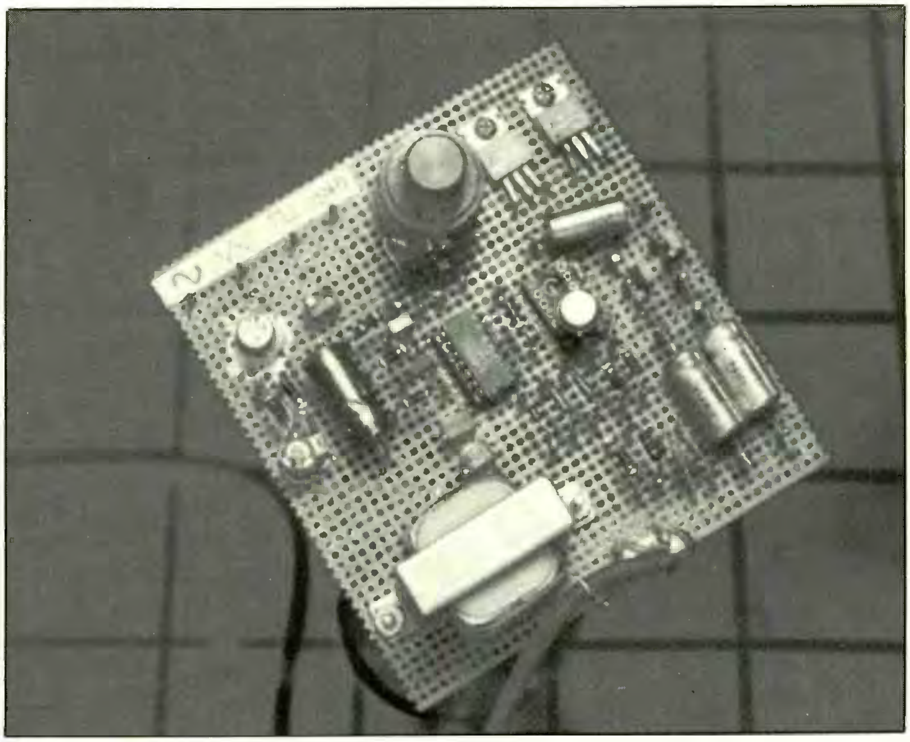
A Low-Cost Function Generator

This project delivers individually adjustable sine, triangle and square waves simultaneously over a frequency range of less than 1 Hz to almost 300 kHz into almost any load impedance

By Anthony J. Caristi



A commercial multipurpose signal source that can deliver a wide range of signal waveforms and frequencies into almost any load impedance usually costs $200 or more. With modern integrated-circuit technology, however, high cost need not be the case. The sine/triangle/square-wave function generator to be described is such an example. Built around a relatively inexpensive precision waveform generator chip from Intersil, the entire project costs less than $50 to build, including enclosure.

Depending on choice of options, the function generator can be made to cover a frequency range of less than 1 Hz to almost 300 kHz. The square-wave output has a respectable risetime that is close to 0.1 microsecond, and sine-wave distortion is typically less than 2 percent. Output impedance, at less than 1 ohm, makes the generator suitable for driving almost any load to be encountered in modern electronic circuits. Hence, except for extremely critical applications, this generator is suitable for use on both a hobbyist's and a professional's testbench.

About the Circuit

As shown schematically in Fig. 1, the function generator is designed around a low-cost integrated circuit (*IC3*) that has been designed by Intersil to serve as a precision waveform generator/voltage-controlled oscillator with only a minimum of external components. Operating frequency is selected externally by means of a given value of capacitance connected between pin 10 of the chip and the negative (– 15-volt) supply rail and the voltage applied to pin 8 by means of potentiometer *R2*. Possible range from this IC is 0.001 Hz to almost 300 kHz. With the values specified for *C6*, *C7* and *C8*, three overlapping frequency ranges covering 15 Hz to 100 kHz can be selected with RANGE switch *S2*.

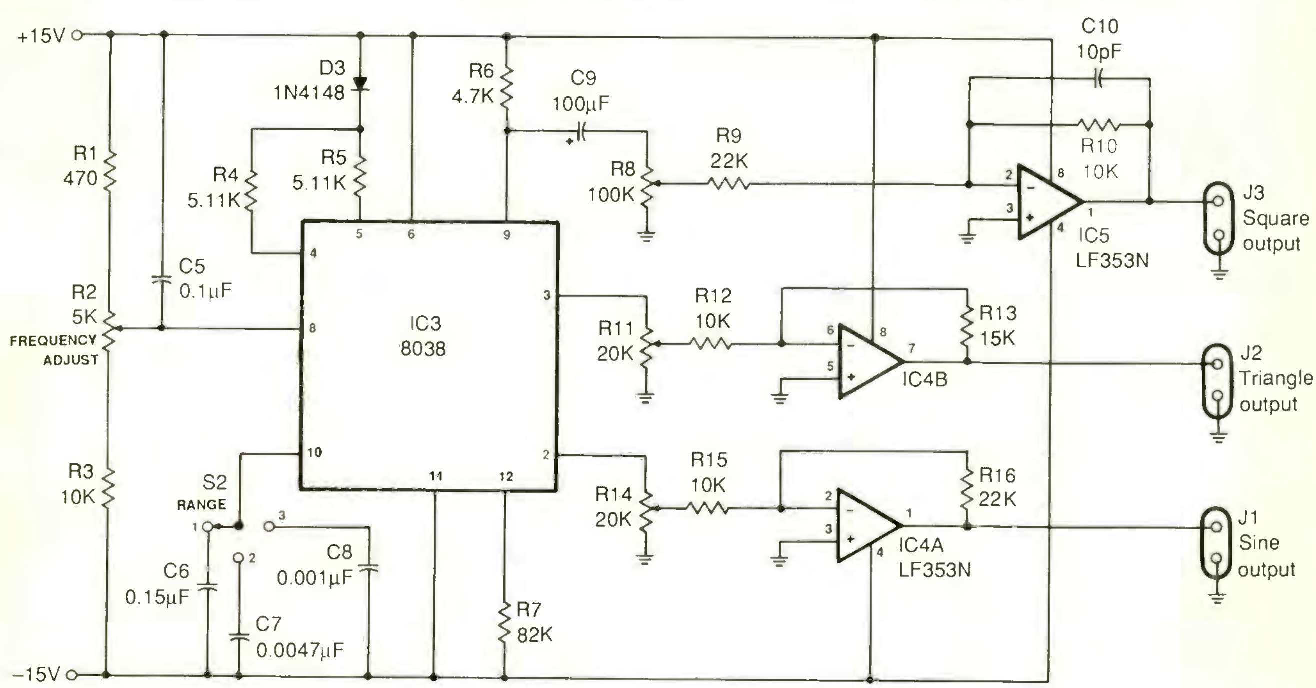
Since the chip's operating frequency is inversely proportional to the value of capacitance used, the choice of values can be changed to suit individual requirements. Also, if you want a greater range or operating frequencies, you can add bands simply by using a rotary switch with a greater number of positions to accommodate more capacitors.

For any given value of capacitance

inserted between pin 10 of *IC3* and the −15-volt rail, the frequency adjustment range provided by *R2* is about 40:1. For the values shown for *C6*, *C7* and *C8*, the frequency bands are 15 Hz to 600 Hz, 500 Hz to 20 kHz and 2.5 kHz to 100 kHz.

Simultaneous sine, triangle and square waveforms appear at pins 2, 3 and 9 of *IC3*. Amplitudes of the sine and triangular waveforms are about 6 and 9 volts peak-to-peak, respectively. The square-wave output is about 25 volts peak-to-peak.

Note that the circuit contains three amplitude adjustment controls (*R8*, *R11* and *R14*) and three output buffer amplifiers (*IC5*, *IC4B* and *IC4A*, respectively) so that each of the waveforms can be independently adjusted over a range of at least 12 volts peak-to-peak. With an amplitude of 12 volts peak-to-peak, the sine wave is equal to 4.2 volts rms.



PARTS LIST

Semiconductors

D1,D2—1N4001 rectifier diode
D3—1N4148 diode
IC1—LM7815CT +15-volt regulator
IC2—LM7915CT −15-volt regulator
IC3—ICL8038 precision waveform generator (Intersil)
IC4,IC5—LF353N high-slew-rate op amp

Capacitors (25 WV or more)

C1,C2—220-µF electrolytic
C3,C4,C5—0.1-µF ceramic disc
C6—0.15-µF ceramic disc or paper
C7—0.0047-µF ceramic disc or paper
C8—0.001-µF ceramic disc or paper
C9—100-µF, 35-volt electrolytic
C10—10-pF ceramic disc
C11—22-µF, 35-volt electrolytic

Resistors (¼-watt, 5% tolerance)

R1—470 ohms
R3,R10,R12,R15—10,000 ohms
R6—4,700 ohms
R7—82,000 ohms (see text)
R9,R16—22,000 ohms
R13—15,000 ohms
R4,R5—5,110-ohm, 1% tolerance metal-film
R2—5,000-ohm linear-taper panel-mount potentiometer
R8—100,000-ohm linear-taper panel-mount potentiometer
R11,R14—20,000-ohm linear-taper panel-mount potentiometer

Miscellaneous

F1—1-ampere slow-blow fuse
I1—Panel-mount neon-lamp assembly with current-limiting resistor
J1,J2,J3—Phono jack, binding post or other suitable output connector
S1—Dpdt toggle switch
S2—Single-pole, three-position, non-shorting rotary switch (see text)
T1—12.6-volt power transformer (Radio Shack Cat. No. 273-1385A or equivalent)
Printed-circuit board or perforated board with holes on 0.1-inch centers and suitable soldering or Wire Wrap hardware; suitable enclosure (see text); ac line cord with plug; pointer-type control knobs (5); two 8-pin and one 14-pin DIP IC sockets; dry-transfer lettering kit and clear acrylic spray or tape labeler (see text); ½-inch spacers; machine hardware; hookup wire; solder; etc.

Note: The following items are available from A. Caristi, 69 White Pond Rd., Waldwick, NJ 07463: Ready-to-wire pc board, $8.95; 7815 and 7915 regulators, $2.95 each; ICL8038 precision waveform generator, $9.95; LF353N high-slew-rate op amp, $3.50 each; two 5,110-ohm, 1-percent tolerance resistors, $1.25. Add $1 P&H. New Jersey residents, please add state sales tax.

Fig. 1. Basic schematic diagram of the sine/triangle/square-wave function generator.

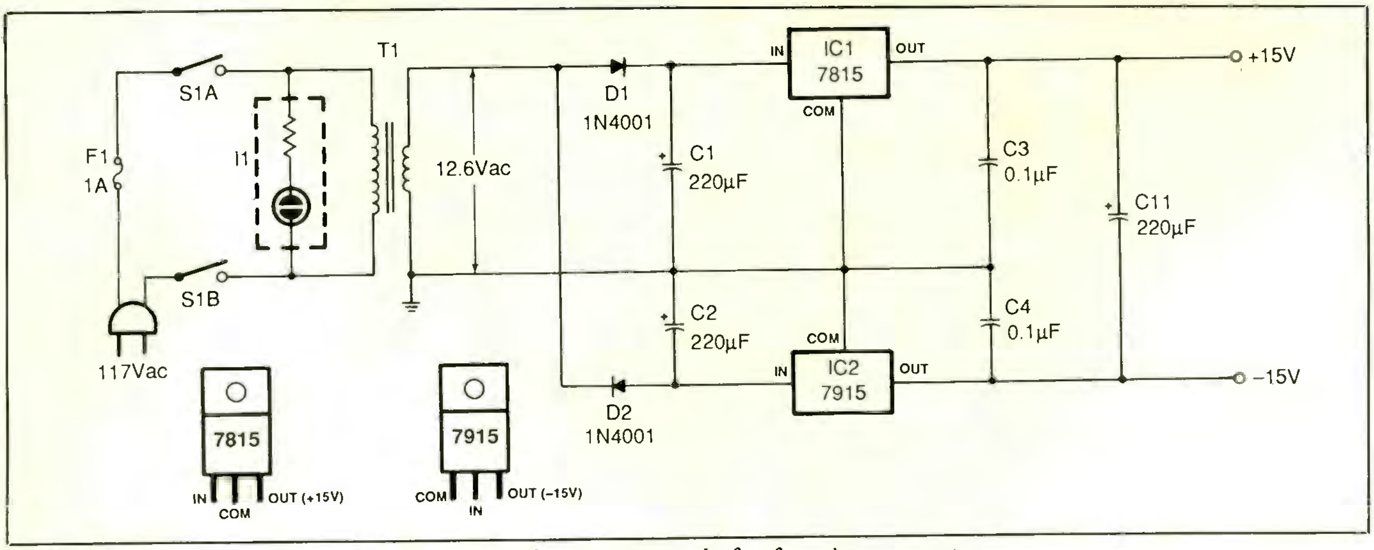


Fig. 2. Bipolar power supply for function generator.

Output impedance of the function generator is less than 1 ohm, as provided by operational amplifiers *IC4* and *IC5*. To preserve the fast risetime of the square-wave output at *J3*, a high-slew-rate LF353N op amp was chosen. Because ordinary op amps will not produce fast risetimes, they should not be used in this circuit.

The low output impedance of this generator can source a reasonable amount of current into virtually any load impedance. The outputs of the circuit are direct-coupled to preserve low-frequency response and should not be connected to any circuit that has a dc component unless a blocking capacitor is used.

Since the oscillator chip's output waveforms are sensitive to power-supply ripple voltages, it is necessary to use stable and pure dc voltages for the + 15-volt and − 15-volt supplies. As shown in Fig. 2, this is accomplished with fixed + 15-volt *IC1* and fixed − 15-volt *IC2* regulators.

To assure ripple-free outputs, the unregulated voltages fed into the inputs of the regulators should be at not less than 18 volts. The transformer used to power this project should deliver at least 14.5 volts rms at the lowest ac line voltage that will be encountered. Under the light load conditions of this project, the power transformer specified in the Parts List for *T1* will provide sufficient output voltage at a 117-volt ac line potential.

Power transformer *T1* drives a bipolar voltage doubler to provide the necessary positive and negative voltages to the regulators. Ripple voltage fed to the inputs of *IC1* and *IC2* is kept sufficiently low by filter capacitors *C1* and *C2*. Though larger values of filter capacitance can be used, avoid using values that are too small or power supply ripple will appear at the outputs of the regulators and, ultimately, in the output waveforms at *J1*, *J2* and *J3*.

Construction

This circuit is simple enough to be hard wired on ordinary perforated board with holes on 0.1-inch centers and using suitable solder or Wire Wrap hardware. Alternatively, you can use a printed-circuit board fabricated yourself using the actual-size etching-and-drilling guide shown in Fig. 3 or a ready-to-wire board from the source given in the Note at the end of the Parts List. Whichever way you choose to go, use sockets for *IC3*, *IC4* and *IC5*.

Regulators *IC1* and *IC2* install directly on the board without the use of sockets. Since very little power is drawn by the circuit, you do not need heat sinks on the regulators.

Figure 3 shows the component locations and orientations for populating the printed-circuit board. Use this illustration as a guide to laying out the components on perforated board as well.

Wire the board exactly as shown, installing first the IC sockets in the appropriate locations and then proceed to the resistors. Next, install the electrolytic capacitors and diodes, taking care to properly orient them before soldering their leads to the pads on the bottom of the board. When installing regulators *IC1* and *IC2*, make certain each goes in its respective location and is properly based. Referring back to Fig. 1, note the differences in pin identification for the + 15-volt 7815 and − 15-volt 7915 regulators.

RANGE switch *S2*, the output amplitude controls, and the SINE, TRIANGLE and SQUARE OUTPUT jacks all mount off the board, on the front panel of the selected enclosure. When wiring potentiometers *R2*, *R8*, *R11* and *R14* into the circuit, all adjustments should go in the clockwise direction to increase frequency and amplitude. If you have any doubts as to what potentiometer lugs wire to which holes, you can use an ohmmeter to make the final determinations.

Other components that mount off the board include pilot-lamp assembly *I1* (which consists of a neon lamp and current-limiting resistor in a panel-mount housing), POWER switch *S1* and fuse *F1*. These also mount on the project's front panel, except *F1*, which mounts near the entry hole for the ac line cord.

Select an enclosure that is large enough to accommodate the circuit-board assembly, controls, jacks, POWER indicator and fuse holder without crowding. You can use a plastic enclosure with a metal front panel or an all-metal enclosure. Machine the front panel so that the the mounting holes for *R14*, *R11* and *R8* form a line across the front of the panel along its center axis. Strike a line 1½ inch below the control hole line and parallel to it and drill the holes for the jacks or binding posts. Then the same distance above the control holes and centered between the first and second and the second and third drill the holes for mounting the rotary switch and remaining control. The POWER switch and lamp assembly mount in two other holes drilled in out-of-the-way locations.

When you are finished machining the front panel, drill the entry hole for the ac line cord through the enclosure's rear panel. For the fuse holder, you can use either a clip type that mounts via a single machine screw or a more convenient (and expensive) panel-mount bayonet type. The size of the mounting hole needed will depend on the type of holder used. Only two more holes remain to be drilled—for mounting the circuit-board assembly on the floor of the enclosure, via the same holes that mount *T1* to the circuit board. Deburr all holes.

Temporarily mount the controls, switches and jacks in their respective locations in the proper orientations.

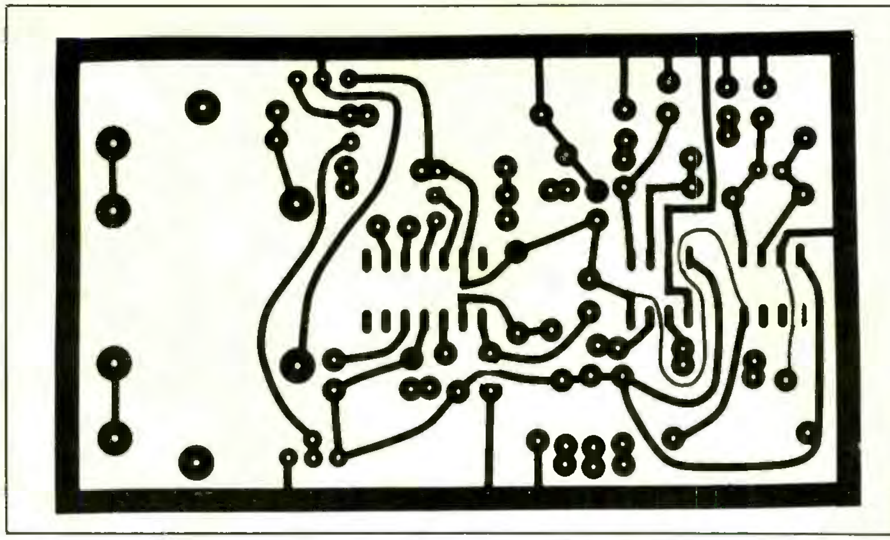


Fig. 3. Actual-size etching-and-drilling guide of function generator's printed-circuit board.

Place on the shafts of the rotary RANGE switch and all potentiometer controls a control knob. Note distances away from the holes the panel markings are to go. Then remove all components from the panel and set them aside.

Using a dry-transfer lettering kit or a tape labeler, label the panel with appropriate legends. If you use a dry-transfer lettering kit, follow up with two or three *light* coats of clear acrylic spray to protect the legends.

When the panel is ready, mount the components permanently. Tightly twist together the fine wires in each conductor of the line cord and sparingly tin with solder. Pass the prepared end of the line cord through its hole (line the hole with a small rubber grommet if you are using a metal enclosure) and tie a knot in it about 6 inches from the end inside the enclosure to serve as a strain relief. Then mount the fuse holder.

Wire the neon-lamp assembly across the POWER switch's open—*not* toggle—contacts but do not sol-

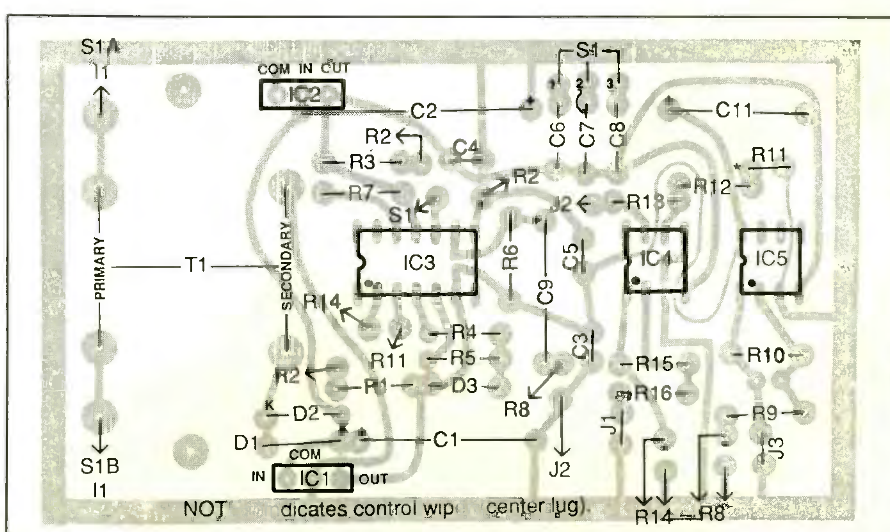


Fig. 4. Wiring diagram for pc board and layout for perforated- board.

der. Remove ¼ inch of insulation from both ends of 22 5-inch lengths of hookup wire. Plug one end of these wires into the signal and ground holes for *J1*, *J2* and *J3* (six wires); the holes for *S2* (four wires); and the holes for *R2*, *R8*, *R11* and *R14* (12 wires). Mount the circuit-board assembly using ½-inch spacers and machine hardware.

Connect and solder the free ends of the two wires for *T1*'s primary to the same lugs of the toggle switch to which *I1* is connected. Wire one side of the fuse holder to one toggle lug of the toggle switch and the line cord to the other toggle lug and the remaining fuse-holder lug.

Referring to Fig. 4, connect and solder the free ends of wires on the circuit-board assembly to the appropriate lugs of the panel-mounted potentiometers. Remember that you want the controls to be wired so that clockwise rotation increases frequency in the case of *R2* and increases amplitude of the output signals for the other potentiometers. Finally, connect and solder the last of the wires to the OUTPUT connectors.

Checkout and Use

Before you attempt to apply power to the generator, check the circuit-board assembly for poor soldered connections and possible short circuits between the closely spaced conductors and especially between the IC socket pads. Reflow the solder on any questionable connections.

With *IC3*, *IC4* and *IC5* still not installed, check the power supply section for proper operation. Plug the project's line cord into an ac outlet and set the POWER switch to ON. (Be very careful to avoid touching any part of the circuit between the ac line cord and *T1*'s primary as you perform your tests. Potentially lethal 117-volt ac line potential appears in this section of the circuit.) The neon lamp should now be on (it should be off when the POWER switch is set to OFF if it is properly wired into the circuit), indicating that ac line power is being delivered to the circuit.

Now use a dc voltmeter set to measure at least 25 volts to check the outputs of the voltage doubler. Connect the meter's common lead to circuit ground at the negative side of *C1* and touch the "hot" meter lead to first the positive (+) side of *C1* and then the negative (−) side of *C2*, which should yield readings of about +19.5 and −19.5 volts, respectively. Without removing the common meter lead from where you connected it, touch the meter's hot lead to first the positive and then the negative leads of *C11*, which should give readings of between +14.5 and +15.5 volts and between −14.5 and −15.5 volts, respectively.

If you do not obtain the proper voltage readings, check for proper orientation of *D1*, *D2*, *C1*, *C2* and *C11*. Also, check with Fig. 4 to ascertain that *IC1* and *IC2* are each in their respective locations and are properly wired into the circuit. Check the ac potential at the secondary of *T1*, which should measure at least 14.5 volts rms ac. With the line cord unplugged, check to see if the +15-volt and −15-volt supply rails are shorted to each other. Do not proceed until you have cleared up the problem.

Plug the project's line cord into an ac receptacle and turn on the power. Set your meter to measure at least 20 volts dc. Connect its common lead to the negative lead of *C1* and touch the hot meter lead to pin 6 of the *IC3* socket and pin 8 of the *IC4* and *IC5* sockets. You should obtain a reading of +15 volts in all three cases. Similarly, you should obtain a −15-volt reading when you touch the meter's hot lead to pin 11 of the *IC3* socket and pin 4 of the *IC4* and *IC5* sockets.

When you are satisfied that the power supply is working properly and that the power rails are correctly wired to the IC sockets, unplug the line cord and give *C11* time to discharge. Then carefully plug *IC3*, *IC4* and *IC5* into their respective sockets. Make sure that each is installed in the proper orientation and that no pins overhang the sockets or fold under between ICs and sockets.

Use an oscilloscope to check the outputs of the function generator. Set the generator's amplitude controls to maximum clockwise rotation to obtain maximum output amplitude and turn on the project. Examine the waveforms at *J1*, *J2* and *J3*, where you should observe sine, triangular and square waveforms, respectively, of about 12 volts peak-to-peak. If you note that any one or all of the waveforms are displayed at minimum amplitude, the potentiometer for that output amplifier is wired backward and must be rewired for proper operation.

Rotating the FREQUENCY ADJUST control over its entire range should cause the frequency to vary over a 40:1 range, with the frequency increasing as the control is rotated in the clockwise direction. Check each output individually. If you note a decrease in frequency as this control is rotated in the clockwise direction, the potentiometer is wired backwards and must be rewired for proper operation. If the extreme clockwise or counterclockwise settings of this control result in a distorted waveform or no waveform at all at the outputs, you can tailor the limit of the adjustment range by increasing the value of *R1* or *R3* as needed.

This generator is capable of producing a sine-wave output with a distortion figure of less than 2 percent. If you see some distortion, you can increase or decrease the value of *R7* to obtain the purest possible waveform. A variation of 20,000 ohms in either direction should be more than enough to produce an optimum distortion level.

If you do not obtain output waveforms at all, check pins 2, 3 and 9 of *IC3* to make sure the chip is oscillating and generating the three waveforms. If the waveforms are present at these pins, the trouble is in output buffer amplifiers *IC4* and/or *IC5*.

If *IC3* is oscillating, check the wiring associated with the FREQUENCY ADJUST potentiometer and BAND switch. Also make sure that *D3* is properly connected into the circuit.

To demonstrate the low-impedance characteristics of the function generator, set the project for a relatively low frequency (say, 1 kHz) that can be easily "read" on an ac voltmeter. Set the amplitude of the sine-wave output at *J1* to 1 volt rms on the voltmeter. Connect a 100-ohm, ¼- or ½-watt resistor across *J1* and note that the resulting voltage drop is very low, perhaps on the order of a few millivolts. This indicates that the output impedance of the generator is very much less than 100 ohms. A mathematical calculation of the output impedance using the voltage-drop method would yield an impedance of less than 1 ohm.

Of course, the generator cannot drive its full output of 4 volts rms into a very-low impedance like 100 ohms. However, you will find that it will be able to drive about 0.5 volt rms into 50 ohms, which is respectable at that impedance.

The procedure for using the function generator is very simple. First you select the output waveform(s) you want to use. Then you select the band of frequencies needed and adjust the amplitude control(s) for a usable signal level at the output(s). If you are interested in a specific frequency, you adjust the setting of the FREQUENCY ADJUST control until you obtain that frequency. That is all there is to it.

With this function generator on your testbench, you will find that whenever you need a variable signal source to check amplifiers and speakers and for general troubleshooting, it is always ready. Best of all, you can build it for only a fraction of what it would cost you to purchase a commercial instrument. ME