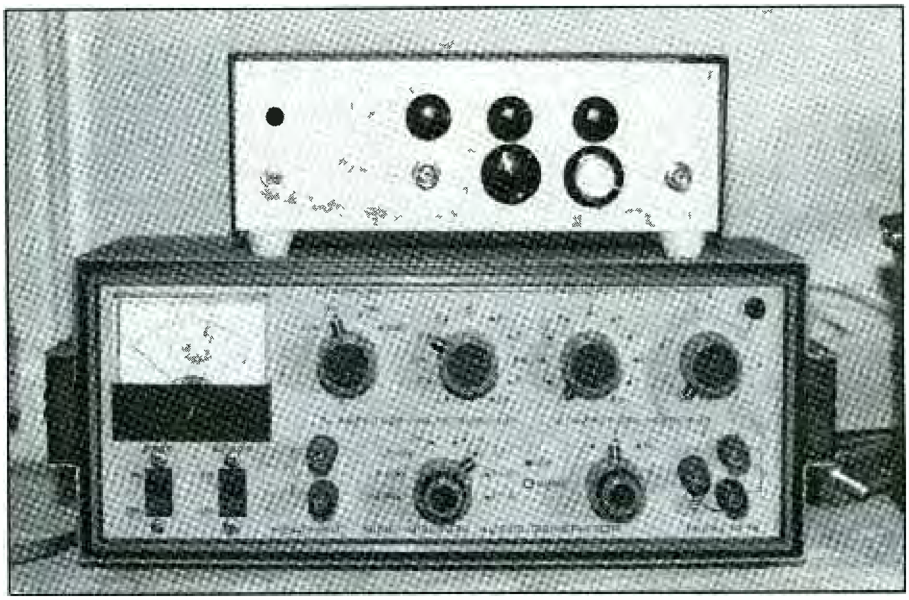
Upgrading an Audio Signal Generator

Modification plans to add swept frequencies and output of triangle waves, variable-width pulses and sine/cosine waveforms to a classic sine/square-wave generator

By Joseph J. Carr



The function generator is a descendant of the classical sine/square-wave audio generator. Modern instruments add pulse and triangle output waveforms to the usual sine and square waves of older audio generators. A typical example of the latter is the Heath Model IG-18 audio generator that has worked well for this author for almost 20 years. Now, however, I have a need for more versatility, so I decided to upgrade my old Heath generator to give much the same performance one obtains from a sweep/function generator. Described here is a converter circuit that upgrades virtually any basic audio generator to provide function-generator capabilities.

This accessory adds triangle waves, variable-width pulses and sine/cosine output waveforms to the existing sine and square waves of a basic audio generator. It can be used with any generator that can output a signal amplitude of 1 volt peak-to-peak or any potential near that level. Its circuit design is fairly simple and relatively easy to assemble from inexpensive and readily available components.

Basic Theory

Conversion of a sine wave into a triangle waveform is accomplished in this project using the Miller integrator circuit, which is shown schematically in Fig. 1(A). The basic circuit consists of an operational amplifier wired in an arrangement that looks like an ordinary inverting follower circuit. However, this configuration has a capacitor in the feedback loop instead of the usual resistor. The capacitor charges under the influence of output voltage V_{out} that, in turn, is a function of input voltage V_{in}. Although the mathematics that defines the integrator is taken from calculus, the only thing you need to know is that the output voltage is the time-average of the input voltage.

Output waveforms for the standard Miller integrator are illustrated in Fig. 1(B). In this particular case, the input signal waveform is a square wave that is generated symmetrically around the circuit's zero-volt reference. When the square wave is at logic high, the output of the Miller integrator starts out low but ramps upward as the capacitor charges. Then when the output waveform goes low, the capacitor begins to discharge and proceeds to charge in the opposite direction. The result of ramping up and down is a triangle waveform. This is how a triangle waveform can be obtained from a square-wave pulse.

Use of a comparator circuit allows the pulse to be generated from the triangle waveform. A comparator is

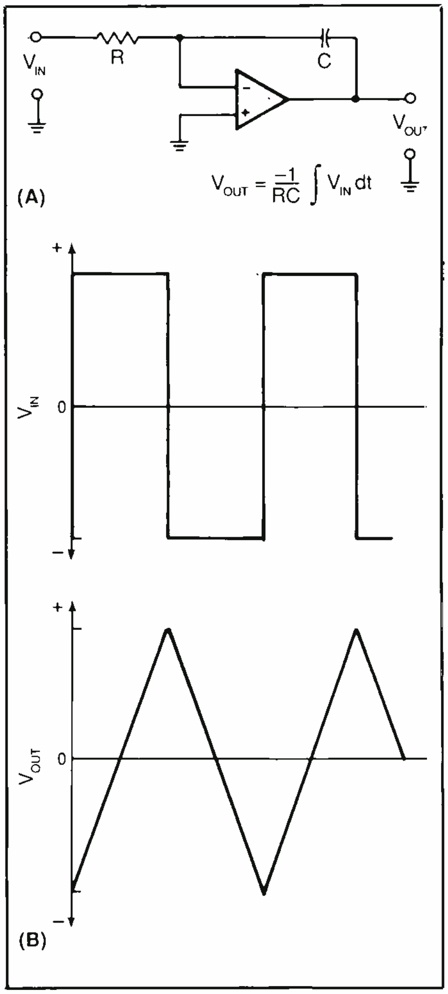


Fig. 1. Simplified Miller circuit schematic diagram(A) and output waveforms (B) from it.

basically an amplifier that has too much gain and, thus, saturates with a very-low-amplitude input signal. An op amp that is run wide open with no feedback network is an example of how a comparator can be made, as shown in Fig. 2.

The gain of the Fig. 2 circuit arrangement is the open-loop gain of the op amp. The open-loop gain of the inexpensive and commonly available 741 op amp, for example, is 300,000. So for a maximum output of 10 volts, the input saturates at an input level of 10 volts/300,000, which is a minuscule 33 microvolts! The output of a comparator can be summed up as follows: (1) When V_{in}

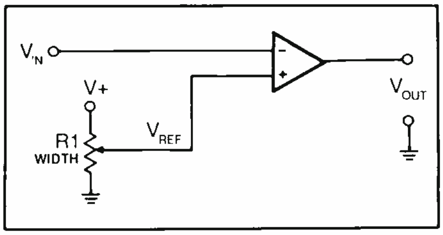


Fig. 2. A simple comparator circuit can be made from an ordinary operational amplifier run "wide open" with no feedback network.

= Vref, the output is low; (2) When $V_{in} = V_{out}$, the output is 0; (3) When $V_{in} = V_{out}$, the output is high.

In Fig. 2, the comparator is shown wired so that a reference voltage is applied to the noninverting (+) input and the triangle waveform is applied to the inverting (−) input. Figure 3 shows the waveforms under two circumstances: (A) is the input waveform (a bipolar triangle waveform), and (B) is the output waveform when the reference voltage is at V1. In this case, the threshold is not tripped until near the peak of the triangle; so the output is low for only a short period of time. When the reference voltage is adjusted to the V2 level, however, the triangle waveform is greater in amplitude than the reference potential for a longer time. The result is a wider output pulse.

About the Circuit

Shown in Fig. 4(A) is the schematic diagram of the accessory's circuitry minus its power supply. The active elements in this circuit are commonly available operational amplifiers. Use of 741 and CA3140 op amps keep the cost of components for the project low. They are easy to obtain from most mail-order and many local electronic component distributors.

Input stage *IC1* is configured in Fig. 4 as a noninverting follower circuit that has a gain of 2. The reason for selecting this particular circuit configuration is its extremely high input impedance, which does not load down preceding circuits. Amplifier *IC2* is a gain-of-1 inverter that produces an output that is the same as that of *IC1*, except that its output waveform is 180 degrees out-of-phase with that from *IC1*.

Op amps *IC3* and *IC4* make up the Miller integrator. These CA3140 devices have extremely high input impedance (specified at 10^{12} ohms) that far exceeds that of the 741 op amp. The reason why we need extremely high input impedance is that the input bias currents are microscopic and will not generate an output voltage that will erroneously charge the feedback capacitor.

The actual integrator here is *IC3*, while *IC4* serves as a buffer to the outside world. If circuits and op amps were perfect performers, there would be no need for *IC4*.

Shown in Fig. 4(B) is the feedback network for the Miller integrator. This consists of a 12-position non-

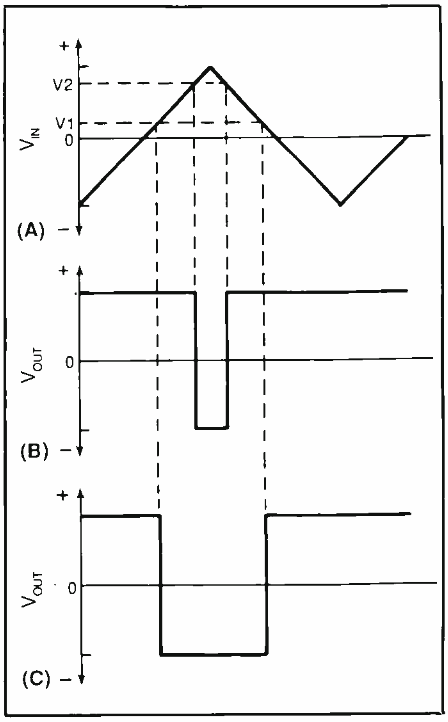


Fig. 3. Waveforms from Fig. 2 circuit: (A) bipolar triangle input waveform and (B) output waveform when reference voltage is at V1 level.

shorting rotary switch that is used to select various values or capacitors and resistors. The resistors convert the integrator into an amplifier that has a gain of −R (in kohms)/12 kohms. Because the gain of an integrator is −1/RC, you must be very careful to avoid using too low a capacitance value if you wish to avoid excessive gain. To this end, *R18* keeps the capacitor discharged in the event that some form of offset voltage (or dc component in the input signal) charges the capacitor.

In Fig. 4(A), you see an OFFSET control at the input to the integrator. This front-panel control has three uses. Firstly, it can cancel the effects of drift. By critical setting of the control, you can insert a "counter-current" that corrects the effects of offsets and bias currents in the op amp. Secondly, the control compensates for offset biases in the input signal. Finally, the control can be used to shape the waveform to something a little different from the norm.

Pulse circuits in Fig. 4(A) are *IC5* and *IC6*. Comparator *IC5* is an LM311 device. Internally based on an operational amplifier, the LM311 is a special-purpose IC comparator. A pull-up resistor is needed between its output and V+ rail. In this case, pull-up resistor *R10* has a value of 5,600 ohms. The value of *R10* is not critical, as long as it is between 3,900 and 10,000 ohms. The comparator's output is the required pulse, which is inverted in *IC6* to make available both polarities.

Amplifier *IC7* serves as the output stage of the project. It is a 741 op amp connected in an inverting-follower configuration. Its gain (0 to −1) is obtained by making the *R8* feedback resistance element a variable LEVEL control that can be adjusted for a value equal to the input resistance to the amplifier at maximum setting. This front-panel control is used as a "master gain" control for the project.

OUTPUT SELECT switch *S2* controls

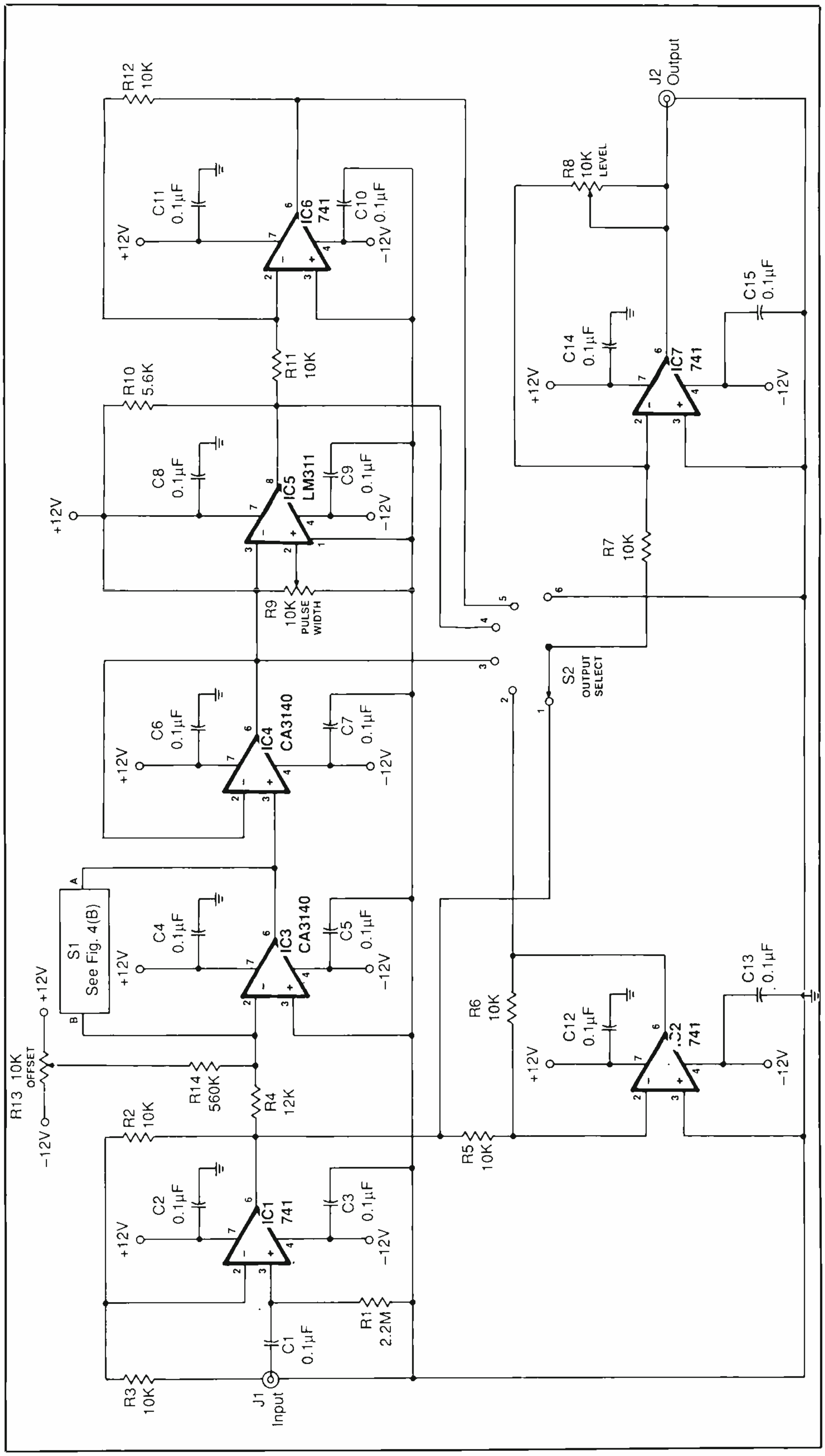


Fig. 4(A). Main schematic diagram of project's basic circuitry minus its ac-operated power supply. Details for S1 circuit are shown in Fig. 4(B).

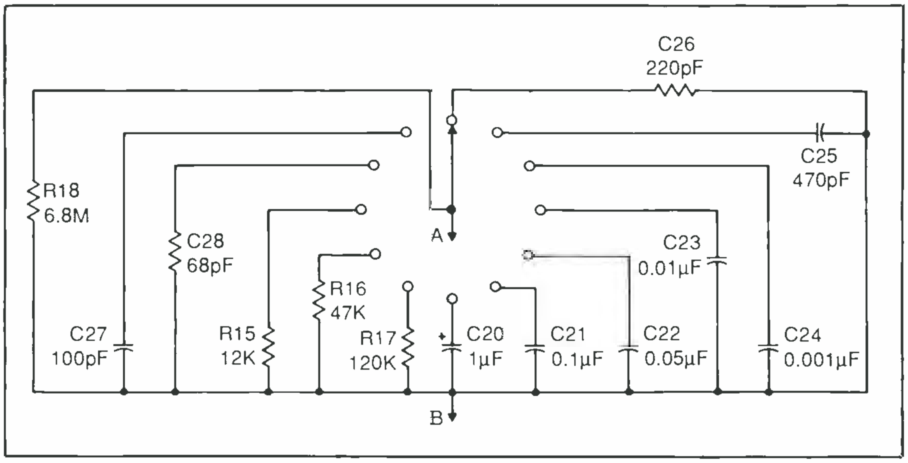
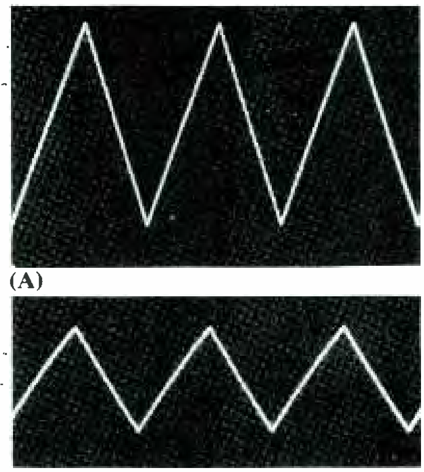


Fig. 4(B). Circuit details for S1.


(A)

(B)

Fig. 5. Triangle output waveform (A) from project driven by 1-volt p-p, 400-Hz input signal (B).

PARTS LIST

Semiconductors

D1,D2—1N4007 silicon rectifier diode
IC1;IC2,IC6,IC7—741 operational amplifier
IC3,IC4—CA3140 operational amplifier (RCA)
IC5—LM311 comparator
IC8,IC9—+12-volt regulator
RECT1—50-volt, 1-ampere bridge rectifier

Capacitors

C1 thru C15—0.01-µF ceramic disc
C16,C17—2,200-µF, 35-volt electrolytic
C18,C19—100-µF, 25-volt electrolytic

Resistors (¼-watt, 5% tolerance)

R1—2.2 megohms
R2,R3,R5,R6,R7,R11,R12—10,000 ohms
R4—12,000 ohms
R10—5,600 ohms
R14—560 ohms
R8,R9,R13—10,000-ohm panel-mount potentiometer

Miscellaneous

F1—0.6-ampere slow-blow fuse
J1,J2—Panel-mount BNC connector
S1—12-position non-shorting rotary switch
S2—6-position nonshorting rotary switch
S3—Spst slide or toggle switch
SO1—Chassis-mount ac receptacle (optional—see text)
T1—12-0-12- or 25.6-volt center-tapped, 250-mA power transformer (see text)
Printed-circuit board or perforated board with holes on 0.1-inch centers and suitable Wire Wrap or soldering hardware; see text); sockets for all DIP ICs; holder for F1; suitable enclosure (see text); optional neon-lamp assembly with built-in limiting resistor (see text); ac line cord (see text); knobs for controls and rotary switches (2 with pointers); lettering kit; clear spray acrylic; machine hardware; hookup wire; solder; etc.

which waveform will be delivered to the input of output amplifier *IC7*. These waveforms are as follows:

1—Input waveform amplified 2×
2—Inverted version of position 1 waveform
3—Triangle waveform
4—Negative-going pulse
5—Positive-going pulse
6—No output

The function-converter project produces several different waveforms: triangle, pulse, cosine and amplified versions of any waveform applied to its input. Figures 5, 6 and 7 were photographed using a 1-volt peak-to-peak input signal from my function generator. Except for the trace shown in Fig. 7, the input waveform in each case was a 400-Hz square wave.

Figure 5 shows a triangle output waveform. Note here that there are two different amplitudes displayed. The difference between them was not the input waveform (both were 1 volt p-p, 400-Hz square waves) but the gain of the integrator—that is, the value of the capacitor used in the feedback network. These differences are switch selectable with controls on the front panel of the project.

Three different pulse widths are shown in Fig. 6. The difference between the waveforms was the setting of potentiometer *R9*. The waveform shown in Fig. 6(C) is the maximum attainable level with this circuit and is nearly a square wave. The narrower pulses in Fig. 6 (A) and (B) are more clearly "pulse-like" waveforms.

One function of the Miller integrator is its its ability to phase-shift a sine wave by 90 degrees. If the input waveform is taken to be a sine, then the output of the Miller integrator will be a cosine waveform. Figure 7 shows the input and output waveforms superimposed on each other. Note here that the similarity of amplitudes is false except at one setting of the integrator switch. Normally, the output waveform's amplitude will be either lower or higher than that of the input waveform. How-

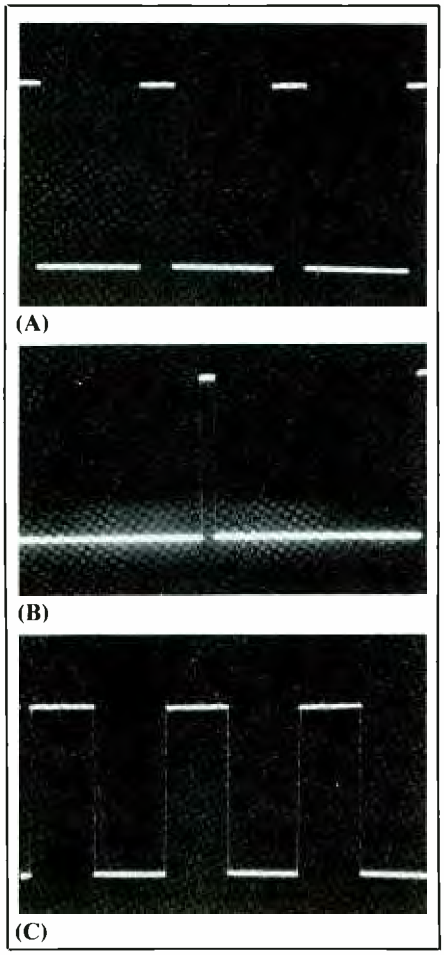


Fig. 6. Three different-width pulses produced by project: (A) is maximum attainable level; (B) and (C) are more clearly "pulse-like" in nature.

ever, I have rearranged the amplitudes by adjusting the oscilloscope's vertical input to more clearly show the phase shift.

Figure 8 illustrates two misadjustments of the project's front-panel controls. In (A), you see incorrect selection of the integrator's time constant (the value of the feedback capacitor). Selecting a different capacitor with the front-panel switch will correct this defect, unless the pseudo-sawtooth is really the waveform you want.

The result of misadjustment of the OFFSET control is illustrated in Fig. 8(B). In this case, the triangle waveform at the integrator's output is clipped. Correct setting of the OFFSET control will eliminate this.

Dc power for the project can be supplied by a pair of 9- to 12-volt dc batteries. However, it is better to use an ac-operated dc power supply. The schematic diagram for this power supply circuit is shown in Fig. 9. This is a standard ± 12-volt, 250-milliampere supply. Bridge rectifier *RECT1* should be rated at not less than 50 volts and 1 ampere PIV, while power transformer *T1* should be either a 12-0-12 volt ac or 25.6-volt ac center-tapped unit rated to deliver at least 250 milliamperes.

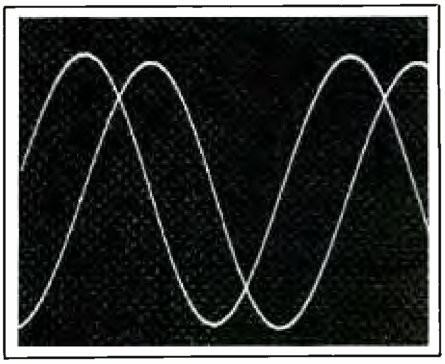


Fig. 7. Input and output waveforms of project superimposed on each other. Amplitudes have been rearranged by adjusting scope's vertical input to more clearly show phase shift.

Construction

There is nothing critical about component arrangement or wire routing. Therefore, you can use any traditional wiring technique to assemble the project. If you wish, you can design and fabricate a printed-circuit board. Alternatively, you can assemble the components on perforated board that has holes on 0.1-inch centers using appropriate Wire Wrap or solder-type hardware, as is shown in the interior view of my prototype in Fig. 10. Whichever way you go, however, be sure to use sockets for the DIP integrated circuits.

Carefully follow Fig. 4 (A) and (B) for wiring the main circuit and Fig. 9 for wiring the power-supply circuit. As you make each conductor and component run, trace it on the appropriate schematic diagram or a photocopy of it. This way you will keep track of what you have done and what remains to be done. Do *not* install the ICs in their sockets until after you have made preliminary voltage checks to ascertain that the circuit has been correctly wired.

Once the circuit-board assembly has been wired, select an enclosure for the project. Though I used a so-called "instrument" case for my prototype (see lead photo), you can use any other type of enclosure that will accommodate the circuit-board assembly and power transformer on its floor and has ample room on its front panel for mounting the various controls, switches and jacks.

Machine the enclosure as needed, drilling mounting holes through the floor for the circuit-board assembly and power transformer. This done, drill an entry hole for the ac line cord and another hole for mounting the fuse holder through the rear panel. (Note: If you wish, you can replace the ac line cord with a chassis-mount male ac receptacle and use a separate plug-in ac line cord for the standard line cord normally used in such projects, as I did in my prototype.) Finally, drill mounting holes for the controls, switches and jacks through the front panel. If you wish, you can also wire a neon-lamp with current-limiting resistor directly across *T1*'s primary conductors after the POWER switch. If you do this, drill yet another hole in the front panel, above the hole for the POWER switch, in which to mount the lamp. Deburr all holes and line the ac cord's entry hole with a rubber grommet.

Pre-wire one lead of *C20* through *C28* and *R5* through *R18* to the appropriate lugs of rotary switch *S1*, as illustrated in Fig. 4(B). Neatly bundle all free capacitor and resistor

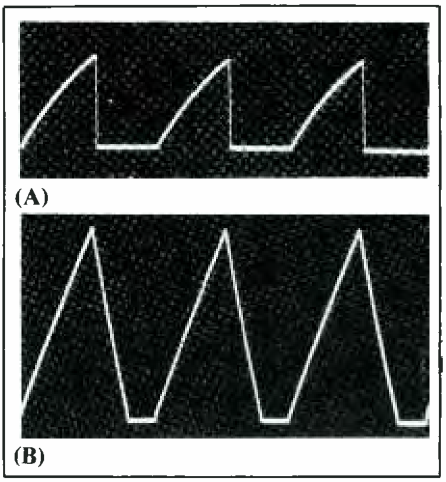


Fig. 8. Results from misadjustment of project's controls: (A) incorrect selection of integrator time constant and (B) wrong adjustment of OFFSET *control.*

leads together. Strip ½ and ¼ inch of insulation from opposite ends of a 6-inch-long hookup wire. If you are using stranded wire, tightly twist together the fine conductors at both ends and sparingly tin with solder. Tightly wrap the end from which the ½ inch of insulation was stripped around the capacitor-and-resistor-lead bundle and solder the connection.

Loosely mount this switch in the hole drilled for it through the front panel and place on its shaft a pointer-type control knob. Rotate the knob through each switch position without allowing the switch to move and lightly mark the position on the panel where the pointer on the knob comes to rest in each case. If the marks are not symmetrically located, remove the knob and reposition the switch as necessary. Replace the knob and once again rotate it through each switch position, marking the location the pointer comes to rest. Remove and set aside the knob and switch. Repeat the entire operation for rotary switch *S2*.

Label the switch positions and functions of all front-panel controls. If you use a dry-transfer lettering kit, protect the legends with several light coats of clear acrylic spray. Allow each coat to dry before spraying on the next.

When the spray acrylic has completely dried, mount the fuse holder on the rear panel and route the ac line cord through its grommet-lined hole (or mount the male ac receptacle in its hole). Then mount the power transformer on the floor of the enclosure and wire its primary circuit to the fuse holder, POWER switch and line cord (and neon indicator if you are using it, lengthening its leads as necessary with hookup wire and insulating the soldered connections with small-diameter heat-shrinkable tubing or insulating plastic tubing).

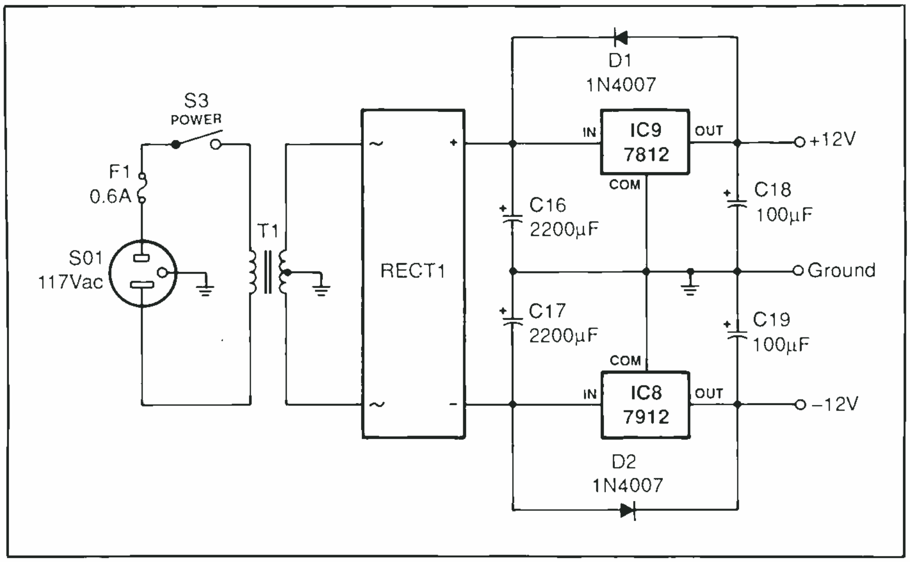


Fig. 9. Schematic of ac-line-powered ±12-volt dc supply recommended for powering the project.

Set the circuit-board assembly inside the enclosure near the power transformer and wire the latter's secondary leads to the appropriate points in the circuit. Then mount the controls, switches and jacks (and neon lamp, if used) in their respective holes in the front panel. Run appropriate lengths of hookup wire between the lugs of these components and the points in the circuit to which they are shown connected in Figures 4 and 9.

Before mounting the circuit-board assembly in place, carefully check all component installations for proper wiring and all soldered connections. If you locate a component that is installed in the wrong location or is installed backward, remove it and correct the installation(s). Reflow the solder on any suspicious connection. When you are satisfied with your wiring, mount the circuit-board assembly in place on the floor of the enclosure using ½-inch or longer spacers and suitable No. 4 or No. 6 machine hardware.

Checkout & Use

With the ICs still not installed in their sockets, plug the project's line cord into an ac outlet and flip the POWER switch to "on." If you installed the optional neon POWER indicator, it should come on.

Connect the common lead of a dc voltmeter or multimeter set to the dc volts function to a convenient circuit ground point, such as the negative lead of *C16* or positive lead of *C17* and leave it so connected for all voltage tests. Now touching the meter's "hot" probe to pin 7 of all IC sockets except that for *IC5*; you should

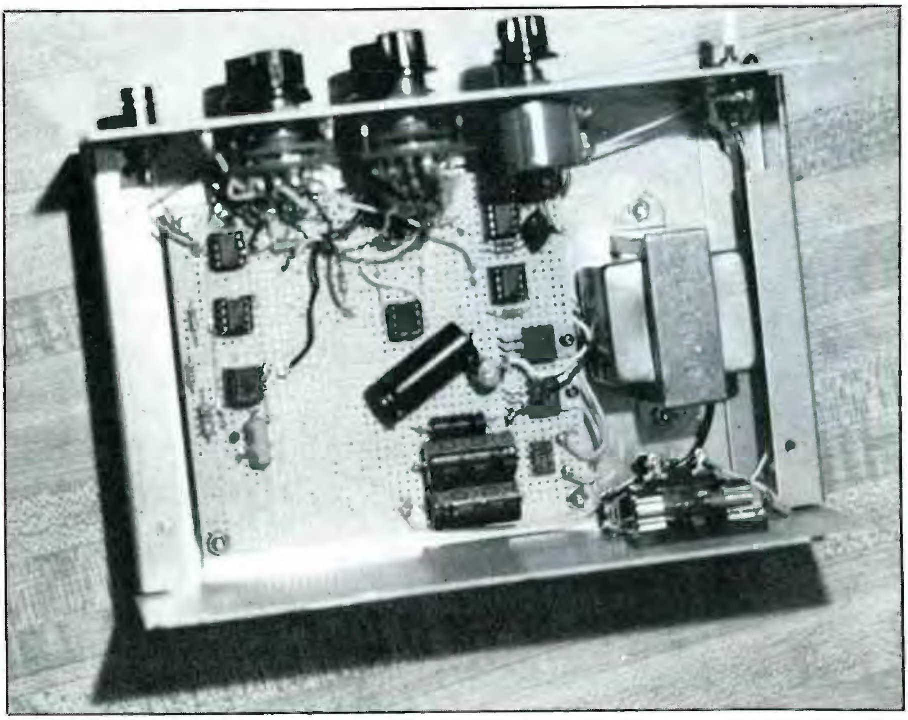


Fig. 10. Interior view of author's prototype. Note that all controls, switches and jacks mount on front panel, circuit-board assembly and power transformer mount on floor of enclosure, and fuse holder mounts on rear wall above entry hole for ac line cord.

obtain a meter reading of + 12 volts. Touching this probe to pin 8 of the *IC5* socket should yield the same reading. Now touch the "hot" probe to pin 4 of all IC sockets; this time the reading should be − 12 volts.

If you do not obtain the + 12 or − 12 volts at any of the points mentioned, check the output line(s) of the power supply. If you fail to obtain a reading or get an incorrect reading at any single point in the circuit, you must power down and troubleshoot to correct the wiring error. Do not proceed to installation of the ICs in their respective sockets until you are certain your wiring is correct.

Once you are sure of your wiring, power down the circuit and allow sufficient time for the charges to bleed off the electrolytic capacitors. Then carefully install the ICs in the sockets. Make sure you install each in its correct socket and that no pins overhang the sockets or fold under between ICs and sockets.

The only way to learn how to use this project is to experiment with the settings of the various controls. Use suitable cables to connect the output of your signal generator to the INPUT jack of the project and OUTPUT jack to the input of your oscilloscope and go to town experimenting with various control and switch settings until you become familiar with the project's operation.

With this accessory, you will breathe new life into your dated audio signal generator. If you do not have an audio signal generator, you can still use this project; simply build any of a number of sine- and/or square-wave generating circuits using operational amplifiers and use these to drive the project. **ME**

Note: Some of the material in this article is based on the author's IC User's Casebook *published by Howard W. Sams & Co., No. 22488; $12.95.*