76   127.6     0.761     37.6
 19.00       0.854     27.3     -5.67   117.3     -5.67   117.3     0.854     27.3
 20.00       0.898     20.8     -7.13   110.8     -7.13   110.8     0.898     20.8
```

`PRINT` ← Response to NEXT?

`FIL` ← Response to OUTPUT?

```
              FILTER CHARACTERISTICS
FREQ   RETURN LOSS(DB)   LOSS(DB)   DELAY(MICROSEC)
11.00      0.494           9.683
                                    0.01523653i
12.00      0.690           8.329
                                    0.02173378
13.00      1.120           6.433
                                    0.03496490i
14.00      2.233           3.958
                                    0.06i844451
15.00      6.026           1.248
                                    0.08278140
16.10
```

```
              FILTER CHARACTERISTICS
FREQ   RETURN LOSS(DB)   LOSS(DB)   DELAY(MICROSEC)
11.00      0.494           9.683
                                    0.015236531
12.00      0.690           8.329
                                    0.021733378
13.00      1.120           6.433
                                    0.034964901
14.00      2.233           3.958
                                    0.061844451
15.00      6.026           1.248
                                    0.082781402
15.10      6.814           1.014
                                    0.088554928
15.30      8.883           0.601
                                    0.095273085
15.50      12.02           0.282
                                    0.100034925
15.70      17.56           0.077
                                    0.102085692
15.90      40.40           0.000
                                    0.101061387
16.10      19.00           0.055
                                    0.097138275
16.30      12.86           0.231
                                    0.090960496
16.50      9.563           0.509
                                    0.083397902
16.70      7.432           0.865
                                    0.075288045
16.90      5.942           1.276
                                    0.069228143
17.00      5.359           1.495
                                    0.050619562
18.00      2.371           3.760
                                    0.028699138
19.00      1.371           5.674
                                    0.017935473
20.00      0.934           7.133
```

← **Response to OUTPUT? (space EXECUTE)**

STOP ← **Response to NEXT?**

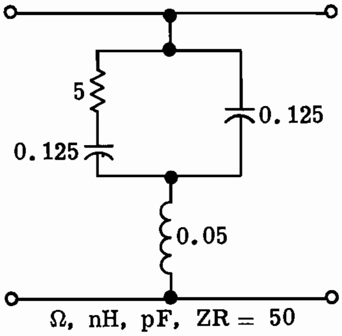
6.3 Lumped model of hot-carrier diode

The circuit run as Example 6.3 can be used as a lumped model for a hot-carrier diode and is discussed in section 1.9.3 of Chapter 1. Note the following:

- All units as well as ZR have their default values.
- SDB is printed as a default output.
- The PLOT program is called after analysis is completed at all frequencies.
- S_{11} is plotted, and the plot is shown as Fig 6.3.
- S_{11} in Fig 6.3 is the input reflection coefficient when the diode is terminated in 50 ohms at port 2.
- Total elapsed time from initial LOAD to the LETTER command was seven minutes. The time to label Fig 6.3 was three minutes.

EXAMPLE

```
                    EXAMPLE 6.3 HOT-CARRIER DIODE

BAMP CASSETTE #1, PN 09839-71102 REVA


K
STCP 5 0 .125 CP .125 LP .05 SER

STEP 2 20 2
```



```
                              S-MATRIX IN MAGNITUDE AND PHASE
                    11                    12                    21                    22
FREQ          MAG       ANG        DB       ANG        DB       ANG       MAG       ANG
  2.000     0.078     -94.7     -0.03      -4.5     -0.03      -4.5     0.078     -94.7
  4.000     0.156     -99.4     -0.12      -9.0     -0.12      -9.0     0.156     -99.4
  6.000     0.233    -104.1     -0.27     -13.4     -0.27     -13.4     0.233    -104.1
  8.000     0.307    -108.8     -0.48     -17.9     -0.48     -17.9     0.307    -108.8
  10.00     0.379    -113.4     -0.75     -22.3     -0.75     -22.3     0.379    -113.4
  12.00     0.448    -118.0     -1.08     -26.6     -1.08     -26.6     0.448    -118.0
  14.00     0.513    -122.6     -1.48     -30.8     -1.48     -30.8     0.513    -122.6
  16.00     0.574    -127.0     -1.95     -35.0     -1.95     -35.0     0.574    -127.0
  18.00     0.630    -131.4     -2.49     -39.0     -2.49     -39.0     0.630    -131.4
  20.00     0.682    -135.7     -3.11     -42.9     -3.11     -42.9     0.682    -135.7

PLOT ←—— Response to NEXT?
S11 ←—— Response to VARIABLE?
MAX MAG= 0.681889986
SCALE
ADJUST PLOTTER ←—— Response to SCALE (full scale = 1 by default)
MF 10 ←—— Response to AGAIN? (place frequency marker at f = 10)
F= 10
LETTER ←—— Response to AGAIN?
     ←—— Type captions and then press STOP
N ←—— Response to AGAIN
     ←—— Space EXECUTE response to VARIABLE?
STOP ←—— Response to NEXT?
```

IMPEDANCE OR ADMITTANCE COORDINATES

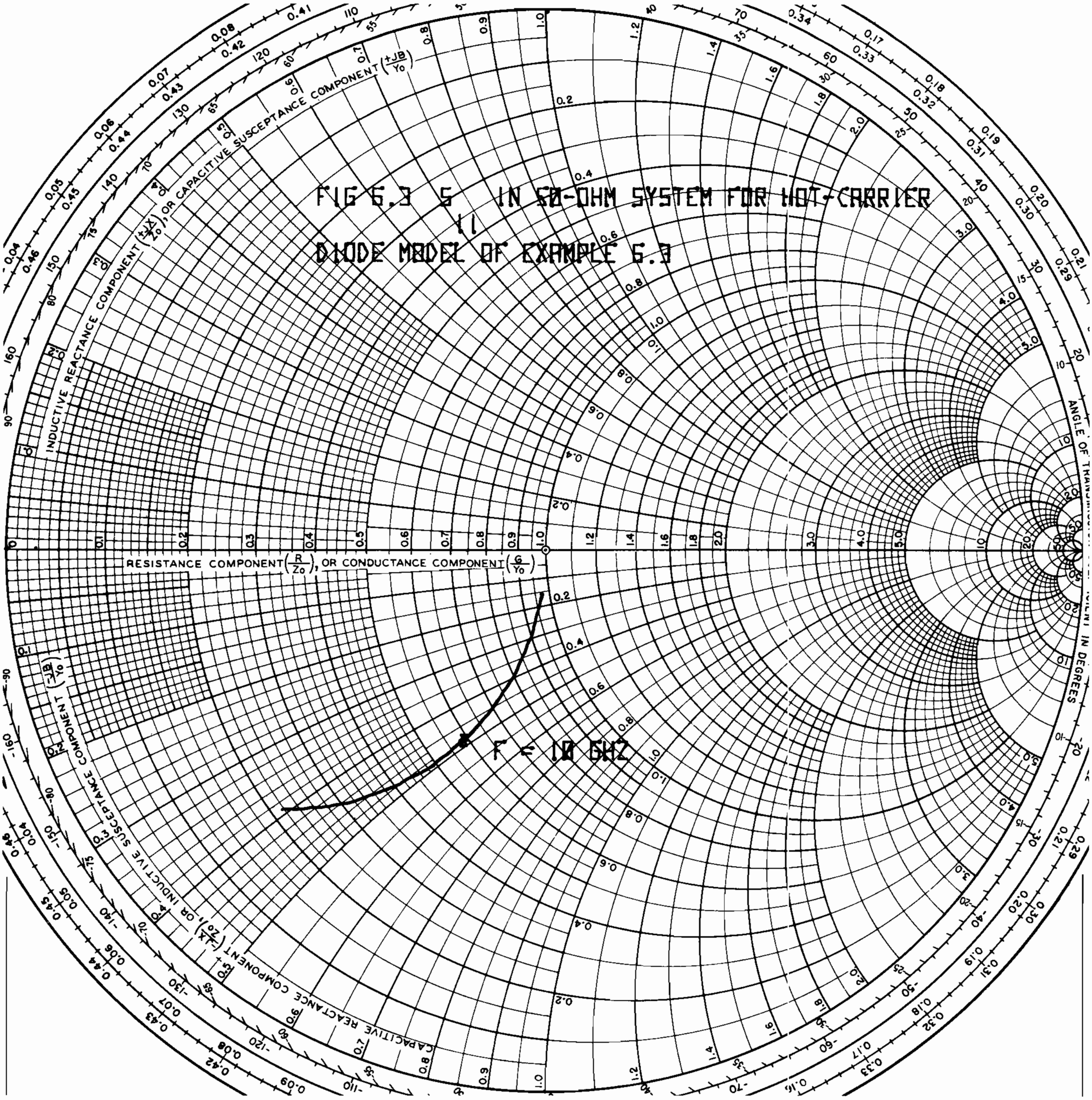


FIG 6.3 S_{11} IN 50-OHM SYSTEM FOR HOT-CARRIER DIODE MODEL OF EXAMPLE 6.3

6.4 Microwave transistor amplifiers

This section contains several examples of circuits that use microwave transistors. The transistors are modeled by the two-port DEV k, $k = 1, 2, 3$. The circuits in Examples 6.4.1 and 6.4.2 are basically the circuit discussed in section 1.9.4 of Chapter 1. Example 6.4.1 shows two analyses using different parameter values for the collector-to-base feedback network. Example 6.4.2 is the same circuit with fixed collector-to-base feedback, but also includes a stability investigation and circuit modification to achieve unconditional stability. The circuit in Example 6.4.3 is the circuit discussed in section 1.4.6.1 of Chapter 1. The circuit in Example 6.4.4 is a two-stage amplifier that uses two different transistors. The transistors are of the same type, but they have slightly different S-parameters. The S-parameters used are actual measured values for transistors similar to the HP 35821E at 15V and 15MA bias.

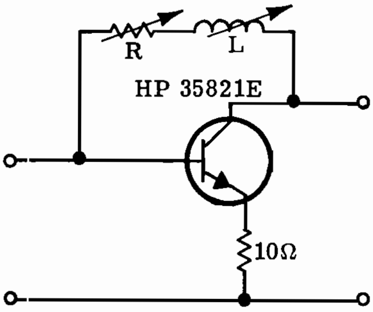
6.4.1 Single-stage amplifier

The following are the points of interest:

- In the circuit description TEL replaces the parameter value for both RS and LS in the collector-to-base feedback network. These values are requested and printed as explained in steps 301-308 of the user instructions in Chapter 1, section 1.10.
- The S-parameters for the transistor are obtained from the DEV data file named HP35821E as explained in subset 2 of the user instructions in Chapter 1.
- The editor is called after the second run and the circuit is listed. The purpose of this listing is to display the circuit line (sequence) numbers assigned by Bamp '30 and also to show the TEL flags for the two-ports RS and LS.

EXAMPLE

```
              EXAMPLE 6.4.1   SINGLE-STAGE AMPLIFIER

BAMP CASSETTE #1; PN 09839-71102 REVA

K
RS TEL LS TEL DEV 1 HP35821E PAR RP 10 SER

STEP .1 .5 .1 1
```



```
   10 R= 200 ←
   20 L= 30  ←
```

Values of R and L in first run

```
                         S-MATRIX IN MAGNITUDE AND PHASE
                 11                 12                21                 22
FREQ         MAG     ANG       DB      ANG       DB      ANG       MAG       ANG
 0.100     0.093  -161.0   -14.85     -2.0     8.61   176.2     0.047      17.6
 0.200     0.076  -167.6   -14.87     -4.0     8.45   174.7     0.110      39.6
 0.300     0.050  -161.8   -14.90     -6.6     8.54   169.9     0.195      45.8
 0.400     0.028  -131.9   -14.97     -8.6     8.87   165.4     0.269      48.4
 0.500     0.031   -44.4   -15.19    -10.0     9.80   161.4     0.341      45.6
 1.000     0.195   -88.4   -18.42     -7.9    11.10   128.6     0.648      12.5
```

```
R ←
```

Response to NEXT? Calls for re-run

```
   10 R= 198 ←
   20 L= 32  ←
```

Values of R and L in re-run

```
                         S-MATRIX IN MAGNITUDE AND PHASE
                 11                 12                21                 22
FREQ         MAG     ANG       DB      ANG       DB      ANG       MAG       ANG
 0.100     0.094  -163.2   -14.82     -2.2     8.57   176.5     0.045      22.9
 0.200     0.076  -171.5   -14.84     -4.4     8.42   175.2     0.113      42.8
 0.300     0.047  -169.2   -14.88     -7.2     8.55   170.6     0.201      47.6
 0.400     0.019  -137.1   -14.97     -9.4     8.93   166.2     0.280      49.5
 0.500     0.034   -23.9   -15.20    -11.0     9.91   162.2     0.356      46.3
 1.000     0.207   -85.2   -18.84     -8.6    11.30   128.2     0.674      11.2
```

```
EDIT ←
```

Response to NEXT?

```
LIST0 ←
```

Response to EDITOR?

```
GHZ OH  NH  PF  CM  ZR= 50
SDB
 10   RS   CAS    TEL 198
 20   LS   CAS    TEL 32
 30   DEV   1    PAR    HP35821E
 40   RP   SER    10
FREQUENCIES: 0.1   0.2   0.3   0.4   0.5   1


STOP ←
```

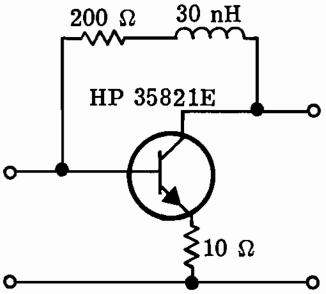
Response to EDITOR?

6.4.2 Stability of single-stage amplifier

The circuit in Example 6.4.2 is the same as that in Example 6.4.1 except that the collector-to-base feedback parameters are fixed at 200 ohms and 30 nH. Points to be emphasized are:

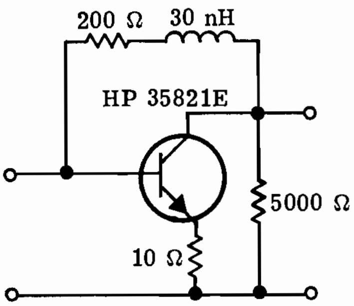
- The PRINT program is called immediately after analysis is completed and SDB has been printed. the output requested is AMP.
- K < 1 at f= 1 GHz indicates potential instability.
- The map program is called, and a map of Γ_{in} is requested at f= 1 GHz.
- The mapped output is shown as Fig 6.4.2. From Fig 6.4.2 it can be seen that if the output resistance is 5000 ohms or less, then $|\Gamma_{in}| < 1$ for any shunting reactance.
- The plot is labeled using the LETTER mode, and then the editor is called.
- The circuit is listed and a shunting resistance of 5000 ohms is cascade at the output. Line number 50 is used for the shunting resistance, but any number greater than 40 could have been used.
- The modified circuit is run. The fact that K is greater than 1 at f = 1 GHz indicates that the modified circuit is unconditionally stable at this frequency.
- Calculation of transducer gain is illustrated at f = 0.1 GHz.

EXAMPLE



```
                EXAMPLE 6.4.2  MICROWAVE AMPLIFIER

BAMP CASSETTE #1, PN 09839-71102 REVA

K
RS 200 LS 30 DEV 1 HP 35821E PAR RP 10 SER
 .1 .2 .3 1 ← Set of discrete frequencies

                           S-MATRIX IN MAGNITUDE AND PHASE
                  11                  12                    21                    22
FREQ        MAG     ANG        DB      ANG        DB     ANG       MAG       ANG
 0.100     0.093  -161.0     -14.85    -2.0       8.61   176.2     0.047     17.6
 0.200     0.076  -167.6     -14.87    -4.0       8.45   174.7     0.110     39.6
 0.300     0.050  -161.8     -14.90    -6.6       8.54   169.9     0.195     45.8
 1.000     0.195   -88.4     -18.42    -7.9      11.10   128.6     0.648     12.5

PRINT ← Response to NEXT?

AMP ← Response to OUTPUT?

                              AMPLIFIER CHARACTERISTICS
 FREQ          K       GA MAX    GU MAX       GAMMA MS          GAMMA ML
 0.100       1.255      8.692     8.658     0.146   169.1    0.114       3.2
 0.200       1.263      8.571     8.524     0.147  -167.7    0.172     -25.5
 0.300       1.237      8.783     8.715     0.156  -142.7    0.265     -38.9
 1.000       0.985      INF      13.632

MAPLOAD ← Ignored response to OUTPUT?
        ← Space EXECUTE response to OUTPUT?
MAPLOAD ← Response to NEXT?

Z-LOAD ONTO INPUT REFLECTION COEFFICIENT PLANE
GAMMA ←
F= 1  ← Plot Γin at 1 GHz

MAG T= 0.299380219    ANG T= 118.9250706
MAG R= 0.741818726    ANG R= 162.4196845
RE  N= 187.7625917    IM  N= 90.66709345

1 ADJUST PLOTTER ← Response to SCALE?
NEXT
RP 5000
NEXT
LETTER
     ← Supply captions and then press STOP
NEXT
EDIT
```

EXAMPLE



Modified Circuit

```
LIST0
GHZ OH   NH   PF   CM   ZR= 50
SDB
 10    RS    CAS     200
 20    LS    CAS     30
 30    DEV    1      PAR     HP35821E
 40    RP    SER     10
FREQUENCIES: 0.1    0.2    0.3    1

50 RP 5000 ←— Line to be inserted
LIST
 10    RS    CAS     200
 20    LS    CAS     30
 30    DEV    1      PAR     HP35821E
 40    RP    SER     10
 50    RP    CAS     5000
FREQUENCIES: 0.1    0.2    0.3    1
RUN
                              S-MATRIX IN MAGNITUDE AND PHASE
                      11                 12                  21                22
FREQ        MAG      ANG        DB      ANG         DB     ANG        MAG       ANG
 0.100    0.090   -160.4    -14.90    -2.0        8.57   176.2     0.042      19.7
 0.200    0.074   -167.0    -14.92    -4.0        8.40   174.6     0.105      41.3
 0.300    0.048   -160.2    -14.95    -6.6        8.49   169.9     0.189      46.8
 1.000    0.197    -88.1    -18.49    -8.0       11.03   128.6     0.635      12.5
PRINT
AMP
                              AMPLIFIER CHARACTERISTICS
 FREQ         K      GA MAX    GU MAX        GAMMA MS          GAMMA ML
 0.100      1.265     8.638     8.609     0.139    168.2   0.104       3.5
 0.200      1.274     8.512     8.471     0.138   -167.9   0.162     -26.7
 0.300      1.249     8.715     8.655     0.146   -142.3   0.254     -40.0
 1.000      1.009    14.163    13.438     0.698   -119.9   0.896     -10.0
GT
.1 ←— Frequency
0 ←———————————— Γ source
0 ←—— Γ load
                                  REFL COEFFS
FREQ          SOURCE           INPUT            LOAD            OUTPUT           GT
 0.100   0.000      0.0   0.090  -160.4  0.000      0.0  0.042    19.7     8.566
.1 ←— Frequency
0 ←——————————— Γ source
* ←—— Γ load = Γ*out
                                  REFL COEFFS
FREQ          SOURCE           INPUT            LOAD            OUTPUT           GT
 0.100   0.000      0.0   0.106  -168.2  0.042   -19.7  0.042    19.7     8.574
   ←—— Space EXECUTE response to Frequency?
STOP ←—— Response to OUTPUT?
   ←—— Response to NEXT?
```

IMPEDANCE OR ADMITTANCE COORDINATES

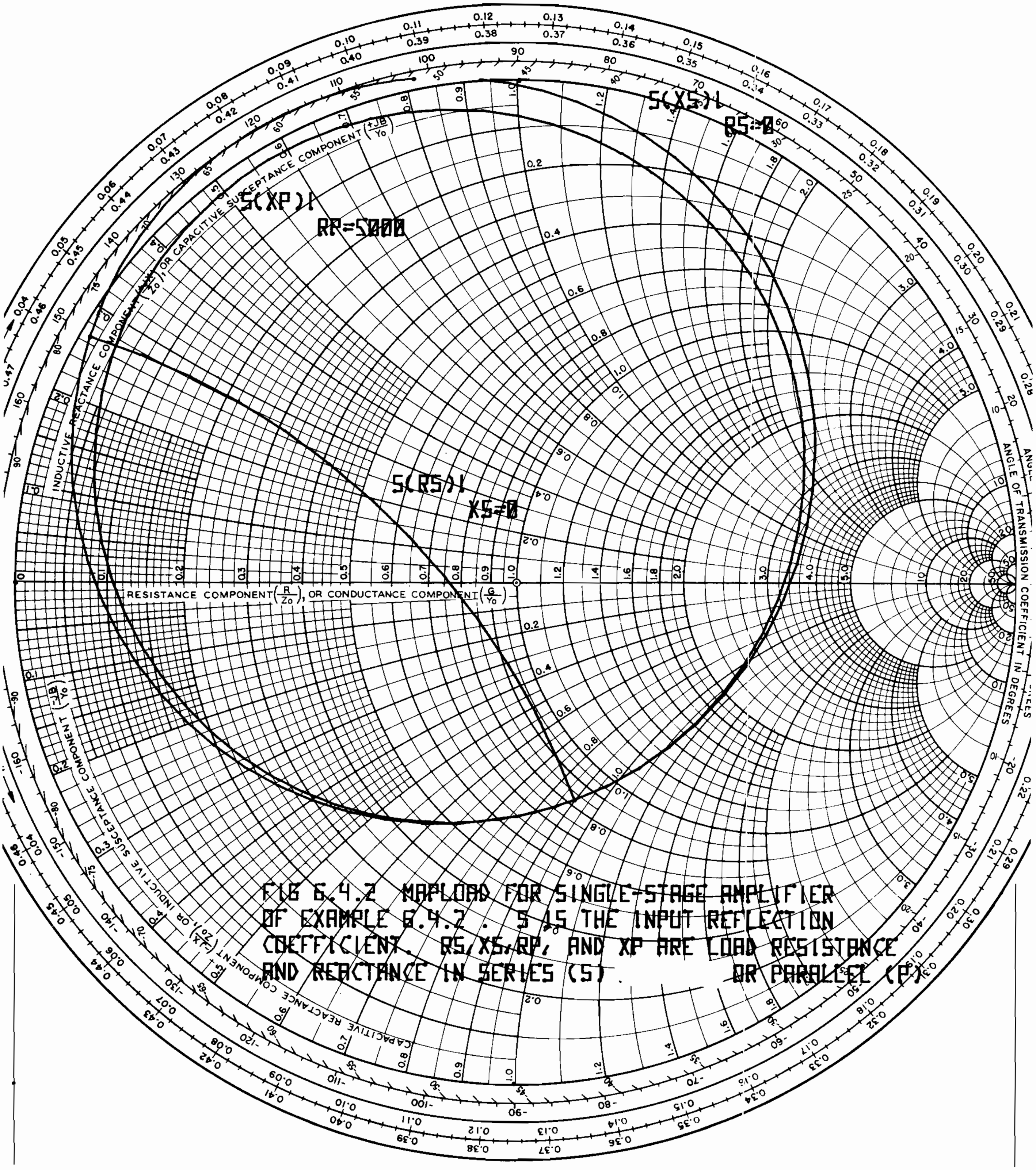


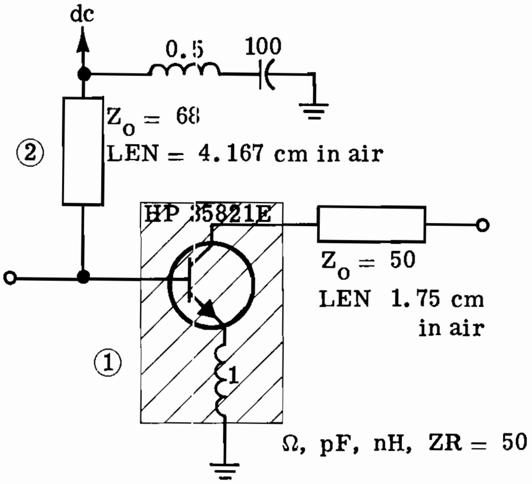
FIG 6.4.2 MAPLOAD FOR SINGLE-STAGE AMPLIFIER OF EXAMPLE 6.4.2 . S IS THE INPUT REFLECTION COEFFICIENT. RS,XS,RP, AND XP ARE LOAD RESISTANCE AND REACTANCE IN SERIES (S) OR PARALLEL (P)

6.4.3 Output stage with bias and matching stubs

The circuit in Example 6.4.3 is that discussed in section 1.4.6.1 of Chapter 1 and represents an output stage. The primary purpose of this example is to show how the auxiliary operation SHU k , can be used to build up stubs. A second purpose is to illustrate how to use TEL inputs and plots for design by iteration. A third purpose is to show how to use the editor to insert circuit elements. Note the following:

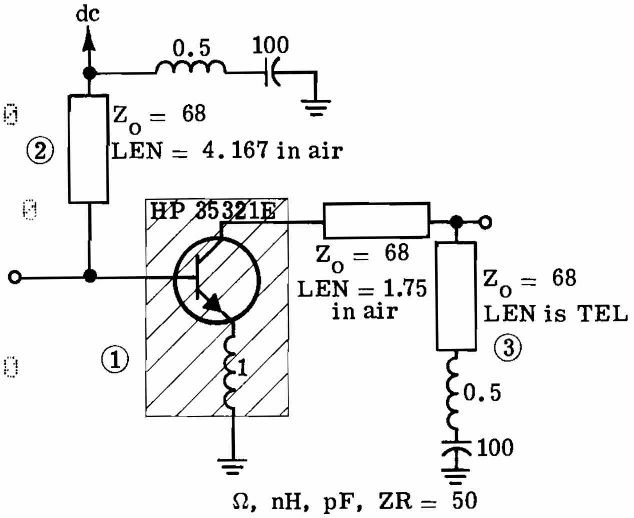
- The tuning stub is not included in the first run.
- After the first run, editor is called and the elements required for the tuning stub are inserted.
- The second run is with a tuning stub slightly longer than optimum.
- The third run provides a better output match over the frequency range.
- Encircled numbers on the circuit sketch refer to storage locations.

EXAMPLE



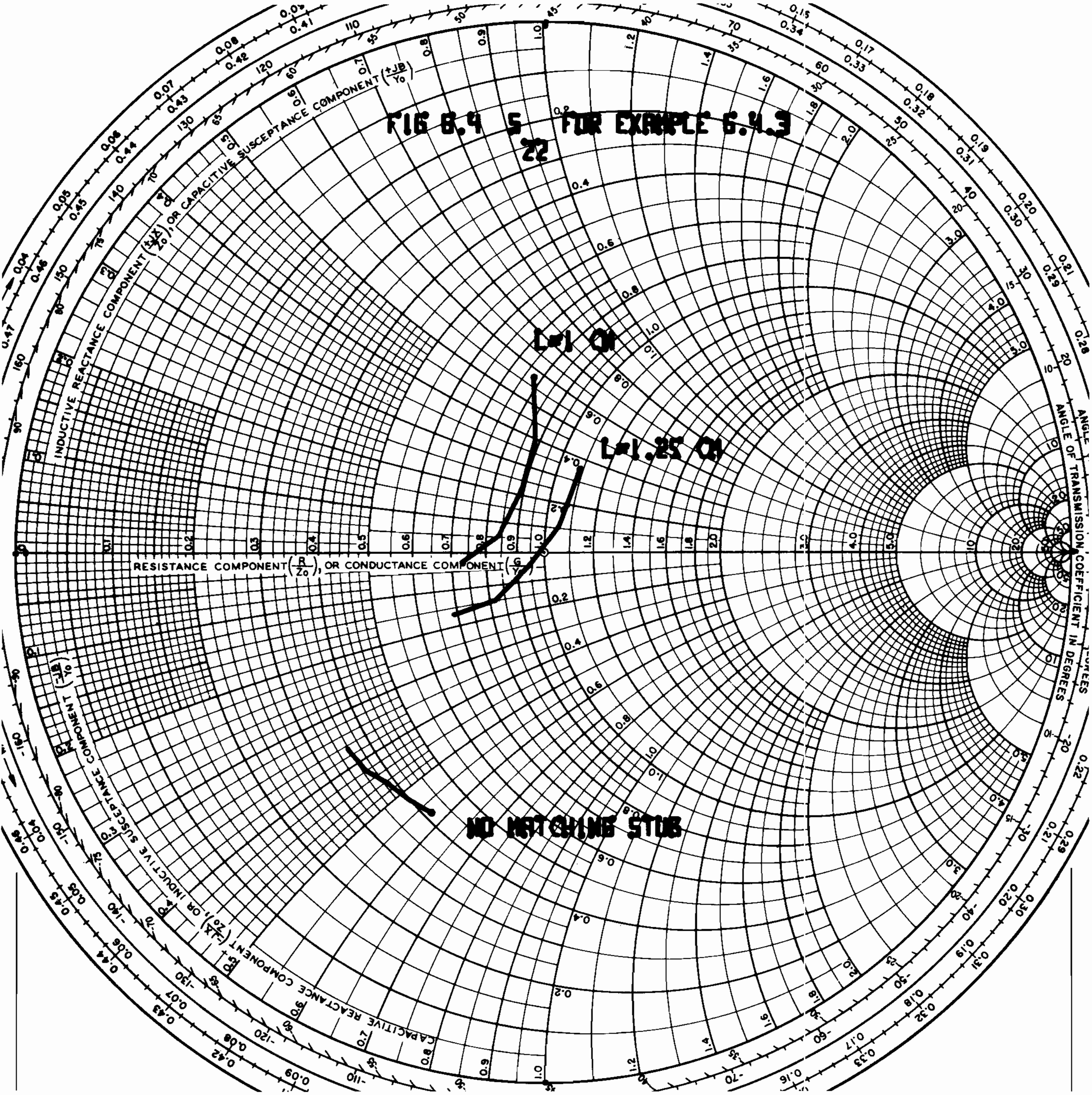
```
                 EXAMPLE 6.4.3   OUTPUT STAGE WITH BIAS AND MATCHING STUBS

BAMP CASSETTE #1, PN 09839-71102 REVA

K
DEV 1 HP35821E LP 1 SER HOLD 1

TL 68 4.167 1 STCP 0 .5 100 SHU 2

USE 2 USE 1 TL 50 1.75 1

STEP 1.6 2 .1

                           S-MATRIX IN MAGNITUDE AND PHASE
                   11                12                21                 22
FREQ          MAG      ANG        DB      ANG        DB      ANG       MAG      ANG
 1.600      0.173    149.2    -15.81    48.6       7.74    31.5     0.534   -113.8
 1.700      0.160    154.6    -15.17    44.9       7.37    25.0     0.531   -119.5
 1.800      0.153    158.6    -14.63    40.5       6.90    19.2     0.526   -124.4
 1.900      0.138    165.1    -14.12    37.0       6.68    13.5     0.532   -129.8
 2.000      0.134    170.2    -13.58    32.6       6.21     7.6     0.525   -135.5

PLOT ◄── Response to NEXT?
S22 ◄── Response to VARIABLE?
MAX MAG= 0.534456697
SCALE
ADJUST PLOTTER
N ◄── Response to AGAIN?
 ◄── Space EXECUTE response to VARIABLE?
EDIT ◄── Response to NEXT?
LIST
 10    DEV    1     CAS     HP35821E
 20    LP     SER    1
 30    HOLD   1
 40    TL     CAS    68     4.167     1      0      0
 50    STCP   CAS    0      0.5    100
 60    SHU    2
 70    USE    2      CAS
 80    USE    1      CAS
 90    TL     CAS    50     1.75      1      0      0
FREQUENCIES: 1.6    1.7    1.8    1.9    2

61 TL 68 TEL 1
62 STCP 0 .5 100
63 SHU 3                   ◄── Inserted circuit elements
100 USE 3
LIST
```

EXAMPLE



```
 10    DEV   1    CAS    HP35821E
 20    LP    SER   1
 30    HOLD  1
 40    TL    CAS   68    4.167     1    0    0
 50    STCP  CAS   0     0.5    100
 60    SHU   2
 61    TL    CAS   68    TEL 0      1    0    0
 62    STCP  CAS   0     0.5    100
 63    SHU   3
 70    USE   2    CAS
 80    USE   1    CAS
 90    TL    CAS   50    1.75      1    0    0
 100   USE   3    CAS
FREQUENCIES: 1.6  1.7  1.8  1.9  2
R
  61 LEN= 1 ◄—— tuning stub is 1 cm long
                         S-MATRIX IN MAGNITUDE AND PHASE
                  11                  12                  21                  22
FREQ         MAG     ANG        DB      ANG         DB      ANG        MAG      ANG
 1.600     0.474  -159.6     -14.85    99.3        8.69    92.1      0.332     94.0
 1.700     0.504  -169.8     -13.94    89.3        8.60    69.3      0.216     95.1
 1.800     0.505   179.9     -13.30    79.4        8.23    58.1      0.130    110.2
 1.900     0.495   171.8     -12.71    70.8        8.08    47.3      0.095    159.6
 2.000     0.467   162.5     -12.30    61.6        7.50    36.9      0.159   -173.6

PLOT
S22
MAX MAG= 0.331672582
SCALE
 ◄—— space EXECUTE
N ◄—— answer to AGAIN?
 ◄—— space EXECUTE
RUN ◄—— response to NEXT?
  61 LEN= 1.25 ◄—— tuning stub is 1.25 cm long
                         S-MATRIX IN MAGNITUDE AND PHASE
                  11                  12                  21                  22
FREQ         MAG     ANG        DB      ANG         DB      ANG        MAG      ANG
 1.600     0.437  -169.9     -14.47    89.0        9.07    71.9      0.172     67.6
 1.700     0.450  -178.5     -13.75    79.8        8.79    59.9      0.058     64.1
 1.800     0.441   172.7     -13.24    70.9        8.30    49.5      0.037   -143.0
 1.900     0.422   166.1     -12.75    63.1        8.05    39.6      0.131   -137.2
 2.000     0.392   158.6     -12.38    55.1        7.42    30.1      0.209   -146.4

PLOT
S22
MAX MAG= 0.208932950
SCALE

LETTER

N

STOP
```

IMPEDANCE OR ADMITTANCE COORDINATES



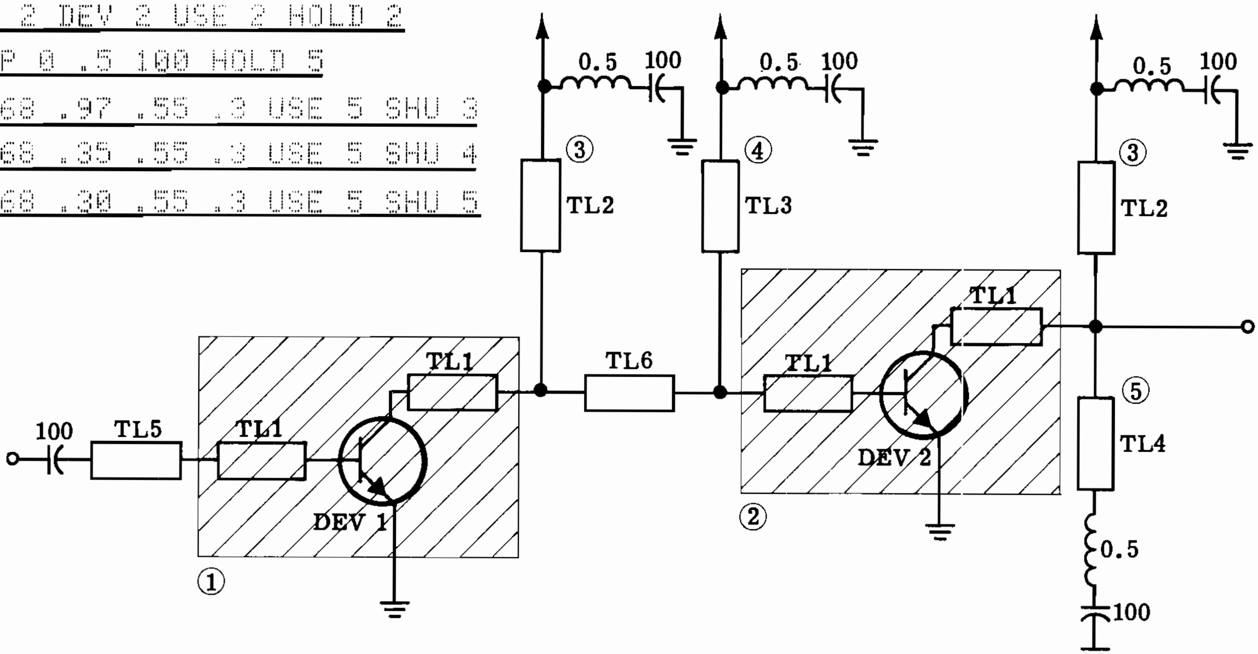
6.4.4 Two-stage amplifier

The circuit in Example 6.4.4 is a two-stage amplifier using two transistors that have slightly different S-parameters. The DEV S-parameters are typed in from the keyboard rather than read from a DEV data cassette. You should note the following points.

- The line TL1 is a parasitic line associated with the transistor.
- The parasitic lines are cascaded with DEV 1 and DEV 2 and the resulting composite two-ports are stored in storage locations 1 and 2 (see first two lines in the circuit description).
- All lines are lossy. They have zero shunt conductance per unit length, but non-zero series resistance per unit length. The values of R/unit length apply at 2 GHz.
- Lengths are expressed in inches (see first line of circuit description).
- Encircled numbers on the circuit schematic correspond to storage locations.
- Note the typographical error and refer to diagnostic message 3.1.1 in Chapter 3.
- Editor is used to list the circuit after the run is completed.

EXAMPLE

```
              EXAMPLE 6.4.4   TWO-STAGE AMPLIFIER
K
IN TL 50 .152 .56 .65 HOLD 2 USE 2 DEV 1 USE 2 HOLD 1

USE 2 DEV 2 USE 2 HOLD 2
STCP 0 .5 100 HOLD 5
TL 68 .97 .55 .3 USE 5 SHU 3
TL 68 .35 .55 .3 USE 5 SHU 4
TL 68 .30 .55 .3 USE 5 SHU 5
```



```
CS 100 TL 20.5 .43 .505 .05
USE 1 USE 3 TL 69 .24 .55 .3
USE 4 US 2 USE 3 USE 5
REPLACE THIS ITEM:   US
USE    2 USE 3 USE 5
1.5 1.6 1.7 1.8

DATA(F,11,12,21,22) FOR DEV 1

1.5 .553,161.2 .059,50.7 3.247,53.8 .507,-56.4
1.6 .548,158.3 .062,49.4 3.084,50.6 .512,-59.0
1.7 .545,155.3 .066,49.0 2.903,47.0 .517,-60.7
1.8 .545,151.9 .069,48.0 2.778,44.4 .519,-62.9
/
S
MP
DATA(F,11,12,21,22) FOR DEV 2

1.5 .584,165.2 .058,46.5 3.233,55.0 .488,-60.4
1.6 .580,162.5 .062,46.4 3.078,51.8 .493,-63.0
1.7 .573,159.6 .065,45.7 2.896,48.3 .498,-64.6
1.8 .574,156.0 .068,44.7 2.773,45.7 .498,-66.9
/
S
MP
```

	$\sqrt{L/C}$	LEN	V_r	R	G	Ref freq for R
TL1	50	0.152	0.56	0.65	0	2
TL2	68	0.97	0.55	0.3	0	2
TL3	68	0.35	0.55	0.3	0	2
TL4	68	0.30	0.55	0.3	0	2
TL5	20.5	0.43	0.505	0.05	0	2
TL6	68	0.24	0.55	0.3	0	2

Ω, nH, pF, IN ZR = 50

Note typographical error
-- retype USE only

Bamp reconstructs line and reprints from corrected entry

No more data for DEV 1

Data for DEV 1 are SMP

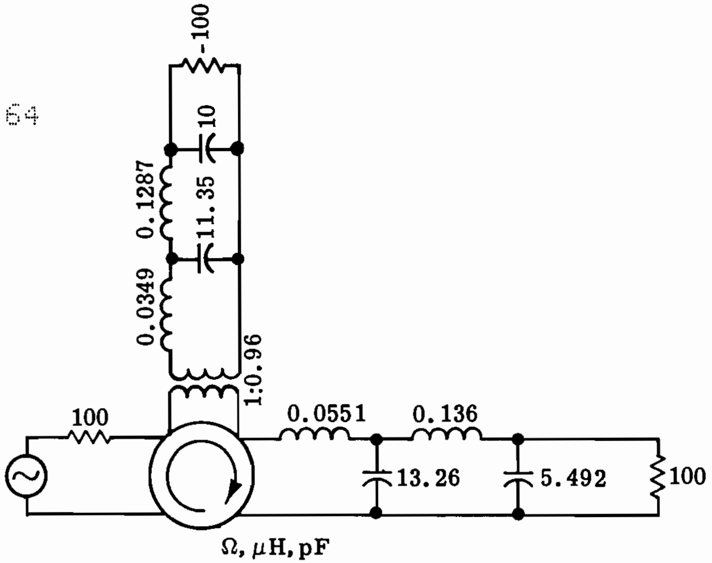
```
                                S-MATRIX IN MAGNITUDE AND PHASE
                      11                              12                              21                             22
FREQ             MAG          ANG            DB        ANG            DB        ANG           MAG        ANG
  1.500       0.382         93.5       -45.44       62.2         24.30       73.8        0.496        85.1
  1.600       0.427         30.8       -42.40       29.6         25.46       36.2        0.406        58.1
  1.700       0.553        -25.7       -40.98       -2.5         24.86       -7.9        0.289        16.7
  1.800       0.654        -67.7       -41.72      -45.5         22.59      -48.1        0.201       -38.1

EDIT<——— Response to NEXT?
LIST0
GHZ OH   NH   PF   IN   ZR= 50
SDB
 10    TL    CAS    50     0.152    0.56     0.65    0
 20    HOLD  2
 30    USE   2    CAS
 40    DEV   1    CAS
 50    USE   2    CAS
 60    HOLD  1
 70    USE   2    CAS
 80    DEV   2    CAS
 90    USE   2    CAS
 100   HOLD  2
 110   STCP CAS    0      0.5   100
 120   HOLD  5
 130   TL    CAS    68     0.97     0.55     0.3   0
 140   USE   5    CAS
 150   SHU   3
 160   TL    CAS    68     0.35     0.55     0.3   0
 170   USE   5    CAS
 180   SHU   4
 190   TL    CAS    68     0.3   0.55     0.3   0
 200   USE   5    CAS
 210   SHU   5
 220   CS    CAS    100
 230   TL    CAS    20.5     0.43     0.505    0.05     0
 240   USE   1    CAS
 250   USE   3    CAS
 260   TL    CAS    68     0.24     0.55     0.3   0
 270   USE   4    CAS
 280   USE   2    CAS
 290   USE   3    CAS
 300   USE   5    CAS
FREQUENCIES: 1.5   1.6   1.7   1.8

STOP
```

6.5 Negative resistance, non-reciprocal amplifier

The circuit in Example 6.5 is the circuit discussed in section 1.9.5 of Chapter 1. Note the following:

- The 100-ohm source and load impedances are handled by setting ZR = 100.
- The total run time was 12 minutes from initial LOAD to the LETTER command. Approximately six minutes were required to label the plot, Fig 6.5.

```
    EXAMPLE 6.5  NEGATIVE RESISTANCE, NON-RECRIPROCAL AMPLIFIER

BAMP CASSETTE #1, PN 09839-71102 REVA

K
ZR 100 UH MHZ TF .96 LS .0349 CP 11.35 LS .1287 CP 10 RP -100 CIR 1

USE 1 LS .0551 CP 13.26 LS .136 CP 5.492

ESTEP 10 700 20

                         S-MATRIX IN MAGNITUDE AND PHASE
                 11                     12                     21                    22
FREQ        MAG      ANG         DB     ANG         DB     ANG         MAG      ANG
 10.00     0.028     58.6      -0.00    -6.8      27.78   -28.8      0.001     85.7
 12.51     0.034     50.6      -0.00    -8.5      27.78   -36.0      0.001     84.8
 15.64     0.043     40.4      -0.00   -10.7      27.77   -45.1      0.002     83.8
 19.56     0.054     27.4      -0.00   -13.3      27.76   -56.5      0.002     82.8
 24.46     0.068     10.4      -0.00   -16.7      27.75   -70.7      0.003     82.1
 30.59     0.086    -11.8      -0.00   -20.9      27.73   -88.7      0.004     82.2
 38.25     0.111    -41.7      -0.00   -26.2      27.70  -111.4      0.005     84.1
 47.84     0.151    -81.9      -0.00   -32.8      27.65  -140.4      0.006     88.7
 59.83     0.231   -134.8      -0.00   -41.2      27.54  -178.0      0.010     95.6
 74.82     0.408    159.2      -0.00   -51.9      27.17   131.8      0.018    100.7
 93.56     0.723     79.4      -0.01   -65.6      25.59    63.8      0.038     98.8
 117.0     0.990     -9.8      -0.03   -83.6      21.13   -18.0      0.087     88.1
 146.3     1.059    -99.3      -0.18  -108.2      14.25  -103.5      0.201     67.5
 183.0     1.048    163.6      -0.94  -143.1       6.56   161.5      0.442     34.8
 228.8     1.021     53.3      -3.83   171.6      -1.34    52.3      0.766     -9.4
 286.2     1.005    -46.5      -9.71   129.4      -9.18   -47.0      0.945    -51.1
 357.9     1.001   -119.5     -17.03    98.8     -16.94  -119.7      0.990    -81.4
 447.6     1.000   -172.2     -24.70    76.9     -24.69  -172.3      0.998   -103.2
 559.7     1.000    148.2     -32.44    60.6     -32.44   148.2      1.000   -119.4
 700.0     1.000    117.5     -40.20    48.0     -40.20   117.6      1.000   -131.9

PLOT
SDB21
MIN=-40.19998135   MAX= 27.78021164
FREQ SCALE
10 1000 LOG
VER SCALE
35 -35
ADJUST PLOTTER(LL,UR)
LETTER

N

STOP
```



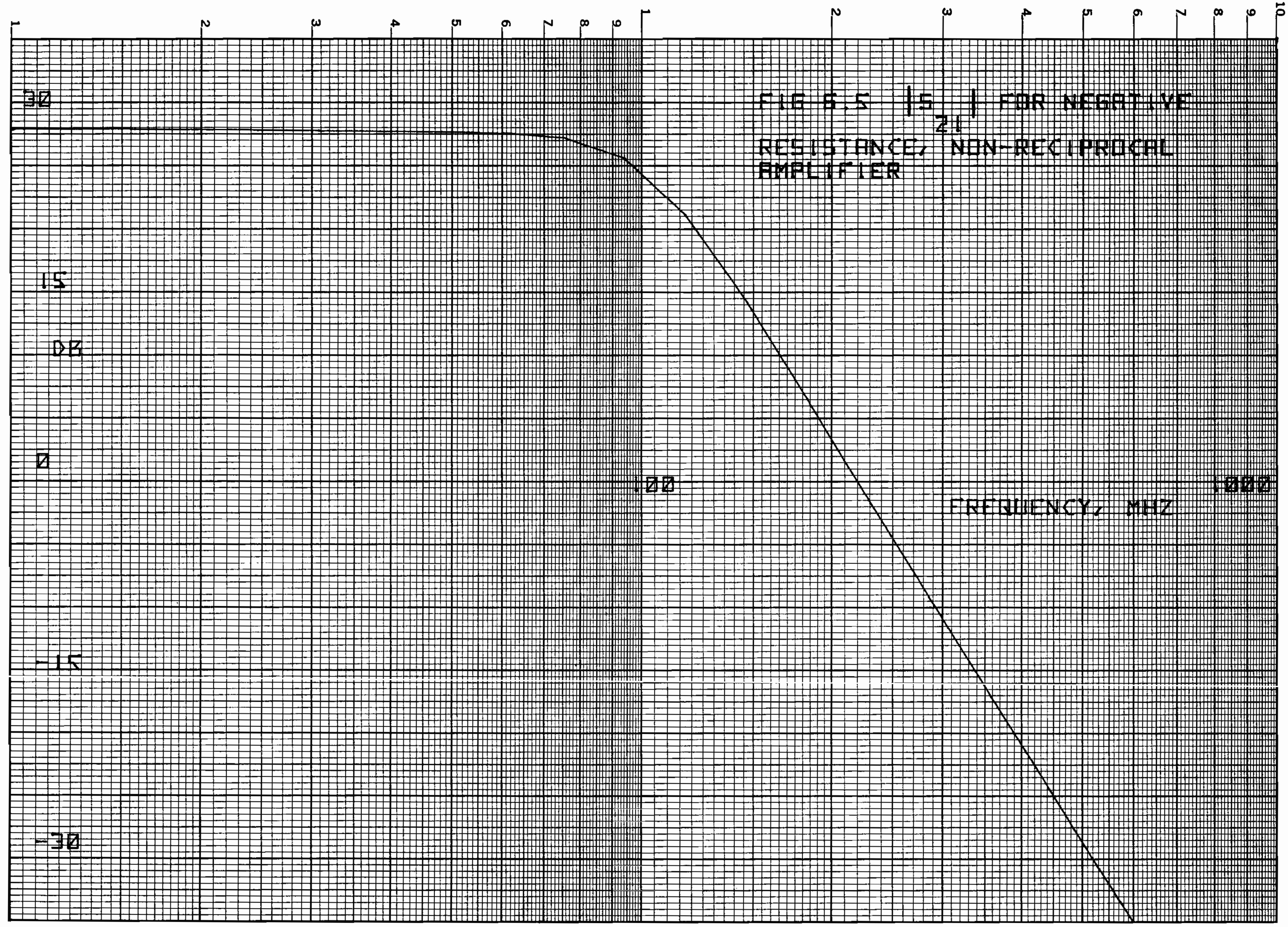


FIG 6.5 $|S_{21}|$ FOR NEGATIVE RESISTANCE, NON-RECIPROCAL AMPLIFIER

6.6 3-dB branch-line coupler

Example 6.6 is the 3-dB branch line coupler discussed in section 1.9.6 of Chapter 1. Note the following:

- An error was made in the first line of input. Bamp could find only two parameters for the second transmission line and assigned them as follows

$$\sqrt{L/C} = 507.5$$
$$LEN = 1$$

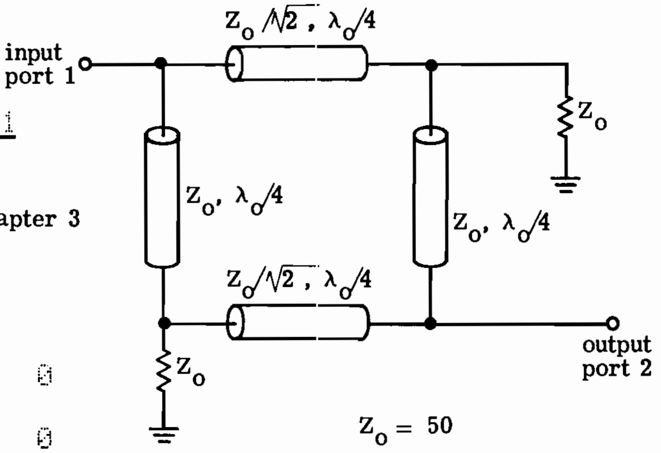
- The prompt V/C, R, G = ? then appeared in the display. The line being processed was reconstructed from this entry, and the line was re-printed.
- The value 1 was assigned to V/C; R and G were assigned the value 0.
- Editor was called after the frequencies were entered. The listing shows the error in line 30.
- Line 30 was re-typed, a part of the circuit was re-listed to verify that the correction was made, and then the circuit was run.

```
        EXAMPLE 6.6  3-DB BRANCH-LINE COUPLER


BAMP CASSETTE #1, PN 09839-71102 REVA


K
TL 35.35 7.5 1 RP 50 TL 507.5 1 HOLD 1

1 HOLD  1
USE 1 USE -1 PAR
```

Note error: failed to supply space or comma

Typed in 1 for V_r (see diagnostic message 3.1.2 in Chapter 3

Reconstructed line



$Z_o = 50$

$f_o = 1$ GHz

```
STEP .8 1.2 .05

LIST
  10     TL     CAS     35.35    7.5    1    0    0
  20     RP     CAS     50
  30     TL     CAS     507.5    1      1    0    0
  40     HOLD   1
  50     USE    1      CAS
  60     USE   -1      PAR
FREQUENCIES: 0.8    0.85     0.9    0.95      1      1.05      1.1    1.15
  1.2
```

note error

```
30 TL 50 7.5 1
LIST 20,40
  20     RP     CAS     50
  30     TL     CAS     50     7.5    1      0      0
  40     HOLD   1
```

retype line 30

```
RUN

                           S-MATRIX IN MAGNITUDE AND PHASE
                  11                     12                     21                    22
FREQ        MAG      ANG         DB     ANG          DB     ANG          MAG       ANG
 0.800     0.375    120.3       -3.36 -135.3        -3.36 -135.3        0.375     120.3
 0.850     0.287    111.8       -3.15 -146.6        -3.15 -146.6        0.287     111.8
 0.900     0.192    103.8       -3.04 -157.9        -3.04 -157.9        0.192     103.8
 0.950     0.095     96.6       -3.01 -169.1        -3.01 -169.1        0.095      96.6
 1.000     0.000    180.0       -3.01  180.0        -3.01  180.0        0.000     180.0
 1.050     0.095    -96.6       -3.01  169.1        -3.01  169.1        0.095     -96.6
 1.100     0.192   -103.8       -3.04  157.9        -3.04  157.9        0.192    -103.8
 1.150     0.287   -111.8       -3.15  146.6        -3.15  146.6        0.287    -111.8
 1.200     0.375   -120.3       -3.36  135.3        -3.36  135.3        0.375    -120.3


STOP
```

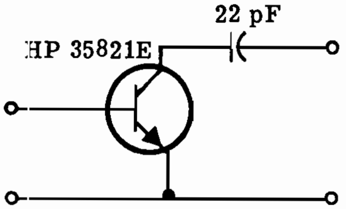
6.7 Using the editor

The main purpose of Example 6.7 is to show some of the editing capability. Note the following:

- The editor is used to modify the circuit description by inserting three two-ports (LP 1, TL 50 0.346 0.4, and DEV 1 at the output) and also by changing the unit of length to the inch.
- DEV 1 is inserted without the name of a DEV data file, since DEV 1 already appears in the circuit with the required name.

EXAMPLE

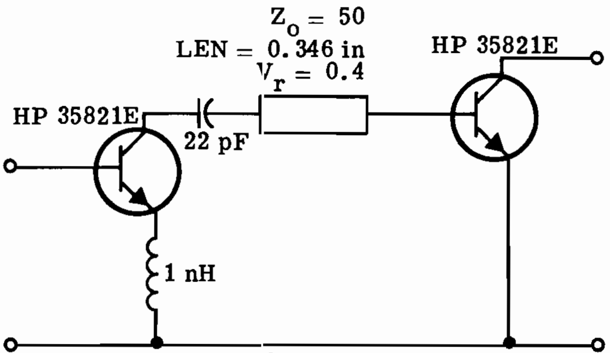
```
                          EXAMPLE 6.7  USING THE EDITOR
BAMP CASSETTE #1, PN 09839-71102 REVA

K
DEV 1 HP35821E CS 22 SMP

1.4 1.5
```



original circuit

```
                          S-MATRIX IN MAGNITUDE AND PHASE
                    11                 12                 21                 22
FREQ          MAG      ANG       MAG      ANG       MAG      ANG       MAG      ANG
  1.400     0.460    171.8     0.078     58.1     3.294     72.1     0.492    -52.6
  1.500     0.461    169.9     0.081     58.0     3.071     70.0     0.491    -55.4

EDIT
LIST
  10     DEV     1      CAS      HP35821E
  20     CS     CAS      22
FREQUENCIES: 1.4    1.5
 15 LP 1 SER
30 TL 50 .346 .4
IN
40 DEV 1
```

circuit description modifications as EDIT inputs



modified circuit

```
LIST
  10     DEV     1      CAS      HP35821E
  15     LP     SER      1
  20     CS     CAS      22
  30     TL     CAS      50      0.346     0.4     0     0
  40     DEV     1      CAS      HP35821E
FREQUENCIES: 1.4    1.5
REN
```

renumbers circuit (not mandatory)

```
LIST
  10     DEV     1      CAS      HP35821E
  20     LP     SER      1
  30     CS     CAS      22
  40     TL     CAS      50      0.346     0.4     0     0
  50     DEV     1      CAS      HP35821E
FREQUENCIES: 1.4    1.5
RUN
                          S-MATRIX IN MAGNITUDE AND PHASE
                    11                 12                 21                 22
FREQ          MAG      ANG       MAG      ANG       MAG      ANG       MAG      ANG
  1.400     0.208   -138.2     0.012    115.2    10.083    116.5     0.512    -35.0
  1.500     0.234   -145.2     0.014    111.8     9.248    108.7     0.532    -39.2
EDIT
LIST0,0
GHZ OH  NH  PF  IN  ZR= 50
SMP

STOP
```

6.8 Using MAPP

Example 6.8 uses a simple circuit to show how the two-port MAPP can be used. In this example you can think of MAPP as providing the variable impedance Z connected to the emitter. The outputs are plots of the S-parameters for the composite circuits as a function of Z. If $Z = 0$, the S-parameters for the composite circuit are just the S-parameters for the transistors. Note particularly the following:

- Data for DEV 1 are typed in from the keyboard. (S-parameters for the HP 35821E are tabulated in Appendix C.) One reason for typing in the S-parameters, aside from the fact that it is faster than reading from a data cassette when there is but one frequency, is that they are available for quick check against the composite values for the case $Z = 0$.
- $S_{11}(Z)$ is the first plotted output and is shown as Fig 6.8.1. Full scale for this plot is 1 by default. A part of the plot falls outside the unit circle in the S_{11} plane. This means that there are some values of Z that cause instabilities in a 50-ohm system.
- For S_{11}, the fact that

$$|T| + |R| = 1.37$$

together with $\text{Re } N > 0$ imply that $|S_{11}| \leq 1.37$ for $\text{Re } Z > 0$. Full scale of 1.37 or greater ensures that the image of the entire right-half plane is plotted.

- $S_{21}(Z)$ is plotted as Fig 6.8.2. Note that full scale is 20 for the horizontal axis, but 14 for the vertical axis. The clue to selecting these scales is

$$|T| + |R| = 19.9$$

and

$$\text{Re } N > 0$$

The entire image of the right-half plane is obtained and falls inside the circle $S_{21}(XS)_{RS = 0}$.

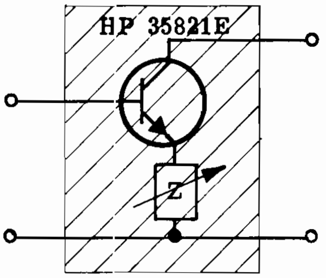
```
                         EXAMPLE 6.8  USING MAPP


BAMP CASSETTE #1, PN 09839-71102 REVA

K
DEV 1 MAPP SER
.1
DATA(F,11,12,21,22) FOR DEV 1

.1 .44,-130 .015,56 18,150 .74,-38
/
S
MP
VARIABLE
S11
MAG T= 0.651932144   ANG T=-49.80641934
MAG R= 0.721646774   ANG R= 37.98938
RE  N= 4.719593406   IM  N= 2.243827330

ADJUST PLOTTER
```

Response to SCALE?

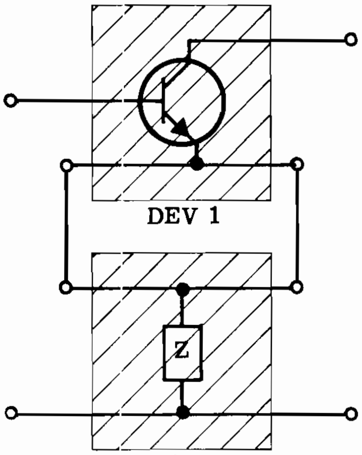
```
NEXT
RP 10
NEXT
ZP 0 0
L= 0     NH
MAG= 0.440159885   ANG=-129.9762818

NEXT
LETTER

NEXT
S21
MAG T= 9.950429574   ANG T= 175.2915389
MAG R= 9.956635175   ANG R=-4.394928058
RE  N= 4.71919008    IM  N= 2.24490563

20 14 ADJUST PLOTTER
```

Response to SCALE?

```
NEXT
RP 10
NEXT
ZS 0 0
L= 0     NH
MAG= 18.0000738  ANG= 149.9995656

NEXT
LETTER

NEXT
STOP
```

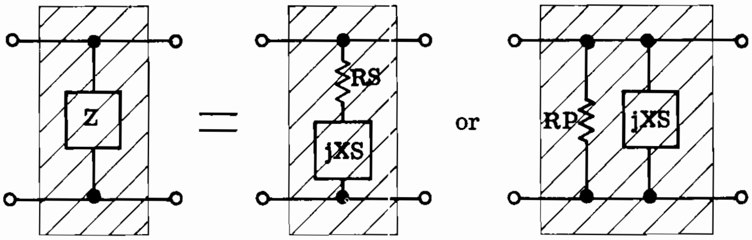


circuit



DEV 1

MAPP
Bamp model



IMPEDANCE OR ADMITTANCE COORDINATES

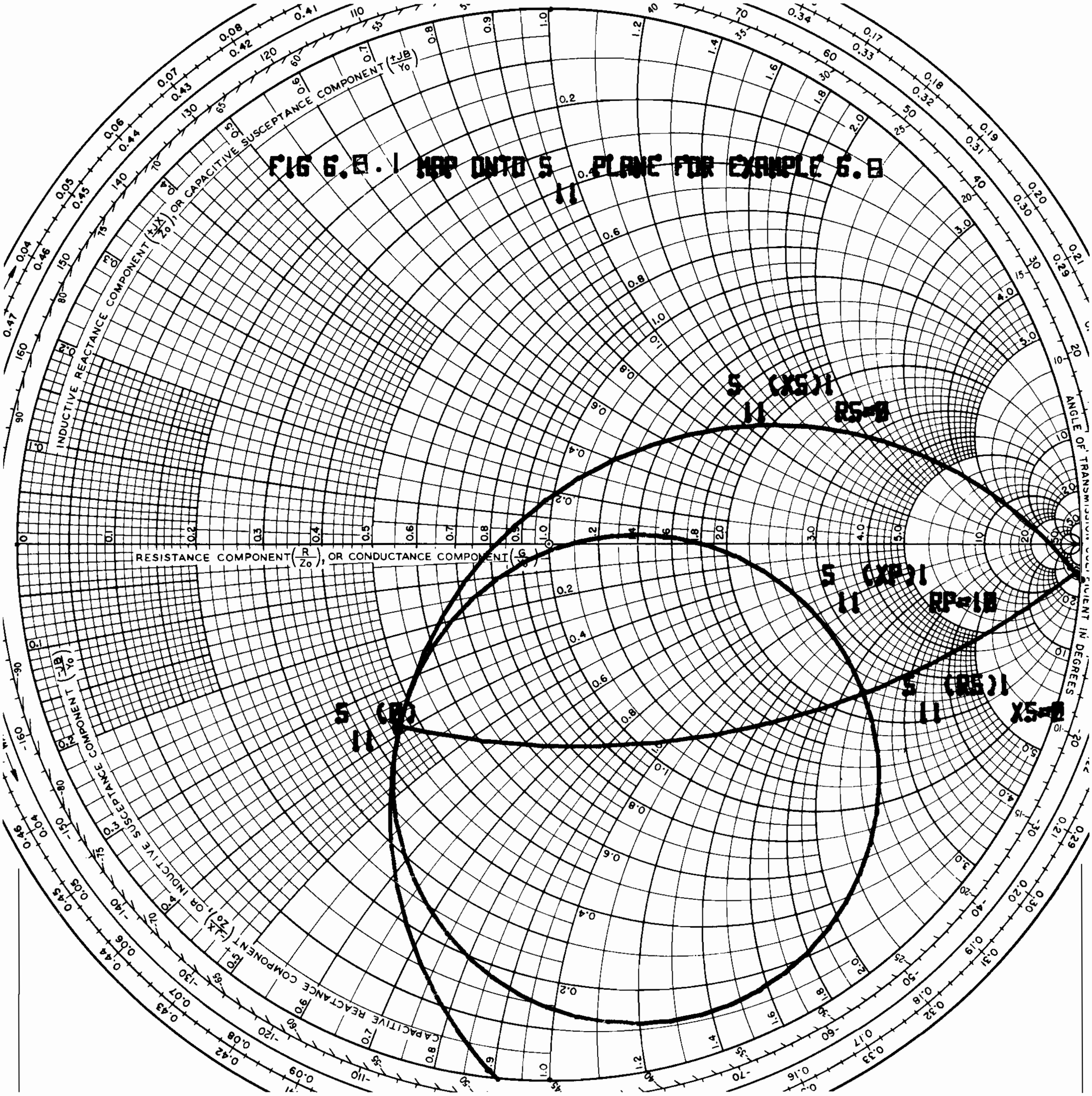


FIG 6.B.1 MAP ONTO S_{11} PLANE FOR EXAMPLE 6.B

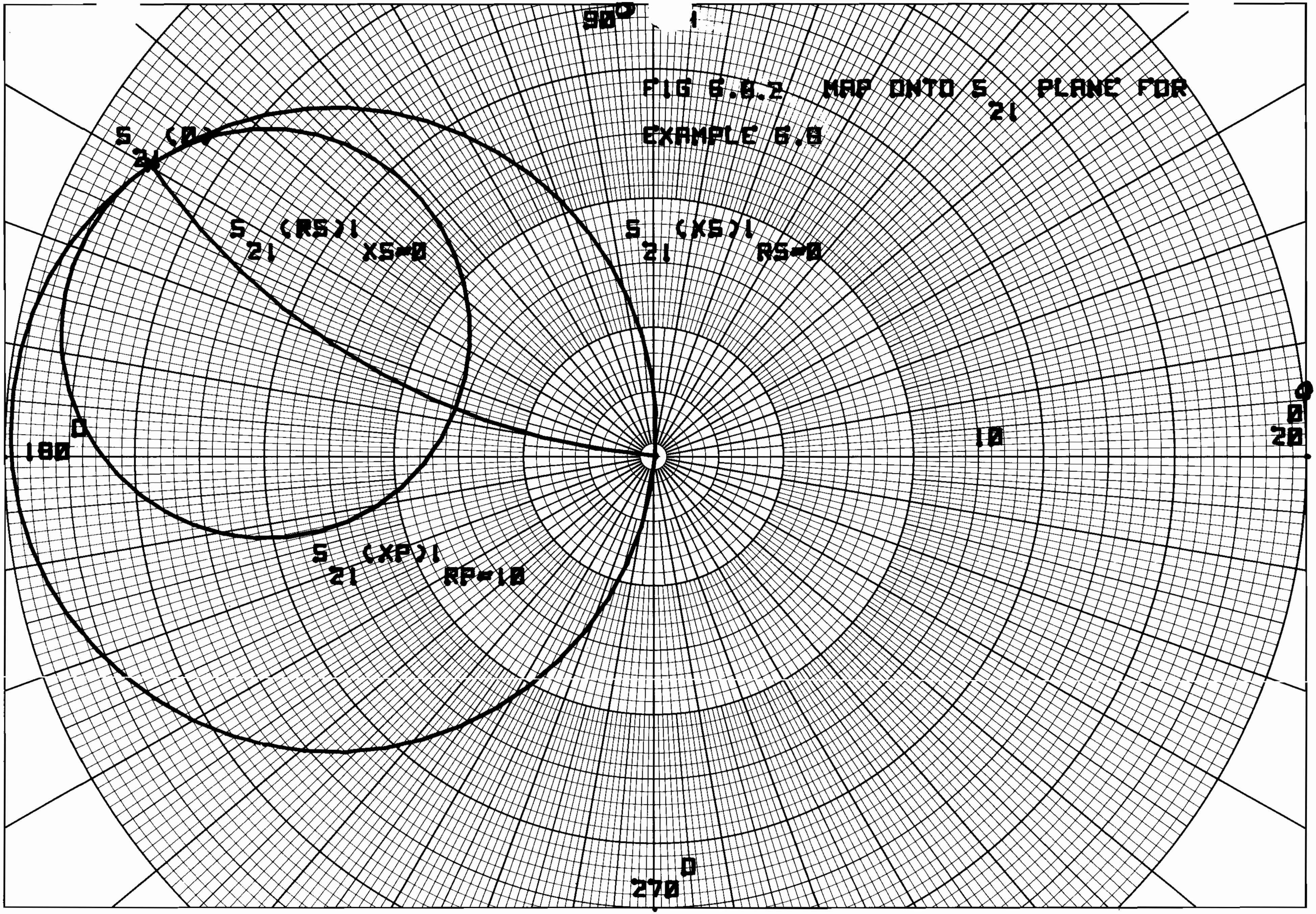


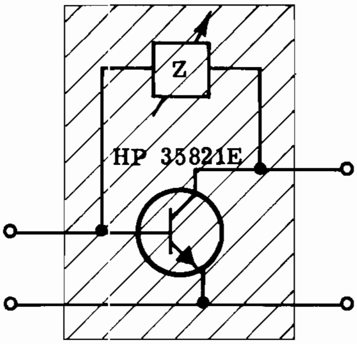
FIG 6.8.2 MAP ONTO S_{21} PLANE FOR EXAMPLE 6.8

6.9 Using MAPS

Example 6.9 uses MAPS for shunt feedback. Note the following:

- As in Example 6.8, data for DEV 1 are typed in from the keyboard.
- For Z an open-circuit, zero series capacitance for example, the S-parameters for the composite two-port are the same as for the transistor alone.
- Two mappings are obtained. One is onto the S_{11} plane and is shown as Fig 6.9.1. The other is onto the S_{21} plane and is shown as Fig 6.9.2.
- For S_{21}, the image of the short-circuit position is obtained by setting ZS = 0. The image of the open-circuit position is obtained by using a series capacitance of zero value.

```
                    EXAMPLE 6.9  USING MAPS

BAMP CASSETTE #1, PN 09839-71102 REVA
K
DEV 1 MAPS PAR
.1

DATA(F,11,12,21,22) FOR DEV 1

.1 .44,-130 .015,56 18,150 .74,-38
/
S
MP
VARIABLE
S11
MAG T= 0.514808355    ANG T= 179.1804506
MAG R= 0.415228822    ANG R=-56.04657447
RE  N= 446.994628     IM  N=-245.1339703
```

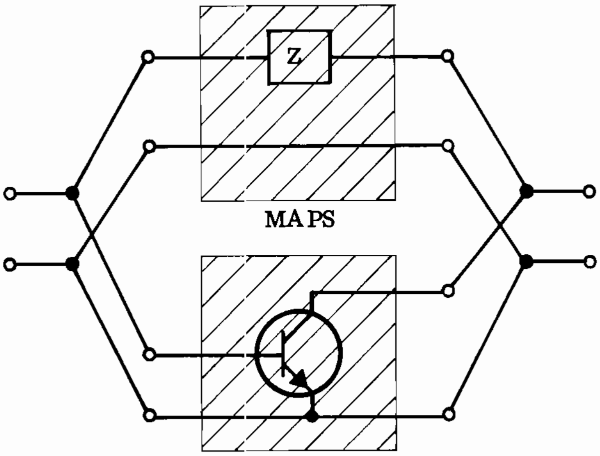


circuit

```
ADJUST PLOTTER
```

Response to SCALE?

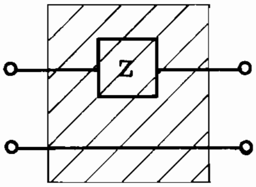
```
NEXT
RS 200
NEXT
RCS 0 0
X= -INFINITY
MAG= 0.440014816    ANG=-130.0011066

NEXT
LETTER

NEXT
S21
MAG T= 10.22950194    ANG T= 178.8510672
MAG R= 10.29969627    ANG R= 121.3642453
RE  N= 447.0025503    IM  N=-245.12125
```

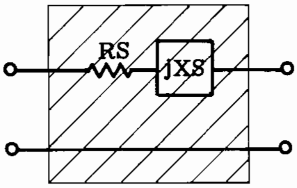


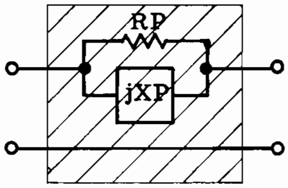
DEV 1
Bamp model

```
20 14
```

Response to SCALE?







```
NEXT
RS 200
NEXT
ZS 0 0
L= 0      NH
MAG= 0.070213010    ANG=-2.475260159

NEXT
RCS 0 0
X= -INFINITY
MAG= 17.99966443    ANG= 150.0002067

NEXT
LETTER
```

IMPEDANCE OR ADMITTANCE COORDINATES

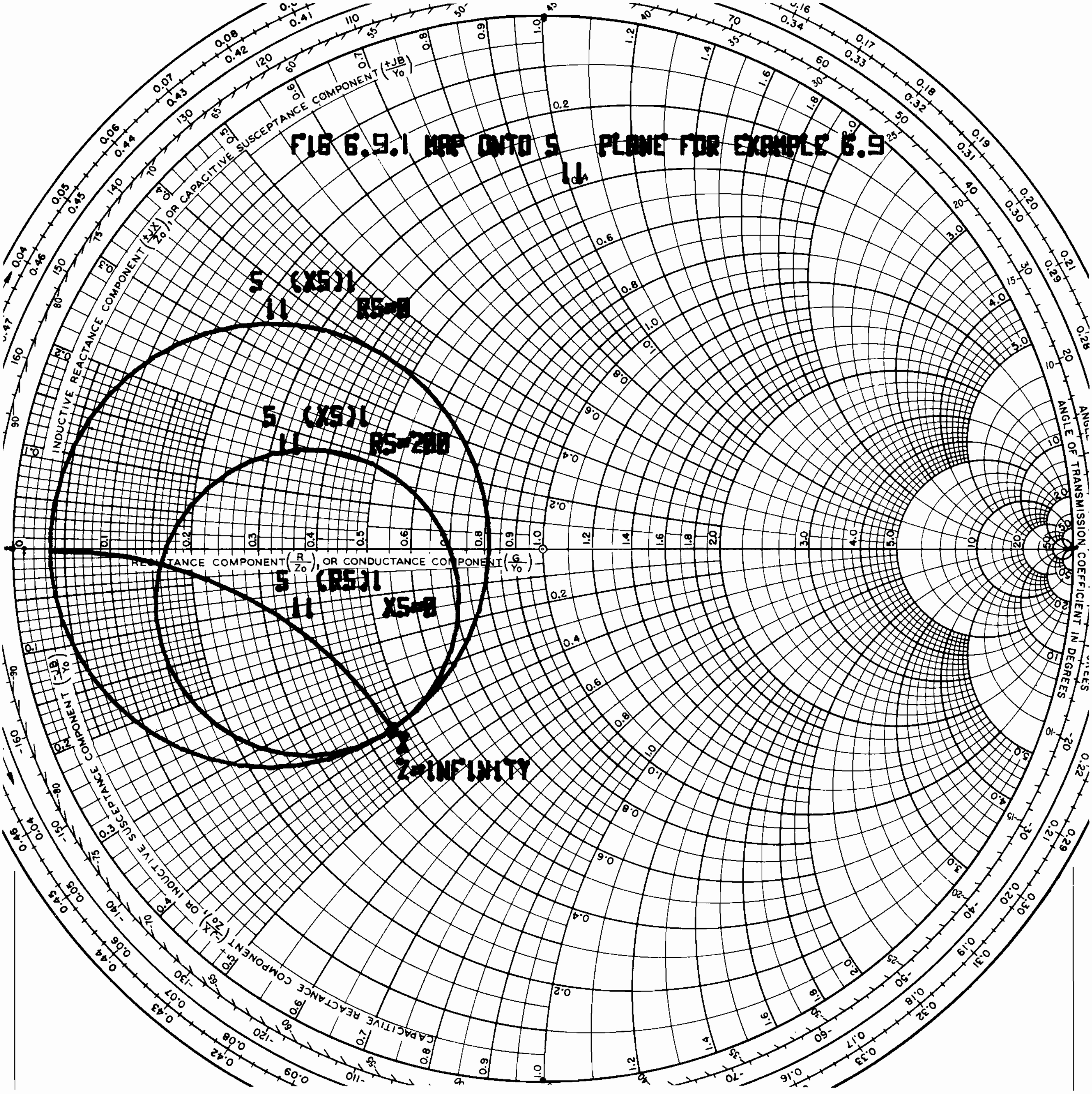


FIG 6.9.1 MAP ONTO S11 PLANE FOR EXAMPLE 6.9

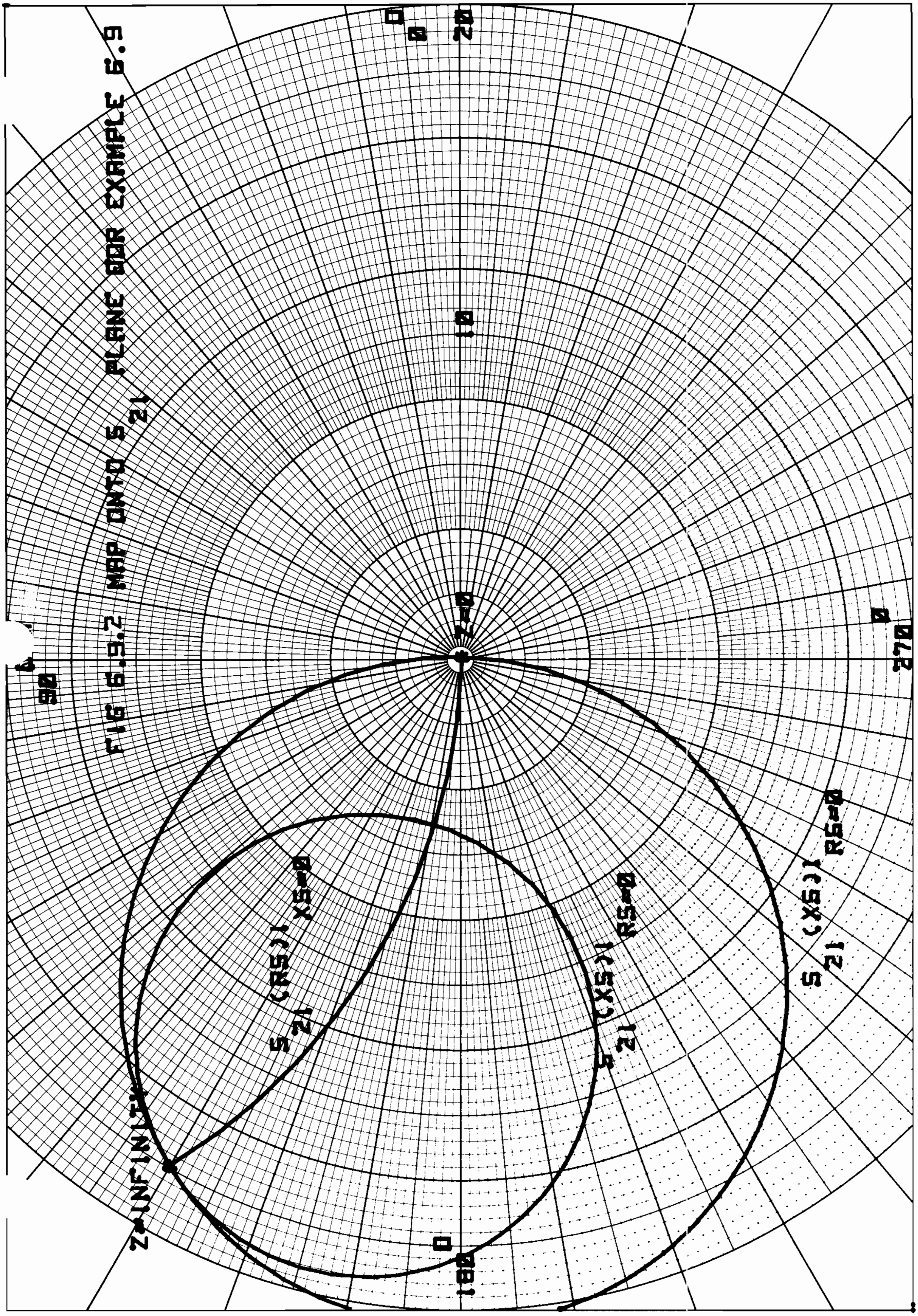


FIG 6.9.2 MAP ONTO S_{21} PLANE FOR EXAMPLE 6.9

6.10 Using Bampdf to create a DEV data file and also to transform from CB to CE

Suppose that the following data are common-base data for a transistor biased say at 15V and 15MA.

	S_{11}		S_{12}		S_{21}		S_{22}	
Freq(GHz)	Mag	Phase	Mag	Phase	Mag	Phase	Mag	Phase
0.25	0.9	175	0.010	120	1.8	-10	0.95	-5
0.50	0.9	173	0.015	120	1.8	-16	1	-12
0.75	0.9	170	0.018	120	1.78	-25	1	-18

Example 6.10 Bampdf is used to write these data into an OLD data cassette under the name TRANS1. The file TRANS1 is listed after it is created. Then the corresponding CE data are computed, stored in file TRANS1CE, and then are listed.

Note that an error was made in entering the S-parameters at f= 0.50 GHz. This error was corrected immediately as explained in step 819 *et seq.* of the user instructions in section 4.5 of Chapter 4.

Free format is used for data entry. The commas were used in Example 6.10 simply to identify the pairs magnitude-phase.

```
          EXAMPLE 6.10   USING BAMPDF TO CREATE A 'DEV' DATA FILE
                         AND ALSO TO TRANSFORM FROM CB TO CE

WRITE ← task
TRANS1 ← data to this file
MP ← data are magnitude-phase
.25 .9,175 .010,120 1.80,-10 0.95,-5
.5 .9,173 .15,120 1.8,-16 1,-12 ← note error in this line
.75 .9,170 .018,120 1.78,-25 1,-18
C .5 ← correct error at f=0.50
/ ← no more data
LIST ← task
TRANS1 ← LIST this file
.25,.75 ← response to FREQUENCY RANGE?
MP ← LIST magnitude-phase
 0.25
 0.9    175    0.01       120
 1.8   -10     0.95      -5

 0.5
 0.9    173    0.015      120
 1.8   -16     1       -12

 0.75
 0.9    170    0.018      120
 1.78      -25     1      -18
N ← do not list again
T ← task
TRANS1 ← source file
TRANS1CE ← destination file
CB ← data in TRANS1 are CB
CE ← desire CE
LIST ← task
TRANS1CE ← LIST this file in magnitude-phase
.25,.75 ← FREQUENCY ANGLE
MP
 0.25
 0.416322464    -152.0499435     0.032360851     22.49493605
 9.206487549     115.2261669     0.498350678    -2.770154075

 0.5
 0.512384330    -162.4583690     0.048096211     53.23981499
 6.354381174     100.7595679     0.416787553    -39.73724723

 0.75
 0.563188194    -171.7890377     0.059927589     58.0423617
 4.228473574     89.9658639     0.368089441    -34.71827597

NO ← do not list again
STOP
```

Chapter VII

APPENDIX

APPENDIX A
THEORY

Appendix A contains a review of those aspects to linear, two-port network theory that have direct relevance to Bamp '30.

A. 1 Characterization of two-ports

Figure A. 1. 1 shows the terminal voltages and currents for a two-port. The current I_1, which flows into terminal 1' flows out of terminal 1. Likewise, I_2 flows into terminal 2' and out of terminal 2. The terminals 1' and 1 together make up port 1; 2' and 2 together form port 2.

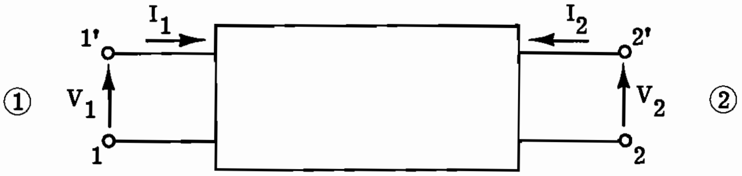


Fig A. 1. 1 Two-port

One or more of the Y-, Z-, G-, or H- matrices usually will characterize the terminal behavior of a linear two-port. Definitions of these matrices can be found in almost any text on linear circuit theory, for example Refs 1 and 2.

The S-matrix, the matrix of scattering parameters, provides an alternative characterization of linear two-ports. Bamp uses S-parameters for computational purposes, but can convert the computed S-matrix of the overall circuit to any one of the Y-, Z-, G-, or H- matrices. The primary reasons for using S-parameters are:

1. S-parameters are convenient for describing microwave components.
2. It is easy to measure the S-parameters of active devices at microwave frequencies.
3. S-parameters offer some computational advantages over Y-, Z-, G-, or H-parameters at any frequency including dC.

Basic definitions of S-parameters can be found in a number of references including Refs 3 and 4. Because S-parameters are less well know than other parameter sets except, perhaps, to microwave engineers, basic definitions are included here for ready reference.

First of all, linear combinations of the terminal voltages and currents are formed to obtain new variables $\mathbf{a}^T = [a_1, a_2]$ and $\mathbf{b}^T = [b_1, b_2]$. In matrix form, the transformation from voltages and currents to a and b can be written

$$\begin{bmatrix} a_i \\ b_i \end{bmatrix} = \frac{1}{2\sqrt{|\text{Re } Z_R|}} \begin{bmatrix} 1 & Z_R \\ 1 & -Z_R^* \end{bmatrix} \begin{bmatrix} V_i \\ I_i \end{bmatrix} \quad ; i = 1,2 \tag{A.1.1}$$

The inverse transformation is then

$$\begin{bmatrix} V_i \\ I_i \end{bmatrix} = \frac{\sqrt{|\text{Re } Z_R|}}{\text{Re } Z_R} \begin{bmatrix} Z_R^* & Z_R \\ 1 & -1 \end{bmatrix} \begin{bmatrix} a_i \\ b_i \end{bmatrix} \quad ; i = 1,2 \tag{A.1.2}$$

In eqs. (A.1.1) and (A.1.2), Z_R is the reference impedance and the asterisk, indicates the complex conjugate. Bamp uses a real reference impedance, and the default value is 50 ohms. However, any other non-zero value, either positive or negative, can be specified. In the remainder of this section Z_R is assumed to be real.

b and a are related by means of the S-matrix. The equation is

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \tag{A.1.3}$$

or in a more concise notation

$$b = S\, a \tag{A.1.4}$$

From Eq. (A.1.3) it is clear that

$$S_{11} = \frac{b_1}{a_1}\bigg|_{a_2=0} \qquad S_{12} = \frac{b_1}{a_2}\bigg|_{a_1=0}$$
$$S_{21} = \frac{b_2}{a_1}\bigg|_{a_2=0} \qquad S_{22} = \frac{b_2}{a_2}\bigg|_{a_1=0} \tag{A.1.5}$$

At microwave frequencies accurate equipment exists for measuring the complex ratios in Eq (A.1.5). This is one of the reasons why S-parameters are used to characterize microwave networks and components.

To see how to compute S-parameters, note from Eq. (A.1.1) that

$$a_i = 0 \quad => V_i = -Z_R I_i \tag{A.1.6}$$

That is, terminate port i in Z_R to make $a_i = 0$. By using Eqs. (A.1.1) and (A.1.6) it is possible to write the ratios in (A.1.5) as follows

$$S_{11} = \frac{Z_1 - Z_R}{Z_1 + Z_R}\Bigg|_{V_2 = -Z_R I_2} \qquad S_{12} = (V_1/V_2)(1 + S_{22})\Big|_{V_1 = -Z_R I_1}$$

$$S_{21} = (1 + S_{11})(V_2/V_1)\Big|_{V_2 = -Z_R I_2} \qquad S_{22} = \frac{Z_2 - Z_R}{Z_2 + Z_R}\Bigg|_{V_1 = -Z_R I_1} \qquad \text{(A.1.7)}$$

Consider, for example, the two-port in Fig A.1.1, which is terminated at port 2 in Z_R.

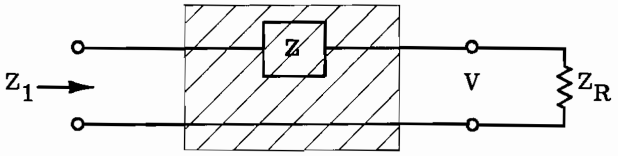


Fig A.1.1

Here the impdeance at port 1 is

$$Z_1 = Z + Z_R$$

and the voltage division ratio is

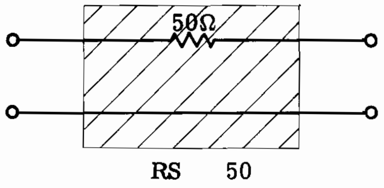
$$V_2/V_1 = Z_R/(Z + Z_R)$$

Substituting these results into Eqs (A.1.7) and simplifying yields

$$S_{11} = \frac{Z}{Z + 2Z_R}$$

$$S_{21} = \frac{2Z_R}{Z + 2Z_R}$$

Because of symmetry, $S_{22} = S_{11}$ and $S_{12} = S_{21}$. Thus, the two-port RS for which R = 50 as shown in Fig A.1.2 has $S_{11} = S_{22} = 1/3$, $S_{12} = S_{21} = 2/3$ in a 50-ohm system



$$S = \begin{bmatrix} 1/3 & 2/3 \\ 2/3 & 1/3 \end{bmatrix}$$

$$Z_R = 50$$

Fig A.1.2 S-matrix for RS 50 in a 50-Ω system

The net power into port i ($i = 1, 2$) is

$$P_i = 1/2 \text{ Re } V_i I_i^* \qquad \text{(A.2.1)}$$

Replacing V_i and I_i by their equivalents in terms of a_i and b_i as given by Eq (A.1.2) and simplifying yields

$$P_i = |a_i|^2 - |b_i|^2 , \quad Z_R > O \tag{A.2.2a}$$

or

$$P_i = |b_i|^2 - |a_i|^2 , \quad Z_R < O \tag{A.2.2b}$$

Thus $|a_i|^2$ and $|b_i|^2$ are interpreted as incident and reflected powers. If $Z_R > O$, then $|a_i|^2$ is the incident power, and $|b_i|^2$ is the reflected power. The net power is the difference between the two. The roles of $|a_i|^2$ and $|b_i|^2$ as incident and reflected powers are interchanged, if $Z_R < O$.

A.2 Two-port connections

The five ways of interconnecting two two-ports are shown in Fig A.2.1. In each case, the result is a composite two-port.

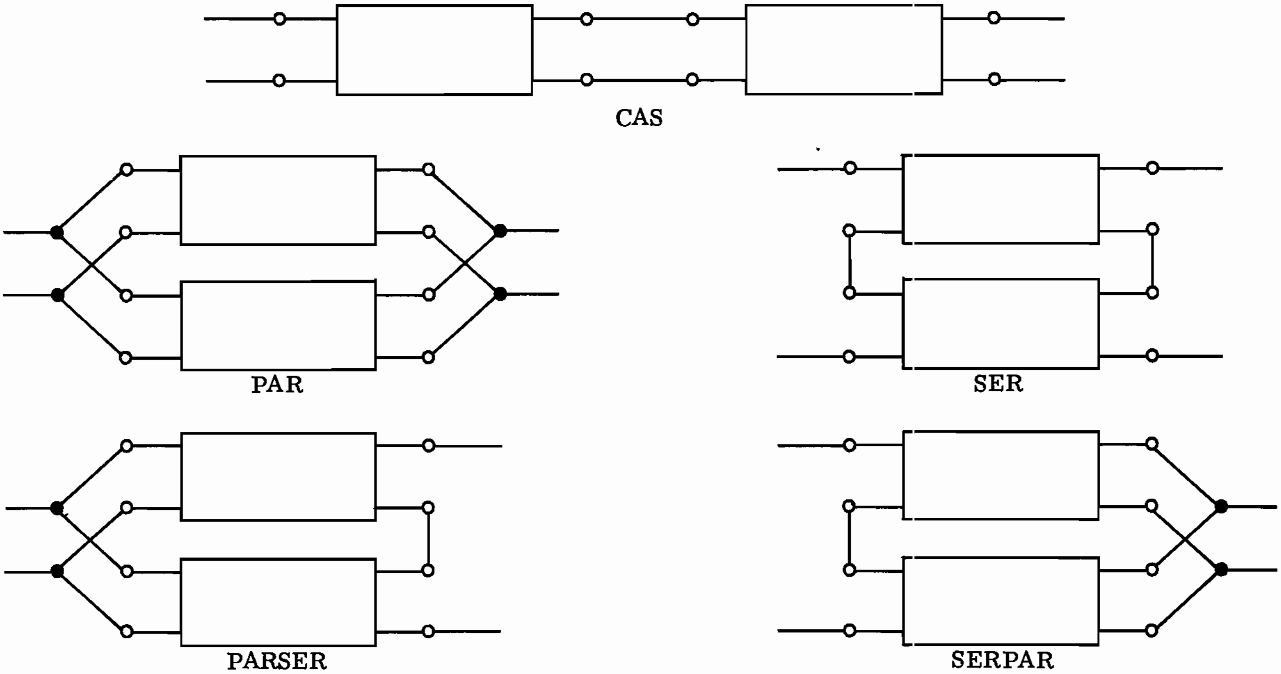


Fig A.2.1 Two-port connections

The fundamental connection is the cascade connection. Anderson and Newcomb, Ref. 7, have shown that all connections can be reduced to what they call cascade-loading. All of the connections that Bamp '30 makes ultimately reduce to cascade connections.

For example, to make a parallel connection, Bamp '30 inserts Y-junctions as shown in Fig. A.2.2. The Y-junctions as well as the two-ports are described by scattering matrices. The junctions are three-ports rather than two-ports.

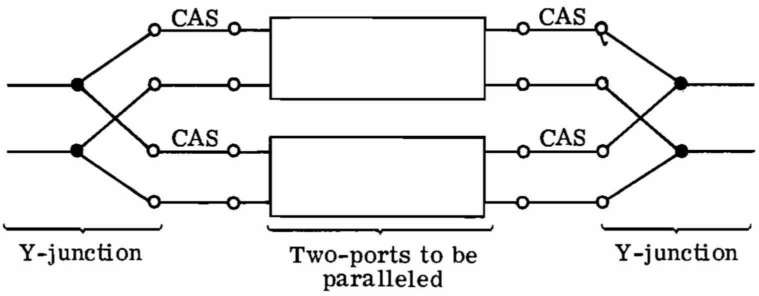


Fig A.2.2 Using Y-junctions to form the PAR connection

T-junctions are used to form the series connection as shown in Fig A.2.3

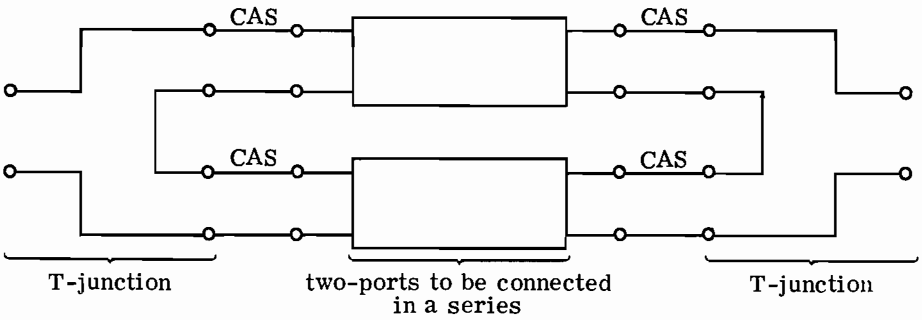


Fig A.2.3 Using T-junctions to form the SER connection

The PARSER connection has a Y-junction on the left and a T-junction on the right. The T-junction is on the left, and the Y-junction is on the right for the SERPAR connection.

To illustrate the simple cascade connection of two two-ports, consider Fig A.2.4.

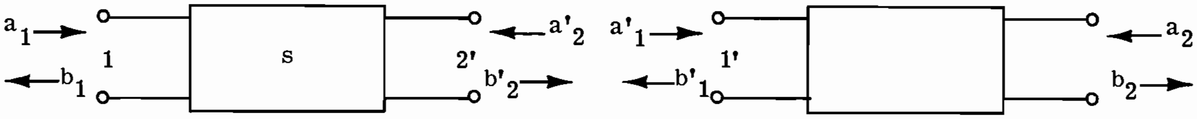


Fig A.2.4 Two disjoint two-ports

The two-port on the left has the scattering matrix

$$s = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix}$$

and that on the right has the scattering matrix

$$S = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$$

For the disjoint two-ports

$$\begin{bmatrix} b_1 \\ b_2 \\ b'_2 \\ b'_1 \end{bmatrix} \quad \begin{bmatrix} s_{11} & 0 & s_{12} & 0 \\ 0 & S_{22} & 0 & S_{21} \\ s_{21} & 0 & s_{22} & 0 \\ 0 & S_{12} & 0 & S_{11} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a'_2 \\ a'_1 \end{bmatrix} \tag{A.2.1}$$

or

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} s_{11} & 0 \\ 0 & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} + \begin{bmatrix} s_{12} & 0 \\ 0 & S_{21} \end{bmatrix} \begin{bmatrix} a'_2 \\ a'_1 \end{bmatrix} \tag{A.2.2}$$

$$\begin{bmatrix} b'_2 \\ b'_1 \end{bmatrix} = \begin{bmatrix} s_{21} & 0 \\ 0 & S_{12} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} + \begin{bmatrix} s_{22} & 0 \\ 0 & S_{11} \end{bmatrix} \begin{bmatrix} a'_2 \\ a'_1 \end{bmatrix} \tag{A.2.3}$$

The connection constraint is (see Fig A.2.4)

$$\begin{bmatrix} b'_2 \\ b'_1 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} a'_2 \\ a'_1 \end{bmatrix} \tag{A.2.4}$$

Substituting Eq (A.2.4) into Eq. (A.2.3) yields

$$\begin{bmatrix} a'_2 \\ a'_1 \end{bmatrix} = \begin{bmatrix} -s_{22} & 1 \\ 1 & -S_{11} \end{bmatrix}^{-1} \begin{bmatrix} s_{21} & 0 \\ 0 & S_{12} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \tag{A.2.5}$$

if

$$1 - s_{22}S_{11} \neq 0 \tag{A.2.6}$$

The condition (A.2.6) is the necessary and sufficient condition for the existence of the inverse matrix in Eq. (A.2.5). If the inverse exists, then Eq. (A.2.6) can be substituted into Eq. (A.2.2) to obtain

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \left\{ \begin{bmatrix} s_{11} & 0 \\ 0 & S_{22} \end{bmatrix} + \begin{bmatrix} s_{12} & 0 \\ 0 & S_{21} \end{bmatrix} \begin{bmatrix} -s_{22} & 1 \\ 1 & -S_{11} \end{bmatrix}^{-1} \begin{bmatrix} s_{21} & 0 \\ 0 & S_{12} \end{bmatrix} \right\} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \tag{A.2.7}$$

The remaining algebra is straightforward and the result is

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} s_{11} + \dfrac{s_{12}s_{21}S_{11}}{1-s_{22}S_{11}} & \dfrac{s_{12}S_{12}}{1-s_{22}S_{11}} \\ \dfrac{s_{21}S_{21}}{1-s_{22}S_{11}} & s_{22} + \dfrac{S_{12}S_{21}s_{22}}{1-s_{22}S_{11}} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \tag{A.2.8}$$

All of this says that for the composite two-port obtained by cascading ports 2' and 1' in Fig A.2.4 the S-parameters are

$$\begin{aligned}
S'_{11} &= s_{11} + \frac{s_{12}s_{21}S_{11}}{1-s_{22}S_{11}} \\
S'_{22} &= s_{22} + \frac{S_{12}S_{21}s_{22}}{1-s_{22}S_{11}} \\
S'_{21} &= \frac{s_{21}S_{21}}{1-s_{22}S_{11}} \\
S'_{12} &= \frac{s_{12}S_{12}}{1-s_{22}S_{11}}
\end{aligned} \tag{A.2.9}$$

Equations (A.2.9) are the equations used by Bamp '30 to cascade two two-ports.

In principle, the remaining connections are handled in the same way, but the calculation is more involved. Because the PAR, SER, PARSER, and SERPAR connections all involve two three-ports and two two-ports the circuit matrix, the analog of Eq. (A.2.1) is a 10 x 10 matrix which in portioned form can be written

$$\begin{bmatrix} b \\ b' \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} a \\ a' \end{bmatrix} \tag{A.2.10}$$

where b and a are two element column vectors whereas b' and a' are eight element column vectors.

A is a 2 x 2 matrix, B is 2 x 8 matrix, C is 8 x 2 and D is 8 x 8. The connection constraint, the analog of Eq. (A.2.4), can be written

$$b' = \Gamma \, a' \tag{A.2.11}$$

Then from Eqs. (A.2.10) and (A.2.11) it follows that

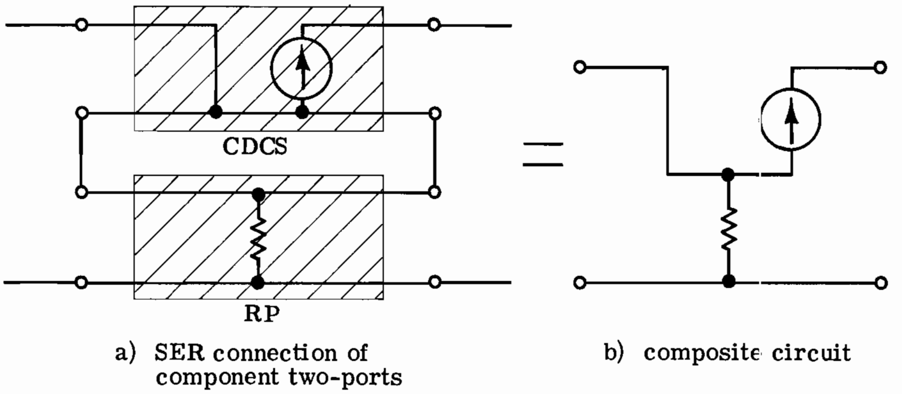
$$\begin{aligned}
b &= A\,a + B\,a' \\
b' &= C\,a + D\,a' \\
a' &= (\Gamma - D)^{-1}\,C \\
b &= \left[A + B\,(\Gamma - D)^{-1}\,C\right] a
\end{aligned}$$

Finally,

$$S = A + B\,(\Gamma - D)^{-1}\,C \tag{A.2.12}$$

which is the equation used by Bamp '30 for all connections (the CAS connection is a simplified special case).

The reader may object that all of this appears excessively complicated in view of the normal procedure of adding Y-matrices to form the PAR connection, of adding Z-matrices to form the SER connection, of adding G-matrices to form the PARSER connection, and of adding H-matrices to form the SERPAR connection. One counter to this objection is that the end result Eq. (A. 2. 12) is not all that complicated; and further, one algorithm handles all connections. Another counter is that Eq. (A. 2. 12) will handle cases where the normal procedure fails. For example, consider Fig A. 2. 5. The ideal current amplifier does not have a (finite) Z-matrix. Therefore, it is not possible to add Z-matrices to form the SER connection. However, the ideal current amplifier does have an S-matrix, and Eq. (A. 2. 12) does not break down. There are many other such examples.



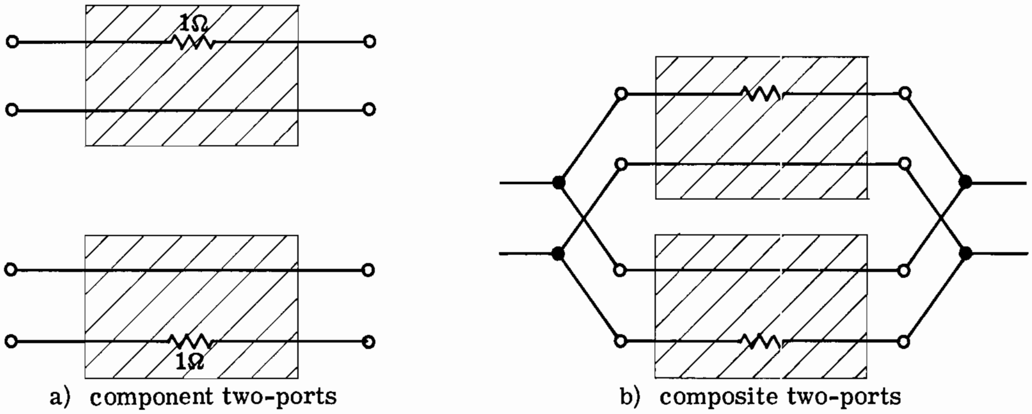
a) SER connection of component two-ports

b) composite circuit

Fig A. 2. 5 SER connection of two-ports when addition of Z-matrices is not possible

Although Bamp '30 does not add the Y-, Z-, G-, and H-matrices to form PAR, SER, PARSER, and SERPAR connections, the end result of the calculation based on Eq. (A. 2. 12) is equivalent to addition of these matrices, whenever the matrices exist. In the remainder of this section these connections are discussed just as if the appropriate matrices were added.

The two-ports and the PAR connection in Fig A. 2. 6 point out another feature of Bamp's interconnection



a) component two-ports

b) composite two-ports

Fig A. 2. 6 Parallel connection in which addition of Y-matrices is not valid scheme. Each of the two component two-ports has the Y-matrix

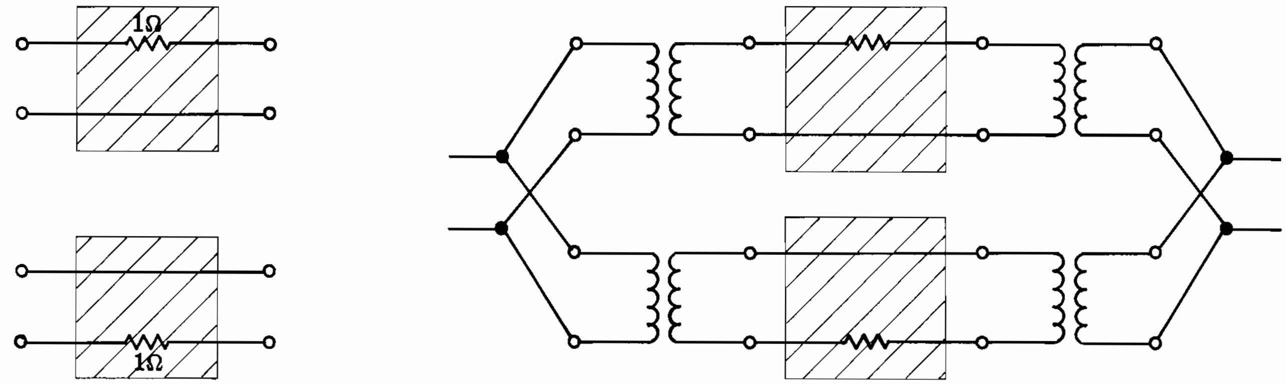
$$Y = \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

but the composite two-port does not have a finite Y-matrix, since the connection shorts each of the resistances.

Now suppose each of the component two-ports is connected between ideal 1:1 transformers as shown in Fig A.2.7. The Y-matrix for the composite two port is

$$Y = \begin{bmatrix} 2 & -2 \\ -2 & 2 \end{bmatrix}$$

which is the sum of the individual Y-matrices.



a) component two-ports

b) composite two-ports

Fig A.2.7 Modification of connection in Fig A.2.6 so that addition of Y-matrices is valid

In forming the PAR, SER, PARSER, and SERPAR connections, Bamp '30 *in effect* embeds the individual two-ports between ideal 1:1 transformers as in Fig A.2.7. There are two ways to view this result. From one point of view, using Figs A.2.6 and A.2.7 as examples, Bamp '30 forces the

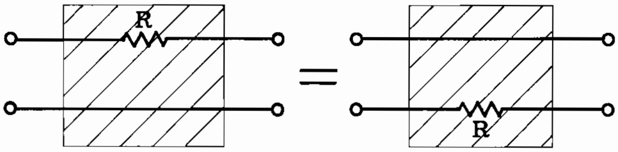


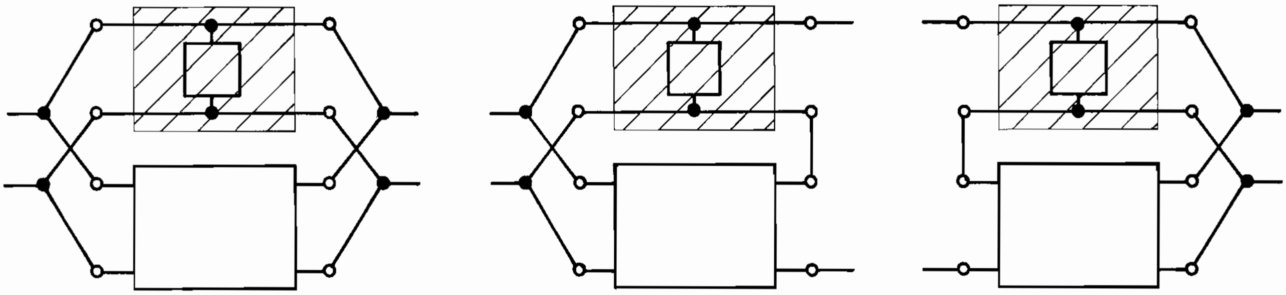
Fig A.2.8 Two different two-ports that are treated by Bamp '30 as identical two-ports equality of two-ports depicted in Fig A.2.8. From another point of view, Bamp '30 creates a two-port whose matrix representation is the sum of the matrix representations of the individual two ports.

For a more complete discussion of difficulties associated with two-port connections, see Ref 1, pp 147-151.

Finally, there are certain connections you should not attempt because of loss of numerical accuracy. These are:

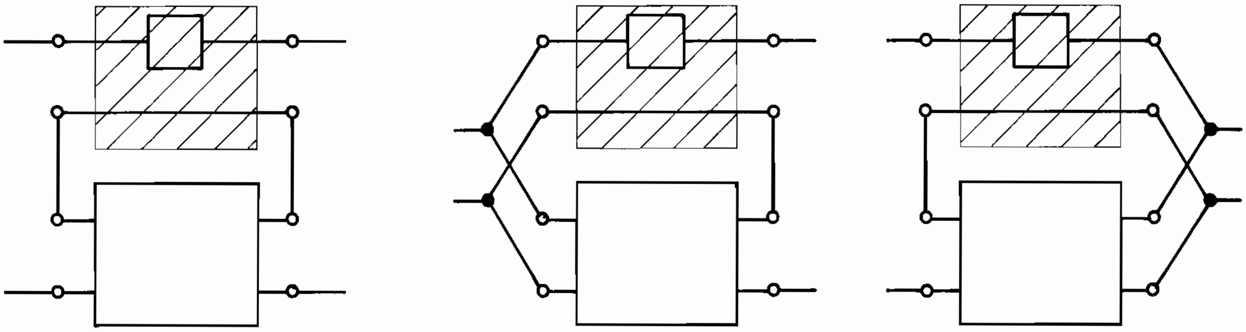
1. Do not use a parallel element in a PAR, PARSER, or SERPAR connection.
2. Do not use a series element in a SER, PARSER, or SERPAR connection.

The forbidden connections are shown in Figs A.2.9 and A.2.10.



PAR PARSER SERPAR

Fig A.2.9 Forbidden connections involving parallel elements



SER PARSER SERPAR

Fig A.2.10 Forbidden connection involving series elements

APPENDIX B
CHANGE REFERENCE IMPEDANCE FOR S-PARAMETERS

As a specific example, suppose you have a set of S-parameters measured in a 50-ohm system. What are the corresponding values in a 75-ohm system? One way to answer the question is to use the Bamp circuit shown in Fig B.1. If the 50-ohm S-paramers are supplied as data for DEV 1, then the computed S-parameters for the composite two-port are the corresponding S-parameters in a 75-ohm system.

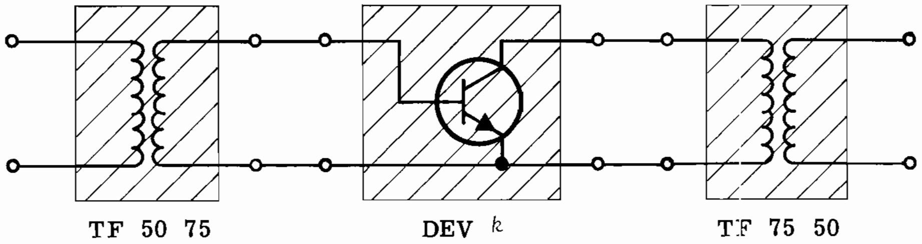


Fig B.1 Bamp circuit for changing the reference impedance for a set of S-parameters from 50 ohms to 75 ohms

If you have only 50-ohm data for a two-port you want to include as DEV k in a Bamp circuit using ZR = 75 you can do the following. Sandwich your two-port between transformers as shown in Fig B.1 and supply your 50-ohm data for DEV k . As an alternative, you can run the circuit in Fig B.1 and then store the computed S-parameters in a DEV data file. You then have S-parameters that can be used directly in a 75-ohm system without the transformers.

For a more general case, suppose the original reference impedance is ZR1 and the new reference impedance is ZR2. In Fig B.1, the value of ZR1 replaces 50, and the value of ZR2 replaces 75.

In example B.1, a subset of the 50-ohm S-parameters are also stored on a DEV data cassette using Bampdf as explained in Chapter 4.

Index for DEV Data Files Series 1

```
BAMPDF CASSETTE #2, PN 09839-71103 REVA
INDEX

FILE NO.  1   NAME: HP35821E
S-PARAMETERS
DATA IN MAG-PAHSE
BIAS:   15V,   15MA
FREQUENCIES(MHZ):

 100   200   300   400   500   600   700   800   900   1000     1100
 1200     1300     1400     1500     1600     1700     1800     1900
 2000     2500     3000     3500     4000     4500

FILE NO.  2   NAME: HP35826E1
S-PARAMETERS
DATA IN MAG-PAHSE
BIAS:   10V,    5MA
FREQUENCIES(MHZ):
 100   200   400   500   600   800   1000     1200     1400     1500
 1600     1800     2000     2500     3000     3500     4000     4500
 5000     5500     6000     6500     7000     7500     8000

FILE NO.  3   NAME: HP35826E2
S-PARAMETERS
DATA IN MAG-PAHSE
BIAS:   10V,   10MA
FREQUENCIES(MHZ):
 100   200   400   500   600   800   1000     1200     1400     1500
 1600     1800     2000     2500     3000     3500     4000     4500
 5000     5500     6000     6500     7000     7500     8000

FILE NO.  4   NAME: HP35826E3
S-PARAMETERS
DATA IN MAG-PAHSE
BIAS:   15V,   15MA
FREQUENCIES(MHZ):
 100   200   400   500   600   800   1000     1200     1400     1500
 1600     1800     2000     2500     3000     3500     4000     4500
 5000     5500     6000     6500     7000     7500     8000

FILE NO.  5   NAME: HP35826E4
S-PARAMETERS
DATA IN MAG-PAHSE
BIAS:   20V,   20MA
FREQUENCIES(MHZ):
 100   200   400   500   600   800   1000     1200     1400     1500
 1600     1800     2000     2500     3000     3500     4000     4500
 5000     5500     6000     6500     7000     7500     8000
```

Index for DEV Data Files Series 1 (cont.)

```
FILE NO.  6   NAME: HP35866E1
S-PARAMETERS
DATA IN MAG-PAHSE
BIAS:   10V,    3MA
FREQUENCIES(GHZ):
 0.1   0.2   0.4   0.5   0.6   0.8   1     1.5   2     2.5   3     3.5
 4     4.5   5     5.5   6     6.5   7     7.5   8     8.5   9     9.5
 10

FILE NO.  7   NAME: HP35866E2
S-PARAMETERS
DATA IN MAG-PAHSE
BIAS:   10V,    5MA
FREQUENCIES(GHZ):
 0.1   0.2   0.4   0.5   0.6   0.8   1     1.5   2     2.5   3     3.5
 4     4.5   5     5.5   6     6.5   7     7.5   9     8.5   9     9.5
 10

FILE NO.  8   NAME: HP35866E3
S-PARAMETERS
DATA IN MAG-PAHSE
BIAS:   10V,   10MA
FREQUENCIES(GHZ):
 0.1   0.2   0.4   0.5   0.6   0.8   1     1.5   2     2.5   3     3.5
 4     4.5   5     5.5   6     6.5   7     7.5   8     8.5   9     9.5
 10

FILE NO.  9   NAME: HP35866E4
S-PARAMETERS
DATA IN MAG-PAHSE
BIAS:   15V,   15MA
FREQUENCIES(GHZ):
 0.1   0.2   0.4   0.5   0.6   0.8   1     1.5   2     2.5   3     3.5
 4     4.5   5     5.5   6     6.5   7     7.5   8     8.5   9     9.5
 10
```

```
LIST
HP35821E
100,4500
MP
 100
 0.44     -130   0.015     56
 18     150    0.74     -38

 200
 0.44     -136   0.02      56
 14     139    0.71     -36

 300
 0.45     -141   0.025     56
 10.8      124   0.67     -34

 400
 0.46     -146   0.031     56
 9      113    0.61     -32

 500
 0.46     -152   0.039     56
 8.32      101   0.58     -39

 600
 0.46     -158   0.044     56
 7.05      96    0.52     -40

 700
 0.46     -164   0.049     56
 6.27      91    0.51     -41

 800
 0.46     -170   0.053     56
 5.55      87    0.5   -42

 900
 0.46     -174   0.057     57
 5.04      83    0.49     -43

 1000
 0.46     -178   0.062     57
 4.53      80    0.48     -44

 1100
 0.46      179   0.066     56
 4.19      77    0.47     -46

 1200
 0.46      177   0.07      55
 3.83      74    0.46     -49
```

```
1300
0.46      175    0.075     55
3.61      72     0.46     -52

1400
0.47      173    0.08      56
3.36      70     0.46     -54

1500
0.47      171    0.083     56
3.13      68     0.46     -57

1600
0.47      169    0.087     56
2.95      66     0.46     -60

1700
0.47      167    0.091     56
2.8    63     0.46     -63

1800
0.47      165    0.095     55
2.62      61     0.46     -65

1900
0.47      163    0.098     55
2.54      59     0.47     -68

2000
0.47      161    0.101     54
2.37      57     0.47     -71

2500
0.47      148    0.12      52
1.91      47     0.48     -80

3000
0.47      138    0.134     50
1.59      39     0.52     -91

3500
0.47      128    0.148     49
1.36      30     0.54     -100

4000
0.47      113    0.168     48
1.29      23     0.56     -109

4500
0.49      97     0.179     44
1.13      15     0.57     -123
```

```
LIST
HP35826E1
100,8000
MP
 100
 0.68     -40     0.018     66
 12     154    0.94     -13

 200
 0.65     -76     0.031     50
 10.7      136    0.84      -21

 400
 0.62     -118    0.041     42
 7.46      110    0.69      -27

 500
 0.61     -131    0.045     39
 6.32      102    0.66      -28

 600
 0.61     -142    0.048     38
 5.46     96      0.63      -30

 800
 0.61     -154    0.052     36
 4.25     85      0.6   -32

 1000
 0.61     -163    0.056     36
 3.46     77      0.58      -35

 1200
 0.61     -172    0.06      36
 2.93     69      0.57      -39

 1400
 0.61     -179    0.063     35
 2.55     63      0.57      -43

 1500
 0.61      179    0.066     35
 2.36     59      0.57      -45

 1600
 0.62      177    0.069     35
 2.23     56      0.57      -47

 1800
 0.62      172    0.073     34
 1.99     50      0.57      -50
```

```
2000
0.63      167   0.077     34
1.8    45     0.57     -56

2500
0.65      159    0.085     32
1.44      31     0.58      -66

3000
0.66      150    0.093     31
1.2    18     0.59     -79

3500
0.66      143    0.104     29
1.02      6      0.61      -92

4000
0.65      135    0.113     27
0.89     -5      0.64      -102

4500
0.64      126    0.125     24
0.77     -15     0.69      -114

5000
0.63      115    0.14      21
0.68     -26     0.7   -122

5500
0.63      105    0.155     17
0.61     -34     0.75      -131

6000
0.64      94     0.17      14
0.54     -43     0.77      -140

6500
0.64      83     0.19      9
0.48     -49     0.77      -147

7000
0.66      72     0.21      5
0.43     -56     0.77      -155

7500
0.67      62     0.232     1
0.37     -63     0.77      -162

8000
0.69      53     0.253    -3
0.33     -68     0.77      -171
```

LISTING

```
LIST
HP35826E2
100,8000
MP
 100
 0.55     -59    0.015    50
 17.96    149    0.89    -17

 200
 0.57     -100   0.024    47
 14.64    127    0.76    -24

 400
 0.59     -138   0.032    45
 9.21     104    0.61    -28

 500
 0.59     -148   0.035    44
 7.66     97     0.58    -29

 600
 0.59     -156   0.038    44
 6.49     92     0.56    -29

 800
 0.6  -167   0.044    44
 4.96     82     0.53    -32

 1000
 0.6  -175   0.049    44
 4.02     75     0.52    -34

 1200
 0.61     180    0.053    43
 3.38     68     0.51    -38

 1400
 0.62     176    0.058    42
 2.9   62    0.51    -42

 1500
 0.62     174    0.061    42
 2.71     58     0.52    -44

 1600
 0.62     171    0.064    42
 2.56     56     0.52    -46

 1800
 0.63     167    0.069    42
 2.29     51     0.52    -49
```

```
2000
0.64     162    0.073    41
2.05     45     0.52    -54

2500
0.65     156    0.084    40
1.64     32     0.53    -65

3000
0.66     149    0.094    38
1.38     20     0.53    -78

3500
0.66     142    0.102    36
1.17     9      0.55    -89

4000
0.66     132    0.112    34
1.02    -3      0.59    -101

4500
0.65     123    0.124    31
0.89    -13     0.63    -111

5000
0.65     113    0.135    27
0.8  -23     0.67     -120

5500
0.64     102    0.15     23
0.69    -29     0.7  -128

6000
0.64     93     0.172    17
0.64    -40     0.73    -137

6500
0.64     82     0.195    11
0.57    -49     0.74    -145

7000
0.66     70     0.215    6
0.51    -56     0.74    -153

7500
0.68     59     0.239    1
0.44    -63     0.74    -160

8000
0.71     51     0.261   -4
0.39    -69     0.74    -169
```

```
LIST
HP35826E3
100,8000
MP
 100
 0.51     -69     0.013     50
 21.66     146    0.88     -17

 200
 0.54     -110    0.019     50
 16.88     124    0.73     -24

 400
 0.57     -144    0.027     50
 10.19     102    0.6   -26

 500
 0.57     -153    0.03      50
 8.4   96     0.57     -27

 600
 0.57     -159    0.033     49
 7.1   90     0.55     -27

 800
 0.58     -168    0.038     49
 5.4   82     0.54     -29

 1000
 0.58     -175    0.044     49
 4.37      74     0.52     -32

 1200
 0.59      180    0.049     48
 3.7   68     0.51     -36

 1400
 0.6   175    0.053     47
 3.15      62     0.52     -40

 1500
 0.6   173    0.056     47
 2.94      59     0.52     -41

 1600
 0.6   171    0.059     47
 2.77      56     0.53     -43

 1800
 0.61      167    0.064     46
 2.47      51     0.53     -46

2000
0.62      162    0.068     46
2.23      46     0.53     -51

2500
0.64      156    0.079     44
1.78      33     0.53     -62

3000
0.65      148    0.089     42
1.49      21     0.54     -74

3500
0.66      141    0.099     39
1.27      10     0.56     -86

4000
0.65      133    0.111     36
1.11     -2      0.6   -97

4500
0.64      124    0.122     33
0.97     -12     0.63     -107

5000
0.63      114    0.137     29
0.87     -22     0.67     -116

5500
0.62      103    0.153     24
0.78     -31     0.7   -125

6000
0.63     93     0.168     20
0.7   -40     0.73     -133

6500
0.64      81     0.192     14
0.62     -49     0.74     -141

7000
0.66      70     0.212     9
0.55     -57     0.75     -149

7500
0.67      60     0.234     4
0.49     -65     0.75     -157

8000
0.68      52     0.256    -1
0.43     -72     0.75     -164
```

```
LIST
HP35826E4
100,8000
MP
 100
 0.51     -76     0.01      50
 24.93    143     0.86     -18

 200
 0.52     -114    0.018     50
 17.82    121     0.72     -22

 400
 0.55     -146    0.024     50
 10.46    100     0.6   -24

 500
 0.56     -154    0.028     50
 8.58     94      0.58     -25

 600
 0.56     -160    0.03      50
 7.21     89      0.56     -26

 800
 0.58     -169    0.036     51
 5.26     79      0.55     -28

 1000
 0.58     -174    0.041     51
 4.49     75      0.54     -31

 1200
 0.59     179     0.048     51
 3.76     69      0.53     -35

 1400
 0.6   174    0.053     50
 3.24     63      0.53     -37

 1500
 0.6   173    0.055     50
 3.02     60      0.54     -40

 1600
 0.6   171    0.057     49
 2.85     57      0.54     -42

 1800
 0.61     167     0.062     48
 2.54     52      0.54     -45
2000
0.62      163     0.066      47
2.28      47      0.54      -48

2500
0.64      156     0.075      45
1.83      34      0.55      -60

3000
0.65      148     0.085      42
1.54      22      0.56      -71

3500
0.66      141     0.095      40
1.31      11      0.58      -83

4000
0.65      134     0.106      37
1.15      0       0.61      -94

4500
0.64      125     0.12       34
1     -8      0.65     -103

5000
0.63      115     0.133      31
0.9  -19      0.68     -111

5500
0.63      103     0.149      26
0.81      -29     0.71      -119

6000
0.63      93      0.164      22
0.73      -38     0.75      -127

6500
0.64      83      0.18       18
0.65      -47     0.76      -134

7000
0.66      70      0.201      13
0.59      -55     0.77      -142

7500
0.68      61      0.229      7
0.52      -64     0.77      -148

8000
0.69      52      0.251      2
0.46      -72     0.76      -156
```

LISTING

```
LIST
HP35866E1
.1;10
MP
 0.1
 0.78     -19     0.013     85
 8.95      165    0.98     -7

 0.2
 0.75     -38     0.025     69
 8.88      153    0.95     -13

 0.4
 0.69     -70     0.039     54
 7.49      132    0.85     -22

 0.5
 0.66     -84     0.044     49
 6.84      123    0.82     -25

 0.6
 0.63     -96     0.048     45
 6.31      115    0.77     -27

 0.8
 0.59     -116    0.054     39
 5.27      103    0.72     -30

 1
 0.57     -131    0.058     36
 4.48      93     0.68     -34

 1.5
 0.55     -155    0.064     32
 3.21      74     0.64     -41

 2
 0.55     -173    0.07      30
 2.48      58     0.62     -48

 2.5
 0.56      177    0.077     29
 2.03      45     0.62     -58

 3
 0.56      164    0.082     29
 1.7    33     0.61      -67

 3.5
 0.56      158    0.091     28
 1.48      22     0.63     -77
```

```
4
0.55       150    0.098      27
1.3    11      0.65      -87

4.5
0.54       142    0.107      25
1.15       1      0.68      -96

5
0.53       132    0.118      22
1.04      -9      0.71      -103

5.5
0.52       123    0.132      20
0.94      -18     0.74      -111

6
0.51       113    0.144      17
0.85      -27     0.77      -118

6.5
0.51       100    0.157      14
0.77      -36     0.79      -126

7
0.52       90     0.167      11
0.7   -45      0.8   -132

7.5
0.54       79     0.182      8
0.63      -53     0.8   -139

8
0.55       69     0.206      3
0.58      -62     0.8   -146

8.5
0.55       59     0.222     -2
0.53      -69     0.81      -154

9
0.54       48     0.236     -7
0.48      -77     0.81      -161

9.5
0.52       37     0.248     -13
0.44      -85     0.82      -169

10
0.5    24      0.261     -21
0.4   -90      0.83      -178
```

```
LIST
HP35866E2
.1,10
MP
 0.1
 0.69     -25     0.012    82
 12.98     162    0.97    -9

 0.2
 0.65     -50     0.022    66
 12.38     148    0.92    -16

 0.4
 0.6   -88    0.034    51
 9.81      125    0.79    -24

 0.5
 0.58     -102    0.037    48
 8.7   116    0.74    -27

 0.6
 0.56     -114    0.04     45
 7.82      109    0.71    -28

 0.8
 0.54     -133    0.045    42
 6.34      97     0.65    -31

 1
 0.54     -146    0.048    40
 5.22      88     0.62    -33

 1.5
 0.53     -166    0.056    39
 3.64      71     0.6   -40

 2
 0.54      178    0.064    39
 2.78      57     0.59    -47

 2.5
 0.54      170    0.074    38
 2.26      44     0.58    -57

 3
 0.55      162    0.082    37
 1.9   33     0.59    -66

 3.5
 0.56      154    0.092    35
 1.64      22     0.6   -77
```

```
4
0.55      146    0.102     33
1.44      11     0.62     -86

4.5
0.54      138    0.112     30
1.27      1      0.66     -96

5
0.52      129    0.126     27
1.15     -8      0.69     -103

5.5
0.52      118    0.14      24
1.04     -17     0.73     -112

6
0.51      108    0.151     20
0.95     -27     0.76     -119

6.5
0.52      96     0.165     17
0.86     -35     0.78     -126

7
0.52      85     0.18      12
0.78     -44     0.78     -132

7.5
0.53      75     0.198     7
0.72     -53     0.78     -139

8
0.54      66     0.213     3
0.66     -61     0.78     -147

8.5
0.54      56     0.225    -2
0.61     -69     0.79     -154

9
0.54      47     0.24     -9
0.57     -77     0.8   -163

9.5
0.53      35     0.254    -16
0.51     -85     0.81     -170

10
0.52      22     0.27     -22
0.48     -91     0.83     -178
```

LISTING

```
LIST
HP35866E3
.1,10
MP
 0.1
 0.52    -41    0.01      85
 20.13    158   0.94     -11

 0.2
 0.53    -75    0.018     64
 17.73    139   0.86     -19

 0.4
 0.53    -115   0.028     50
 12.39    115   0.71     -26

 0.5
 0.53    -128   0.03      48
 10.57    108   0.67     -27

 0.6
 0.52    -137   0.032     46
 9.14     101   0.64     -28

 0.8
 0.52    -152   0.035     46
 7.12     91    0.6   -30

 1
 0.53    -162   0.04      46
 5.8   84    0.57     -32

 1.5
 0.53    -178   0.05      48
 3.96     68    0.55     -38

 2
 0.54     170   0.06      47
 3     55    0.54     -46

 2.5
 0.56     163   0.071     45
 2.42     43    0.54     -56

 3
 0.57     155   0.08      44
 2.03     32    0.55     -65

 3.5
 0.57     148   0.091     41
 1.74     21    0.56     -73

4
0.56     141   0.102     38
1.54     11    0.58     -83

4.5
0.54     132   0.113     35
1.35     1     0.61     -93

5
0.53     123   0.123     31
1.22    -8     0.65     -103

5.5
0.51     113   0.137     27
1.1  -17    0.68     -110

6
0.51     103   0.15      23
1.01    -26    0.72     -118

6.5
0.51     93    0.163     19
0.91    -36    0.74     -125

7
0.53     82    0.182     14
0.83    -44    0.74     -131

7.5
0.54     72    0.2    10
0.75    -53    0.75     -138

8
0.55     62    0.215     6
0.7  -61    0.75     -145

8.5
0.56     53    0.236     1
0.64    -70    0.76     -153

9
0.55     43    0.251    -5
0.59    -79    0.77     -160

9.5
0.54     32    0.27     -13
0.55    -85    0.78     -168

10
0.53     19    0.279    -20
0.5  -93    0.79     -175
```

LISTING

```
LIST
HP35866E4
.1,10
MP
 0.1
 0.49     -48     9.00000E-03     86
 23.5      155    0.92      -12

 0.2
 0.5   -84     0.017     62
 19.9      135    0.83      -20

 0.4
 0.51     -123    0.024     53
 13.27     112    0.68      -25

 0.5
 0.51     -135    0.025     50
 11.18     105    0.65      -26

 0.6
 0.51     -143    0.028     50
 9.59      99     0.62      -26

 0.8
 0.51     -157    0.032     50
 7.4    89     0.59     -28

 1
 0.51     -166    0.036     50
 6.08      82     0.57      -30

 1.5
 0.52      180    0.047     50
 4.09      67     0.56      -37

 2
 0.53      168    0.058     49
 3.1    52     0.57     -44

 2.5
 0.55      163    0.069     47
 2.49      43     0.55      -55

 3
 0.56      155    0.078     45
 2.09      32     0.56      -64

 3.5
 0.56      148    0.087     43
 1.8    21     0.56     -74

4
0.55      140    0.099     39
1.59      11     0.59     -85

4.5
0.54      133    0.11      36
1.39      1      0.62     -93

5
0.53      124    0.123     32
1.26     -8      0.65     -101

5.5
0.51      114    0.137     27
1.14     -17     0.69     -108

6
0.51      104    0.147     23
1.04     -26     0.71     -115

6.5
0.52      94     0.162     19
0.93     -35     0.72     -122

7
0.53      83     0.177     16
0.86     -43     0.73     -128

7.5
0.55      73     0.197     11
0.78     -53     0.74     -135

8
0.56      63     0.216     7
0.72     -61     0.75     -142

8.5
0.56      53     0.231     2
0.66     -69     0.76     -150

9
0.55      43     0.246    -4
0.61     -78     0.78     -157

9.5
0.54      33     0.261    -11
0.57     -86     0.8   -165

10
0.53      18     0.275    -19
0.52     -92     0.82     -173
```

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