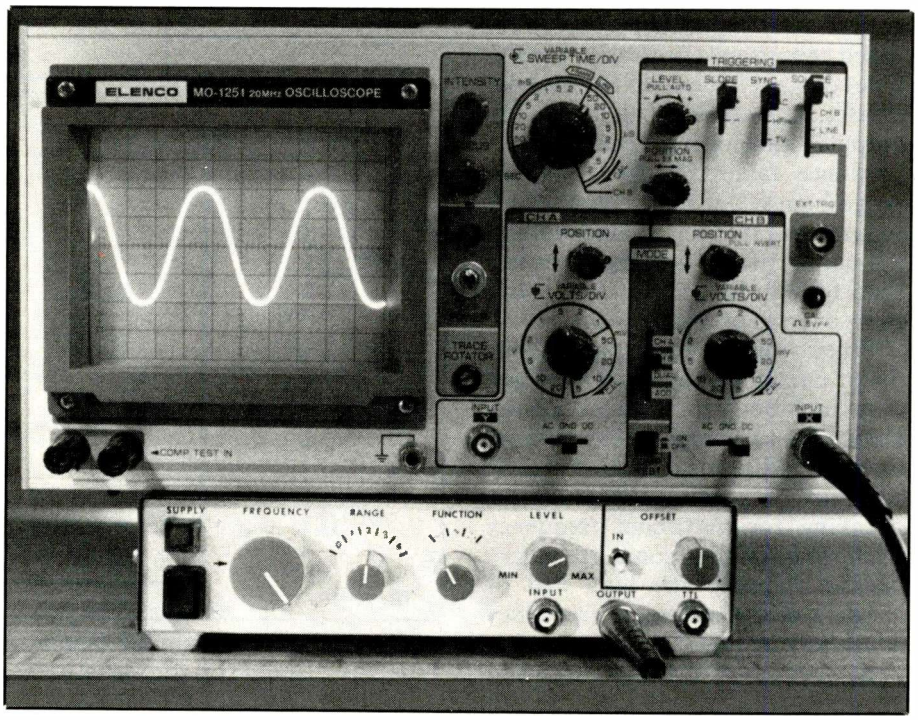
$50 Lab-Grade Function Generator

Full-featured 1-Hz to 250-kHz function generator construction project adds CMOS/TTL compatibility, an FM sweep input, near-zero distortion and a power-amplifier output to drive 50-ohm loads to the usual sine/triangle/square-wave outputs

Second only to the oscilloscope, a Laboratory-Grade Function Generator like the one described here is a real necessity for developing and debugging a broad range of circuits. With it, distortion can be measured, bandwidths extrapolated, clocks created, time constants tested and open circuits found, to name just a few of its almost inexhaustible applications.

Our Function Generator provides the usual sine-, triangle- and square-wave outputs at frequencies ranging from less than 1 Hz to beyond 250 kHz at virtually zero distortion. It offers CMOS and TTL compatibility for digital circuits and a variable ±15 volts. The Generator is also TTL/CMOS compatible for use in digital circuits. Other features include: an FM sweep input; variable offset to ±10 volts; and a power-amplifier output for driving 50-ohm loads. If you were to obtain all these features and functions in a single commercial function generator, the instrument would cost you many hundreds of dollars. By building the Function Generator, your cost should be about $50 or so for all materials, including enclosure.



About the Circuit

The heart of the Generator is a precision waveform generator/voltage-controlled oscillator chip that Digi-Key, among others, sells for less than $5. This is the ICL8038 shown as *IC2* in Fig. 1(A). This particular chip has been around for a number of years and is the foundation upon which every bench-top function generator on the market is built. To fully appreciate the potential of the ICL8038, you should contact Intersil, which makes the chip, via your local representative to request Application Note AO13, "Everything You Always Wanted to Know About the ICL8038." This informative publication explains in detail the functions and features of the ICL8038 and provides a variety of interesting applications for the chip.

Because the ICL8038 is basically a voltage-controlled oscillator (vco), some means for varying its sweep input at pin 2 of *IC2* must be provided. This is the task of operational amplifier *IC1* and its associated circuitry. A near-1,000:1 sweep ratio is provided externally via SWEEP IN jack *J1*.

Any varying voltage applied to pin 2 of *IC2* through *J1* within the range of ±12 volts produces frequency modulation (FM) of the output waveform at FINAL OUTPUT jack *J3* in Fig. 3(C). If no external sweep is used, output frequency is set via FREQ. ADJ control *R1* in Fig. 1(A).

Trimmer potentiometers *R4* (HIGH FREQ TRIM) and *R5* (LOW FREQ TRIM) permit one-time peaking of the upper

and lower frequency limits, respectively. These trimmer controls are adjusted as needed during circuit checkout with a frequency counter or oscilloscope connected to *J3*.

SYMMETRY TRIM control *R8* provides a one-time calibration of duty cycle and sine-wave symmetry. With an oscilloscope connected to *J3*, you adjust *R8* until the sine wave displayed on the CRT of the scope appears as uniform and symmetrical as possible. Further "tweaking" for minimal sine-wave distortion is accomplished by adjusting DIST TRIM controls *R6* and *R7*.

Frequency range is selected via *S2* in Fig. 1(B). As the FREQUENCY RANGE SELECT switch is moved through its positions, it selects different values of capacitance. As the selected capacitance decreases, the RC time constant internal to *IC2* also decreases. This results in an increase in output frequency from the chip. Capacitance values for the *S2* circuit range from 417 μF to less than 100 pF to provide a frequency bandwidth at the output of *IC2* ranging from less than 1 Hz to beyond 250 kHz, with some overlap between ranges.

When selecting the capacitors for the *S2* circuit, exercise care to obtain only high-quality, low-leakage devices. This ensures that the oscillator operates with maximum stability. Trimmer capacitor *C15* permits tweaking for maximum frequency while maintaining some frequency overlap between the high end of range 3 and the lowest frequency available on range 4.

A high-speed CMOS/TTL-com-

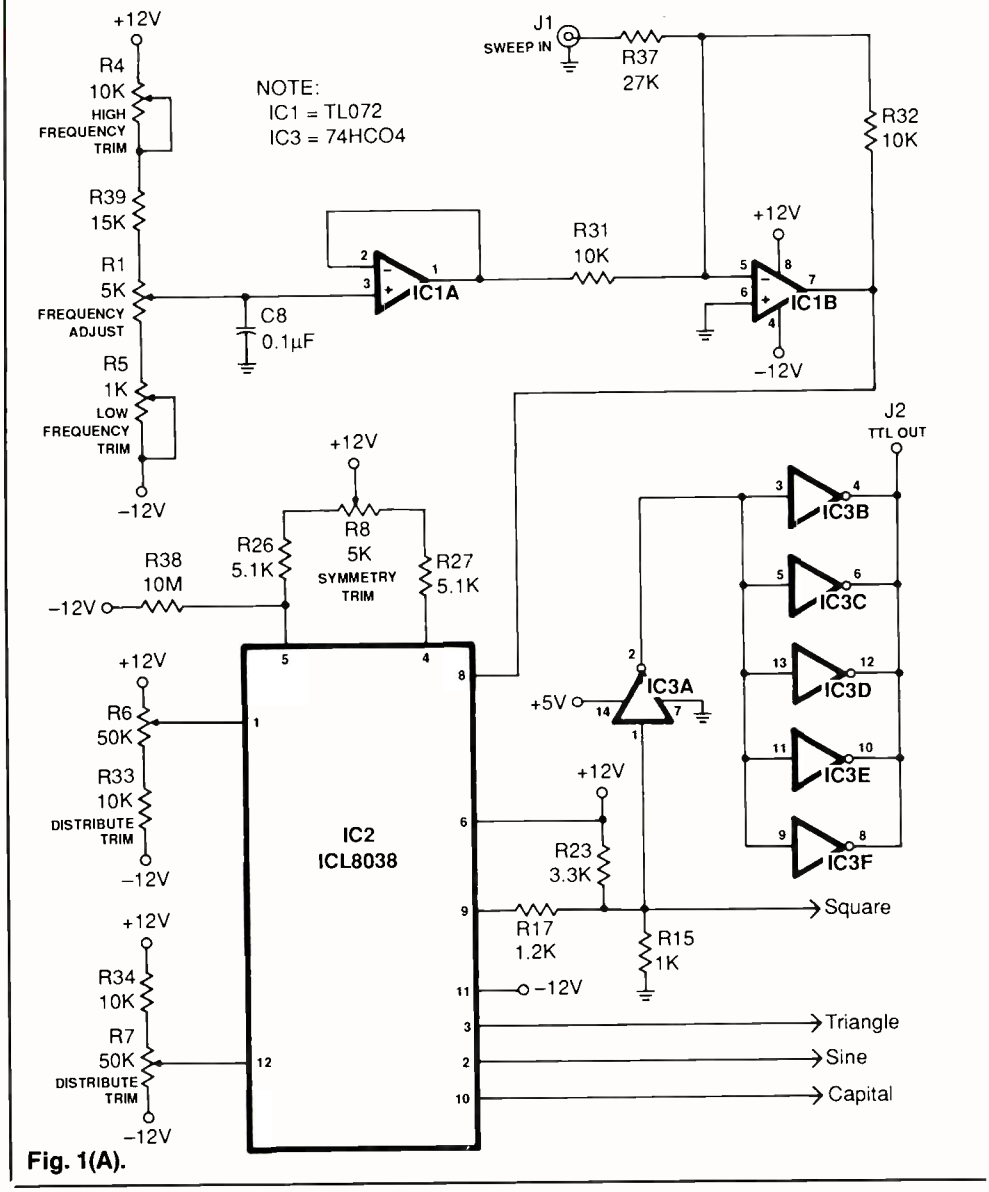


Fig. 1(A).

Fig. 1. Complete schematic diagram of Function Generator is shown here in four parts, labeled (A) through (D).

PARTS LIST

Semiconductors

D1—1N4001 silicon rectifier diode
D2,D3—1N4148 or similar small-signal switching diode
IC1—TL072 or similar internally compensated operational amplifier
IC2—ICL8038 waveform generator
IC3—74HC04 or 74HC14 hex inverter
IC4—7812 fixed +12-volt regulator
IC5—7805 fixed +5-volt regulator
IC6—7912 fixed −12-volt regulator
Q1,Q2,Q3—2N2222 or similar general-purpose npn silicon switching transistor
Q4,Q5—2N3906 or similar silicon pnp switching transistor
Q6—TIP31 silicon npn power transistor
Q7—TIP32 silicon pnp power transistor
RECT1—50-piv, 1-ampere bridge rectifier assembly

Capacitors

C1,C2—100-μF, 35-volt electrolytic
C3—4.7-μF, 35-volt electrolytic
C4—0.47-μF polypropylene or polyester
C5 thru C8—0.1-μF monolithic ceramic
C9,C10—0.33-μF, 35-volt tantalum
C11—0.047-μF polypropylene or polyester
C12—0.0047-μF polypropylene or polyester
C13—390-pF silver-mica or polypropylene
C14—6-to-50-pF trimmer (Radio Shack Cat. No. 272-1340 or similar)

Resistors (¼-watt, 5% tolerance)

R10,R11—10 ohms (½-watt)
R12,R13—33 ohms (½-watt)
R14—100 ohms
R15,R16—1,000 ohms
R17—1,200 ohms
R18,R19,R20—1,800 ohms
R21,R22—2,200 ohms

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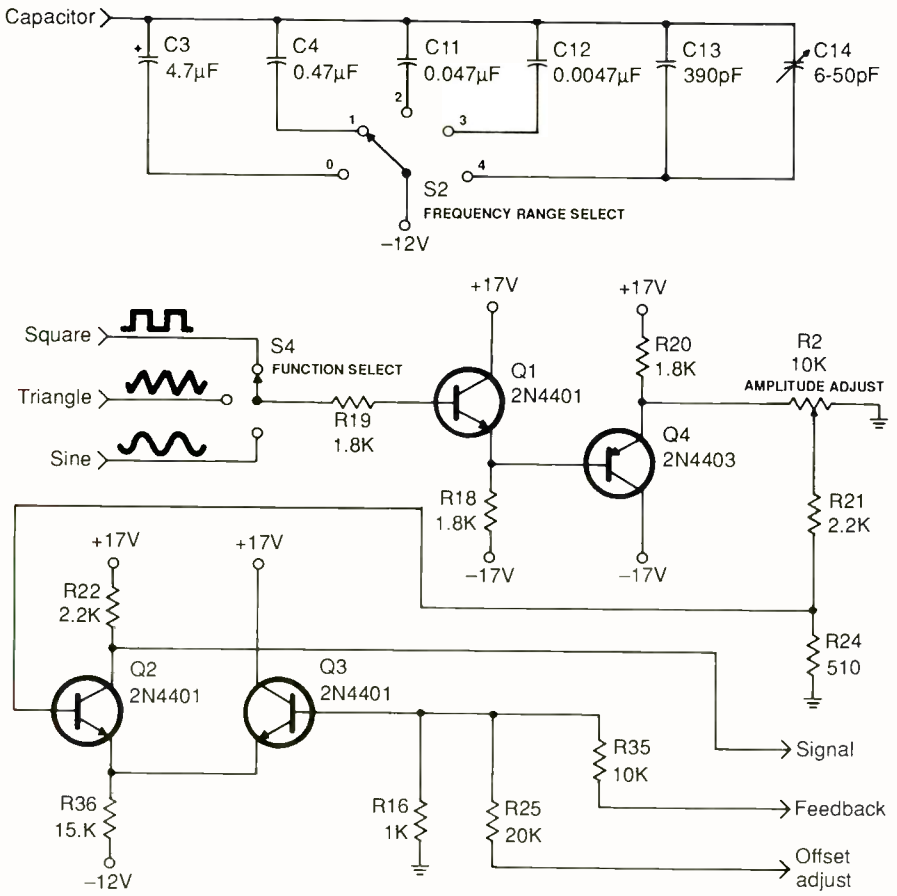


Fig. 1(B).

patible clock output is provided by HCMOS hex inverter *IC3* in Fig. 1(A). TTL OUT *J2* is quite useful as a variable logic clock when designing and troubleshooting digital circuits. Its fan-out is reasonably high. By utilizing the lower-frequency settings, you can better judge the logical operation of a circuit when testing different points in the circuit with a logic probe.

Selection of the sine-, triangle- or square-wave function is made using FUNCTION SELECT switch *S4* in Fig. 1(B). This switch permits you to connect the input of the output amplifier inside the Function Generator to one of the three available waveform output pins of *IC2*. The sine-wave output of *IC2* is on pin 2, the triangle-wave output is on pin 3 and the square-wave output is on pin 9.

Once a selection is made via *S4*, the output from *IC2* is fed to the buffer amplifier consisting of the *Q1/Q4* circuit. The buffered output from this circuit is fed to AMPLITUDE ADJ control *R2* to permit you set the signal amplitude output from *J3*.

A variable dc offset voltage is provided by the *Q2/Q3* circuit, also shown in Fig. 1(B). This offset can be switched between IN and OUT via OFFSET switch *S3* in Fig. 1(C). Infinite variability of the dc offset is provided by OFFSET ADJ control *R3*, while OFFSET TRIM ADJ control *R9* provides one-time calibration of the zero-offset adjustment. With *S3* set to OUT, you should adjust *R9* so that no dc offset is observed on the CRT of your scope connected to *J3*.

A power amplifier capable of driv-

R23—3,300 ohms
R24—510 ohms
R25—20,000 ohms
R26 thru R29—5,100 ohms
R30—6,800 ohms
R31 thru R35—10,000 ohms
R36,R39—15,000 ohms
R37—27,000 ohms
R38—10,000 megohms
R1—5,000-ohm linear-taper panel-mount potentiometer
R2,R3—10,000-ohm linear-taper panel-mount potentiometer
R4—10,000-ohm pc-mount trimmer potentiometer
R5,R9—1,000-ohm pc-mount trimmer potentiometer
R6,R7—50,000-ohm pc-mount trimmer potentiometer
R8—5,000-ohm pc-mount trimmer potentiometer

Miscellaneous

F1—0.5-ampere slow-blow fuse
I1—Neon panel lamp with limiting resistor
J1,J2,J3—Panel-mount BNC jack (Radio Shack Cat. No. 278-105 or similar)
S1—Spst toggle or slide switch
S2—Four-position non-shorting rotary switch
S3—Three-position non-shorting rotary switch
S4—Spdt toggle or slide switch
T1—Shielded 25.2-volt, 450-mA center-tapped power transformer (Radio Shack Cat. No. 273-1366 or similar)
Printed-circuit board or perforated board with holes on 0.1-inch centers and suitable Wire Wrap or soldering hardware (see text); suitable enclosure (Radio Shack Cat. No. 270-272 or similar); sockets for all DIP ICs; fuse holder; three-conductor ac line cord; pointer-type control knobs; rubber grommet; heat-shrinkable tubing; ½" spacers; lettering kit and clear acrylic spray (see text); machine hardware; hookup wire; solder; etc.

ing a 50-ohm load is provided by the push-pull output stage made up of *Q6* and *Q7* in Fig. 1(C). Correct biasing of this output circuit is provided by *Q5*, *D2* and *D3*. Signal feedback is provided by *R35*. As shown, the complete amplifier delivers a no-load output swing of almost ±15 volts, or 30 volts peak-to-peak, with less than 1% distortion.

Power for the Function Generator circuits is provided by the ac-operated circuit shown schematically in Fig. 1(D). The incoming 117 volts from the ac line is stepped down to 24 volts ac by shielded power transformer *T1*. The center-tapped secondary of *T1* provides two separate lines, both referenced to circuit ground, to bridge rectifier *RECT1*. The rectifier assembly converts the incoming ac into +17 and −17 volts pulsating dc. The pulsating dc is filtered to pure dc by *C1* and *C9* in the +17-volt line and *C2* and *C10* in the −17-volt. Both lines are then regulated to +12 and −12 volts by *IC4* and *IC6*, respectively, for delivery to the circuits inside the Function Generator.

Note also that regulator *IC5* in the +12-volt line is used to obtain +5 volts. The only point in the circuit to which the +5-volt line goes is power pin 14 of HCMOS hex inverter *IC3*.

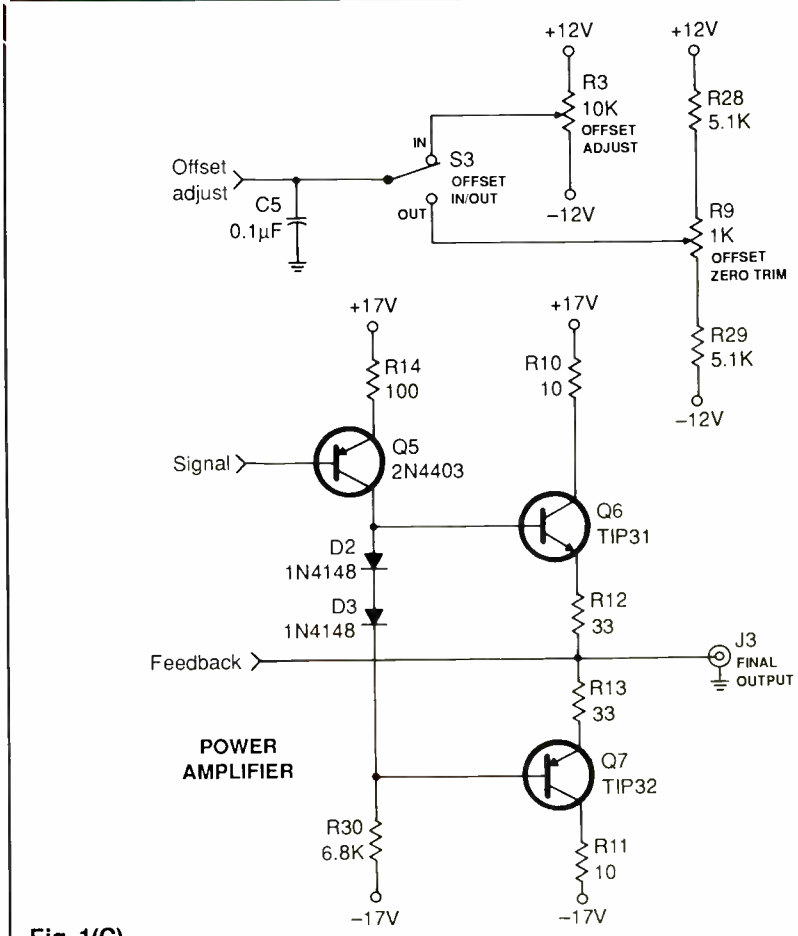


Fig. 1(C).

Construction

The circuitry for the Function Generator is relatively simple and lends itself to just about any method of wiring you wish to use. If you feel ambitious, you can design and fabricate a printed-circuit board on which to mount and wire together the components. Otherwise, use perforated board that has holes on 0.1-inch centers and suitable Wire Wrap or soldering hardware. Whichever way you go, be sure to use sockets for all DIP ICs. Also, if you can obtain it, perforated board that has each hole surrounded by a thin isolated ring of copper will ease securing components in place.

If you use perforated board, begin construction by laying out the circuit in a logical manner, with an eye toward maintaining physical isolation between the input and output circuits. Test fit the components (use the sockets—not the ICs themselves—in the IC locations) to determine ex-

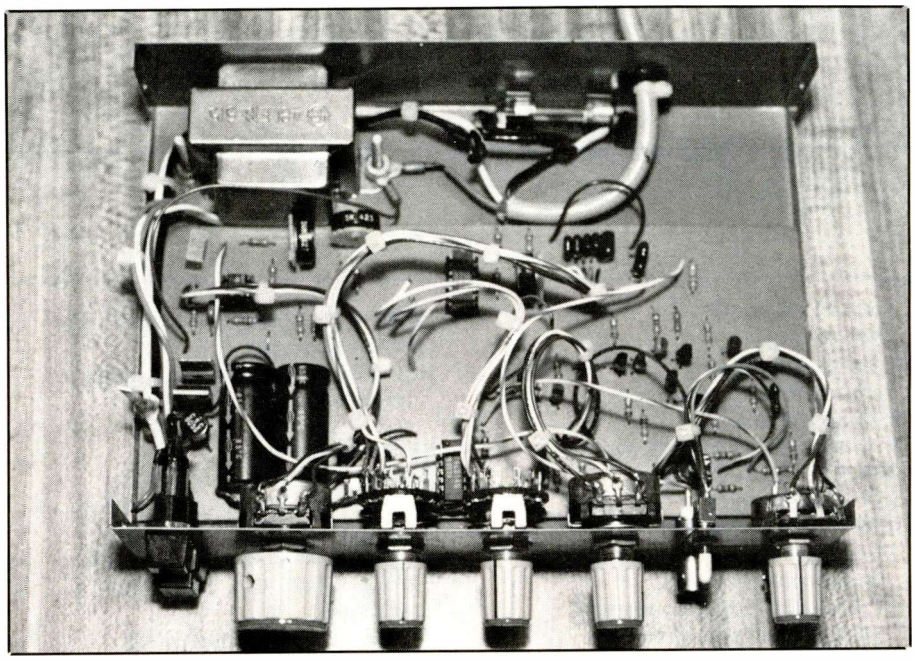


Fig. 2. Interior view of author's prototype shows details for mounting power transformer and fuse holder and how green conductor of ac line cord and ground lead from circuit-board assembly connect to enclosure ground via transformer mounting hardware.

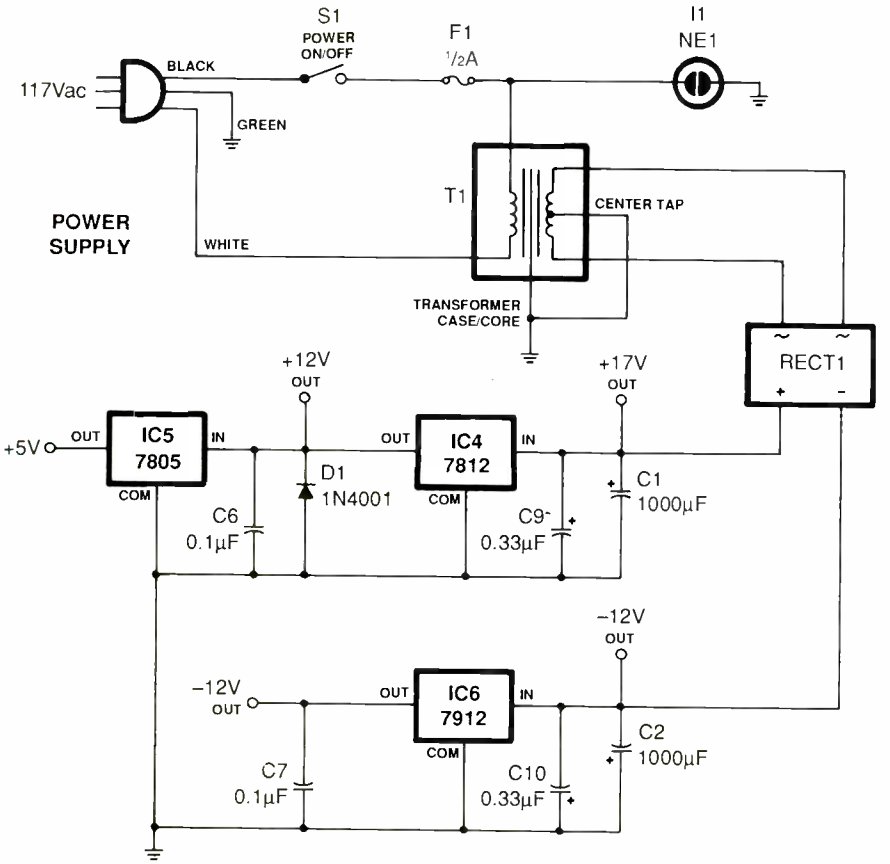


Fig. 1(D).

actly how the layout is to appear. The layout for the prototype project that appears in the lead photo is shown in the Fig. 2 interior-view shot. Notice here that all switches, all but two rotary controls, the jacks, the power transformer, fuse block and power transformer mount off the board. A fairly large enclosure was used for the prototype; so it wasn't necessary to minimize real estate.

Once you know how you want the components to lay out on the board, mount the IC sockets in their selected locations. If your board has copper rings around each hole, tack-solder the four corner socket pins into place. Use solder sparingly if you're using Wire Wrap hardware. Do *not* plug the ICs into the sockets until you've conducted preliminary voltage tests and are certain you have correctly wired the circuit.

When you're ready to wire the circuitry, photocopy all sections of Fig. 1. Then begin wiring the circuit board. As you make each conductor run, trace the appropriate conductor on the schematic. Whenever you reach a point where a connection must be made to an off-the-board component, terminate it in a solder post to which a wire can be connected and soldered after the circuit board is mounted in place.

After wiring the circuit board, carefully go over your wiring to make sure it's correct. If you made any soldered connections, inspect each. If you missed soldering a connection, solder it now. If a connection is suspicious, reflow the solder on it and add solder if needed. Finally, if you locate solder bridges, especially between the closely spaced pins of the IC sockets, clear them away with a vacuum-type desoldering tool or desoldering braid.

Select an all-metal enclosure for your Function Generator. You can use an "instrument" enclosure like the one shown in the lead photo. If you can't find such an enclosure, any other metal project box that can accommodate the circuit board and power transformer on its bottom panel and has sufficient room on its front panel on which to mount the power indicator, controls, switches and jacks will do.

Machine the enclosure as needed. Drill mounting holes for the power indicator, controls, switches and jacks through the front panel; holes through the floor panel for mounting the circuit-board assembly, fuse holder and power transformer; and an entry hole for the ac line cord through the rear panel. When you're done, deburr all holes to remove sharp edges.

Temporarily mount the rotary switches in their respective holes in the front panel. Place pointer-type knobs on their shafts. Adjust switch positioning for symmetrical sweeps, and use a soft lead pencil to mark the pointer location on the panel in each position. When you're done, remove the switches. Then use a dry-transfer lettering kit to label the panel with appropriate legends for all switches and controls. A typical lettering scheme is shown in the lead photo.

Spray two or three light coats of clear acrylic over the entire front panel to protect the legends from scratches while the project is in use. Allow each coat to dry before spraying on the next.

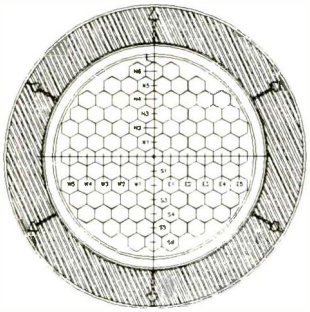
When the acrylic spray has completely dried, mount the circuit-board assembly to the floor of the enclosure using ½" spacers and suitable machine hardware. Then mount the power transformer and fuse holder, also to the floor panel, and the various items that go on the front panel.

Orient the project as shown in Fig. 3 to give you easy access to the lugs on the controls, switches and jacks. Note that the lugs of the controls, switches and jacks are all readily accessible. Using the photocopied schematic, crimp and solder the free ends of the wires coming from the circuit-board assembly to the appropriate lugs of the front-panel-mounted components.

Line the entry hole for the ac power cord with a rubber grommet. Pass the unfinished end of the cord through the grommet and secure a large plastic cable tie to it about 6" from the

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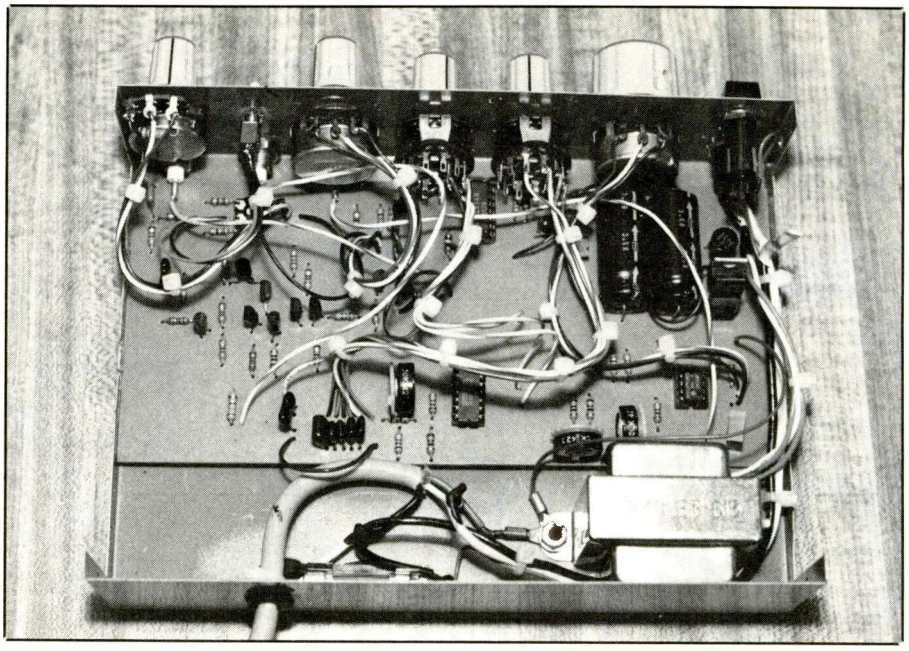


Fig. 3. This interior view shows how lugs of all front-panel-mounted switches, controls and jacks are easily accessible for connection to circuit-board assembly via hookup wires.

unfinished end inside the enclosure. Use the cable tie as a strain relief for the line cord.

Strip ⅜ inch of insulation from all three conductors. Tightly twist together the exposed fine wires in each conductor and sparingly tin with solder. Crimp and solder a spade or ring lug to the green-insulated conductor and another to the ground wire coming from the circuit-board assembly. Make the connection to chassis ground with the machine hardware that secures the near tab of the power transformer to the floor panel. Place a lockwasher on the screw, follow with the two lugs and another lockwasher and, finally, the nut.

Finish wiring the project according to the schematic diagram. Use heat-shrinkable tubing over the connections in the primary circuit of the power transformer.

Checkout & Adjustment

With no ICs plugged into the sockets on the circuit board, plug the line cord into an ac outlet. Clip the common lead of a dc voltmeter or multimeter set to the dc-volts function to the grounding hardware of the power transformer.

Setting the POWER switch to "on" and touching the "hot" probe of the meter to pin 8 of the *IC1* socket and pin 6 of the *IC2* socket should yield a reading of +12 volts. Similarly, touching the "hot" probe to pin 4 of the *IC1* socket and pin 11 of the *IC2* socket should yield a reading of −12 volts. The reading obtained when you touch the "hot" probe to pin 14 of the *IC3* socket should be +5 volts. Next, touching the "hot" probe to the collectors of *Q1* should yield a reading of +17 volts.

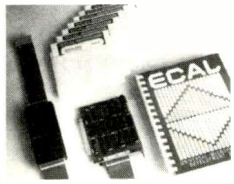
If you fail to obtain the proper reading at any given point, immediately power down your Function Generator and troubleshoot it to determine where the problem exists.

When you're certain you've properly wired the project, remove power from it and allow the charges to bleed off the electrolytic capacitors in the power supply. Then plug *IC1* and *IC3* into their respective sockets. Make sure each is properly oriented and that no pins overhang the sockets or fold under between ICs and sockets. Do *not* plug the 8038 into the *IC2* socket just yet.

Power up the Function Generator and set the OFFSET switch to the OUT position. Measure the dc voltage from the "signal" contact of OUTPUT jack *J3* to ground. If the reading isn't 0 volt, adjust trimmer control *R9* on the circuit board so that it is.

(Continued on page 86)

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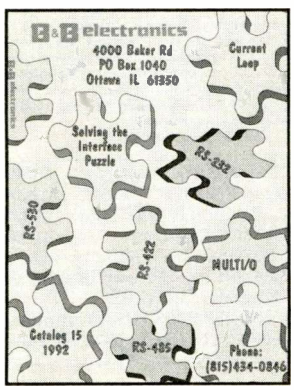
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$50 Lab *(from page 60)*

Next, still monitoring *J3*, set the OFFSET switch to IN and vary the setting of OFFSET ADJUST control *R3* and note this control causes the dc offset should swing between +10 and −10 volts. This done, power down the Frequency Counter.

To accomplish final adjustment of *C15*, *R4* and *R5* through *R8* requires use of an oscilloscope. Set the Generator for a sine-wave output and connect the scope to *J3*. Adjust the settings of *R6*, *R7* and *R8* to obtain the most distortion-free, symmetrical waveform possible on the CRT screen.

With RANGE switch *S2* set to position 2, set FREQUENCY ADJUST control *R1* for maximum output frequency. Follow by adjusting trimmer control *R4* until you obtain a peak in frequency and then back off just slightly. Readjust the setting of *R1* for minimum output frequency and adjust trimmer *R5* to obtain minimum frequency.

If you have a variable dc voltage source, test the SWEEP input at *J1* by applying −12 to +12 volts to the jack. With *R1* set to its middle of rotation, the varying voltage at *J1* should cause the output frequency at *J3* to sweep through its minimum- and maximum-frequency range.

To adjust trimmer capacitor *C15*, disconnect any input to *J1* and set *R1* for maximum output frequency. Now set *S2* to position 3 to select timing capacitor *C13*. Using a frequency counter or oscilloscope, determine and note down the actual frequency of the signal coming out of *J3*. Then set *S2* to position 4, adjust *R1* for the slowest rate and use a non-metallic tool to adjust *C15* for an output frequency that is just below that of the previously measured maximum. This adjustment ensures a frequency overlap between the two highest ranges and eliminates possible "missing" frequencies from the selectable ranges. This completes adjustment of your Function Generator.

As you can see from the foregoing, the Function Generator described here provides all the functions and most of the features of a high-precision bench-top instrument. You'll soon come to rely on it so much that whenever you sit down at your test-bench, you'll power it up at the same time you power up your oscilloscope and multimeter. ■

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