Experimenter's Corner

By Forrest M. Mims

MODIFYING CALCULATORS

NOW THAT "four-banger" electronic calculators are so inexpensive, modifying them for special-purpose applications is an attractive and cost-effective possibility. This month, we'll examine several ways of adding external features to a four-function calculator incorporating an automatic constant. To determine if a calculator you are thinking of modifying has an automatic constant, enter the following keystroke sequence: 1; +; =; =; =. If the display reads 3, the calculator is equipped with an automatic constant feature.

A Calculator Event-Counter. As you discovered when you ran through the simple keystroke sequence given above, a calculator with an automatic constant can count the number of times the "=" key is pressed. To automate this counting ability, it's necessary to connect an external switch across the contacts of the "=" key.

The calculator I modified, a Texas Instruments TI-1200 purchased new for about $6.00, has a 5×4 matrix keyboard. This keyboard is readily accessible by removing the four screws which hold the calculator's front cover in place. It has nine flexible leads, four of which address the vertical columns of keys and five the horizontal rows. The "=" key is accessed by the first and eighth wires from the top left of the keyboard.

Other calculators have different keyboard arrangements, and some recent models do not have a separate keyboard at all. Unless both sides of the circuit board are visible, you'll have to determine which wires access the "=" key by trial and error. Simply enter the sequence: 1; +; =; and, with the help of a jumper, begin shorting pairs of wires or foil conductors leading to the keyboard. Shorting digit keys may overwrite the 1 in the display. If so, reenter the 1; +; = sequence before trying again.

When you find the conductors that lead to the "=" key, carefully solder an insulated wire lead to each of them using a grounded or battery-powered iron. There is room in the TI-1200 and some other calculators for one or more miniature phone jacks. If your calculator has this extra space, drill a mounting hole, install a jack and solder the leads to it. Once the calculator has been reassembled, it can be used for both calculating and event counting.

Many different devices can be used to actuate the "=" function. For manual operation, an ordinary spst pushbutton switch connected to a two-conductor cable and plug is sufficient. For automatic counting, a magnetic reed switch or phototransistor can be used.

Fig. 1. A phototransistor connected to a calculator.

Figure 1 shows how a common npn phototransistor can be connected directly across the "=" key. Flashes of light will then actuate the "=" function. This permits moving objects to be counted without the need for mechanical contact. It also permits such novel applications as counting nearby lightning strokes during a nighttime storm.

A standard npn transistor can also be used as a switch. For example, to determine the maximum count rate for a TI-1200 calculator, I connected a 2N2222 across the "=" key and applied pulses from a variable-rate pulse generator as shown in Fig. 2.

The maximum usable count rate of each of these add-on circuits will be limited by the rate at which the calculator scans its keyboard to detect key closures. The TI-1200 that I modified has a multiplex rate of about 360 Hz, but that doesn't mean the unit will accept 360 closures of the "=" key each second. All twenty key locations are scanned one at a time by the multiplex circuit so, it would at first appear, the maximum number of counts per second is 20. Actually, my unit will accept a maximum of only
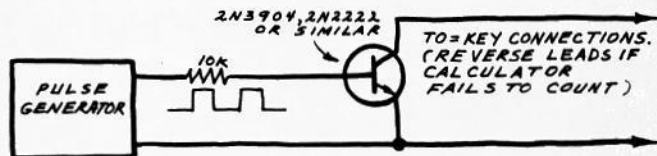

Fig. 2. Using a pulse generator with a calculator.

13.44 counts per second. That's because only those input signals present when the "=" key is in the process of being scanned are accepted. Those which arrive *and* depart between scans are *not* detected.

This can cause problems in applications where the pulse to be counted is very brief. For example, the reason I decided to modify my calculator was to count the number of times the front wheel of my bicycle rotated during specific time intervals (to determine the average speed of the bike) and during various trips (to determine the total distance travelled). A magnetic reed switch secured to the front fork was connected in parallel with the "=" key. A magnet attached to the wheel rim served as its actuator. It didn't take me long to discover that at speeds greater than about 5 mph some wheel rotations were not counted because the switch closed and opened again *between* the time intervals when the calculator was scanning its "=" key. This problem can be remedied by moving the magnet and switch closer to the hub assembly (using care to keep these components and the connecting wires away from the spokes!) or by adding a one-shot between the reed switch and the calculator to stretch out the pulses generated by the switch.

Calculator as a Timer. The addition of a simple timebase permits the TI-1200 or other low-cost calculator to function as a programmable timer. Figure 3, for example, is a simple CMOS timebase that can be assembled on a small circuit board to be tucked either between the display and keyboard or below the battery compartment of a TI-1200.

Two of the gates in a 4011 are connected as an astable multivibrator that delivers a stream of pulses to the LED in an optoisolator. The collector and emitter of the phototransistor in the optoisolator are connected directly across the "=" key.

For 0.1-second resolution, it's necessary to calibrate the timebase so that it generates pulses at a rate of 10 Hz. This can be done by using a physically small trimmer potentiometer for *R1* and connecting a frequency counter to the output of the time-

base. The prototype timebase that I assembled generated a 10-Hz output when $C1$ was nominally $4.7\,\mu F$ and $R1$ was adjusted to 2270 ohms.

To operate the calculator as a timer, enter the sequence: .; 1; + and then close $S1$ (Fig. 3) to allow the timebase to feed pulses to the "=" key. Release $S1$ when the event being timed is over. Read the elapsed time to the nearest one-tenth of a second from the display. You can then use the calculator to convert the time, which is displayed in seconds, into minutes or hours.

For precision timing, a crystal-controlled timebase is required. A few years ago, Charles Stanford described in this magazine a simple, external, crystal-controlled timebase that can be added to most four-function calculators having an automatic constant. (See "How to Convert a 'Four Banger' for Stopwatch Functions."

Fig. 3. CMOS time base converts calculator into timer.

August 1977.) The circuit employs a readily available 3.579545-MHz color-television crystal, a programmable counter/divider, and a divide-by-six counter to provide an accurate 10-Hz output. This pulse train actuates an analog switch connected across the calculator's "=" key.

Charles' circuit is excellent, and I recommend it highly if your timing applications require a high degree of accuracy. Incidentally, if you want to use the foil pattern included as Fig. 2 in the article, note that the component-location designations of $IC1$ and $IC2$ are transposed. The schematic diagram is correct.

Adding an Output Port. Upon the addition of an output port, a low-cost calculator can become a primitive, but useful, digital controller. Microprocessor chips usually have one or more pins designated as ports. The ports permit external devices to influence the microprocessor when they are functioning as input ports or to be controlled by the microprocessor when they are acting as output ports.

There are several ways to add one or more output ports to a calculator. So far, the two simplest methods I've identified are monitoring the minus sign and the decimal point in the display. Let's see how the decimal point can be monitored.

If you enter in the keystroke sequence: 10.0; −; 1.0 on a TI-1200 or similar calculator, the display will be decremented by 1.0 each time the "=" key is pressed. That is, the display will read 10.0; 9.0; 8.0; . . . 2.0; 1.0; 0.; −1.0; etc. Notice that when the count reaches zero the decimal point moves one place to the right. When the count is above or below zero, however, the decimal point stays at least one place to the left of the lowest-order digit in the display.

This makes possible the use of the lowest-order decimal point as an output port. All you have to do is find the contacts on the display that lead to the lowest-order digit and the decimal point.

The TI-1200 display has 17 connection tabs. Tab 9 is connected to the common cathode of the lowest-order digit and tab 13 is connected to the decimal point.

Figure 4 shows one way to interface an external circuit to a decimal-point output port. The LED/LASCR optoisolator provides a latching action that keeps a LED or other output device continuously on once it has been triggered. The calculator display will keep a record of the number of trigger events that occur after the LASCR has fired.

A typical application for a calculator modified to include an output port is a programmable timer (such as one for darkroom use) that is capable of controlling an external device. If the timebase is deliver-
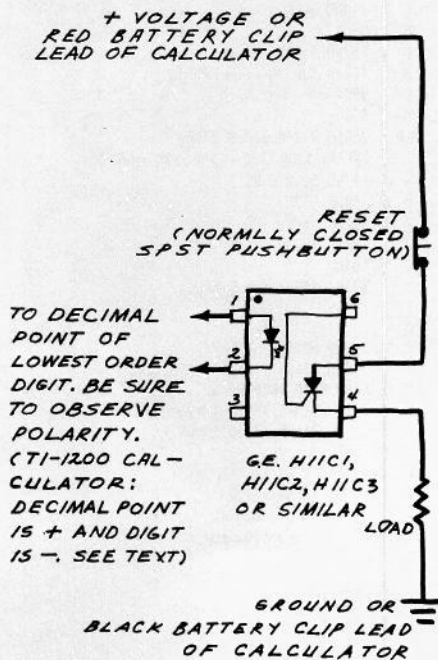
Fig. 4 Adding an output port to a calculator.

ing pulses at a rate of 10 Hz, a maximum delay of up to 9,999,999.0 seconds (more than 115 days!) is available, assuming that the calculator is programmed to decrement the total by 0.1 per clock pulse and that the power supply does not fail. Using a slower clock rate or reducing the tally in much smaller increments can easily increase the longest possible time delay to years!

With a little care, you should be able to fit both the timebase and output-port circuits into the vacant space inside a TI-1200 or similar calculator. Alternatively, the additional circuits can be installed in a small enclosure and interfaced with the calculator using miniature phone plugs.

The output port has a number of applications other than timing. For example, you can program the calculator to count a given number of events (revolutions of a wheel, openings of a door, passing of cars, etc.) and then generate an output signal when the desired number have tak-

en place. Unless you make special modifications which affect the use of the keyboard, the calculator can be used for its normal purpose when it's not being used for special applications.

Going Further. With a little experimentation, you will be able to come up with some clever applications of your own for modified calculators. For starters, you can remotely actuate any key on a calculator keyboard using the same techniques we've described in this column to actuate the "=" key. Keep in mind that the automatic constant feature of the TI-1200 and

many other calculators works for all four primary arithmetic functions.

For advanced applications, consider modifying more powerful calculators. Some programmable calculators are now available for under $50. If you're not concerned about voiding the warranty of a programmable (or if it has expired), you might consider adding external circuits employing some of the methods described in this column. One possibility is a beeper that's automatically actuated when a long program is completed. Automatic data entry at a specified point in a program is another. ◇