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Three New Pocket Calculators: Smaller, Less Costly, More Powerful

HP's second-generation pocket calculator family now includes a basic scientific model, a programmable scientific model, and a business model.

by Randall B. Neff and Lynn Tillman

IN 1972, HEWLETT-PACKARD INTRODUCED the HP-35 pocket scientific calculator,[1] the first in a family of calculators that eventually grew to include six members, from the original HP-35 to the sophisticated fully programmable HP-65.[2]

Now there is a second generation of HP pocket calculators. Currently this new calculator family has three members, designated HP-21, HP-22, and HP-25. The HP-21 (Fig. 1) is a basic scientific calculator that replaces the HP-35, the HP-22 (Fig. 2) is a business calculator, and the HP-25 (Fig. 3) is a programmable scientific calculator. State-of-the-art technology has been applied in the new family to achieve the major design goal of low cost with no sacrifice in reliability or quality.

Most parts are common to all three calculators, the fundamental differences occurring in the read-only memory (ROM) that contains the preprogrammed functions. In each calculator is an integrated circuit that is a small, slow, but powerful microcomputer. It executes microprograms that are stored in the ROM. When the user presses a key, a microprogram is activated to perform the function corresponding to that key.

The ROM comes in blocks of 1024 ten-bit words. Each block adds factory cost. But until all of the ROM has been allocated, features can be added, omitted, or modified and functions can be made more or less accurate without increasing factory cost at all. The firmware designer's challenge is to make these no-cost choices in some optimal way for each calculator.

HP-21 Scientific

The HP-21, the first calculator in the new family, was designed as a direct replacement for the HP-35. Because the HP-21 was to have 33% more microprogram ROM than the HP-35, everyone involved in the project wanted additional features and functions. New features were packed in until all the ROM was used. The HP-21 has all the functions of the HP-35 plus controlled display formatting, polar to rectangular conversions, radian mode in trigonometric calculations, and storage arithmetic.

One major change in these HP-21 family calculators from the HP-35 family is a shorter twelve-digit display. The HP-35 display had fifteen digits: two signs, ten mantissa digits, two exponent digits, and a decimal point. The new twelve-digit display was required because of the narrower plastic case of the

Cover: *The three pocket calculators in HP's second generation—the HP-21 Scientific, the HP-22 Business and Financial, and the HP-25 Programmable Scientific—are smaller and deliver more performance at lower prices than their predecessors.*

In this Issue:

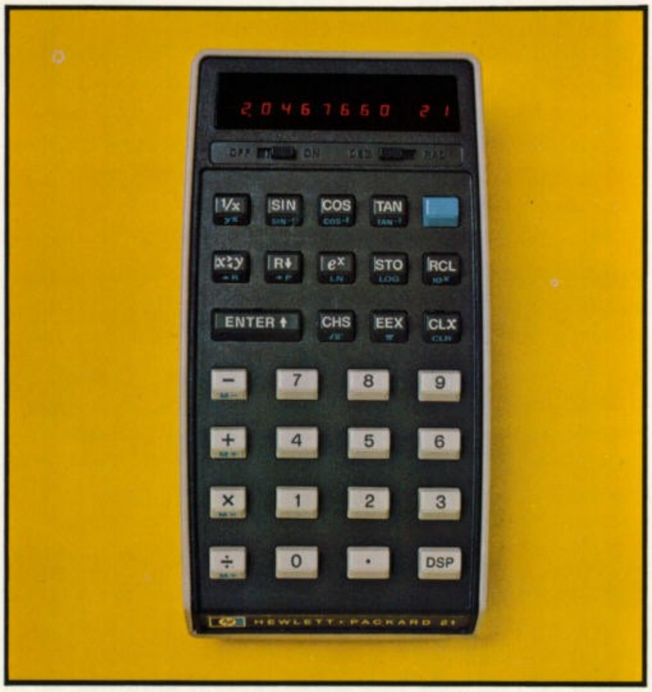


Fig. 1. *HP-21 Scientific Calculator*

new family.

In spite of the shorter display, there was still a requirement that the calculator have ten-digit precision. To meet this requirement, the decimal point was moved so that it appears next to a digit. Also, a decision was made to show a maximum of eight mantissa digits when an exponent is displayed, so two of the display digits do double duty, sometimes as mantissa digits, and other times as exponent sign and digit.

The HP-21 never gives a misleading zero answer. When the user has specified fixed notation and the non-zero answer of a function would be formatted as a zero, the HP-21 changes to scientific notation for that answer. When the HP-21 shows zero, it means the answer is zero to ten digits.

HP-22 Business

The HP-22, the business member of the new calculator family, was intended to be an "HP-70-Plus". Again, experience from programming the HP-70 and many new microinstructions allowed the product to grow functionally until it provided an array of mathematical, statistical, and storage capabilities in addition to the financial functions we had originally hoped to add.

The HP-22 is the first of our financial calculators to include e^x and **ln** functions on the keyboard. It is also the first of our financial calculators to provide linear regression and linear estimate. These functions, as well as arithmetic mean and standard deviation, are executed using data automatically accumulated with the **Σ+** key. In combination, the arithmetic and statistical functions allow calculation of such things as exponential and logarithmic regression, power curve fit, and trend lines with uneven periods, a powerful set of computational tools for the financial analyst and forecaster.

Greatly expanded storage is available to the user. There are ten user-addressable registers with storage arithmetic similar to that of the HP-25. There are also five financial storage registers—one associated with each of the basic financial parameters (**n**, **i**, **PMT**, **PV** and **FV**).* The basic functions defined by these five top row financial keys are the same as those in the HP-70 and HP-80.[4]

These registers combined with internal status indicators (one for each parameter) and an internal data-input counter form a flexible system for solving financial calculations. When the calculator is turned on, the system might be thought of as looking like this:

Status Indicators (none set)

n Register	i Register	PMT Register	PV Register	FV Register
□	□	□	□	□
0.00	0.00	0.00	0.00	0.00

Data Input Counter: 0

The financial functions require that the contents of exactly three of the financial parameter registers be specified as input data, that is, three status indicators must be set and the data input count must equal three.

When data is entered the associated status indicators are set and the data input counter is incremented. For example, if two items of data have been entered (say n = 360 and PMT = 341.68) the system might look like this:

n Register	i Register	PMT Register	PV Register	FV Register
■	□	■	□	□
360.00	0.00	341.68	0.00	0.00

Data Input Counter: 2

If a status indicator is already set, entering data for that parameter will simply overwrite the previous register contents. For example, pressing n in the above situation would cause the 360.00 to be overwritten with whatever was in the display. The status indicator would remain set and the counter would remain at 2. Once three status indicators are set, pressing a financial key for which the status indicator is *not* set will trigger an attempt to execute that function.

* n: number of time periods; i: interest rate per period; PMT: payment amount; PV: present value or principal; FV: future value

Fig. 2. *HP-22 Business Calculator*

Say the system looks like this:

■	■	■	□	□
360.00	.75	341.68	0.00	0.00
n Register	i Register	PMT Register	PV Register	FV Register

Data Input Counter	3

Pressing **PV** will cause calculation of PV in terms of n, i and PMT while pressing **FV** will cause calculation of FV in terms of n, i and PMT.

When a function is executed and an answer is calculated, the answer is stored in its associated register for possible later calculations. The status indicators and counter remain unchanged because the input parameters have not changed.

There is a reset function, which resets all five status indicators and resets the counter to zero, allowing a different combination of input parameters to be specified. However, the data remains in the registers and can be recalled using the **RCL** prefix key.

Besides the new flexibility in the basic financial functions some new functions have been added: %Σ (percent of sum), **ACC**(accumulated interest), **BAL** (remaining balance), and the annuity switch (**BEGIN ◧ END**).

A running total can be kept using the **Σ+** key. The %Σ function can then be used to find what percent of that total any given number is.

Accumulated interest and remaining balance are also new. Just enter the loan amount PV, the periodic interest rate i, and the payment amount PMT. To find the accumulated interest between two periods, say from payment 13 through payment 24 enter the payment period numbers in storage registers 8 and 9 and press **■ ACC**. If you then press **■ BAL** the HP-22 will calculate the remaining balance on the loan after the payment indicated in register 9 is made (in this case after payment 24).

Annuities are often referred to as being "ordinary annuities" or "annuities due". These terms distinguish situations where periodic payments are made at the beginning of the period (for example, rents or leases are annuities due) from payments made at the end of the month (a mortgage, for example, is an ordinary annuity). The HP-22 features the annuity switch to make this distinction. Place the switch in the **BEGIN** position and any annuity calculations will be made assuming that payments occur at the beginning of the payment period. Place the switch in the **END** position and annuity calculations will be made assuming that payments occur at the end of the payment periods.

The HP-22 uses the same general solution techniques for the financial functions as the HP-80.[4] Execution of the equations involves numerous internal subroutine calls to +, −, ×, ÷, y^x, and ln (this is particularly true for the iterative solutions for i). This means that the standard round-off errors in these routines are compounded by the time the final solution is reached. To improve the final results given by the HP-22, improvements were made to the standard HP-21-family arithmetic subroutines. The y^x algorithm was extended to handle negative numbers to integer powers—for example $(-2)^2$ or $(-2)^{-2}$—and a subroutine was developed to calculate the expression $(1+y)^x$, which occurs frequently in financial equations.

HP-25 Programmable Scientific

The HP-25 was originally conceived as an advanced scientific calculator. It was specified as having 2048 microinstructions, twice as many as the HP-21. Also, it was to contain a new integrated circuit, a sixteen-register data storage chip. Because of improved microinstructions and experience gained by microprogramming the HP-21, the HP-25 finally appeared not only as a scientific calculator with many more functions than the HP-21, but more importantly, with 49 steps of user programming.

The real power of the HP-25 is its easy programming. The programming is based on key phrases rather than keystrokes. A key phrase is simply a sequence of keystrokes that together perform one function or operation. For example, both **f SIN** and **STO + 5** are key phrases, but they contain two and three keystrokes, respectively. The program memory contains numbered locations for 49 key phrases. When

Fig. 3. *HP-25 Programmable Scientific Calculator*

the user writes a program, the calculator merges keystrokes into key phrases and stores the instructions in program memory.

Editing a program is particularly easy. In program mode, the display shows the step number and the key phrase stored there (see page 6). The key phrase is displayed as the row-column coordinates of the keystrokes that make it up. The digit keys are represented by a zero followed by the digit, and the other keys are described by a row digit followed by a column digit. For example, the **f** key is in the first row of keys and the fourth column, so its coordinate is 14. The key phrase **f SIN** appears as 14 04, and **STO + 5** appears as 23 51 05.

One innovative feature of the HP-25 is the behavior of the **SST** (Single Step) key in run mode. This key was designed to help the user debug programs. It allows the user to execute his program one key phrase at a time. When the **SST** key is held down, the display shows the line number and the key phrase that is to be executed next. Releasing the **SST** key executes just that key phrase, and the numerical results appear in the display. This new feature makes debugging programs quite easy because the user can tiptoe through his programs, seeing both the key phrases and their results, one phrase at a time. The display when the **SST** key is held down includes the step number, so checking program flow and branching is easy.

The HP-25 contains a number of functions that make programming simpler. In program mode, the **SST** key and the **BST** (Back Step) key allow the user to step forward and backward through the program memory. Eight comparisons allow the program to react depending on the data in the calculation stack. Together with the **GTO** (Go To step number) operation, programs can branch and loop based on numeric results. A function that is new to pocket calculators is **PAUSE**. When encountered in a program, the calculator stops for a second, displays the most recent result, and then continues the program. This is useful when programming iterative functions because one can watch the function converge or diverge.

The HP-25 has line-number-based static programming. Key phrases go into numbered locations in memory, overwriting the previous contents. Branching in the program is to the step number of a phrase. This is in contrast to the HP-65 type of programming.[3] In the HP-65, keycodes shift around in the unnumbered memory as steps are inserted and deleted, and branching goes to label keycodes contained in the memory.

The HP-25 merges keystrokes into key phrases using a microcoded finite state machine. The machine carefully checks for undefined key sequences. When a valid key phrase is completed, an eight-bit code is fabricated. If the calculator is in run mode, the code is immediately decoded and executed. In program mode, the code is copied into the program memory and then decoded to generate the row-column display. The data registers used for program storage are 56 bits long. Each register can contain seven key phrase codes. Seven such registers comprise the program memory, so all together there are 49 key phrase locations.

The HP-25 contains a data storage integrated circuit with sixteen registers of 56 bits each (14 BCD digits). Seven registers are for user programming, eight are for user data, and one is used for the **LAST x** function.

Another innovative feature of the HP-25 is a new mode of formatting the displayed result, called engineering notation. This is a selectable format that makes calculated answers easier to understand. Imagine a problem that deals in physical units of measure, such as seconds. Say the answer to the problem in scientific notation is 5.00   −05. Now this is a valid answer, but not as clear as it could be. Setting the HP-25 into engineering notation gives the answer as 50.0   −06 which is easy to read instantly as 50 microseconds. Engineering notation forces the power-of-ten exponent to be a multiple of three and adjusts the decimal point to give the correct answer. If the above answer is multiplied by 10, it gives 500.   −06 or 500 microseconds. Multiplying again by ten gives 5.00   −03 or five milliseconds.

Design Details

Several improvements in the instruction set of the

An Example of HP-25 Programming

A simple ecological model of interacting populations consists of rabbits with an infinite food supply and foxes that prey on them. The system can be approximated by a pair of nonlinear, first-order differential equations:

$$\frac{dr}{dt} = 2r - \alpha rf \qquad \text{(change in rabbits with time)}$$

$$\frac{df}{dt} = -f + \alpha rf \qquad \text{(change in foxes with time)}$$

where r is the number of rabbits, f is the number of foxes, and α is a positive constant to show how frequently rabbits and foxes meet. When $\alpha = 0$ there are no encounters; the rabbits keep breeding and the foxes starve. For a specific α, the probability of encounter is proportional to the product of the numbers of foxes and rabbits. A reasonable choice for α is 0.01.

One way to solve this problem numerically is a simple Euler method, solving equations of the form:

$$x_{n+1} = x_n + h \cdot f(x_n)$$

using a small step size h, where h represents a small increment of time. The equations become:

$$r_{n+1} = r_n + h \cdot (2r_n - \alpha r_n f_n)$$

$$f_{n+1} = f_n + h \cdot (-f + \alpha r_n f_n)$$

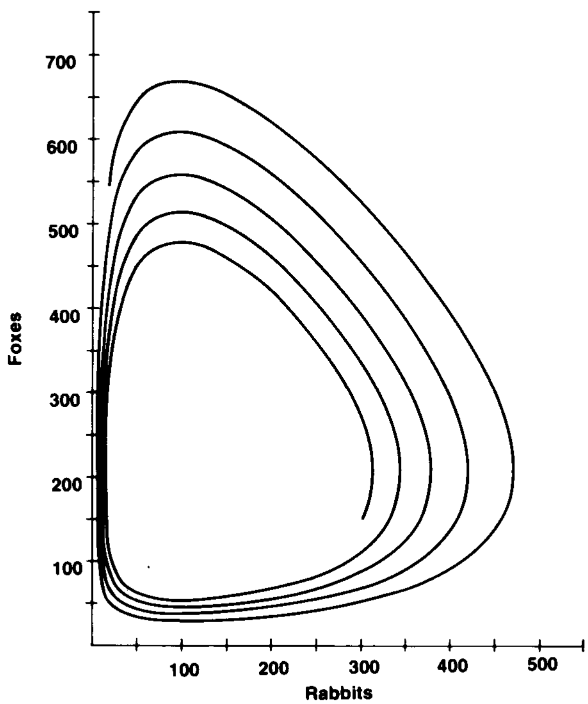
The features of the HP-25 make it ideally suited for problems of this type. The results can be plotted by hand on a graph of foxes versus rabbits. Note that the calculations give ten-digit floating-point numbers, but the display is always truncated to an integer.

Example:

$\alpha = 0.01$
$h = 0.02$
$r_0 = 300$
$f_0 = 150$

A plot of foxes versus rabbits is a circular loop with a period of about five time units (250 iterations). The rabbit minimum is 14, the maximum is 342 on the first loop. The fox minimum is 54 and the maximum is 478 on the first loop.

$r_0 = 100$, $f_0 = 200$ is a constant solution.



HP-25 Program Form

Title *Rabbits vs Foxes* Page __ of __

Switch to PRGM mode, press [f] [PRGM], then key in the program.

DISPLAY LINE	CODE	KEY ENTRY	X	Y	Z	T	COMMENTS
00			f_0	r_0			rabbits, ENTER↑, foxes
01	23 02	STO 2	f_0	r_0			Save initial foxes
02	22	R↓	r_0			f_0	
03	23 03	STO 3	r_0			f_0	Save initial rabbits
04	14 11 05	f FIX 5	r_0			f_0	change display format
05	24 02	RCL 2	f_n				Start loop here
06	31	ENT↑	f_n	f_n			foxes
07	31	ENT↑	f_n	f_n	f_n		
08	24 03	RCL 3	r_n	f_n	f_n		rabbits
09	24 00	RCL 0	α	r_n	f_n	f_n	encounter factor
10	61	×	αr_n	f_n	f_n	f_n	
11	61	×	$\alpha r_n f_n$	f_n	f_n		number of meetings
12	23 04	STO 4	$\alpha r_n f_n$	f_n	f_n		Save
13	21	x⇄y	f_n	$\alpha r_n f_n$	f_n		
14	41	−	$\alpha r_n f_n - f_n$	f_n			change in foxes
15	24 01	RCL 1	h	$\alpha r_n f_n - f_n$	f_n		Step size (time)
16	61	×	Δf	f_n			current change foxes
17	51	+	f_{n+1}				new number foxes
18	15 41	g x<0	f_{n+1}				If negative, then
19	00	0	0				change to 0
20	23 02	STO 2	f_{n+1}				Save new number
21	24 03	RCL 3	r_n				rabbits
22	02	2	2	r_n			
23	61	×	$2r_n$				
24	24 04	RCL 4	$\alpha r_n f_n$	$2r_n$			number of meetings
25	41	−	$2r_n - \alpha r_n f_n$				change
26	24 01	RCL 1	h	$2r_n - \alpha r_n f_n$			Step size
27	61	×	Δr_n				Change in rabbits
28	24 03	RCL 3	r_n	Δr_n			
29	51	+	r_{n+1}				new number rabbits
30	15 41	g x<0	r_{n+1}				If negative, then
31	00	0	0				change to 0
32	23 03	STO 3	r_{n+1}				Save new number
33	14 01	f INT	$\lfloor r_{n+1} \rfloor$				truncate to integer
34	24 02	RCL 2	f_{n+1}	$\lfloor r_{n+1} \rfloor$			foxes
35	14 01	f INT	$\lfloor f_{n+1} \rfloor$	$\lfloor r_{n+1} \rfloor$			truncate to integer
36	33	EEX	1. 00	$\lfloor f_{n+1} \rfloor$	$\lfloor r_{n+1} \rfloor$		
37	05	5	1. 05	$\lfloor f_{n+1} \rfloor$	$\lfloor r_{n+1} \rfloor$		
38	71	÷	$\lfloor f_{n+1} \rfloor / 10^5$	$\lfloor r_{n+1} \rfloor$			divide foxes by 10^5
39	51	+	$r_{n+1} \cdot f_{n+1}$				make double display
40	14 74	f PAUSE	$r_{n+1} \cdot f_{n+1}$				Pause for 2
41	14 74	f PAUSE	$r_{n+1} \cdot f_{n+1}$				seconds
42	13 05	GTO 05					Loop
43							
44							
45							
46							
47							
48							
49							

REGISTERS	
R_0	α encounter factor
R_1	h Step size
R_2	f_n foxes
R_3	r_n rabbits
R_4	$\alpha r_n f_n$ number encounters
R_5	
R_6	
R_7	

Note: the variables in the stack are incomplete. This listing does not include variables in the stack when they are no longer relevant.

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HP-25 Program Form

Title *Rabbits vs Foxes* Page of

Programmer

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Key in program			
2	Store α	α	STO 0	
3	Store step size	h	STO 1	
4	Input rabbits	r_0	↑	
5	Input foxes	f_0	f PRGM R/S	
	program loops, pausing to give a dual display of rabbits · foxes			rabbits · foxes
	for additional problems: go to step 4		R/S	

HP-21-family microprocessor made life much easier for the microprogrammer. Three of the most useful improvements were 12-bit subroutine addresses, the digits-to-ROM-address instruction, and the data register instructions.

In the HP-35 microprocessor, the microinstruction address was only eight bits long. Each 256-word ROM would turn itself on or off as ROM-select instructions dictated. There was only one level of subroutine and the return address had only eight bits. The HP-21 microprocessor uses a twelve-bit address. A given ROM responds only when it sees an address it contains. Subroutines can be located on different ROMs and easily return to the correct next instruction. The new processor can save two twelve-bit subroutine return addresses. Two levels make it possible for one subroutine to call another.

A new processor instruction takes two calculated digits as the next microprogram address. This instruction is exactly like a computed GO TO instruction in some programming languages. This instruction made the HP-25 possible. It is used for both key phrase execution and key phrase display. The eight-bit key phrase code is broken down into groups of phrases such as GTO codes, STO codes, f, and g codes. Then the code is either used to generate a display (for the SST key) or is executed (run mode).

The data storage chip used in the HP-35 family required that a calculated address be sent from the processor to activate one register. Then the register could be written into or read from. When the HP-25 data storage chip was designed, this mode of operation was retained, because a calculated address is needed for STO, RCL, and programming. However, enough microinstructions were available to define separate instructions to read or write in each register. This simplified the HP-22 microprogramming by allowing any financial register to be accessed internally with a single microinstruction.

One change in the system design of the HP-21 family was putting the display segment drive in the ROM integrated circuit. Which segment to power is determined by an accessory ROM composed of sixteen words of seven bits each. The words 0 to 9 are used to generate the digits. One word, 15, is a blank. Three of the remaining words generate the letters E, r, and o, which the HP-21 family uses to spell "Error," telling the user that an operation is illegal. One remaining word generates the letter F. This is used by the HP-25 to spell "OF" when a storage register overflows. Since the display generator is a tiny ROM on the microcode ROM, it can be changed to create new characters for new calculators.

Acknowledgments

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References

1. T.M. Whitney, F. Rodé, and C.C. Tung, "The 'Powerful Pocketful': an Electronic Calculator Challenges the Slide Rule," Hewlett-Packard Journal, June 1972.
2. C.C. Tung, "The 'Personal Computer': A Fully Programmable Pocket Calculator," Hewlett-Packard Journal, May 1974.
3. R.K. Stockwell, "Programming the Personal Computer," Hewlett-Packard Journal, May 1974.
4. W.L. Crowley and F. Rodé, "A Pocket-Sized Answer Machine for Business and Finance," Hewlett-Packard Journal, May 1973.

Randall B. Neff

Randy Neff did the microprogramming for the HP-21 and HP-25. Born in Houston, Texas, Randy attended Rice University in Houston, receiving his BS and MS degrees in electrical engineering in 1972 and 1973. He joined HP's Advanced Products Division in 1973. A member of ACM, he's now a programmer in the integrated circuit laboratory of Hewlett-Packard Laboratories. Randy enjoys reading science fiction and working with wood. He's married and lives in Palo Alto, California.

Lynn Tillman

Lynn Tillman did the microprogramming for the HP-22 and its predecessor, the HP-70. With HP since 1973, she's now production engineer for the HP-22. Lynn received a BS degree in secondary education from the University of Texas at Austin in 1969. After teaching ninth-grade science for a year, she returned to the campus, this time at the University of California at Berkeley, and received an AB degree in computer science in 1972. Born in Mattoon, Illinois, Lynn grew up in Gallup, New Mexico, working weekends and summers in an Indian trading post. She's married, lives in Los Altos, California, and relaxes by producing handmade rugs and collecting glassware from the 1930's.

Inside the New Pocket Calculators

The HP-21 type of calculator isn't just a stripped-down version of older HP pocket calculators, but an entirely new design.

by Michael J. Cook, George M. Fichter, and Richard E. Whicker

THE HP-21 AROSE FROM THE NEED to follow its predecessor, the HP-35, with a lower-priced hand-held scientific calculator. The HP-35 was, in a way, a tough act to follow. Its low-cost successor couldn't be merely a stripped-down factory special, for it isn't possible to change part of the HP-35 design without destroying the integrity of the design.

Instead, the HP-21 required a totally fresh design with an integrity of its own, taking advantage of late refinements of technology in the areas of displays, integrated circuits, batteries, and assembly.

The HP-21, for the most part, uses the architecture of the HP-35 but requires fewer integrated-circuit packages to implement all the functions found in the earlier chip set (see Fig. 1). Two reductions in package count were obtained by combining the anode drivers with the ROM into one 18-pin plastic package and by incorporating all the arithmetic, register, and control circuits on a second chip in a 22-pin plastic package. Clock driving circuits are contained on each chip, thereby saving one more package.

Another improvement, both in cost and in appearance, is the use of a smaller, two-cell battery. The nominal 2.5-volt supply must be converted to four volts for operating the displays, resulting in some loss of efficiency, but since the bipolar display cathode driver now used does not require a converted voltage, the loss is nearly made up.

Arithmetic, Control, and Timing Circuit (ACT)

This circuit combines the functions of the first generation's arithmetic and register circuit, control and timing circuit, and clock driver circuit and includes several new capabilities. All of these circuits could not simply be put together unchanged because more pins would have been required than were on the package. To reduce this number, several pins are used for multiple functions. The cathode driver scans the key rows, so the ACT circuit needs only five lines to scan the key columns and one line to synchronize the cathode driver, instead of the previous design's eight lines for the key rows and five lines for the key columns. One line is used to send display data to the ROM and anode driver as well as to send addresses and receive instructions. The older design used ten lines for these functions.

The addressing structure has been changed to allow direct addressing of 4096 instructions. This means that at the end of a subroutine, control can pass back to the calling location from any location, instead of from only 255 locations. An additional level of subroutine nesting is included, so one subroutine can be called from within another. The number of status bits is increased to 16, and a four-bit register has been added to remember the display format requested by the user.

The original HP-35 stack is retained, but there are now two storage registers on the ACT circuit instead of only one. This is not readily apparent to the HP-21 user unless he needs to use the full stack and do transcendental functions at the same time. In the HP-35 the highest entry of the stack was lost, whereas in the HP-21 it is not lost. The stack registers are labeled X (display), Y, Z, and T. The storage registers are M and N. There are three working registers: A (= X), B, and C.

The ACT circuit also performs hexadecimal (modulus 16) arithmetic in addition to decimal. This function is used in display formatting in the HP-21 and HP-25, but may be of more interest to designers if the ACT circuit is to be used in instruments.

Data Storage Chip

This optional chip is used in the HP-22 and HP-25. To allow it to store programs, it was arranged that keycodes could be sent either to the ROM or to the A

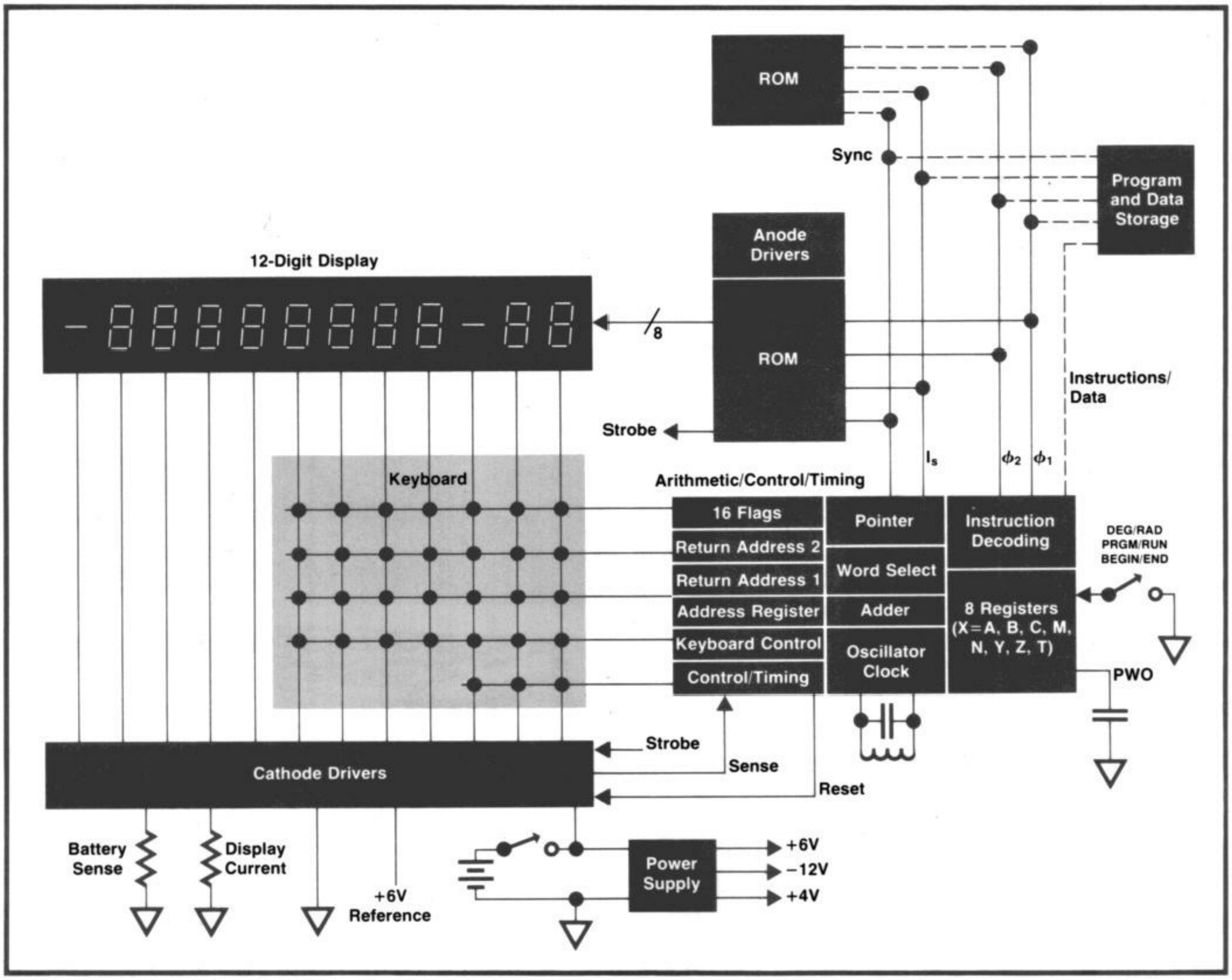


Fig. 1. *The three members of the HP-21 family differ in the amount of read-only memory and data storage they contain. Keys activate microprograms stored in the ROM, causing the arithmetic, control, and timing circuit to perform the indicated function.*

register on the ACT chip, and that the A register could send previously stored keycodes to the ROM. The C register communicates with the data storage registers, so by exchanging portions of the contents of the A and C registers, keycodes could be sent to and retrieved from the data storage registers. To aid in editing programs (i.e., sequences of keycodes), a circular shift function was added to the A register. This enables the data in the A register to be rotated without losing information.

The data storage chip is more versatile than its predecessor in that direct register addressing is possible, that is, the instruction itself contains the number of the register into which data is to be stored, or from which data will be retrieved. Previously a register number had to be built up in the C register, and then two instructions used, "C to data address" and either "C to data" or "data to C." These indirect data register addressing instructions are also still available.

ROM

The ROM consists of 10,240 bits of read-only memory, organized as 1024 words of 10 bits each. Four pages of microinstructions can be stored on one chip, and up to four chips can be addressed directly by the ACT circuit.

12-bit addresses are received on the instruction/address (I_S) line, least significant bits first. The two most significant bits enable one of four chips to output instructions onto the I_S line. Thus, up to 4096 microinstructions may be programmed in a maximum system. Unlike the HP-35 quad ROM, any 12-bit address sent to the ROM chip will be recognized, regardless of previous addresses.

Display Circuit

During each 56-bit word time, the ACT chip sends information to the ROM/display chip for displaying one digit. A character ROM in the display circuit converts the input to seven-segment format and then multiplexes through the segments sequentially. With a 12-digit display, the duty cycle for each segment is 1/96 or about 1%. This requires a peak current of 30 mA to maintain an average current of 300 μA. This is a relatively high current for MOS and requires devices well over 100 mils (0.25 cm) wide.

To allow the use of multiple ROMs without duplicating the display function, a mask option can eliminate all power consumed in this portion of the chip. Typically, ROM 0 contains the display function and all other ROMs do not.

Five of the characters in the display ROM may be reprogrammed to any seven-segment character. Three of these characters generate E, r, and o to spell Error.

Packaging the New Pocket Calculators

by Thomas A. Hender

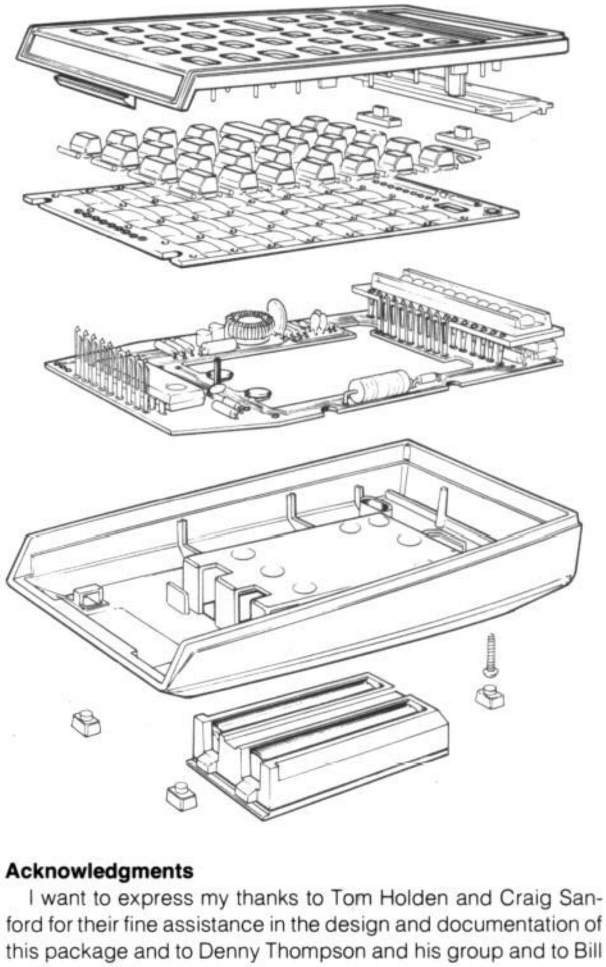
Objective: design a "shirt-pocket" calculator package for minimum factory cost, with reliability equal to or better than that of the HP-35 family. HP quality standards must be maintained.

Shirt-pocket size was achieved by reducing the number of keys from 35 to 30 (one less horizontal row) and by spacing the keys closer together. Spacing is the minimum deemed comfortable for the majority of users. Also, the display was reduced from 15 to 12 digits, and decimal points share positions with their digits.

The HP-21 uses only two rechargeable size AA NI-Cad batteries instead of the three required in the HP-35 family. This feature saves almost thirty grams of weight. The total weight of the HP-21 is 165 grams. Apart from the obvious weight saving accompanying its smaller size, the HP-21 package contains fewer parts: no backbone support, no key-spacing grid and no display window welding frame. Structural rigidity is designed into the monocoque or box shape of the battery compartment in the bottom case, and in the heat-staked egg-crate configuration of the top case and keyswitch printed circuit assembly (plastic posts on the top case fit through holes in the keyswitch printed circuit assembly; heat is then applied to deform the ends of the posts and rivet the two parts together).

Lower production costs of this package are mainly due to minimal assembly time, including testing. Only two screws fasten the HP-21 together—a reduction of ten from the HP-35. The display is an integral plug-in assembly. Modular construction eases handling and any necessary touch-up operations; for instance, there are no electronic components or soldering on the keyswitch printed circuit assembly.

The battery pack case doubles as part of the calculator's bottom outside surface, eliminating a separate battery-retaining panel. The battery jumper spring provides the force that holds the pack in the calculator, so latches are not needed. Battery terminals are automatically assembled into the logic board during fabrication. This feature eliminates the manual wiring and terminal fastening required in the previous generation's design. The ac terminal pins are mounted similarly. Electrical integrity is provided by a flow-soldering operation which connects all electronic components to the logic board. All keys except the blue prefix key are molded in two clusters, which are mechanically separated during loading into the keyboard bezel. This reduces the number of parts handled from thirty to three and minimizes assembly operator errors and fatigue. That this innovation works is largely because of the creative efforts of the plastic mold designers and craftsmen of the HP Manufacturing Division, whose continuing high standards of excellence contributed much to the success of the HP-21. The over-center breakaway tactile feel of our former calculator keys has been retained, and the molded design of the key-strip actuating surfaces on the undersides of the keys eliminates the control bumps needed on earlier models.



Acknowledgments

I want to express my thanks to Tom Holden and Craig Sanford for their fine assistance in the design and documentation of this package and to Denny Thompson and his group and to Bill Boller of the HP Manufacturing Division for seeing to it that necessary things were done on time. Finally, recognition is due to the cooperative people in production and to Gabe Bonilla and Cliff Planer of the model shop for their painstaking efforts, particularly during the concept phase of the project.

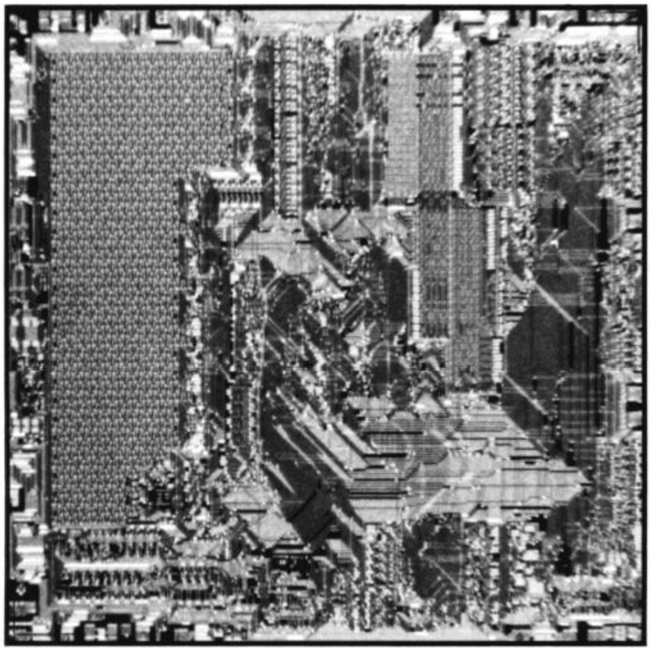


Fig. 2. *Arithmetic, control, and timing chip.*

Cathode Driver

In designing the cathode driver circuit for the HP-21 calculator, the main objective was to have a circuit with extremely low power consumption, a prime requirement for the HP-21 since only a two-cell battery pack is used. Functionally, the custom designed bipolar driver chip consists of a 12-bit shift register, twelve cathode drivers each with a current limiting feature, low-battery detection circuit, input buffer, and timing control gating. The 12-bit shift register turns on the twelve cathode drivers one at a time.

The LED digit display drive technique used in the HP-21 is different from that employed in the HP-35. In both cases the segment drivers (anode) and the digit drivers (cathode) are scanned one digit at a time, one segment at a time, but the HP-21 does it by switching dc voltages while the HP-35 uses an inductive charge-discharge method. When they are on, the anode drivers of the HP-21 are dc sources for the individual LED segments, while the anode drivers for the HP-35 drive each LED segment indirectly by first charging an inductor which then discharges through the LED segment. The HP-21 method requires significantly fewer components.

Acknowledgments

The authors would like to thank the following people for their contributions to this project: Bosco Wong for the design of the cathode driver chip, Les Moore for the assembly and debugging of the breadboard, Mark Linsky for the design of the power supply and recharger, Ed Liljenwall for the industrial design, and Ernst Erni and Chung Tung for their support throughout the project.

Richard E. Whicker

Rich Whicker, project leader for the HP-21 series, graduated from the University of Illinois in 1966 with a BSEE degree. For the next six years he did MOS logic design for a semiconductor company, then continued in that specialty after joining HP in 1972. Born in San Francisco, Rich now lives in Santa Clara, California. He's married and has three children, a daughter and two sons. For a change of pace from the job Rich plays piano, builds radio controlled models and, like a bus driver who goes for a drive on his holiday, works out electronic ideas of his own.

Michael J. Cook

Mike Cook developed the ACT chip for the HP-21 series. He joined HP in 1973 with an extensive background in the design of MOS LSI circuits. Born in Watford, Hertfordshire, England, Mike earned his BSc and MSc degrees in electrical engineering at the University of Southhampton in 1963 and 1966, then came to the United States to work for an aircraft company as a systems designer. Later he joined a semiconductor company, designing more than 50 MOS LSI circuits and serving briefly as MOS applications and marketing manager for that company in Germany. He speaks German and French as well as English and is a student of comparative linguistics. Mike is married, has three daughters, and lives in Cupertino, California. His interests include classical music, color printing, and sketching.

Correction

The article entitled "Active Probes Improve Precision of Time Interval Measurements" (Hewlett-Packard Journal, October 1975) understated the accuracy achieved by the Model 1722A Oscilloscope in time interval measurements. The accuracy of the Model 1722A for main time base settings between 100 ns/div and 20 ms/div is specified conservatively as ±0.5% of measurement ±0.02% of full scale for measurements less than 1 cm, and ±0.5% of measurement ±0.05% of full scale for measurements greater than 1 cm. Typical measurement accuracies are more than three times better than this. The time base calibration period has not been specified because it has not been a significant contributor to inaccuracy. Experience shows that yearly calibration may be sufficient for instruments maintained in a laboratory environment. The time base temperature coefficient is specified as ±0.03%/°C and short term stability is better than 0.01%.

Thomas A. Hender

Tom Hender was responsible for the product design and packaging of the HP-21 series. Born in Cobourg, Ontario, Canada, he served in the Royal (British) Navy during the second world war, then attended British Admiralty College (Devonport Division), graduating in 1947 with a BSc degree in mechanical engineering. His engineering career includes work on punched-card machines, line printers, point of sale terminals, and related peripheral mechanisms. He joined HP in 1973. Tom is married, has three daughters, and lives in San Jose, California. He serves his church as choir director and enjoys photography, chess, and model railroading.

George M. Fichter

George Fichter designed the read-only memory for the HP-21 series. A native of New York City (Brooklyn), he graduated from Stevens Institute of Technology with a BS degree in 1965, spent six years as a U.S. Air Force meteorologist, and then returned to school at the University of Washington, earning a BSEE degree in 1972 and an MS in computer science in 1973. He joined HP in 1973. George is married and has a son and a daughter. An accomplished musician, he plays French horn and experiments with computer music using an HP 2100 Computer. He's also learning to fly and hopes to get his private pilot's license this year. The Fichters live in Los Altos, California.

FEATURES AND SPECIFICATIONS

HP-21 Scientific Calculator

PREPROGRAMMED FUNCTIONS

ARITHMETIC: +, −, ×, ÷
LOGARITHMIC: e^x, ln x, log x, 10^x
TRIGONOMETRIC: sin x, arc sin x, cos x, arc cos x, tan x, arc tan x
OTHER: y^x, $\sqrt{x}$, 1/x, π, rectangular/polar coordinate conversion, degrees-radians mode selection
REGISTER ARITHMETIC: addition, subtraction, multiplication, or division operations can be performed on data in storage register.

NUMERIC NOTATION

FLOATING POINT: 10 digit mantissa and sign
SCIENTIFIC: A sign and integer followed by up to seven possible decimal places. The exponent consists of a sign and two digits.
MIXED FLOATING POINT AND SCIENTIFIC: Mixed numeric notation may be entered as data. After performance of any operation data reverts to floating point or scientific notation as applicable.
ROUNDING TO LAST DISPLAYED DIGIT: Internal operations are calculated to within 10 digits.

DISPLAY

NUMERIC AND DECIMAL POINT: Eight-segment, light-emitting diode (LED). Digit and decimal point are contained within a single eight-segment LED digit.
SIGN: Eight-segment light-emitting diode
12-digit display including two sign digits
MAXIMUM DISPLAY NUMBER: $\pm 9.9999999 \times 10^{\pm 99}$
DISPLAY FORMAT: Fixed notation and scientific notation as specified
SPECIAL INDICATIONS:

Overflow:	All nines (9.9999999 99)
Underflow:	Zero in scientific notation. In fixed notation automatically reverts to scientific notation for small numbers that would otherwise appear to be zero.
Low Battery:	Inverted decimal points for 30 seconds to ½ hour before display blanks.
Improper Operation:	"Error" written on display.

DYNAMIC RANGE: $9.999999999 \times 10^{99}$ to $1. \times 10^{-99}$ and 0.
NUMBER OF KEYS: 30, 1 on/off switch, 1 degree/radian switch
MEMORY REGISTERS: six total
Four working registers in an operational stack
One storage register
One hidden register for trigonometric function computation

DATA ENTRY

Exponent entry
Negative number entry (CHS)

PACKAGING

High-impact, contoured beige plastic (ABS) calculator case
All solid state electronics
Light-emitting diode (LED) display

SPEED: a one second maximum for all preprogrammed functions (200 kHz clock speed)

POWER

RECHARGERS: European, 103-127 and 206-254 Vac 50-60 Hz; U.K. Desktop, 206-254 Vac, 50-60 Hz; United States, 90-127 and 180-254 Vac, 50-60 Hz. 5 watts, plastic box. Recharger warm to the touch in normal operation
BATTERY: 350 mW derived from 2-cell quick recharge nickel-cadmium battery pack. Operating time 3 to 5 hours. Approximately 6 hours to recharge completely discharged battery pack when calculator is not in operation. Approximately 17 hours to recharge completely discharged battery pack when calculator is operating under maximum load (all 8's displayed). Battery pack must be in place for calculator to operate.

WEIGHT

CALCULATOR WITH BATTERY PACK: 6 oz (170 grams)
RECHARGER: 5 oz (142 grams)
SHIPPING WEIGHT: 1½ lb (682 grams), approximately

CALCULATOR DIMENSIONS

LENGTH: 5⅛ in (13.02 cm)
WIDTH: 2 11/16 in (6.83 cm)
HEIGHT: 1 3/16 in (3.02 cm)

PRICE IN U.S.A.: $100

HP-22 Business Calculator

FINANCIAL FUNCTIONS:

n	Number of periods
i	Periodic interest rate
PMT	Periodic payment amount
PV	Present value of money
FV	Future value of money
12×	Converts yearly periods to monthly periods
12÷	Converts annual interest to interest rate per month
ACC	Computes accumulated interest between any two time periods of a loan
INT	Calculates simple interest
BAL	Gives remaining loan balance at any point in time
%Σ	Percent one number is of total
%	Calculate percentage of a number
Δ%	Percent of difference between two numbers

BEGIN-END SWITCH: This switch is a special convenience which works in conjunction with the financial keys in calculating payments due at the beginning or end of the period for annuities, leases, loans and other transactions.

STATISTICAL FUNCTIONS:

Σ+	Provides the number of entries and sums two variables
Σ−	Adjusts data, corrects an incorrect Σ+ entry
L.R.	Linear regression; linear functions between two points
$\hat{y}$	Linear estimate
$\bar{x}$	Mean or arithmetic average
s	Standard deviation

MATHEMATICAL FUNCTIONS:

ln	Computes natural logarithm (base e) of value in display
e^x	Natural antilog; raises e to value in display
y^x	Raises number in Y register to value in display
$\sqrt{x}$	Square root of number in display

ARITHMETICAL FUNCTIONS:

−	Subtract
+	Add
×	Multiply
÷	Divide
CHS	Changes a positive number to a negative number

MEMORY REGISTERS:

10 separate addressable memories with full register arithmetic
5 financial registers
4 operational stack registers with stack roll-down for review

DATA MANIPULATIONS; DISPLAY CONTROL; STORAGE FUNCTIONS:

x⇄y	Exchange contents of the X and Y registers
R↓	Rolls down the stack to review contents
CLX	Clears display
CLEAR	Clears display, stack and storage registers; resets financial status indication
RESET	Resets financial status indicators and clears only statistical data
ENTER↑	Copies number displayed in X register into Y register; also separates numerical entries by moving entries up in operational stack
RCL	Recalls a number to the X register from a storage register
STO	Stores displayed value into one of the 10 storage registers
■	Gold shift key; selects functions printed in gold on keyboard

DISPLAY:

10 significant digits (8 + 2 digit exponent displayed in scientific notation).
Fixed decimal notation with automatic overflow and underflow into scientific notation
Scientific notation with dynamic range of 10^{-99} to 10^{99}
Automatic decimal point positioning and selective round-off
Indicators for improper operations (Error in display) and low battery condition (lighted decimal points)
Light-emitting diode (LED) display recessed for better contrast in harsh lighting

DESIGN SPECIFICATIONS:

Operates 3 to 5 hours on rechargeable batteries (under 6 hours to recharge) or ac
Specially designed recessed plug to prevent erroneous insertion of improper unit
Solid state electronics with all critical connections gold-plated
Tactile feedback keyboard. Positive contact action assures accurate entry of data
Heavy gauge compact case contoured to fit the hand
Ultrasonically welded impact resistant case
Plastic liquid-barrier shield under keyboard sealed to resist entry of moisture
Keys are double injection molded to help prevent the legend from wearing off.

PHYSICAL SPECIFICATIONS:

CALCULATOR LENGTH: 5⅛ in (13.02 cm)
CALCULATOR WIDTH: 2 11/16 in (6.83 cm)
CALCULATOR HEIGHT: 1 3/16 in (3.02 cm)
CALCULATOR WEIGHT: 6 oz (170.1 g)
RECHARGER WEIGHT: 5 oz (141.8 g)
SHIPPING WEIGHT: approx 1½ lb (680 g)
OPERATING TEMPERATURE RANGE: 32°F to 113°F (0°C to 45°C)
CHARGING TEMPERATURE RANGE: 59°F to 104°F (15°C to 40°C)
STORAGE TEMPERATURE RANGE: −40°F to 131°F (40°C to 55°C)

POWER REQUIREMENTS:

AC: 100-127 V or 200-254 V, ±10%, 50 to 60 Hz, 5 watts
BATTERY: 2.75 Vdc nickel-cadmium rechargeable battery pack

PRICE IN U.S.A.: $165

HP-25 Programmable Calculator

PROGRAMMING:

Program writing capability
Single step execution or inspection of a program
Pause (to display intermediate result)
Program editing capability
8 relational tests: $x<y$, $x=y$, $x \neq y$, $x<0$, $x \geq 0$, $x=0$, $x \neq 0$
Conditional branching
Direct branching

KEYBOARD COMMANDS:

TRIGONOMETRIC FUNCTIONS:
- 3 angular modes (degrees, radians, grads)
- Sin x
- Arc sin x
- Cos x
- Arc cos x
- Tan x
- Arc tan x
- Rectangular coordinates ⇄ polar coordinates
- Decimal angle (time) ⇄ Angle in degrees (hours)/minutes/seconds

LOGARITHMIC FUNCTIONS:
- Log x
- Ln x
- e^x
- 10^x

STATISTICAL FUNCTIONS:
- Mean and standard deviation
- Positive and negative summation giving n, Σx, Σx^2, Σy, Σxy

OTHER FUNCTIONS:
- Integer (gives only integer portion of number)
- Fraction (gives only fractional portion of number)
- Absolute (gives absolute value of x)
- y^x, $\sqrt{x}$, 1/x, π, x^2, %
- Register arithmetic in all 8 addressable registers
- Addition, subtraction, multiplication or division in serial, mixed serial, chain or mixed chain calculations.

DATA STORAGE AND POSITIONING OPERATIONS:
- Data entry
- Stack roll down
- x,y interchange
- Data storage
- Data recall
- Change sign
- Enter exponent

MEMORY:

4-register stack
"Last x" register
8 addressable registers
Program memory for storage of up to 49 steps

LIGHT-EMITTING DIODE DISPLAY:

Displays up to 10 significant digits, 8 plus two-digit exponent in scientific and engineering notation, and appropriate signs. Three selectable display modes: fixed point (with automatic overflow and underflow into scientific), engineering, and scientific, with dynamic range of 10^{99} to 10^{-99}. Automatic decimal point positioning. Selective round-off; range 0-10 digits in fixed point; 0-8 digits in scientific; 0-8 in engineering notation. "Error" appearing in display indicates improper operation; low battery indicator.

GENERAL SPECIFICATIONS: Operates on fast-charge battery pack or ac. (Battery recharges in 6-17 hours.) Tactile feedback keyboard. Polyethelene liquid-barrier shield under keyboard. Compact case of high-impact plastic with recessed display. Recessed recharger/ac plug receptacle. Solid state electronics.

OPERATING SPECIFICATIONS:

POWER: AC: 115 or 230 V, ±10%, 50 to 60 Hz, 5 watts. Battery: 500 mw derived from nickel-cadmium rechargeable battery pack.
WEIGHT: HP-25: 6 oz (170 g) with battery pack. Recharger: 5 oz (142 g).
SHIPPING WEIGHT: Approx 1.5 lbs (.7 kg).
DIMENSIONS:
- LENGTH: 5.1 inches (13.0 cm)
- WIDTH: 2.7 inches (6.8 cm)
- HEIGHT: 1.2 inches (3.0 cm)

TEMPERATURE RANGE:
- OPERATING: 32°F to 113°F (0°C to 45°C)
- CHARGING: 59° to 104°F (15°C to 40°C)

PRICE IN U.S.A.: $195

MANUFACTURING DIVISION: ADVANCED PRODUCTS DIVISION
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Cupertino, California 95104 U.S.A.