# A Programmable FUNCTION GENERATOR

*Produces laboratory-accuracy sine/square/triangle waveforms through crystal control*

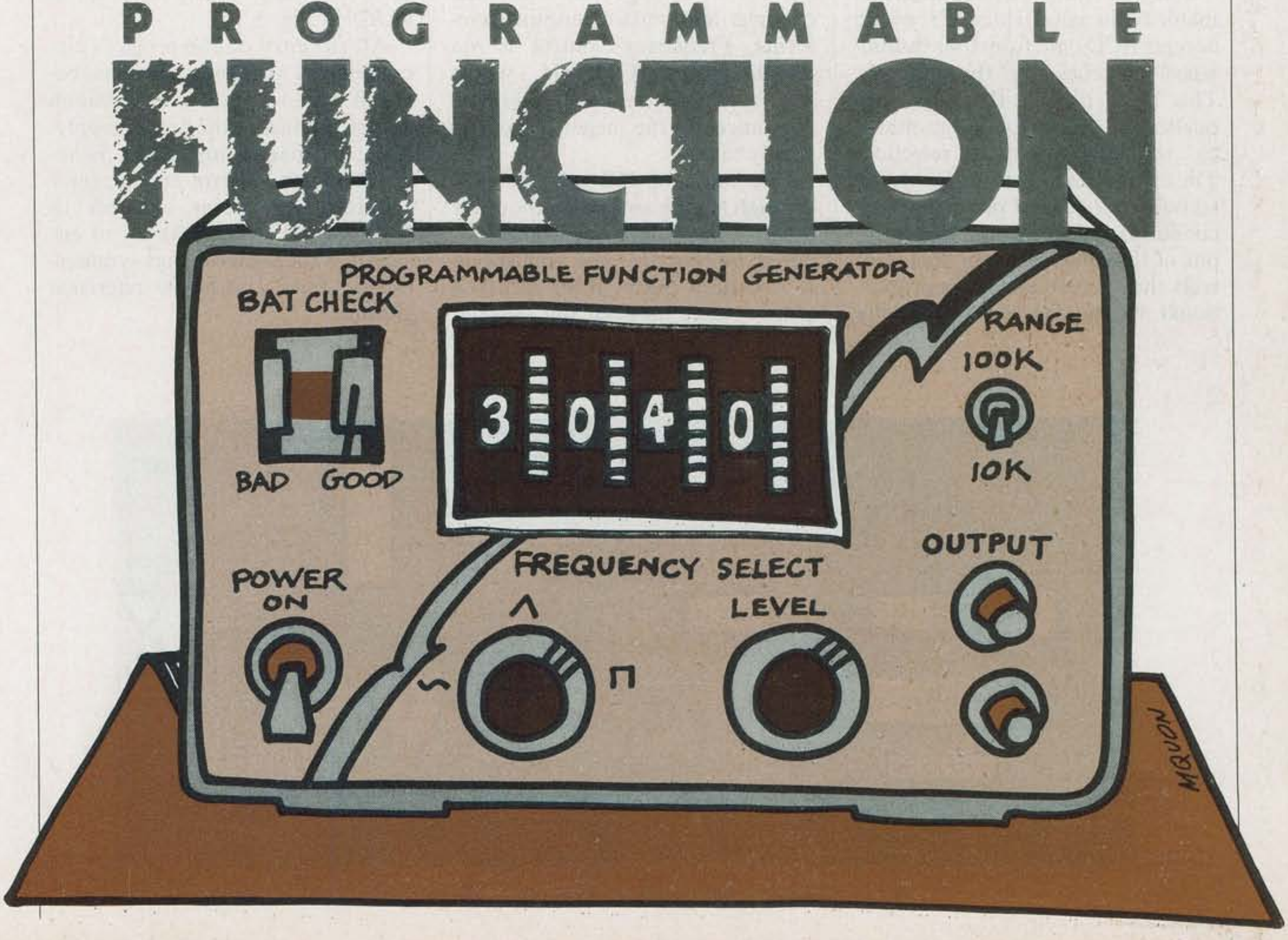
*By Gary McClellan*

THE UBIQUITOUS function generator is a versatile general-purpose test instrument in the tradition of the multimeter and the oscilloscope. Like these instruments, the function generator finds a host of applications in virtually every area of electronics, from audio to digital. The low-cost programmable function generator described here has few of the shortcomings of other such instruments. It also has features you'd normally expect to find in far more expensive instruments.

Thanks to crystal control, the programmable function generator's frequency range (20 to 10,000 Hz in 1-Hz steps and 200 to 100,000 Hz in 10-Hz steps) can have a calibrated accuracy of ±0.005% or better, which is true laboratory-grade quality. Even without instrument calibration, the project's basic accuracy is in the range of ±0.01%, an impressive figure by itself.

Available at the programmable function generator's output are sine, square, and triangle waveforms, all buffered to drive low-impedance loads and direct coupled to provide excellent low-frequency response. Sine-wave distortion ranges from less than 0.5% THD at all frequencies up to 10,000 Hz and to 3% beyond.

**General Description.** The programmable function generator is built around a single chip that has



very low sine-wave distortion characteristics. The basic circuit of the instrument, shown in Fig. 1, consists of two phase-locked loops (PLLs). (CMOS devices are used throughout to keep power requirements low.) The first PLL is a frequency synthesizer made up of *IC1*, *IC2*, and *IC3* and their associated components.

The output of oscillator/divider *IC1*, controlled by a conventional 3.58-MHz color TV crystal, goes to the phase-detector portion of *IC2*, whose output is, in turn, coupled to its companion voltage-controlled oscillator (vco). Coupling here is via a loop filter that converts the output of the phase detector into a smoothed dc voltage that controls oscillator frequency. The loop filter also stores the dc for short periods when the phase detector goes into its high-impedance state.

The vco's output drives programmable frequency divider *IC3*, which accepts BCD data from four thumbwheel switches (*S1* through *S4*). This stage divides the input frequency by the factor programmed by thumbwheel-switch selection. The divided output from *IC3* is the second input to the phase detector contained in *IC2*. Hence, the dc output of the phase detector that controls the vco's frequency is proportional to the frequency (actually phase) difference between the two inputs.

The selected vco frequency is passed to frequency divider *IC4*, a dual decade counter. To obtain 1- and 10-Hz resolution on the 10- and 100-kHz ranges, respectively, the first PLL must operate at some high frequency that can be successively divided to produce a frequency in the desired range. To accomplish this, *IC4* divides by 10 for the 100-kHz range and divides by 100 ($10 \times 10$) for the 10-kHz range, depending on whether RANGE switch *S5* is set to LO or HIGH. The complete schematic diagram of this portion of the circuit is shown in Fig. 2.

The second PLL in the system is made up of *IC5*, *IC6*, *IC7*, *Q1*, and their associated components. This tracking-filter circuit accepts the signal selected by the RANGE switch and delivers clean sine, triangle, or square waveform signals from the logic-level signals delivered by *IC5*.

Function generator *IC6* is essentially a wide-range vco with sine, triangle, and square output waveforms. Frequency control is via VMOS power FET *Q1*, which serves as an electronically variable resistance in the negative-voltage supply to *IC6*.

One input of *IC5* is from *IC4*, through RANGE switch *S5*; the other input comes from *IC6*, whose output is buffered by one element in *IC7*. Output pulses from *IC5* (the error voltage between the selected input from *IC4* and the oscillator in *IC6*) are coupled through a loop filter that smooths the dc output to drive *Q1*. This locks the output frequency of *IC6* to the dc output of *IC5*, which in turn can be traced directly to the crystal oscillator.

Output waveforms (sine, triangle, or square) are selected with *S6*. LEVEL control *R32B* provides the means for adjusting the amplitude of the output signal. The output of *IC6*, selected with *S6*, is passed to buffer *IC8* for connection to external devices. The complete schematic diagram for this portion of the project is shown in Fig. 3, which is a continuation of the circuit shown in Fig. 2.

Since the generator requires a bipolar source of power from a pair of rechargeable 9-volt batteries, some means must be used to create a reference ground for the needed positive and negative voltages. This is accomplished with the power supply circuit made up of 12-volt regulator *IC10* and operational amplifier *IC9* in Fig. 3.

All circuitry on the project's circuit board assembly connects between the +12-volt and common (negative) lines of the power supply. Some off-board components, namely the LEVEL control and OUTPUT connectors, however, connect to *IC9*'s output ground (GND) to ensure that the signal swings symmetrically above and below reference ground.

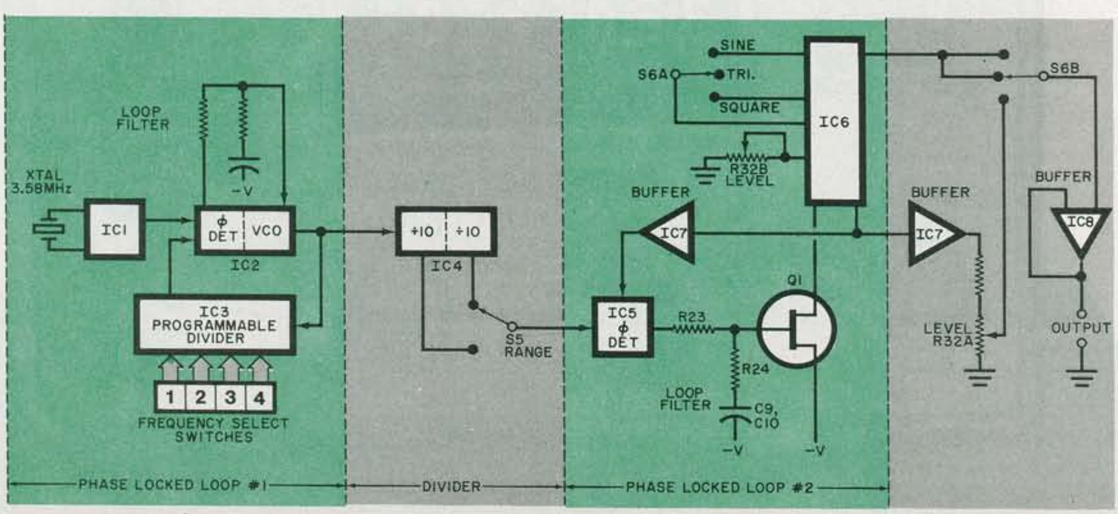



*Fig. 1. The basic circuit consists of two phase-locked loops.*

Op amp *IC9* serves as a buffer, with resistors *R29* and *R30* forming a voltage-divider network between the +12-volt and common buses. As a result, the +V and −V are at +6 and −6 volts, referenced to GND at the output of *IC9*.

An expanded-scale voltmeter consisting of *M1*, *R33*, and zener diode *D3* monitors the condition of the battery's charge state. It's designed to cover a range of 13 to 14.5 volts across two-thirds of its scale, which indicates simple BAD/GOOD conditions.

Since *IC10* stops regulating at about a 13.8-volt input level, it's important to recharge batteries *B1* and *B2* just as or before the meter's pointer swings into the BAD area on the scale.

The meter's circuit works on the "knee" of the zener diode. When the input from *B1* and *B2* is less than 12 volts, *D3* isn't biased, resulting in no indication on *M1*. At an input of 12 volts, *D3* begins conducting and passes current through limiting resistor *R33* and the meter.

## PARTS LIST

B1,B2—Rechargeable 9-volt battery
C1,C17—0.1-µF, 25-V disc capacitor
C2—33-pF disc capacitor
C3—5-to-20-pF trimmer capacitor (E.F. Johnson No. 275-0320-005 or similar)
C4,C14—10-pF disc capacitor
C5—47-pF disc capacitor
C6,C11—1-µF, 16-V tantalum capacitor (do not substitute)
C7—47-µF, 16-V upright pc electrolytic
C8—100-µF, 16-V upright pc electrolytic
C9,C10—22-µF, 16-V tantalum capacitor (do not substitute)
C12—0.0068-µF Mylar capacitor (do not substitute)
C13—100-pF disc capacitor
C15,C16—22-µF, 16-V upright pc electrolytic
D1,D2—1N4148 diode
D3—1N4742 (12-V, 1-W) zener diode
IC1—MM5369 EST oscillator/divider
IC2,IC5—CD4046 CMOS PLL
IC3—CD4059 CMOS counter
IC4—CD4518 CMOS counter
IC6—XR2206 function-generator
IC7—CD4050 CMOS hex buffer
IC8—318 operational amplifier
IC9—356 operational amplifier
IC10—7812 or 340-12T 12-V regulator
J1,J2—5-way binding post (red, black)
J3—Power connector (Switchcraft 712A)
M1—0-to-400-µA meter movement with BAD/GOOD scale
Q1—VN10KM VMOS FET
The following are ¼-W, 5% carbon-film resistors unless otherwise specified:
R1—10 megohms
R2 through R18,R23,R29,R30—100 kilohms
R19,R31—2.2 kilohms
R20,R26,R28,R33—10 kilohms
R21—500-ohm potentiometer (Jim-Pak No. 840P-500 or similar)
R22—20-kilohm potentiometer (Jim-Pak No. 840P-20 or similar)
R24—330 ohms
R25—1 kilohm
R27—100 ohms
R32—50/5-kilohm dual linear-taper pot.
R34—Approx.100 ohms
S1 through S4—Decade thumbwheel switch (Unimax No. SR-21 or similar)
S5—Spdt switch
S6—3-position, 2-pole nonshorting rotary switch
S7—Spst switch
XTAL—3.579545-MHz color TV crystal
Misc.—Printed circuit board or materials for fabricating same; quick-set epoxy cement; one 24-, five 16-, and three 8-pin IC sockets; battery holders and connectors for *B1* and *B2*; control knobs (2); plastic enclosure large enough to house circuitry; ribbon cable; 14-V plug-in battery charger; etc.

***Note: The following is available from Technico Services, P.O. Box 20HC, Orangehurst, Fullerton, CA 92633: etched and drilled printed circuit board (PFG-1) for $12.00 postpaid in U.S. California residents, please add sales tax. Foreign residents, add $3.00 postage and handling for foreign orders.***

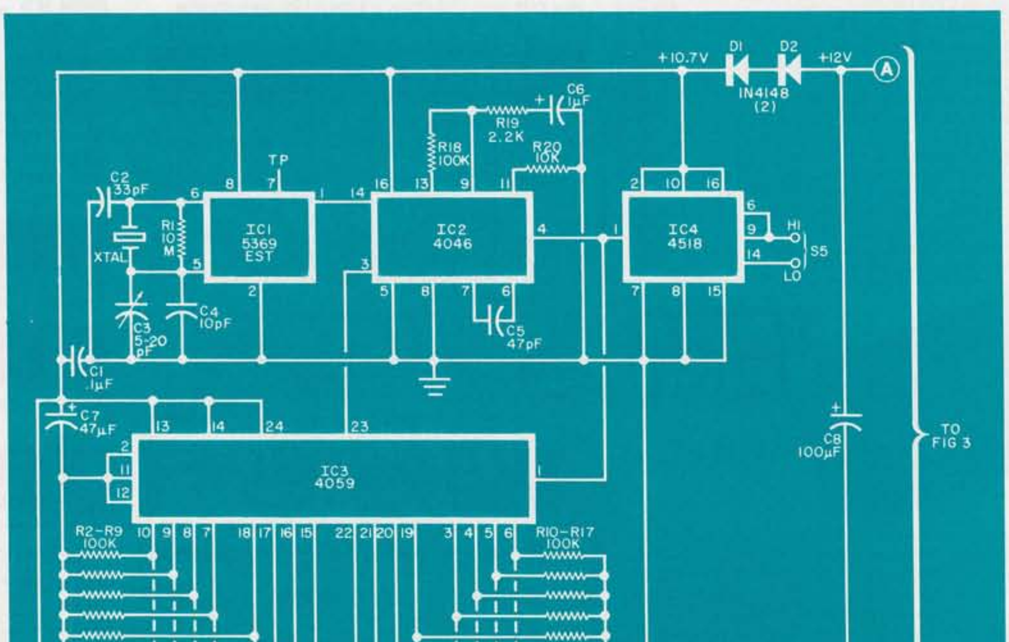
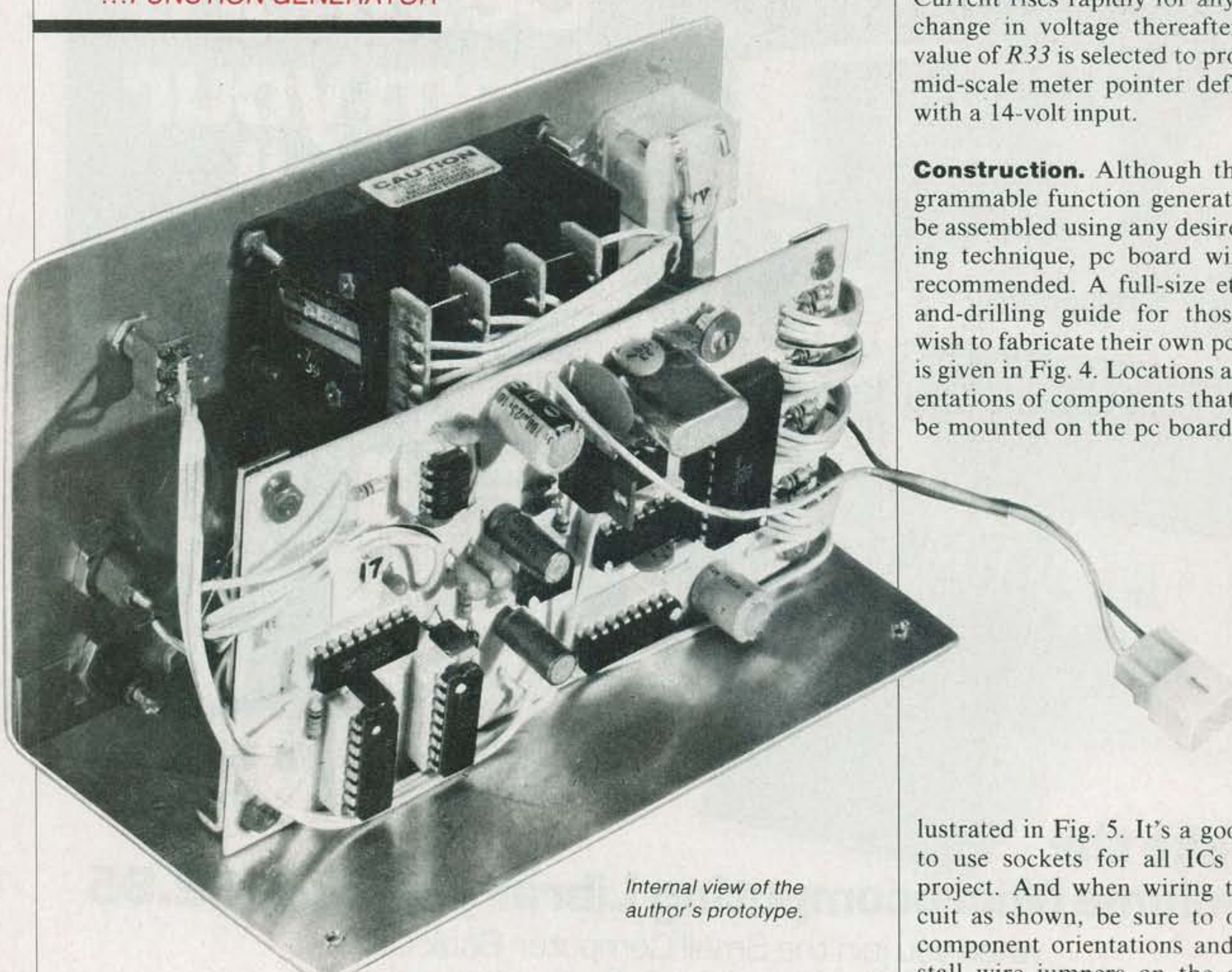



*Fig. 2. The first phase-locked loop is a frequency synthesizer as shown here.*




*Internal view of the author's prototype.*

Current rises rapidly for any small change in voltage thereafter. The value of *R33* is selected to provide a mid-scale meter pointer deflection with a 14-volt input.

**Construction.** Although the programmable function generator can be assembled using any desired wiring technique, pc board wiring is recommended. A full-size etching-and-drilling guide for those who wish to fabricate their own pc board is given in Fig. 4. Locations and orientations of components that are to be mounted on the pc board are illustrated in Fig. 5. It's a good idea to use sockets for all ICs in the project. And when wiring the circuit as shown, be sure to observe component orientations and to install wire jumpers on the compo-

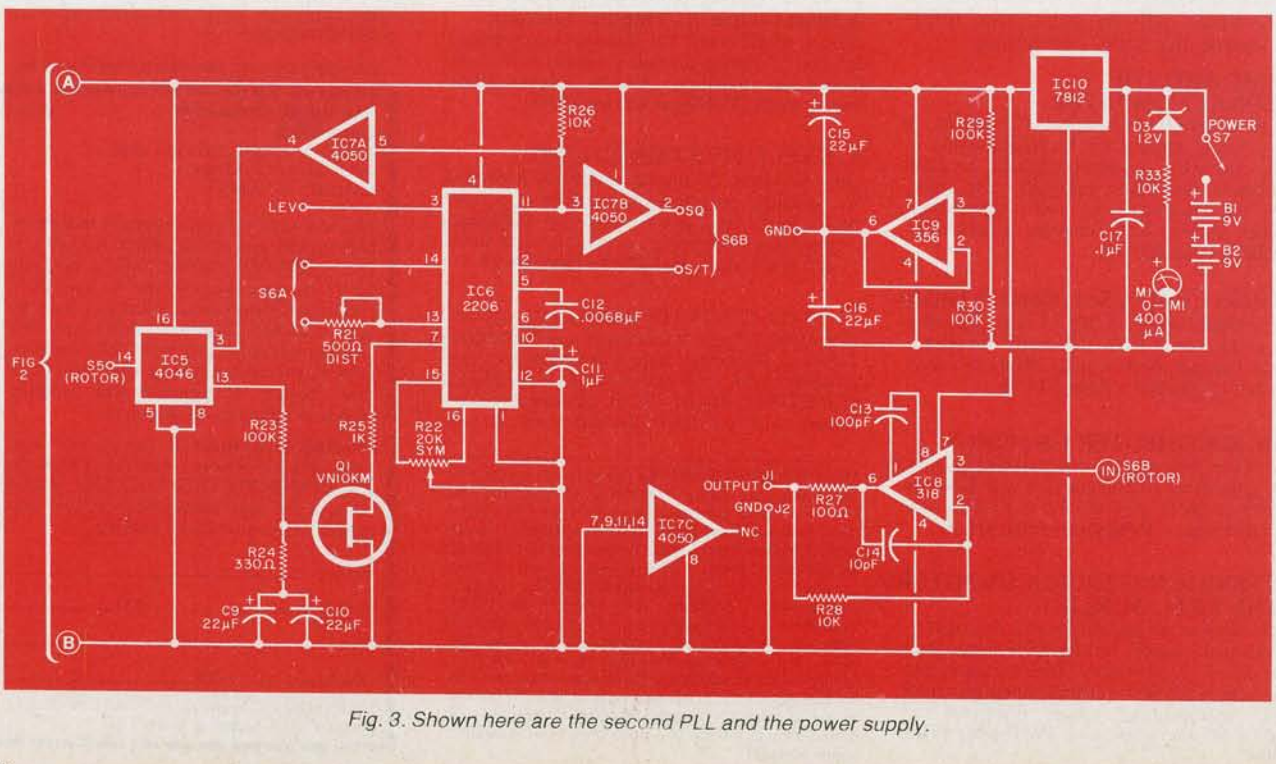



*Fig. 3. Shown here are the second PLL and the power supply.*

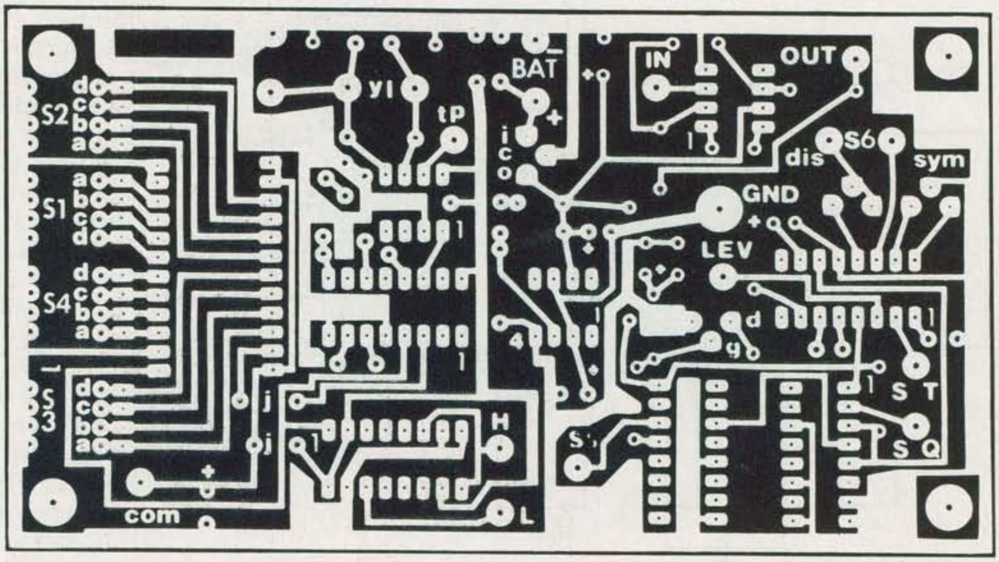



Fig. 4. Full-size etching and drilling guide for pc board.

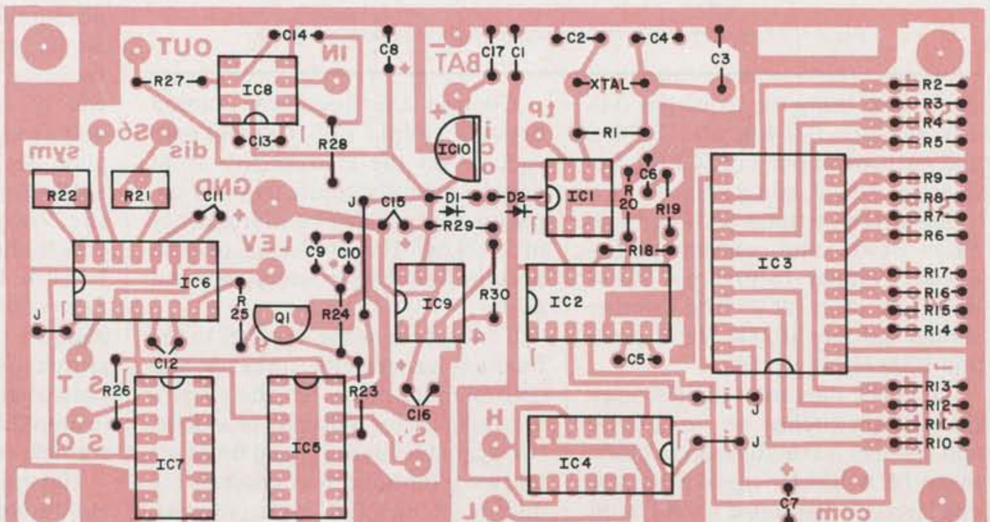



Fig. 5. Locations and orientations of the components on the pc board.

nent side of the board where indicated.

All off-the-board components must be mounted on the walls of the enclosure selected to house the project, via appropriate-size mounting holes. The exception here is with batteries *B1* and *B2*, which mount in brackets that are secured to one of the inside walls of the enclosure with quick-set epoxy cement. An ordinary 4″ × 6″ plastic file box makes an ideal-size enclosure for the project.

Interconnect the off-board components with the pc assembly according to the diagram shown in Fig. 6. Note the use of 4-conductor ribbon cable between thumbswitches *S1* through *S4* and the appropriate solder pads on the printed circuit board.

Upon completion of assembly, use a lettering kit to label identifiers and/or positions of the various controls, switches, connectors, and meter.

**Test and Adjustment.** With the function generator powered up, measure the frequency at pin 1 of *IC1* with a frequency counter. The counter's display should read 100 Hz, which is the reference signal; if it reads 60 Hz, the wrong IC is installed. Make sure that you install an MM5369-EST version in the *IC1* socket before proceeding.

Set thumbwheel switches *S1* through *S4* to 1-0-0-0 and use the frequency counter to measure the frequency at pin 4 of *IC2*, which should be 100,000 Hz. Then set *S1* through *S4* to 2-0-0-0, 4-0-0-0, and 8-0-0-0 and in each case note the frequency measured at pin 4 of *IC2*. The displayed frequencies should be 200, 400, and 800 kHz, respectively. Repeat the switch-setting sequence using 0-1-0-0, 0-2-0-0, 0-4-0-0, and 0-8-0-0 and note that the measured frequencies at pin 4 of *IC2* are 10, 20, 40, and 80 kHz, respectively. Repeat the thumbwheel settings one

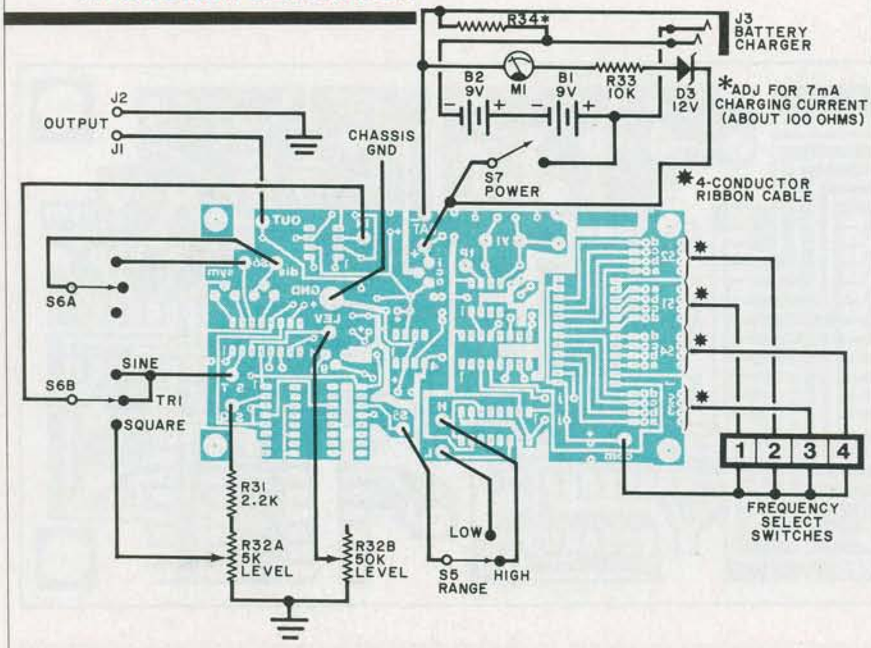



*Fig. 6. Connection of off-board components to the pc assembly.*

more time, using the sequences 0-0-1-0, 0-0-2-0, 0-0-4-0, and 0-0-8-0 and measure at pin 4 of *IC2* the frequencies 1, 2, 4, and 8 kHz.

Return the settings of *S1* through *S4* to 1-0-0-0 and connect the frequency counter to first pin 9 and then pin 14 of *IC4*. The counter should indicate 10,000 Hz at pin 9 and 1000 Hz at pin 14.

To check operation of *IC6*, keep the thumbswitches set to 1-0-0-0 and connect an oscilloscope's probe to pin 14. A 10-kHz signal should be displayed on the scope's CRT with the project's RANGE switch set to HI and 1 kHz with it set to LO. A square-wave signal should be present at pin 11 of *IC6* and pin 3 of *IC5*.

Once the programmable function generator has been tested, you can proceed to adjustments with an oscilloscope and accurate frequency counter. If you don't have access to these instruments, you can skip this section. Basic accuracy of the instrument, even without formal calibration procedures, will be sufficient for all but critical testing.

Begin the adjustments procedure by setting POWER switch *S7* to ON, FREQUENCY SELECT thumbwheel switches to 1-0-0-0, RANGE switch to LO, and function switch *S6* to SQUARE. Position LEVEL control *R32* to the center of its rotation.

Connect the frequency counter between TP (pin 7 of *IC7*) and GND jack *J2* on the instrument's front panel. Carefully adjust trimmer capacitor *C3* for a displayed frequency of 3,579,545 Hz. This done, disconnect the frequency counter and set it aside.

Connect the scope's probes to the function generator's OUTPUT and GND binding posts. Set the scope's vertical gain for a display of at least two graticule divisions and horizontal sweep time and sync controls for display of one full cycle, starting and ending at the ends of the graticule. Adjust trimmer potentiometer

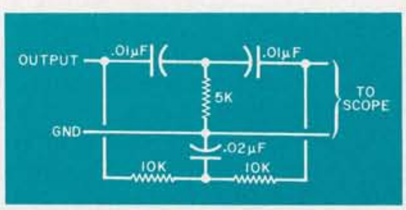



*Fig. 7. Filter to be used in viewing project output on scope.*

*R22* until the waveform changes state at the center of the graticule, producing positive and negative signal peaks of equal size on the CRT screen.

There are three ways to adjust for minimum sine-wave distortion. One is to set the function switch to SINE and adjust trimmer potentiometer *R21* (DIST) for a clean approximation of a sinusoid waveform at the output of the function generator. Using this technique, distortion can be brought to within 3%. If the sine wave flattens during adjustment, decrease signal amplitude with the LEVEL control to restore the sinusoid shape to the monitored waveform.

An alternative approach to making the distortion adjustment requires building of the bridged-T filter shown schematically in Fig. 7. (Use 1% tolerance resistors and matched capacitors when assembling this circuit.) With this filter connected to the project's OUTPUT and GND binding posts, use an oscilloscope to observe the signal present directly at the project's output connectors (before the filter) while adjusting the LEVEL control for a 2-to-3-volt peak-to-peak signal. Then move the scope probes to the output end of the filter and adjust the scope's vertical gain for a usable display. Set the function generator's FREQUENCY SELECT switches for the lowest-amplitude display, which should be in the neighborhood of 1590 Hz with the component values specified in Fig. 7. Disregard the least-significant-digit switch (*S4*), since the units position switch generates such small changes in amplitude that they won't be discernible on the scope's CRT.

Having adjusted for minimum amplitude, adjust DIST control *R21* to minimize the displayed signal. All peaks should have equal amplitude. In the prototype, this point occurred at about a 9-mV peak-to-peak signal level.

The third and, by far, most accurate approach to minimizing distortion is with the aid of a total harmonic distortion (THD) analyzer. If you have access to such an instrument, connect it to the programmable function generator's OUTPUT and GND binding posts and set the FREQUENCY SELECT switches for a 1-kHz output. Then adjust the project's DIST control for the lowest possible measured distortion figure. This is a one-time-only adjustment; the DIST control need never be touched again unless you replace *IC1* or *IC6*. ◇