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An Electronic Desk Calculator You Can Build

THE PINNACLE OF DIGITAL PROJECTS—ADD, SUBTRACT, DIVIDE, AND MULTIPLY TO 16 DIGITS OF DISPLAY FOR UNDER $180

COVER STORY BY ED ROBERTS/MITS

JUST HOW MANY functions can be performed by a single integrated circuit? No one knows the ultimate answer to that question, but it's a cinch that semiconductor fabrication techniques that have produced what is known as "Large scale integration" (LSI) are well on the way to the final goal. You will understand why when you build the "POPULAR ELECTRONICS Calculator," the first hobbyist project to use these latest semiconductor devices. With this breakthrough in design, you can build, for less than $180, a desk calculator which is the equivalent of many costing between $400 and $600. The calculator has a 128-word, 1920-bit memory and can add, subtract, multiply, divide, and operate on constants.

An outstanding feature of the calculator is that, while the display shows only eight digits at one time, calculations can actually be made to sixteen digits. Momentarily depressing a display shift key results in the instantaneous recall and display of the eight least significant digits (LSD). (Depending on the location of the decimal point; LSD to the right of the decimal point resulting from an operation such as division cannot be displayed.)

Another convenient feature of the calculator is the overload warning indicator. If the calculator is asked to perform an impossible operation (such as dividing by zero), an "E" is displayed on the extreme left-hand readout. The E is also displayed if too many digits are entered to begin with.

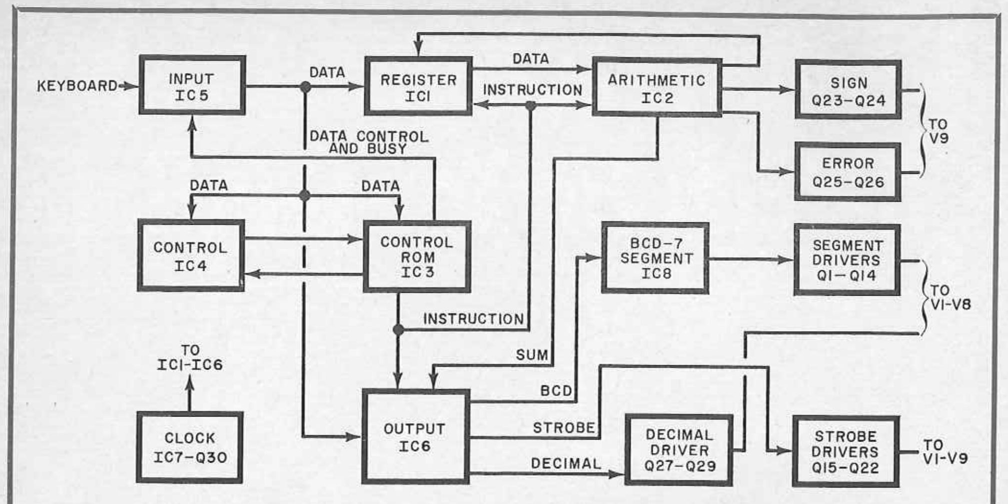


Fig. 1. Although this basic logic flow looks relatively simple, there are over 8000 transistors in this circuit, mostly in six LSI chips. The keyboard enters digits and operations, while the nine display tubes present final readouts.

PARTS LIST

The following are available from MITS, 2016 San Mateo, N.E., Albuquerque, NM 87110:

Complete calculator kit, including case, $179.00 plus $5 for postage, insurance, and handling.

Complete calculator assembled, $275, plus $5 for postage, insurance, and handling.

Display board assembly, $65, plus $3.50 for postage, etc.

Main board, keyboard, case, hardware, etc., less LSI's, $65, plus $2.50 for postage, etc.

Six LSI IC's (EA S-80), $75; keyboard, $21; display board, $12.50; main board $13.50; capacitor board, $4.50.

Five foil patterns, component layout diagrams, full-size mechanical interconnection, and complete schematics (M100-P), $2.00, postpaid.

In this calculator, leading zeros are suppressed, unless the number is less than one. Thus, .415 is displayed as 0.415, not 00000.415; and 3.1416 is displayed as is, not 0003.1416. This results in a much more easily read display, with fewer resulting errors.

An interesting construction feature of the calculator is that double-sided printed circuit boards are used. Plated-through holes serve to connect the two sides. The use of these boards serves several purposes: an excessive number of jumper wires is eliminated; the overall size of the calculator is considerably reduced; and the task of getting good solder connections is greatly simplified by the plated holes.

The calculator is also the first POPULAR ELECTRONICS project to use electro-luminescent display tubes. Volume production of the tubes has reduced their price so that it is possible to take advantage of their superior qualities.

Basic Design. The overall logic design of the calculator is shown in Fig. 1. There are six large-scale integrated circuits: *IC1*, the read-write memory register; *IC2*, arithmetic; *IC3*, read only memory (control); *IC4*, control; IC5, input; and *IC6*, output. The six LSI's are the equivalent of over 8000 transistors. They employ the common method of serial-parallel addition—digits are added in parallel and words serially.

All other parts and circuits in the calculator may be considered as auxiliaries to the LSI IC's. The keyboard, for instance is custom designed to operate with the LSI's used. It has, in addition to the digits 0 through 9, all the standard calculating instruction keys. The "constant multiply key" is separate since it is an on off function and requires a latching switch rather than a momentary contact. Although the use of the keyboard shown on the prototype is recommended because its performance is known to be

adequate, a satisfactory keyboard using standard momentary contact, normally open pushbutton switches can be constructed using the keyboard matrix shown in Fig. 2. In choosing a switch, remember that the bounce time of the key is highly critical, as it is closely related to the clock frequency of the calculator. In general, the bounce time must be less than 512 clock cycles or 2 milliseconds.

The clock circuit provides the timing base for calculator operations which must operate in a sequenced manner. The clock frequency determines the rate at which the calculator performs operations. Although the LSI IC's are designed to operate at a clock frequency no higher than 200 kHz, the clock in the calculator operates at 130 kHz to provide an adequate margin while still giving extremely fast operation.

Integrated circuit *IC7* uses diode transistor logic (DTL) and has three NAND gates connected to form an astable multivibrator which oscillates at 130 kHz. The output of the oscillator is buffered by a fourth NAND gate and is fed to the voltage amplifier, *Q30*. The output of *Q30* is a square wave with rise and fall times of less than 100 nanoseconds. This output is used by all of the LSI's as a reference signal.

Decoding functions are performed by *IC6* and *IC8*. Output *IC6* determines which digit to display (based on time); determines what the BCD data is for that digit; transmits that information to the decoder; determines the proper place of the decimal point; and detects leading non-significant zeros and suppresses them. Decoder *IC8* is a BCD-to-seven-segment converter that takes the number from *IC6* and sends the correct signals to the display section.

Data presented to the display section is in BCD format in serial form. (Digits of a number are relayed sequentially, rather than simultaneously.) The largest number is presented first. The output of *IC8* (Fig. 3) is in the form of lines which are pulsed in accordance with the number to be displayed. Each line feeds a segment driver circuit (*Q1* through *Q14*) which converts the pulses into voltages compatible with the display tubes. Each segment driver is connected to the same segment of tubes *V1* through *V8* (the

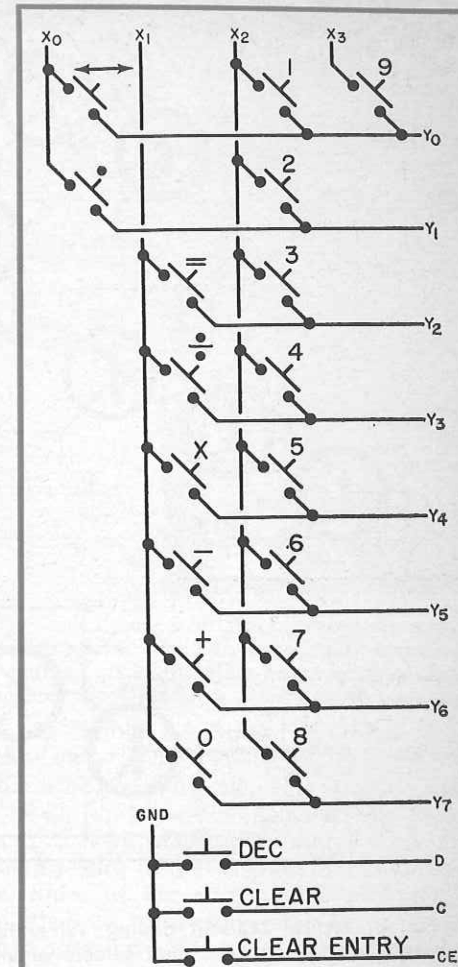


Fig. 2. The keyboard matrix may use a commercial keyboard, or any good pushbutton switches. Connections are to similarly marked board terminals.

EDITOR'S NOTE

This article presents an exciting new breakthrough construction project—a modern, high-speed 16-digit calculator. This makes it possible for anyone to own his own home calculator and at the same time complete a fascinating electronics hobby project. Although the project is an involved one, the construction is no more difficult than most, if a reasonable amount of care is used in its assembly. It is well within the capabilities of most amateur electronics enthusiasts.

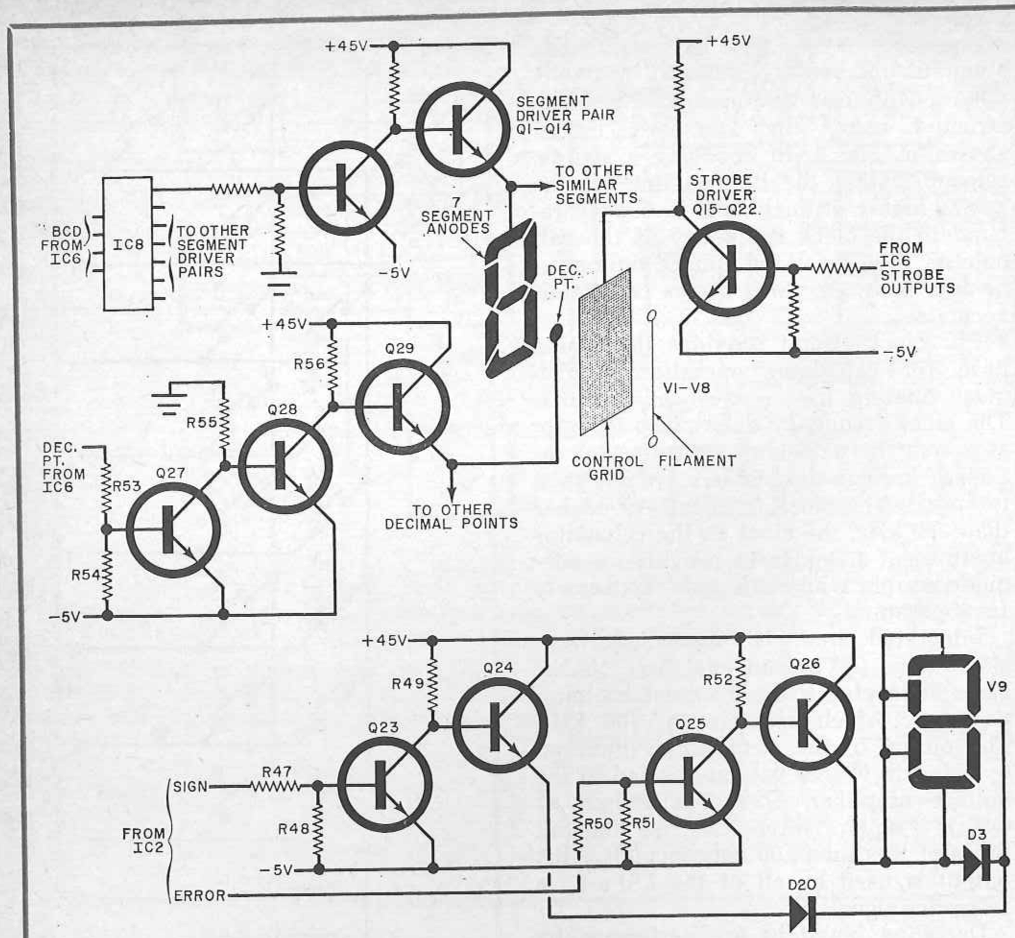


Fig. 3. Typical readout driving. All similar readout segments are driven simultaneously while strobe circuit selects which tubes are actually on. The circuit at the bottom illustrates how ninth tube displays either a "minus" or "E" (error) signal.

numerical displays). That is, segment one of tubes *V1* through V8 is driven by one segment driver, segment two of all tubes is driven by another segment driver, and so on. Thus, any time a number is relayed from the output IC, the segment driver provides plate voltage to the proper segments of all the numerical display tubes. However, none of the tubes will illuminate since a control grid voltage must be simultaneously applied. This is the job of the strobe drivers (*Q15-Q22*).

In addition to providing data to the decoder, *IC6* determines the display tube on which the number is to appear. When a strobe drive line is actuated, it provides a negative voltage to the strobe driver base, switching off the transistor and raising its collector potential to a high positive value. The collector is connected to the control grid of a display tube. When the grid goes positive, current flows to any plate elements in the tube which have been switched on by the decoder and segment drivers. This causes the phosphor on the selected segments of the tube to glow.

Output *IC6* begins the process with tube *V8* by actuating its strobe line. Then approximately 500 microseconds later, the strobe line switches to *V7;* and so on through *V1*. Thus, each tube is turned on approximately 250 times a second. With the rapid switching and the natural fluorescence of the tubes, the display appears to be on constantly.

In addition to the strobe lines, *IC6* has a decimal driver output, coupled through *Q27, Q28,* and *Q29* to the decimal points on all the display tubes. Output *IC6* determines which digit should be the one's digit and activates the decimal driver line simultaneously with the activation of the strobe driver for that digit.

Tube *V9* displays the sign and error indications. Arithmetic *IC2* activates *Q23* and *Q24* to provide plate voltage to the center element of *V9* to form the minus sign when this tube is strobed. The overflow line from *IC2* drives *Q25* and *Q26* to provide plate voltage to *V9* and form the "E" for error.

The electro-luminescent display tubes operate in a manner quite similar to a cathode ray tube. Electrons from the filament are accelerated past a control grid toward positively charged phosphor coated plates. When the electrons impinge on a plate, they cause the phosphor to glow. In the tubes are seven segments which, by various combinations, can form the numbers 0 through 9. Each individual segment is a plate.

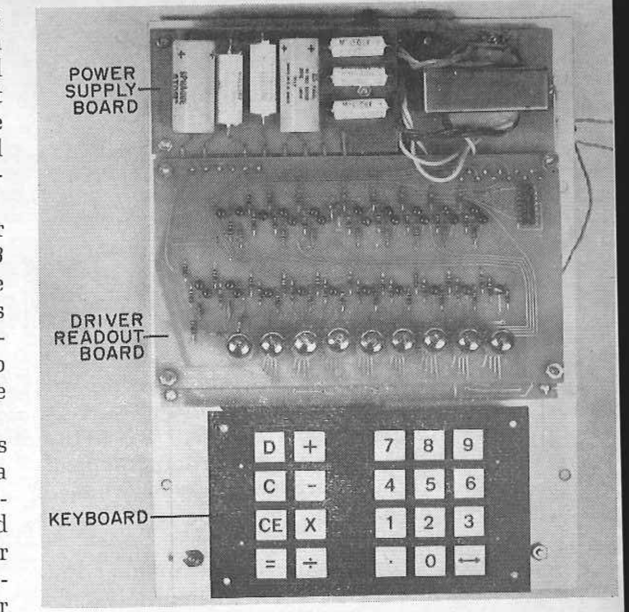
The power supply in the calculator has five output voltage: an unregulated +45V for the plates of the display tubes; an unfiltered, unregulated −2.4V for the series-parallel filament drive of the display tubes; a regulated −14V and −26V for the LSI IC's; and a regulated −5V for the other semiconductors. Regulation is provided by zener diodes.

Construction. The calculator consists of three PC boards and the keyboard. The six LSI IC's and the power supply are mounted on the largest board; the display tubes and associated circuits are on the second board; and power supply filter capacitors are on the smallest board.

The foil patterns for the boards are too large for reproduction here. They may be obtained as noted in the Parts List.

The main board, with the LSI's must be assembled with great care. Before installing the six LSI's, take a good look at them. The only difference between them is an identifying number stamped on the top surface. The pins are slightly pre-sprung to insure good contact. Each has a dot or notch to identify pin 1. Use a 25-to-30-watt soldering iron (not a gun).

When installing the display tubes, their



The calculator has lots of room to assist construction. The driver-readout board is mounted above the main board using spacers to tilt the readouts for better visibility.

leads should be clipped in rotation so that each lead is about 1/8 inch shorter than the previous one. This simplifies installing the tubes in their sockets. Make sure that all tubes are mounted correctly with regard to the viewing plane. The remainder of the components (one IC, 4 diodes, 29 transistors, and 56 resistors) can then be soldered in place. Observe polarities and, again, use a low-power soldering iron. Any holes on the board that remain empty are connections to the foil pattern on the back of the board.

Interconnections between the three boards are made with short lengths of insulated wire, color coded to prevent errors.

The large board forms the "base" of the calculator, with the display board above it, tilted so that the display is at the desired angle. The small board is mounted directly over the power supply end of the main board.

Checkout. Other than a detailed inspection, making sure that all components are properly installed and that there are no solder bridges, there is no way to check the complete assembly prior to operation. Pay particular attention to board-to-board and keyboard-to-board connections. Remember that a mistake found during pre-operation inspection is easily corrected; once the power is on, it could be quite expensive.

Use. Operating the calculator is so simple that it takes only a few minutes to "catch on." Here are the basics:

The button labeled "C" clears the entire machine. Any time you want to start all over, use it; but avoid it if you are in the middle of a computation and don't want to start over.

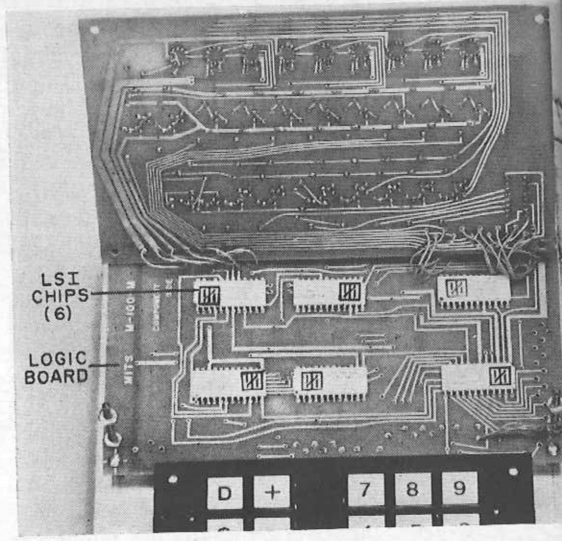
When you first turn the calculator on, the decimal point will be on the far right tube. To move it, press the "D" button and one of the number buttons, depending on how many spaces you want to move the decimal. Press the two buttons simultaneously.

Now pressing any of the number buttons enters a number. To multiply, add, subtract, or divide this number by any other, press the appropriate function button, then the second number, and then the "equals" button.

If, at any time, you enter a wrong number and want to get rid of it but not the previous calculations, press the "CE" button. This clears only the last number entered, and you can enter the correct number and proceed with the calculation.

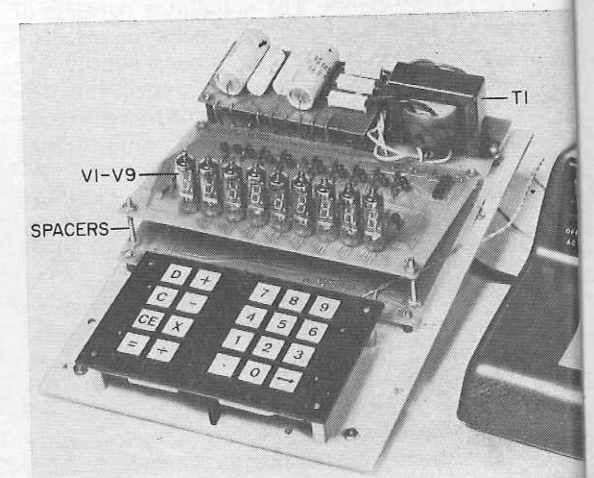
When you enter too many digits to be displayed or try to do something impossible (like dividing by zero), the E light will come on. If you subtract a large number from a smaller one, a minus sign will appear at the left.

To multiply or divide by a constant, turn on the constant "K" switch, enter the first number to be operated on and then the constant. Pressing the equal button will give the answer. Then to operate on any other number, enter the number and press the equal sign. For instance, if 5 is to be a constant, and you want to multiply it by 20, 30, and 40. Press 20, the times sign, 5, and the equals sign. The answer is 100. Now the 5 is entered as a constant. Press 30 and the equals sign, the answer is 150; press 40 and the equals sign, the answer is 200. This function is very valuable in calculating interest, percentages, etc. To change the constant, clear the machine. Be sure to turn off the K switch when you are through working with constants.



The two main boards have in-line interconnects, while the keyboard connections are at the bottom of the logic board. Note the six large LSI's on the double-sided board.

The button with the two-headed arrow is used to view the least significant digits of a number that is over 8 digits long (to left of decimal). For instance, with the decimal at the extreme right, multiply 789,456 by 789,456. The answer will appear as 623240775936 but only the first four digits will appear at first. To see the other eight digits, press the arrow-head button. ◈



The complete calculator including injected plastic case. Note how the display board is tilted via spacers to fit the case window.

UNDERSTANDING RECEIVER NOISE FIGURE AND SENSITIVITY

MEANING OF AN IMPORTANT SPEC AND HOW IT IS MEASURED

BY JAMES T. WEST

ONE of the first characteristics mentioned in the specifications for a receiver is "sensitivity." Unfortunately, the value given (usually in microvolts) is not as reliable an indication of quality as it might seem. To give the term sensitivity any meaning, more must be known about the conditions under which the measurement was made. In communications equipment, a receiver's sensitivity is usually defined as "the input voltage, from a matched source, required to produce a 10-dB S/N (signal-to-noise ratio), measured at the i-f stage output." Since the amount of noise power presented to a receiver is dependent on its bandwidth, the sensitivity is also dependent on that bandwidth.

Thus a good sensitivity voltage for one type of receiver may be a poor value for another. For instance, 2 microvolt sensitivity might be excellent for an FM BCB receiver, yet entirely inadequate for use on CB. To evaluate properly a receiver's performance, then, we need a quality factor which is independent of bandwidth and unaffected by whatever standard of S/N we employ.

While receivers may be designed to perform different types of service, use different bandwidths, and produce different S/N outputs, the final requirement is the same: a wanted signal must be discernable from random noise. A certain amount of input noise is unavoidable, but it is imperative that the receiver add as little noise as possible. The basic receiver quality factor indicates the amount of noise added by the receiver and is appropriately called the "noise figure." To understand the importance of the noise figure, however, it is necessary first to develop a few other concepts.

Understanding Noise. To many of us, the term noise is rather elusive. This is partly due to the fact that we do not distinguish properly between thermal (or device) noise, which is caused by random electron motion in matter, and the various forms of environmental noise. It is thermal noise which is of interest in studying noise in receivers. The amount of noise energy generated by random electron collisions in matter is proportional to temperature and is referred to as "thermal white noise." In any resistive material, thermal noise represents an amount of "noise power," and, due to its random nature, it appears evenly distributed in frequency across the entire spectrum. However, the exact amount of noise power which affects a receiver or r-f amplifier is restricted by the receiver's bandwidth. For narrow-band r-f amplifiers, the noise bandwidth may be as-