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Character Impact Printer Offers Maximum Printing Flexibility

This new printer is fast and reliable, and has features previously unavailable in a calculator peripheral, including programmable horizontal and vertical tabulation, variable character spacing, and plotting ability.

by Robert B. Bump and Gary R. Paulson

A NEW CHARACTER IMPACT PRINTER, Model 9871A, extends the output capabilities of all 9800-Series Calculators and other computing devices. Under program control, the printer can fill out forms, create reports, draw charts and plot graphs.

A character-impact printer offers several advantages not available on line printers or thermal page printers. For example, any paper can be used, including multiple-copy paper. This allows printing on different sizes or types of paper, including preprinted forms. Also useful for forms is the flexibility provided by variable character and line spacing and margins.

Model 9871A (Fig. 1) is a page-width printer that accommodates paper up to 15 inches wide and prints up to 132 columns at 10 characters per inch. It has an average printing speed of 30 cps and handles six-part paper in single-sheet or continuous-feed form. A form-feed accessory for continuous z-fold paper has an adjustable pin-feed tractor mechanism and a basket to receive the printed paper. A viewing feature advances the paper to show the last character printed, if desired.

A bidirectional platen and plotting instructions provide graphics capabilities (see Fig. 2). Plotting can be carried out to a resolution of 120 dots per inch on the horizontal axis and 96 dots per inch on the vertical.

Interchangeable fonts can provide symbols for various languages and other special characters. In addition to the standard 96-character, upper/lower case Roman character font, optional fonts are now available for ASCII symbols and for European language symbols.

Programmable tabs with four-direction tabbing are useful for tabular data and arrays. A 158-character buffer allows high-speed data to be stored, freeing the calculating device for other tasks. A character substitution feature allows any predefined character to be replaced by a string of characters. This can be used to generate special symbols or accent marks requiring multiple strikes. A self-test routine is built in. The standard interface allows operation with all 9800-Series Calculators, and an HP-IB (IEEE Standard 488-1975) interface is available for bus operation.

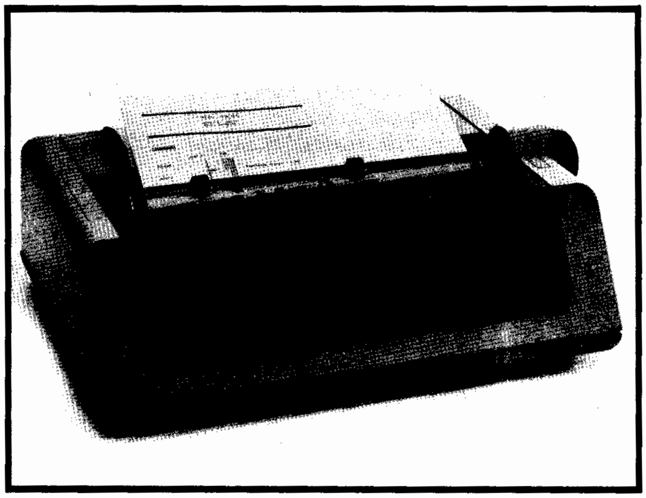

Fig. 1. *Model 9871A Printer is a page-width impact printer for use with all HP 9800-Series Calculators. It prints up to 132 columns at 10 characters per inch. Printing speed is 30 characters per second.*

Design Overview

The 9871A Printer prints each character by striking the appropriate character on a plastic disc (Fig. 3). The plastic disc was chosen for two reasons. First, the character must be stationary during the print cycle for best print quality. To meet this requirement and still have reasonable speed (30 characters per second), a light font that can be positioned quickly and accurately is needed. Second, reliability and service

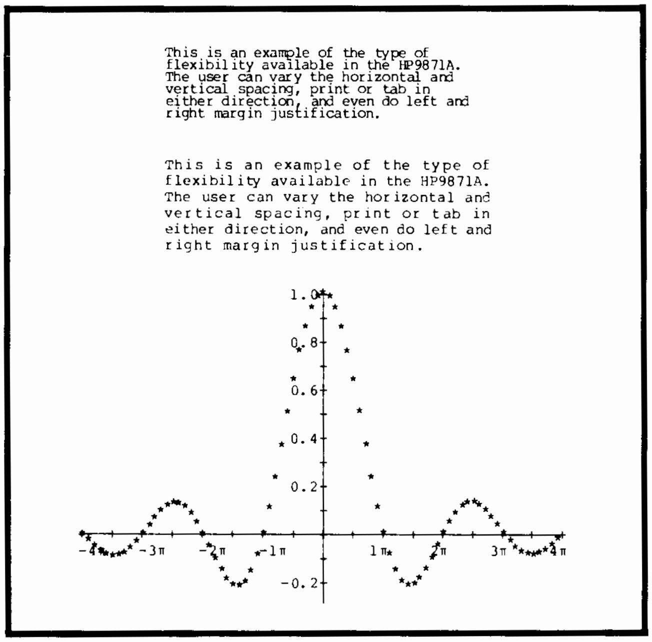

Fig. 2. *A bidirectional platen and plotting instructions provide graphics capabilities. Character and line spacing and four-direction tabbing are also under program control.*

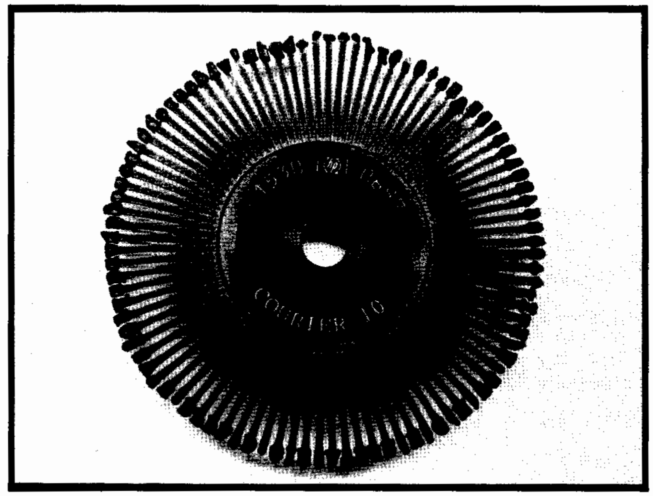

Fig. 3. *Interchangeable 96-character print discs provide standard Roman characters, ASCII symbols, or European language symbols.*

frequency are related to the number of moving parts, and the print disc positioning mechanism requires very few. The 9871A Printer has only ten moving parts, compared to several thousand in the common typewriter.

Helping to reduce parts count and achieve a mean time between failures (MTBF) greater than 500 printing hours are new designs for the print disc drive, the ribbon drive, and the paper drive, and the use of a microprocessor for control. The microprocessor allowed most functions to be implemented in firmware, thereby minimizing electronic hardware, maximizing design flexibility, and making it possible to improve performance by adding features at little or no additional cost. The disc drive control system would have been particularly difficult to implement in hardware because of its complex transfer function, but it is easily implemented in firmware. Also the ease and speed of firmware changes were valuable in the development of the disc control system.

Differential Print Disc Drive

A prime consideration in the design of the printer was minimizing the mass and inertia of the print font

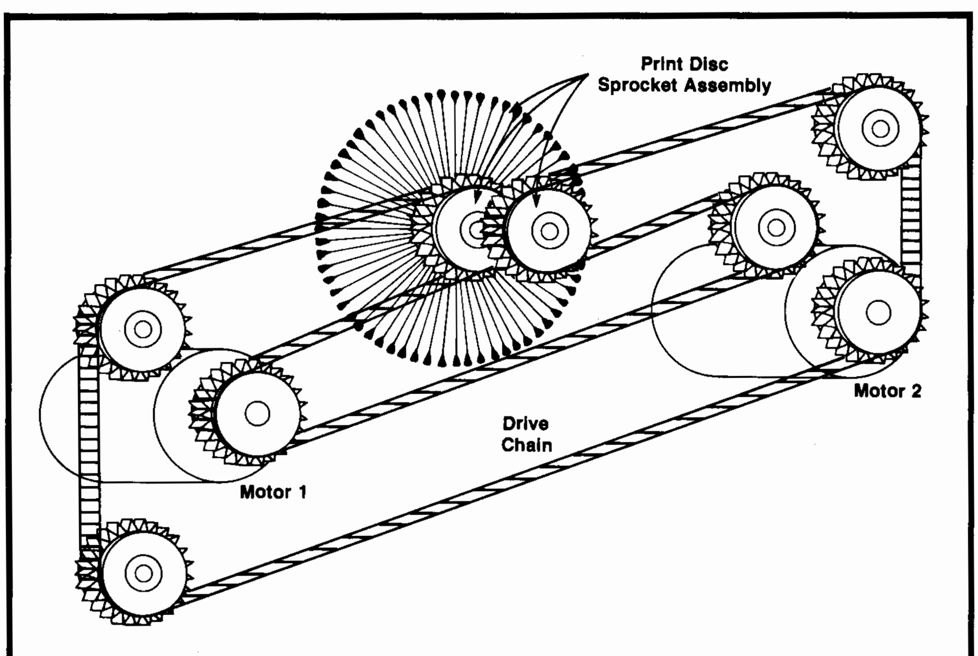

Fig. 4. *Translation and rotation of the print disc are controlled by two fixed motors. Motion is transferred to the disc by means of a chain-and-sprocket differential drive (the print disc and sprockets rotate as a unit). The design minimizes the mass and inertia of the print disc and its carrier.*

Computer Museum

and the elements that carry it. Plastic print discs have inherently low mass and low rotational inertia, but the motor/encoders commonly used to rotate such discs are heavy and place an extra load on the translational positioning motor.

Differential stringing removes the rotational motor/encoder from the carrier mechanism. Two frame-mounted motors together effect both translation and rotation of the print element, resulting in a carrier 60% lighter than other comparable designs. The two motors are relatively small and together consume less space and power than the much larger motor that would be required simply to translate the otherwise heavier carrier.

The differential drive mechanism resembles two parallel gear racks with a pinion between them (Fig. 4). The "racks" are actually a continuous chain consisting of urethane cross pins overmolded on two parallel stainless steel cables. The chain accurately transfers the motor rotations to the "pinion"—the print disc and attached sprockets—and has adequate stiffness (high axial spring constant) and stretch resistance.

When both "racks" move in the same direction by the same amount the "pinion" moves in the same direction without rotating. Moving the "racks" in opposite directions by the same amount causes the "pinion" to rotate without translating. Any desired rotation and translation can be obtained by an appropriate choice of "rack" displacements and directions.

Ribbon Drive

The ribbon drive (Fig. 5) is also designed for light weight and mechanical simplicity. The enclosed-spool ribbon cartridge was chosen for its size, weight, and worldwide availability. A small dc motor with a torque-multiplying gearhead drives the ribbon from spool to spool, reversing direction automatically when the end of the ribbon is reached.

Assume the motor is rotating counterclockwise. This causes clockwise rotation of the sungear. Since the swing arm and the sungear are frictionally coupled, the swing arm and planet gear are rotated into contact with spindle gear 2, winding ribbon onto the takeup reel. When the supply reel has emptied, the ribbon stops, causing the motor load and current to rise sharply. This is sensed and the motor polarity is reversed, sending the planet gear into contact with spindle gear 1 so the ribbon rewinds onto the supply reel.

Paper Drive

The major elements of the paper drive are a platen and a paper guide. The paper guide consists of a foam-molded polycarbonate frame in which are suspended individually-spring-loaded rollers. The rollers provide nearly constant pressure between the platen and the irregular surface of the paper.

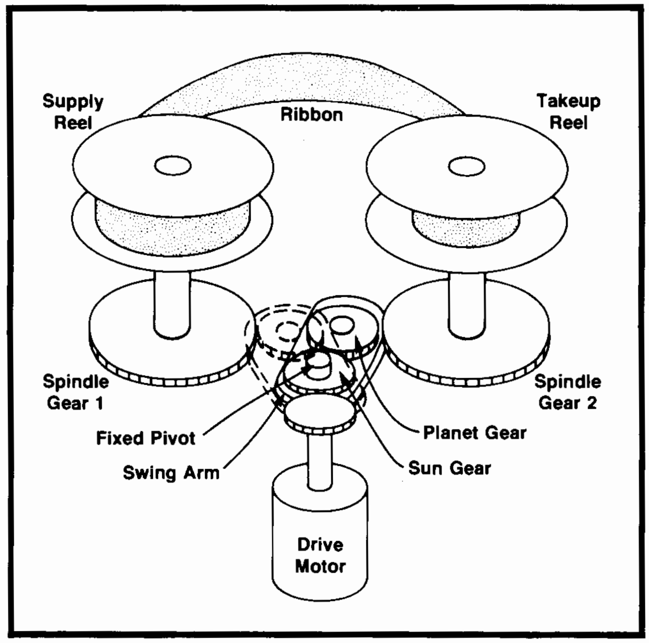

Fig. 5. *Ribbon drive, designed for light weight and simplicity, reverses direction automatically when the end of the ribbon is reached. Ribbon cartridges are available worldwide.*

The hard rubber platen is driven by a four-phase, 1.8° stepper motor. Bipolar, half-step drive is used, with two levels of coil current, one for low torque for a static platen detent, and one for high torque for rotating the platen. A four-phase motor with half-step drive requires eight states to determine coil currents, so the printer's control ROM has an eight-word table to generate these states. Direction is controlled by incrementing the table address. When the platen is first activated, a software ramp accelerates the motor up to 400 steps per second. This feeds paper at four inches per second. If the ramp were not used, the step rate would have to be less than 300 steps per second, the maximum speed to which the platen can be accelerated in one step.

Position Control Firmware

Fig. 6 is a flow chart of the printer control firmware. At turn-on, the positions of the carrier and disc are not known, so the HOME routine drives the carrier against a stop beyond the left margin. This allows the motor position count for both motors to be set to an initial value representing home for the carrier horizontal position and the disc angular position. After this, both motors are monitored so that their positions are always known.

A typical printer cycle starts with the LOAD routine reading a character from the buffer or input lines. If it is a printed character, the PCHAR routine will prepare for printing by moving the ribbon, increasing platen

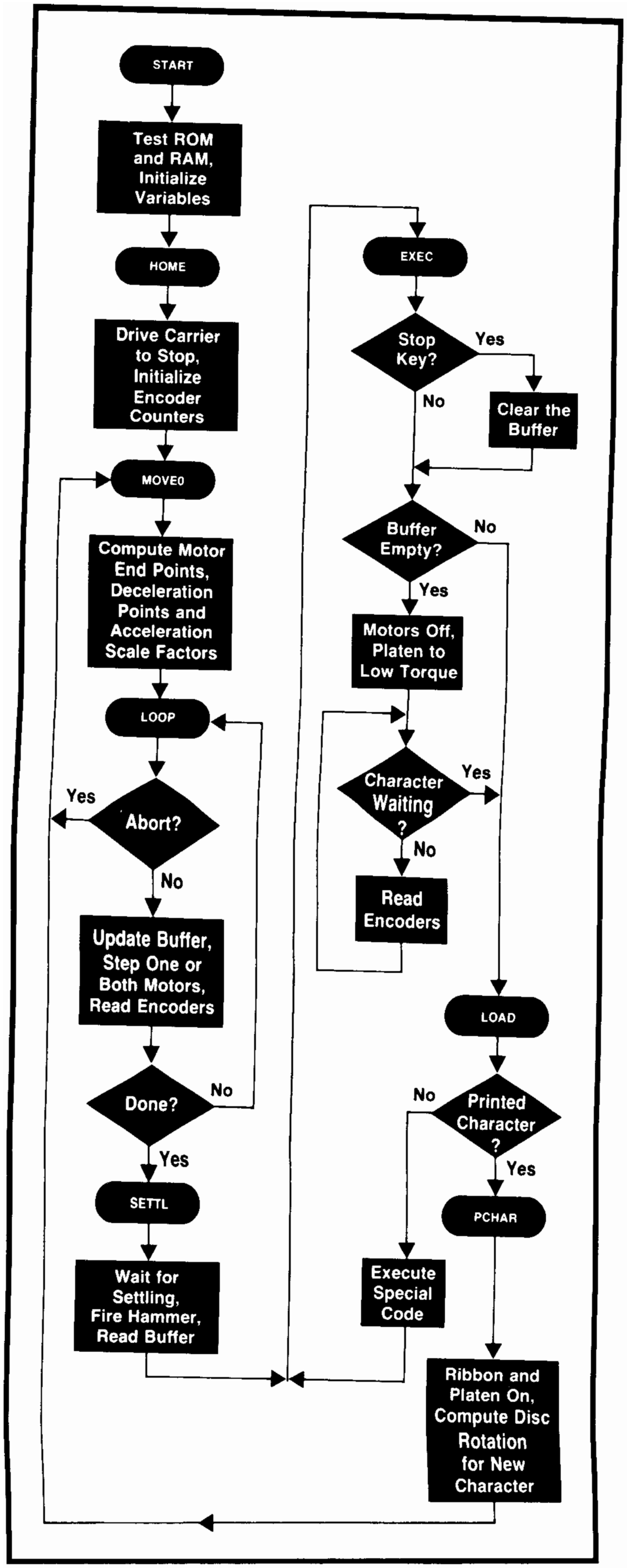

Fig. 6. *Flow chart of printer control firmware.*

holding torque, and getting the hammer intensity from a look-up table. The disc rotation from the previous position is calculated and the horizontal spacing is loaded to test for a left-margin truncation or a right-margin forced carrier return and line feed.

The MOVE0 routine computes the motor end positions and position changes, and the point to switch from acceleration to deceleration. Since the load that one motor sees depends upon the motion of the other motor, an optimum drive depends upon the relative motion between the two motors. For a given move, the ratio of disc rotation to carrier translation is used to determine the necessary acceleration. The software ramp used to accelerate the stepper motor is scaled by this ratio to produce the appropriate acceleration.

The LOOP routine requires the move to be restarted as long as the access cover is open (sensed by a switch to prevent carrier motion and protect the operator) or if a stepper position is more than four steps away from the desired position, since in this event the stepper will fall out of sync and not follow its pulse train. If not aborted, the routine will insert a waiting character into the buffer. The motor with the larger required movement will be stepped once, and the other motor may be stepped or skipped to allow it to move proportionally to its end point. After each step, the position count is brought up to date and compared, first to determine when to start deceleration and second to exit the routine at the end point.

The SETTL routine delays hammer firing to allow any resonances to die out. The hammer energy is controlled by both the character printed (e.g., small energy for ".") and the rear-panel intensity setting. While the hammer is retracting, a buffer character can be read. The EXEC routine allows a STOP key to terminate printing and clear the buffer. If no characters remain to be printed, the platen relaxes, the drive motors are turned off, and the printer waits for the next input. The motor positions are monitored so that position accuracy is maintained even if the carrier or disc are disturbed.

Special operations such as tabs, plotting, and character substitutions are accessed by an escape code. 27 different routines provide these special operations. The read/write memory stores the tab locations, print variables, and character substitution lists as well as the character buffer.

The firmware also generates the logic signals for individual coil control of both carrier steppers and the platen stepper and controls the ribbon drive, hammer drive, and status lines to the calculator.

Position Control Hardware

A four-bit up-down counter takes the difference between the steps fed to the motor and the encoder pulses that result from motor rotation. This error signal is monitored by the processor for position feedback for that motor. The processor is a 16-bit NMOS microprocessor designed and built by HP. Read-only memory is supplied by two 1K×16-bit, NMOS ROMs

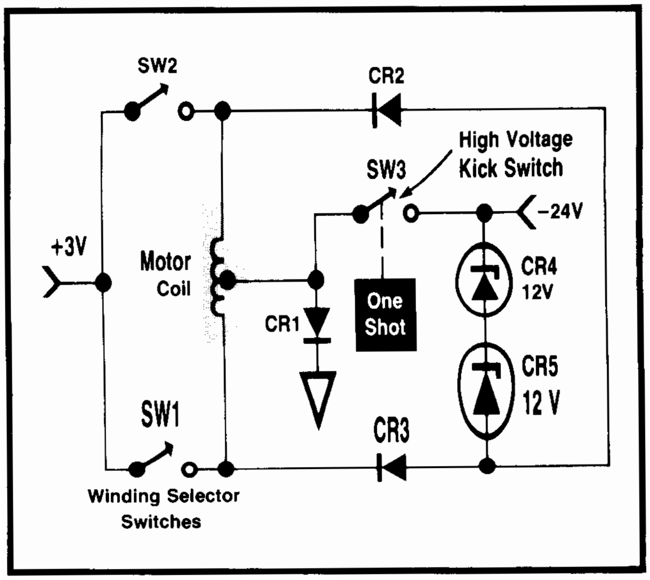

Fig. 7. *To overcome the inductance of the print disc stepper motors, a 20:1 voltage overdrive pulse is applied, bringing the current up to rating 20 times faster than normal.*

also of local origin. Read/write memory uses four 256×4-bit commercial RAMs. An interface buffer chip, also developed by HP, provides conversion from NMOS to TTL logic levels and a three-state data bus.

Stepper Motors as Servo Elements

An average print rate of 30 characters per second requires accelerations up to 40,000 radians per second per second to cover the distance in the time allowed, after deducting settling and hammer times. The load requires more than 40 ounce-inches of torque and up to 10,000 steps per second to achieve this acceleration. A major obstacle to this high step rate is the inductance of the stepper motors, which limits the rate of current rise. To overcome this, a 1.3-volt motor was chosen; a 20:1 voltage overdrive pulse brings the current up to rating 20 times faster than normal (Fig. 7).

The stepper motor was chosen for high reliability and long life compared to a dc servo motor. It has a high restoring torque for small angular errors, and allows use of a relatively coarse and inexpensive encoder for position feedback. The encoder is a slotted disc mounted on the motor's rear shaft. Infrared LEDs provide light that, modulated by the disc rotation, illuminates a monolithic silicon sensor (Fig. 8). The encoder develops two signals 90° out of phase for quadrature direction detection and relative position detection of 1/400th revolution. Each signal is derived from a Schmitt comparator driven by the difference between the voltages from a pair of sensors 180° out of phase. This differential detection gives immunity to LED intensity variations. It also makes it unnecessary to adjust the hysteresis for each LED, while maintaining good phase accuracy.

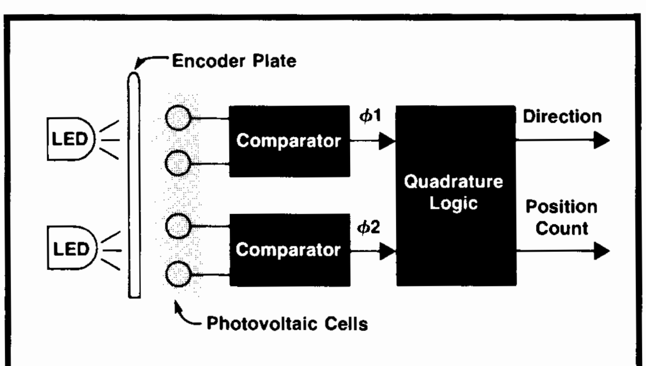

Fig. 8. *Position feedback encoder is simple and inexpensive. Infrared light from two light-emitting diodes is modulated by the rotating print disc and detected by a monolithic silicon sensor. Logic circuits extract the position and direction information.*

Robert B. Bump

Bob Bump was the electronics project leader for the 9871A Printer. He joined HP in 1962, just after receiving his BSEE degree from California Institute of Technology He also holds an MSEE degree from Colorado State University. Bob developed the 208A Oscillator, the 465A Amplifier, and the analog controls for the 675A Sweeping Signal Generator. Then, transferring to HP's Avondale, Pennsylvania Division, he designed electronics for the 7620A and 5700A Gas Chromatographs, concentrating on electrometers. Returning to his native state of Colorado, he developed software for add-on ROMs for the 9810A and 9830A Calculators. Married, and the father of 2 young boys, Bob is active in his church and is interested in conservation and politics. A bicycle enthusiast, he rides approximately 4000 miles per year.

Gary R. Paulson

With a BSME degree from the University of Minnesota, a new wife, a new home, and a new job on successive weeks in mid-1968, Gary Paulson began his career at HP working on the 9120A printer. Then followed the product design of the 9810A, 9820A, and 9830A calculators. While working on the 9871A as mechanical project leader, he authored several patent applications, and received his first patent on the differential drive used in the 9871A. Gary lists among his interests woodworking, travel, Oregon Trail pioneer history, and mountaineering. Of the latter, he says that what began as a casual interest in a few of Colorado's 14,000 ft. peaks, yearly becomes an obsession to "climb 'em all!"