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Popular Electronics

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BUILD THE

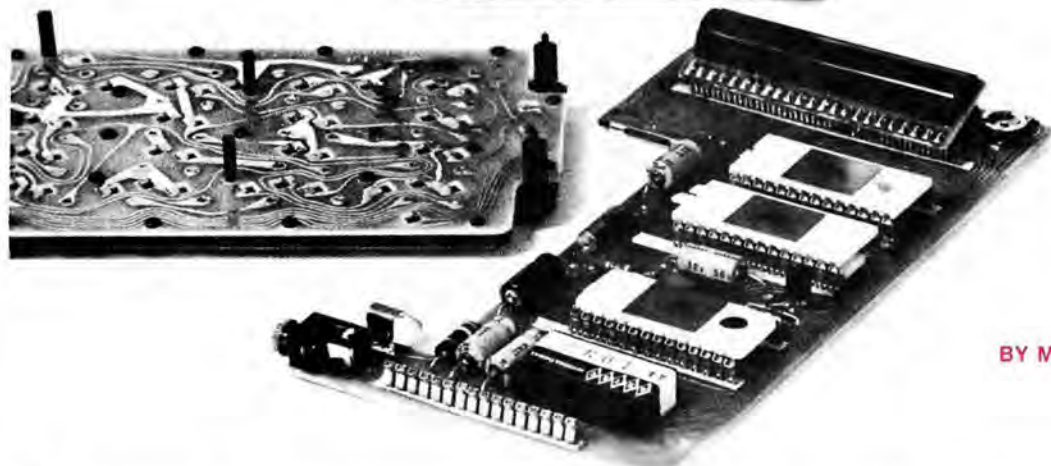
"Senior Scientist" Calculator

10 LEVELS OF ADDRESSABLE MEMORY



This new-generation scientific calculator features combinatorial, statistical, and probability functions, plus ten levels of addressable memory.

NOW... BUILD THE 'SENIOR SCIENTIST' CALCULATOR



BY MARTIN MEYER

THE simple four-banger electronic calculator can do little more than add, subtract, multiply, and divide. Since it was first introduced, however, we have welcomed at least two other "generations" of calculators—each with added capabilities. Now, we've taken another quantum jump in calculator capability with the "Senior Scientist." In addition to the functions that most scientific calculators can perform, (roots, powers, trigonometrics, summations, factorials, various conversions, nested parentheses, etc.) the Senior Scientist makes available combinatorial, statistical, and probability functions. Furthermore, it has 10 levels of storage memory that can be addressed independently in any order desirable. And it's a snap to build this

advanced hand calculator, whose kit price is just \$115.

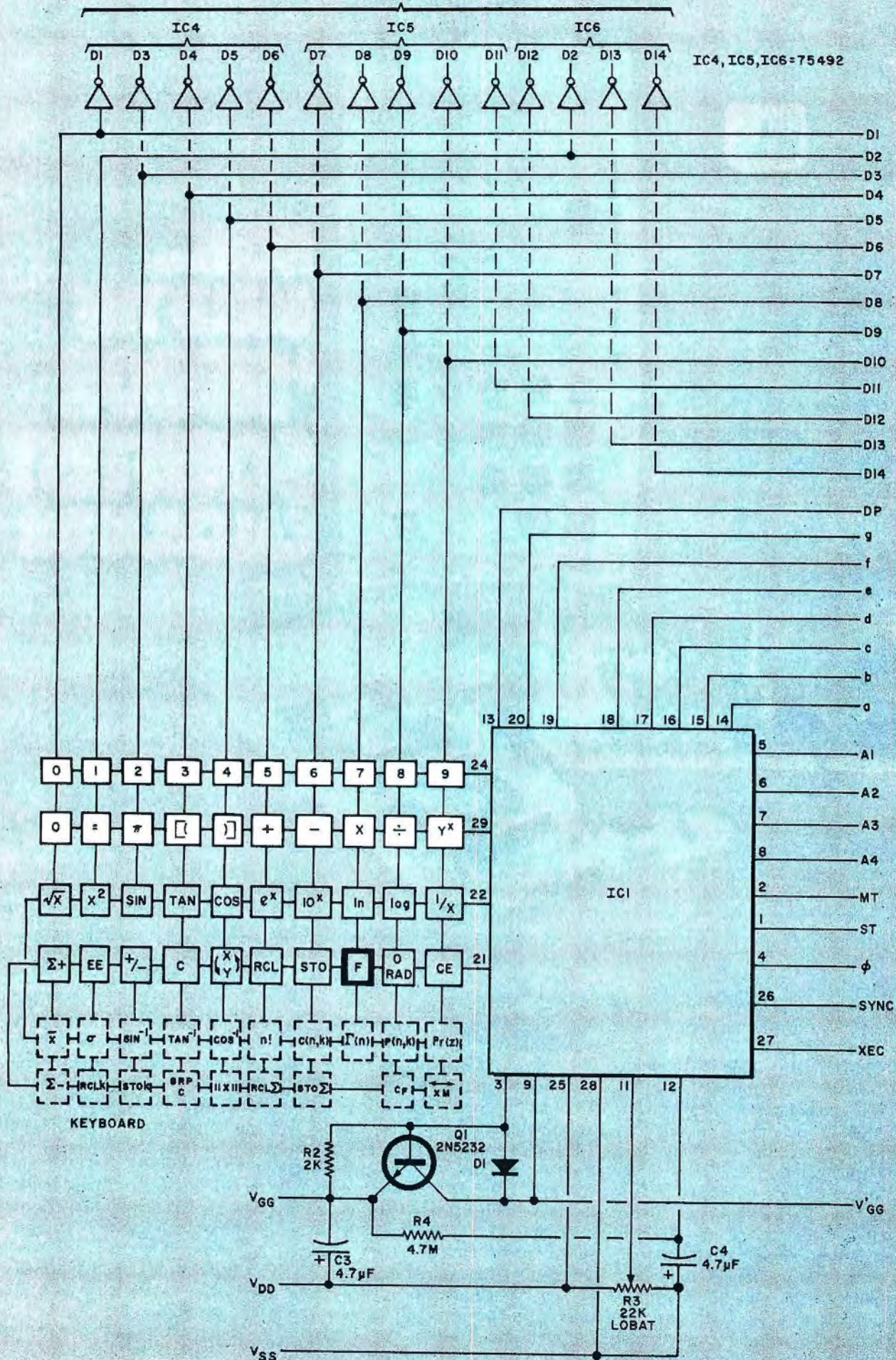
The Specifics. There are 40 keys on the Senior Scientist's keyboard, divided into two groups of 20 keys each. The lower 20 keys are assigned the numbers 0 through 9, decimal point, arithmetic functions (+, -, ×, ÷, =), π, exponentiation (x^y), and two-level parentheses functions. These are all single-function keys. Of the remaining 20 keys, 19 are assigned double-function status, while the remaining key (labelled F) serves the single function of shifting the dual-function keys to their alternate functions.

The calculator's LED display consists of a 12-place arrangement. The left-most place is reserved for indicating mantissa sign, calculation error,

degrees/radians status (degrees implied, bar segment on for radians), and low-battery condition. Ten digits of the display are for the mantissa, while two are for the exponent. The sign for the exponent is located between the mantissa and exponent displays. (Only the - sign is displayed for both mantissa and exponent; + is implied.) The calculator has a built-in battery saver feature that blanks the display after a preset (adjustable) time when no operations are being performed; this is indicated by the - sign for the exponent coming on. For easy identification, the exponent displays are half the size of the displays used for the mantissa and are shown as superscripts at the right.

The ability to solve complex and
(Continued on page 35)

DIGIT DRIVERS



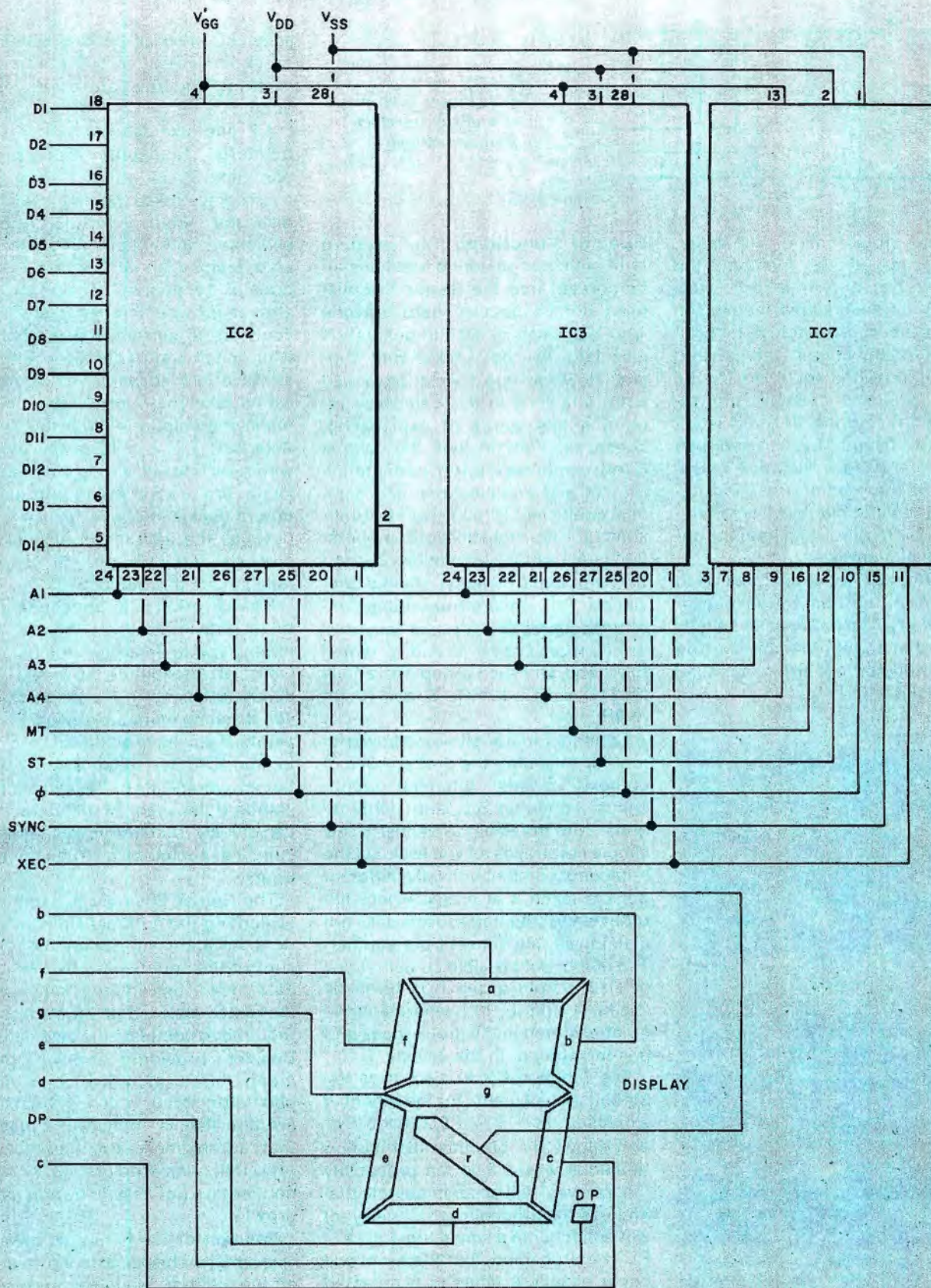


Fig. 1. Schematic of calculator is shown above and opposite. Unshaded keys are primary functions. Others are dual-function keys. Arrangement here is electrical—actual layout shown in photograph.

time-consuming mathematical problems is greatly enhanced by the calculator's two-level parenthetical capability. In stating an equation, in-

formation contained within the parentheses defines a specific variable. The solution of this variable is computed and retained. This allows a

problem to be entered as it is written or stated.

The 10 levels of memory greatly enhance the calculator's power, giving

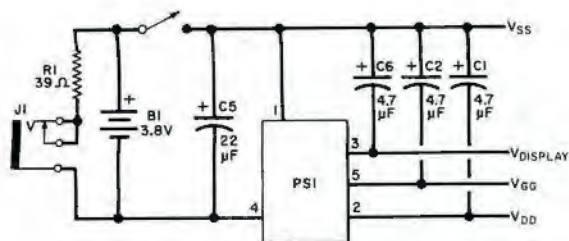


Fig. 2. Power supply uses a dc/dc converter to step up voltage.

a simple programming capability. Without the 10-level memory, the calculator has three memory levels (sum, sum-of-the-squares, index). The 10-level memory is a single IC that can be added at any time. It "plugs" into the holes provided for it on the pc board; no board changes are required. Entry into the 10 levels is accomplished by pressing STO and then the numeral (0 to 9) key that corresponds to the memory location desired. To recall a number from memory, simply press RCL and then the appropriate numeral key.

The Senior Scientist operates up to five hours on its built-in nickel-cadmium battery. The battery can be fully recharged in about nine hours, using the ac adapter/recharger supplied with the kit.

PARTS LIST

- B1—3.8-volt rechargeable nickel-cadmium battery
- C1, C2, C3, C6—4.7- μ F, 20-volt electrolytic capacitor
- C4—56- μ F, 6-volt electrolytic capacitor
- C5—22- μ F, 10-volt electrolytic capacitor
- D1—1N914 silicon diode
- IC1, IC2, IC3—Mathematical integrated circuit set
- IC4, IC5, IC6—75492 hex inverter integrated circuit
- IC7—10-level memory integrated circuit
- J1—Miniature phone jack
- PS1—Dc/dc converter assembly
- Q1—2N5232 npn transistor
- R1—39-ohm, 1/8-watt resistor
- R2—2000-ohm, 1/8-watt resistor
- R3—20,000-ohm, linear-taper miniature pc potentiometer
- Misc.—Keyboard; 14-digit LED display assembly; printed circuit board; case; ac adapter/recharger; Molex Soldercons (124); masking tape; solder; etc.

Note: The following items are available from Netronics Research & Development Ltd., 27 Eagle St., Spring Valley, NY 10977: complete kit of parts, including assembly/instruction manual: battery; ac adapter/recharger; soft carrying case, and 10-level memory IC (N2000MX) for \$114.95; same kit minus memory IC (N2000X) for \$99.95; keyboard (N201) for \$12; double-sided pc board with plated-through holes (N202) for \$5.50; 47A026 memory IC (IC8) for \$15; 75492 IC's for \$1.50 each; dc/dc converter assembly (N203) for \$5.80; mathematics IC set (IC1, IC2, IC3) (N204) for \$65 per set; 14-digit LED display assembly (N205) for \$19.50. New York state residents please add sales tax.

Special Functions. The standard arithmetic and scientific functions incorporated into the Senior Scientist need not be detailed here. Anyone who has used a second-generation calculator will be familiar with their use. However, the special advanced math functions in this calculator require a few words of explanation. These functions include the gamma [$\Gamma(n)$]; combinatorial ($n!$); permutation [$P(n,k)$] and combinations and binomial coefficient [$C(n,k)$]; normal probability [$Pr(z)$]; statistical group operation (such as the summations $\Sigma+$ and $\Sigma-$), arithmetic mean (\bar{x}), standard deviation (σ), square-root-of-the-sum-of-the-squares ($\|x \times y\|$); and factor reversal (transposing x and y terms) functions, and such group operations as STO k , RCL k , RCL Σ , and group (GRP) clear.

Combinatorial analysis is a powerful tool for obtaining the probabilities of complex events, binomial coefficients, combinations, and permutations. With the Senior Scientist, a few simple keystrokes let you evaluate the number of combinations of n different objects taken k at a time where the order of the resulting subsets does not distinguish one subset from another. The number of possible combinations of size k from group n is given by $C(n,k) = n/[k!(n-k)!]$, where k is the number stored in the group index and n is the number in the display.

The function $C(n,k)$ also gives the binomial coefficients for the binomial expansion $(a + b)^n = \sum_{k=0}^n C(n,k)a^{n-k}b^k$ and allows the binomial distribution functions where P is the probability that an event will occur in a single trial and q is the probability that the event will not occur in a single trial ($q = 1 - P$). The probability that the event will occur exactly k times in n repeated trials is given as $C(n,k)P^kq^{n-k}$. This is known as the binomial probability function, since its terms for $k = 0, 1, 2, 3 \dots n$ correspond to the successive terms for the binomial expansion.

The Senior Scientist also evaluates the number of permutations of n different objects taken k at a time where, from a group of n items, k items are

selected under conditions where the order of the resulting subgroups does distinguish one subgroup from another.

As one example of using combinatorial functions, evaluate the condition $C(n,k)$, where n is 7 and k is 4. Six keystrokes on the calculator give the solution as 35. Another example: how many different five-man teams can be formed from a pool of 16 people? Again, six keystrokes provide an answer of 4368. If you were to perform these problems with pencil and paper, even with the aid of a less advanced calculator, it would take you considerable time to reach the solutions. With the Senior Scientist, you can have the answer within seconds of stating the problem. (Note: We are not going into the details of the keystroke sequence to use here, as the instruction manual that comes with the IC's and calculator kit fully covers this subject.)

Normal probability functions are a thing unto themselves. Besides permitting you to determine the area of a Gaussian distribution curve, the probability functions in the calculator let you do some mundane things. For example, if you have an installation containing 4000 light bulbs, each of which has an average life of 1000 hours and a standard deviation of 200 hours, you can quickly calculate how many lamps can be expected to fail in the first 700 hours.

The Senior Scientist is capable of evaluating the arithmetic mean, standard deviation, and square root of the sum of the squares of any data. The data need be entered only once; thereafter, only single keystrokes are required to complete the calculations. Besides providing the arithmetic mean, the calculator can solve geometric mean, which is the type of average that is applied in situations that approximate a geometric progression, geometric growth, or exponential law (for example, population growth).

Solution of the harmonic mean is also simple. This mean is the measure of the central tendency to employ when dealing with rates or prices, such as mph, dollars/gallon, etc. An example of this type of problem is the old school math question that requires the student to determine the average speed of an airplane flying a square course that is 100 miles long on each side and where the speed is

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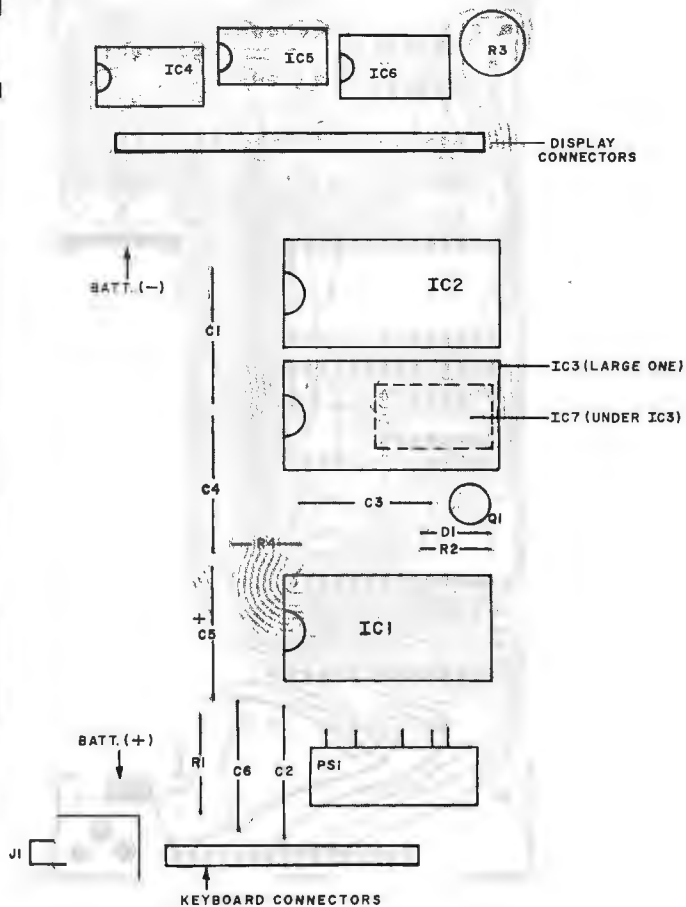
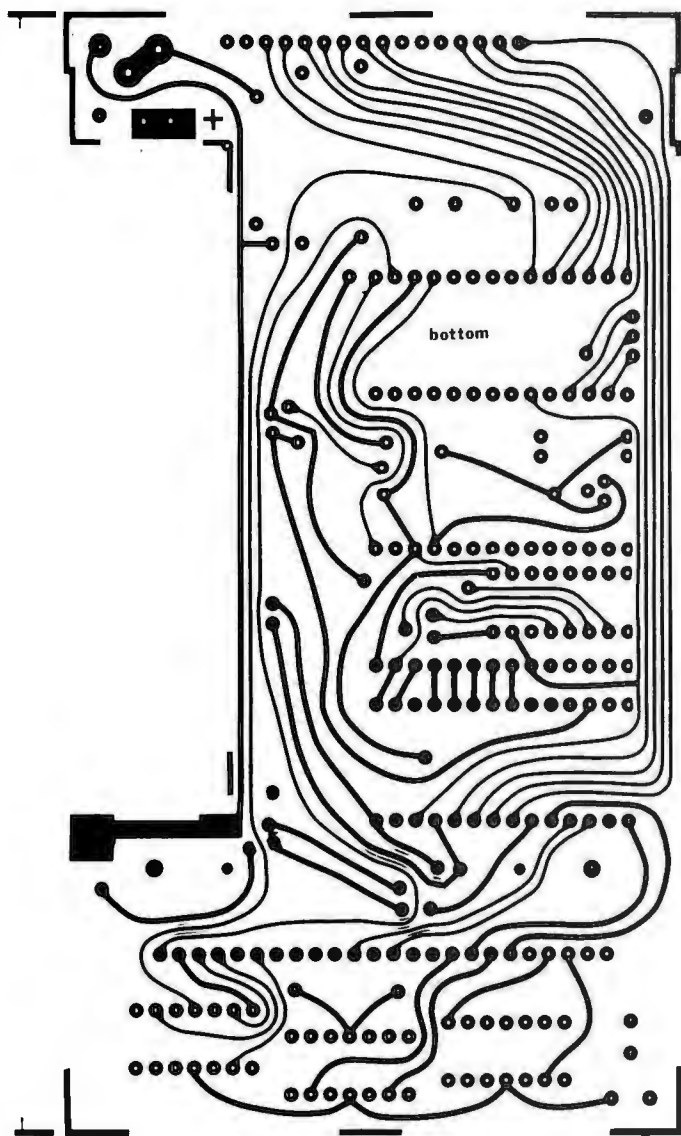
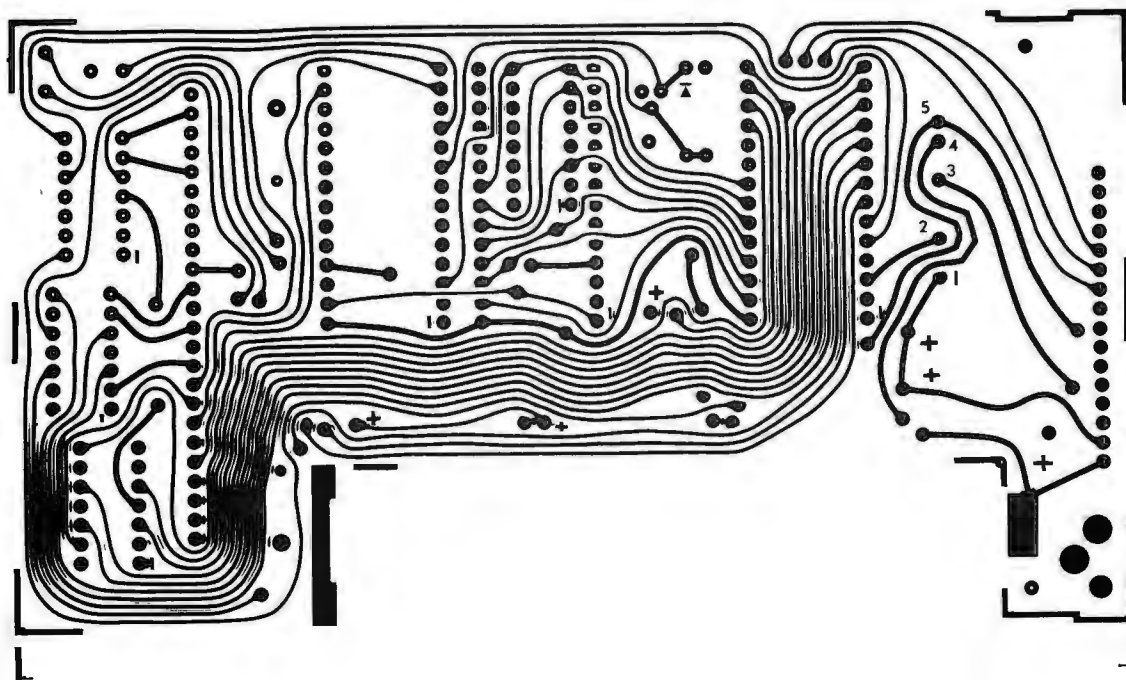


Fig. 3. Etching and drilling guides for the two sides of the printed circuit board are shown at left and below. Component placement is made as shown above on the top side of the board (below). Be sure to observe polarities and placement of IC's.



100 mph on the first leg, 200 mph on the second, 300 mph on the third, and 400 mph on the fourth. With a few simple keystrokes, the Senior Scientist provides an answer of 192 mph.

Last but not least, the calculator can evaluate the gamma function of all positive values of n where $n \leq 2$. The gamma function can be considered as a type of interpolation of the factorial function of nonintegral values of n .

With the features and functions incorporated into the Senior Scientist, it is not difficult to see that this is a calculator that will be highly useful for any science, technology, and mathematics major right on through college and beyond.

About the Circuit. The schematic diagram of the Senior Scientist's basic circuit is shown in Fig. 1. It would be pointless to attempt a stage-by-stage analysis of this circuit, especially since what goes on inside of mathematical integrated circuits *IC1* through *IC3* would require a manual to explain. Consequently, only the high-lights are presented here.

The schematic shows a 40-key matrix for the keyboard. The unshaded boxes in the upper two rows are the single-function keys. The shaded boxes in the second two rows are the dual-function keys and are labelled with their primary functions. The secondary functions of these keys are illustrated by the phantom boxes in the last two rows. The F key, shown with a heavy outline box is responsible for shifting the two-function keys to their secondary functions.

Integrated circuits *IC1*, *IC2* and *IC3* form the special mathematics system that is responsible for all of the arithmetic and mathematics functions in the calculator. Integrated circuits *IC4*, *IC5*, and *IC6* isolate the display system from the low-power math IC's and provide the necessary drive current for the display. Last but not least, *IC7* is the 10-level memory system.

The power supply circuit for the calculator is shown in Fig. 2. This circuit employs an ingenious dc-to-dc converter that boosts the voltage available from battery *B1* to the level required by the calculator circuit. By employing this scheme, physical battery requirements are minimized and the calculator is kept to hand-held size.

Construction. There is no practical way to assemble the calculator without using a printed circuit board. The

board requires conductors on both sides. You can make your own board by using the actual-size etching guide shown in Fig. 3, but you will not be able to plate-through the holes as required. So, don't forget to solder component leads to both sides of the board.

Start assembly by soldering the battery clips (see Fig. 3 for component placement) to both sides of the board. Next, install *IC4*, *IC5*, and *IC6*. Solder their pins directly to the pads on the board. Do *not* use sockets. (The pin-1 pads for all IC's are indicated by short bars on the top of the board near the respective pads.) Install the capacitors, dc/dc converter, diode, power jack, potentiometer, and resistors.

Cut six 1½" (3.8-cm) lengths of ⅛" (3.2-cm) wide masking tape and press them onto the top of the board over the lead holes for *IC1*, *IC2*, and *IC3*. Press a 2½" (6.4-cm) length of the tape over the display board connector holes and a 2" (5.1-cm) length over the keyboard connector holes.

Break off a strip of 23 Soldercons and force their pointed ends through the tape and into the display connector holes. (Note: The hole at the far right is not used.) Solder the Soldercons to the pads on the board and carefully break away the connecting strip. Similarly, install 16 Soldercons at the bottom of the board for the keyboard and six sets of 14 Soldercons in the *IC1*, *IC2*, and *IC3* holes.

Before you remove the remaining IC's from their protective carrier, you must familiarize yourself with the following procedures to avoid damaging them by static electricity:

- Wear only anti-static clothing, such as cotton, when working with MOS devices. (Synthetics readily build up static charges.)

- Ground your work surface.
- Ground yourself; wrap a length of wire mesh around your wrist and terminate it at a cold water pipe or the grounding screw of an electrical outlet.

- Ground your soldering tip in a similar manner, but use heavy solid wire—not mesh—around the tip.

- Always install a MOS device immediately into its circuit after removal from its protective carrier and replace it in the carrier immediately after removal from the circuit.

- NEVER install a MOS device in, or remove it from, a circuit to which power is applied.

- Always install MOS devices last.

Once you have familiarized yourself with the proper procedures to use, remove *IC7* from its carrier and install it into place on the board, without using Soldercons. This done, install the remaining IC's.

Plug the display and keyboard assemblies (they come ready to use), into their respective connectors. When the keyboard is properly seated, two plastic posts on it drop into small holes in the pc board. The foam plastic on the back of the display board should be compressed against *IC4*, *IC5*, and *IC6*.

At this point, you can check out the calculator. Slip the battery into its connectors and turn over the calculator. Turn on the power; a 0, followed by a decimal point should come on. If not, the battery needs to be charged. Charge it, with the battery charger, for about an hour. (Note: If you operate the calculator at any time, the battery must be installed.)

Press C, 9, STO, 1, C, 5, STO, 5. The number 9 should now be stored in the second level of memory (0 is the first level) and 5 in the sixth level of memory. Now, press C, RCL, 1 (9 displayed), +, RCL, 5 (5 displayed), =; the display should now read 14.

Finally, press C, 8, Σ+, 5, Σ+, 3, Σ+, F, RCL; the answer displayed should be 16, which is the sum of 8 + 5 + 3. Set the power switch to OFF.

Potentiometer *R3* sets the point in the battery's charge condition at which the battery-low indicator (L) is displayed in the left-most digit. Set the pot to the center of its rotation initially. Then if you find that the L comes on too soon or doesn't come on soon enough, you can readjust the pot's setting.

To complete assembly, insert the bottom of the calculator assembly into the top half of the case and swing the assembly into place. It is properly positioned when the keyboard fits snugly into the case surround and a pair of plastic posts protrude through the bottom of the pc board. Thread a pair of small nuts onto the plastic posts to hold the assembly firmly in place. (It may be necessary to pre-thread the posts.) Insert the two lugs on the bottom of the back half of the case into the slots in the top half and snap the halves together.

Plug the adapter/charger into the jack on the side of the Senior Scientist and the plug into a wall outlet and let the battery charge for at least nine hours. ♦

Out of Tune

In "Now You Can Build a Scientific Programmable Calculator" (May 1976), there is an error in the program for solving $x - 3 =$ on page 38. Steps 12, 13, and 14 (GO TO, 2, and 0) will cause the machine to subtract 11 from x instead of 1. It will also cause the program to "not count" the number of times it goes through a loop, and the ultimate answer to any x with this program will be 0. The proper instructions should be GO TO, 1, and 8, respectively.