PROGRAM ANY WAVESHAPE *YOU CAN IMAGINE*

A voltage-controlled oscillator circuit with RAMs synthesizes waveshapes without using complex filters

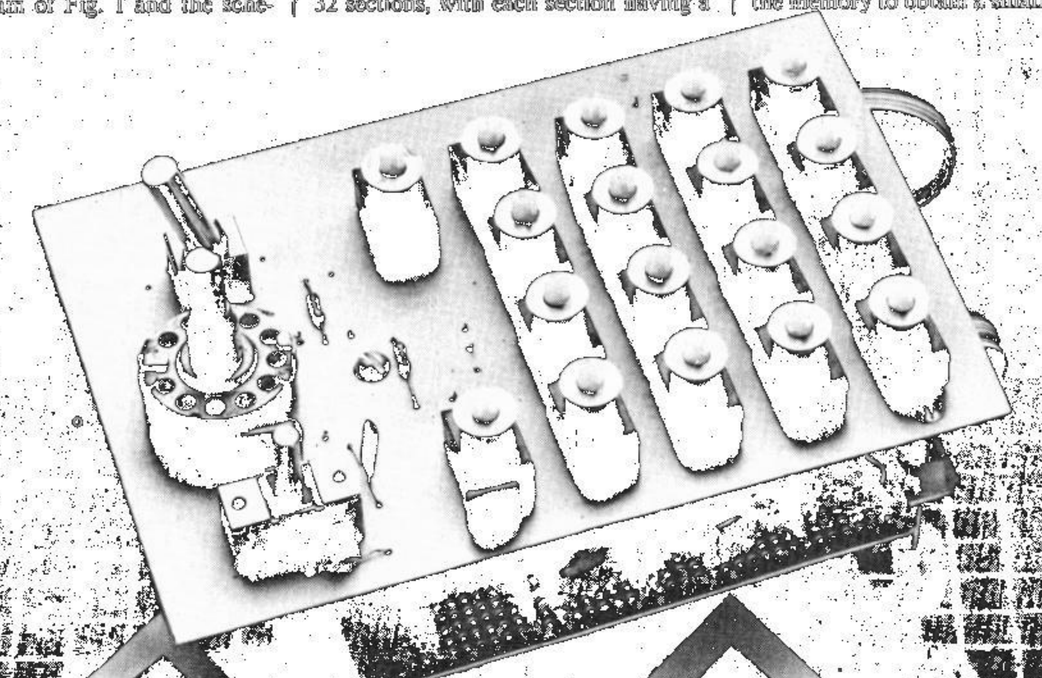
By R. S. Lasher

USING a programmable voltage-controlled oscillator (vco) makes it possible to synthesize almost any waveshape without having to pass a fundamental waveform (square, triangle, or sine) through a filter. The circuit shown in this article uses two computer RAM chips to "construct" a waveshape preprogrammed by the user and was designed to replace a conventional voltage-controlled oscillator in a synthesizer. With a few simple revisions, it is possible to use this circuit as a versatile sequencer. The circuit utilizes CMOS devices for high speed and low operating power.

Circuit Operation. As shown in the block diagram of Fig. 1 and the schematic of Fig. 2, the circuit includes five basic building blocks: the vco, a 6-bit counter, a memory, a keyboard and encoder, a digital-to-analog converter, and an output stage. The vco is a precision circuit that produces a square-wave output whose frequency is linearly proportional to the input voltage level. The operating point of *IC1* is determined by *R11* and switch-selected *C1*, *C2*, or *C3*. Three frequency ranges can be selected by *S2*: 100-10,000 Hz for audio, 1-100 Hz for very low frequencies, and 0.1-1 Hz for sequencer applications.

The square-wave output from pin 7 of *IC1* is divided by 32 in *IC2* to form a six-bit address for memory *IC3* and *IC4*. This divides the desired wave shape into 32 sections, with each section having a unique voltage level. The voltage level of each section is loaded into the memory formed by *IC3* and *IC4*, two random-access memory chips. (A 15-bit number signifying a specific voltage level is stored at each memory address.) As each address is called in order by *IC2*, the output changes to the voltage level preprogrammed by the user.

The effective size of the memory is 6 bits by 5 bits but can be expanded to 7 bits by 5 bits. However, it was found that, if the memory is expanded past 6 bits, the frequency of the vco is much higher than the maximum operating limits. If the circuit is going to be used only on the lower two frequency settings of *S2*, it is possible to expand the memory to obtain a smaller error in



the final output. It should be kept in mind, however, that for each address of memory, a voltage level will have to be keyed in. This will make it necessary to key in 128 numbers.

Digital-to-analog converter *IC5* changes the digital output to an analog current signal. The latter is then converted into a voltage signal suitable for use in a voltage-controlled synthesizer by op amp *IC6*.

To enter a waveform into the memory, the memory should be switched into the WRITE mode by applying a high (via *S2B*) to pins 8 and 6 of *IC8*. The 6-bit counter, *IC2*, should be reset to zero by applying a high to pin 2 of *IC2* via *S4*. The 16-key keyboard is decoded by *IC7*. As a key is closed, *IC7* sends a data available signal to *IC8A*. If READ/WRITE switch *S2* is in the WRITE mode, a high is passed to *IC8*, and the gate will produce a low at pin 10 when the data is to be written into the memory. This is done because, if the data or the address is changed while the memory is in the WRITE mode, the data could be lost. Therefore, after the data is stabilized, the READ/WRITE signal is brought low to begin the next address.

The keyboard is comprised of 16 keys, used to program *IC3*, and SHIFT key *S3*, which will program *IC4*. The SHIFT key allows the use of just 16 keys instead of 32. The 16 keys are debounced by an internal circuit of *IC7* and *C5*. This capacitor also controls the time delay between the data output signals and the data-available signal, since *C6* controls the sampling rate of *IC7*.

When there are no keys depressed, the output enable, pin 14, is forced into a low state. This forces the data output pins into a high-impedance or a three-state mode. When a key is depressed, the data-available signal goes high and, if the READ/WRITE switch is in a WRITE position, *IC8* produces a low signal. This enables the output pins into their respective levels, depending on which key is depressed.

Construction. The oscillator can be wire-wrapped using lengths of wire that are as short as possible. Keep in mind that, when an output frequency above 10 kHz is desired, there will be a signal above 500 kHz passing through the *S2* circuit, so keep these leads as short as possible. Handle all CMOS chips with

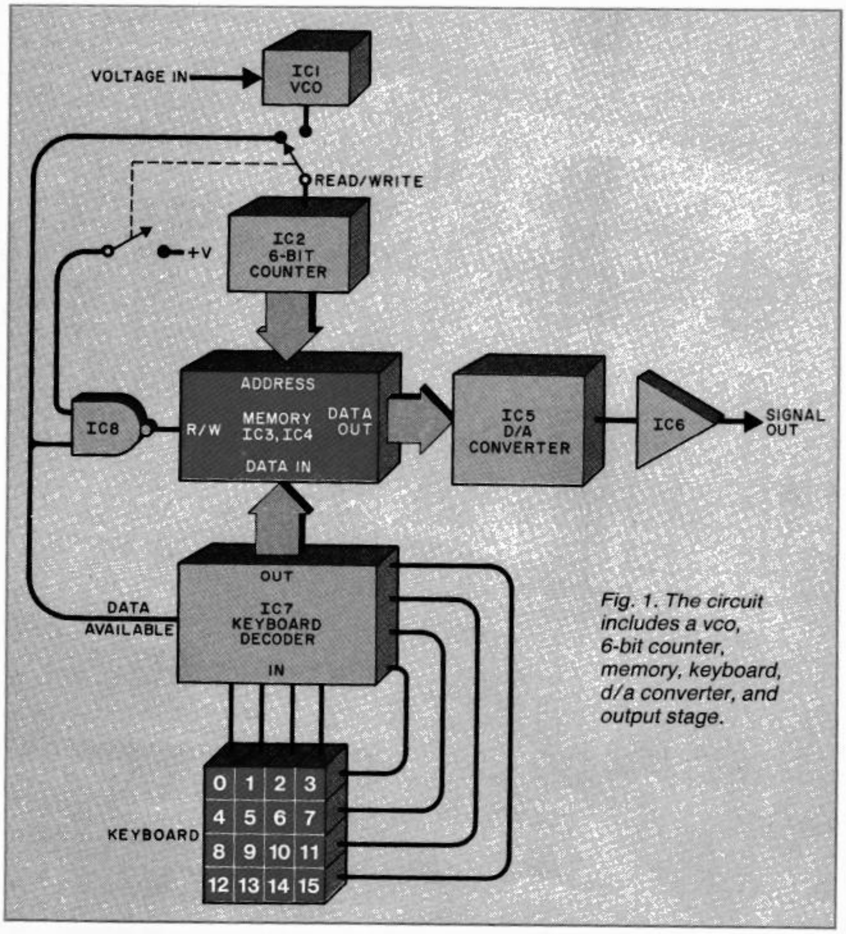


Fig. 1. The circuit includes a vco, 6-bit counter, memory, keyboard, d/a converter, and output stage.

> *"A number of vco's can be used to create a series of waveforms that will generate avant garde music."*

care to prevent static breakdown. A grounded metal enclosure should be used to reduce any r-f interference generated by *IC1*.

The power supply can be any source of voltage between ±4 and ±6 volts dc, with a typical circuit that can be used shown in Fig. 3.

Use. The circuit can be used in either of three modes: as a vco, as an envelope generator (which is essentially a low-frequency signal), or as a sequencer. Other than the programmability, there is very little difference between this vco and any other.

To program the circuit, use a graph having 32 divisions vertically (voltage) and 64 divisions horizontally (time) and sketch the desired waveform between these bounds. With READ/WRITE switch *S2* set to WRITE, depress *S4* to RESET the system to zero, then use the keyboard to enter the voltage value at each horizontal division. If the voltage scale exceeds 15 units, use the SHIFT switch (*S3*) to add 16 to the key number.

To convert the circuit to a sequencer, break the connection between pins 2 and 3 of *IC2*, and connect pin 3 to parallel-connected pins 1 and 2 of a spare gate within quad gate *IC8*. This forms an inverter. Connect the output of this inverter at pin 3 to pin 13, one input of another spare gate within *IC8*.

Remove the lead coming from *S2A* at pin 1 of *IC2*, and connect the switch lead to pin 12 of *IC8*. Both inputs to this gate are now made. The output at pin 11 will be the inverse of the clock signal when the counter is in the first 64 counts. When the seventh bit goes high, the gate (*IC8*) will be inhibited and the count will stop if pin 11 of *IC8* is connected to pin 1 of *IC2*.

To start the sequence, apply a high to pin 2 of *IC2* via RESET pushbutton *S4*. This will reset the counter and force the seventh bit low, allowing clock signals to pass through *IC8*. Counter *IC2* con-

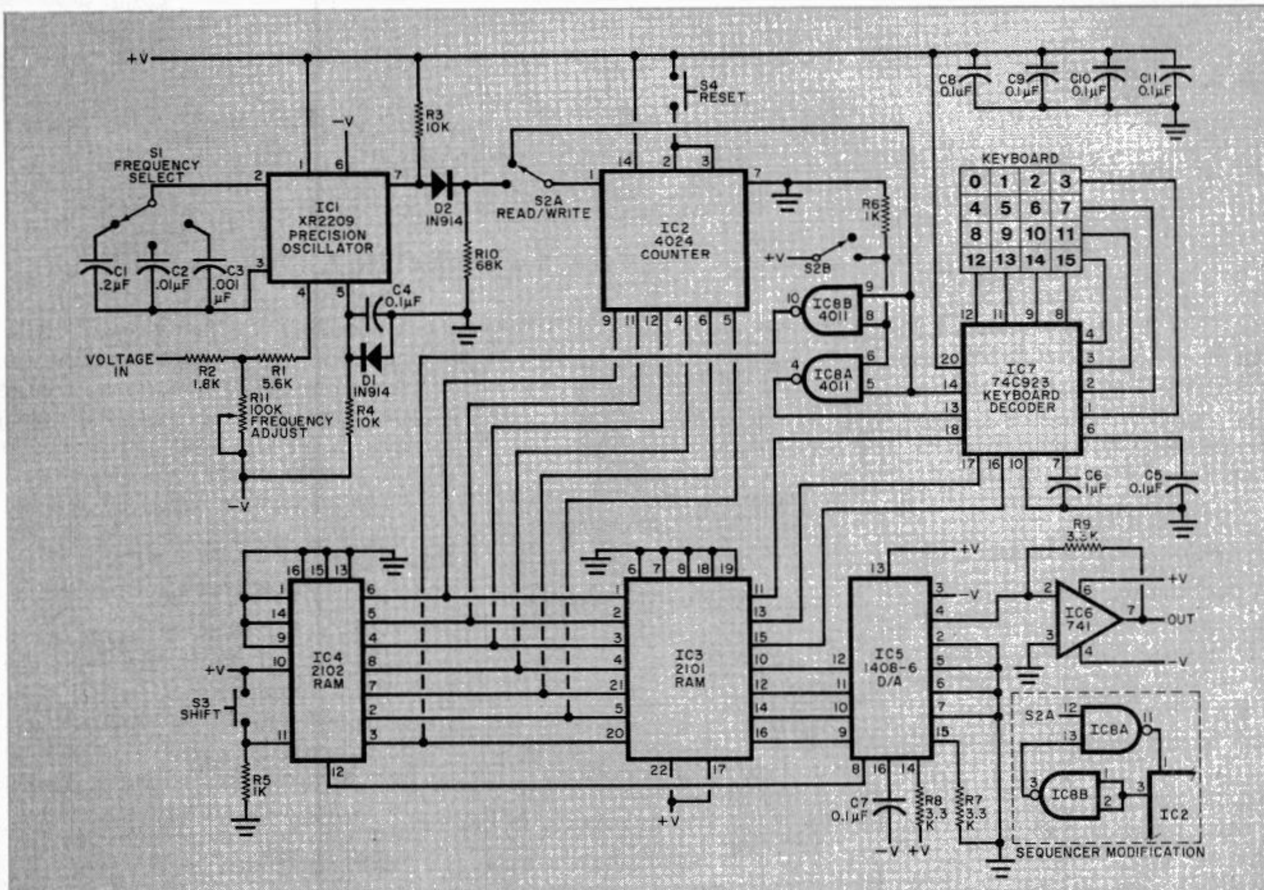


Fig. 2. The vco produces a square-wave output whose frequency is proportional to the input voltage.

PARTS LIST

C1—0.2-µF capacitor
C2—0.01-µF capacitor
C3—0.001-µF capacitor
C4,C5,C7 through C11—0.1-µF capacitor
C6—1-µF capacitor
D1,D2—1N914
IC1—XR2209 precision oscillator (Exar)
IC2—4024 7-stage binary counter
IC3—2101 256 × 4 static RAM
IC4—2102 1024 × 1 static RAM
IC5—1408-6 digital-to-analog converter
IC6—741 op amp
IC7—74C923 keyboard encoder
IC8—4011 quad 2-input NAND gate
R1—5-kilohm resistor
R2—1.8-kilohm resistor
R3,R4—10-kilohm resistor
R5,R6—1-kilohm resistor
R7,R8,R9—3.3-kilohm resistor
R10—68-kilohm resistor
R11—100-kilohm potentiometer
S1—Sp3t rotary switch
S2—Spdt switch
S3,S4—Normally open pushbutton switch
Misc.—16-key keypad, hookup wire, suitable enclosure, mounting hardware, etc.

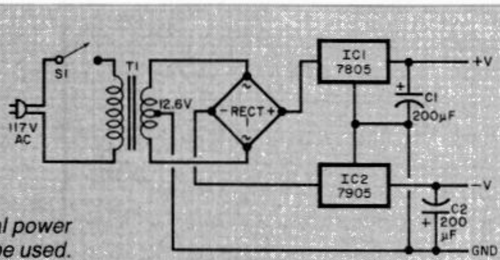


Fig. 3. A typical power supply that can be used.

PARTS LIST

C1,C2—200-µF, 25-V capacitor
IC1—7805 5-V positive regulator
IC2—7905 5-V negative regulator
RECT1—1-A bridge rectifier
S1—Spst switch
T1—12.6-V, 500-mA transformer

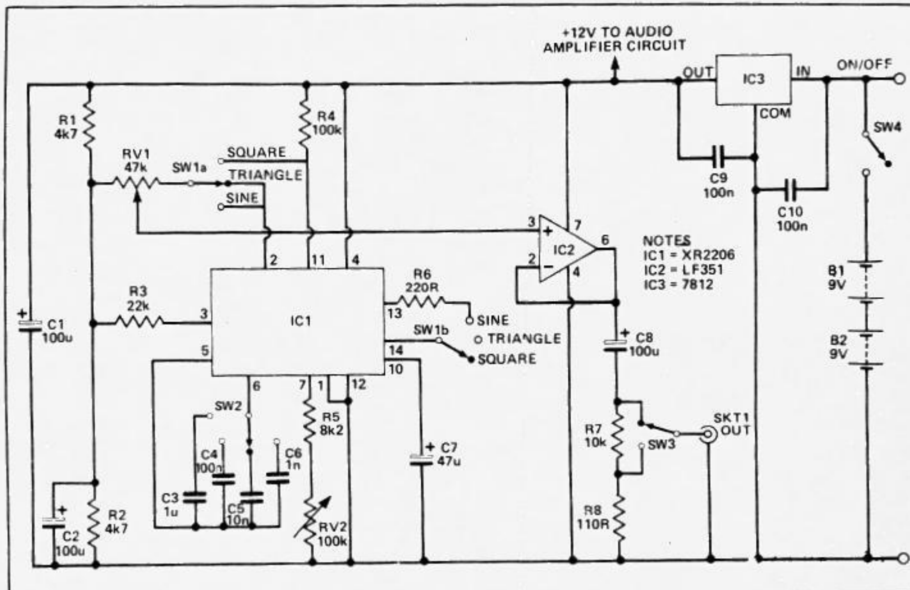
tinues to count until the seventh bit goes high, inhibiting the clock signal.

Both the programmable vco and the sequencer can be used in a number of ways. For example, the vco can be programmed for any waveform the user can imagine, making it ideal for music synthesis. The user can define the required waveform so that a vco (voltage controlled filter) is not required. This allows for re-programming the same sound without having to consider programming a vco. A number of vco's can be used to create a series of unique waveforms for *avant garde* music. On the other hand, the sequencer can be used to program any function that uses a voltage as a control. ◇

TECH TIPS

Signal Generator

G. Teesdale



THIS unit is based on the XR2206 function generator integrated circuit, as can be seen from the circuit. The charge/discharge capacitor connects between pins 5 and 6 of IC1, and in this case four switched capacitors are used to give the unit its four frequency ranges. Variable resistor RV2 is the fine frequency control and C7 is a bypass capacitor for an internal circuit of IC1. The sinewave/triangular output is taken from pin 2 of IC1, and the output from this is normally the triangular waveform. The sinewave signal is obtained by connecting a resistor (R6) between pins 13 and 14 of IC1.

Rather than having separate amplifiers for the triangular output buffer and the sinewave shaping circuit, the XR2206 uses the same amplifier for both functions, and switching in R6 connects the shaping components into the feedback circuit of the amplifier. This resistor could be replaced with a preset resistor, which would then be adjusted to optimize performance, but results should be more than adequate using the specified (fixed) value.

A Programmable

FUNCTION GENERATOR

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

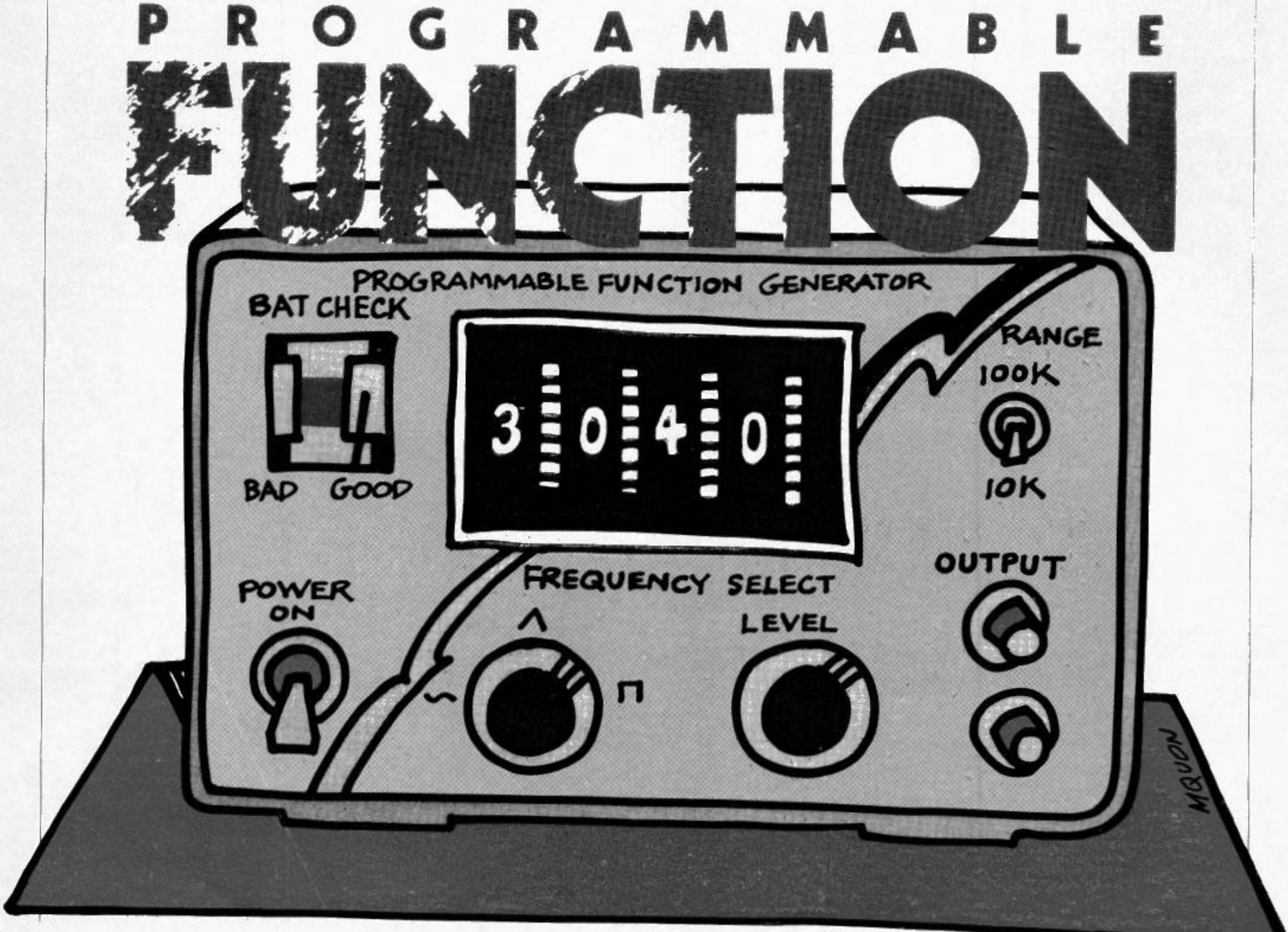
By Gary McClellan

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 × 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.

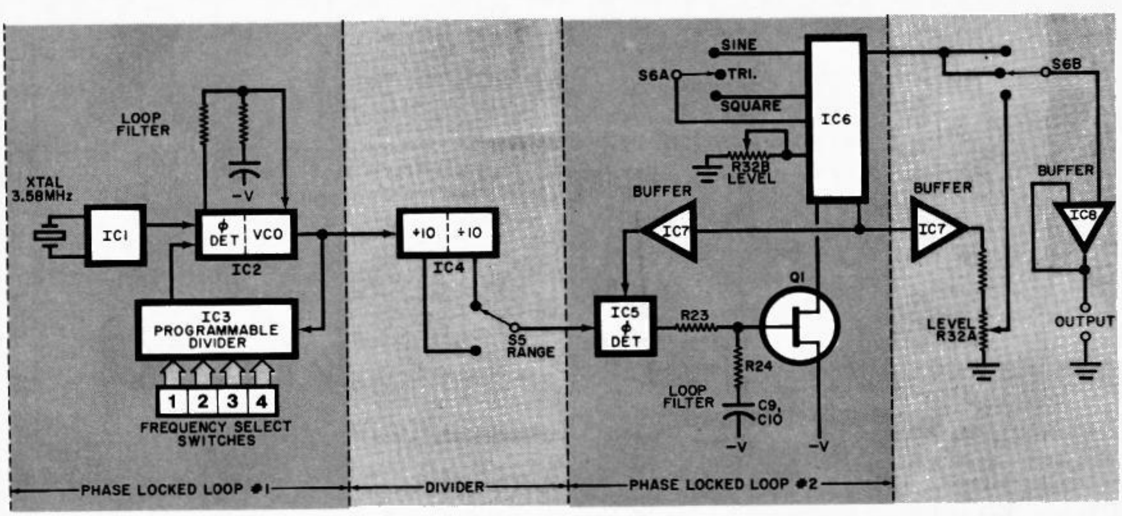


Fig. 1. The basic circuit consists of two phase-locked loops.

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.

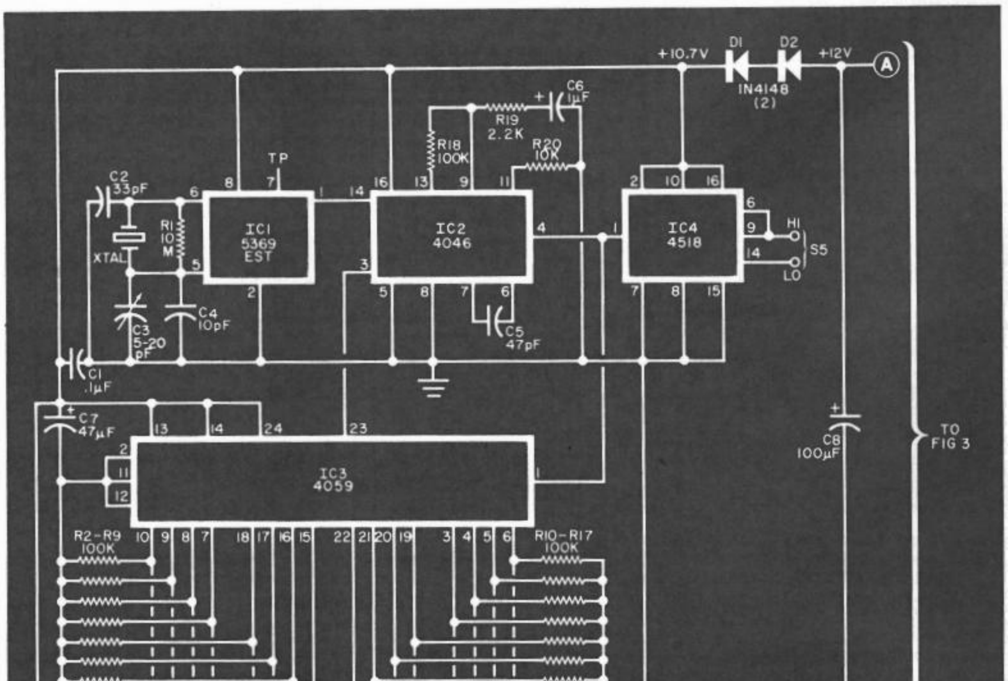
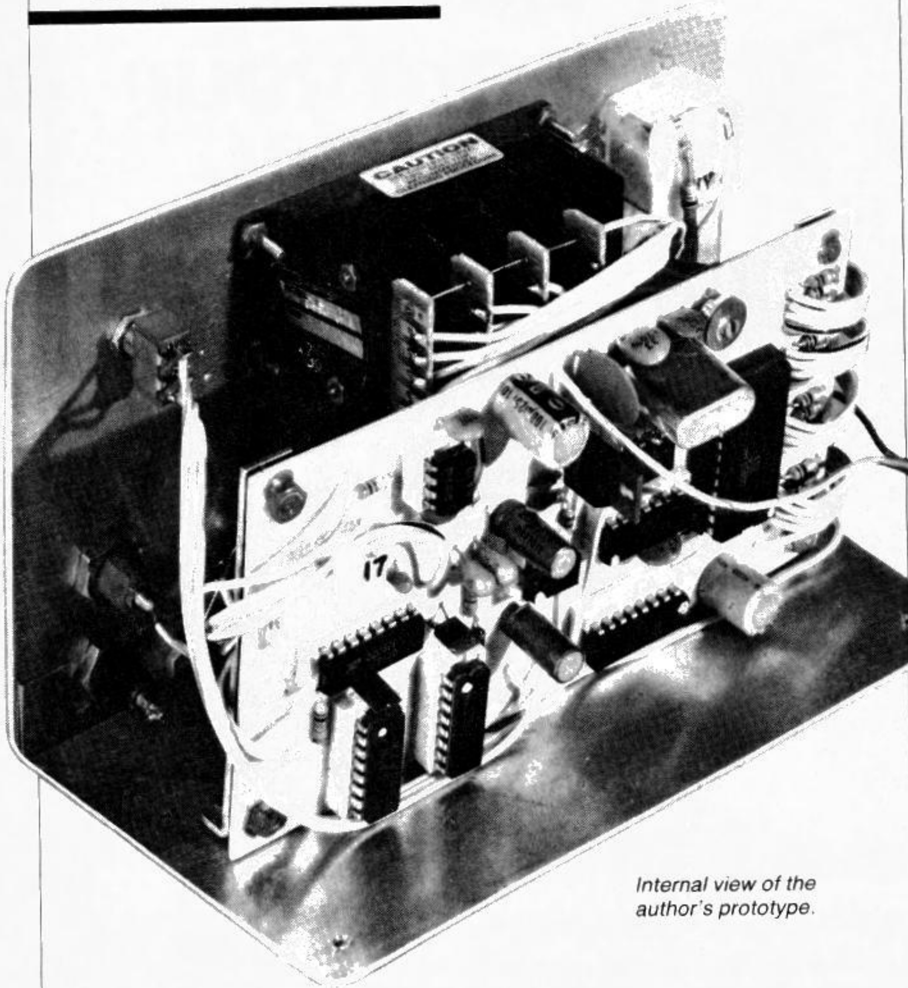


Fig. 2 The first phase-locked loop is a frequency synthesizer as shown here.



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-

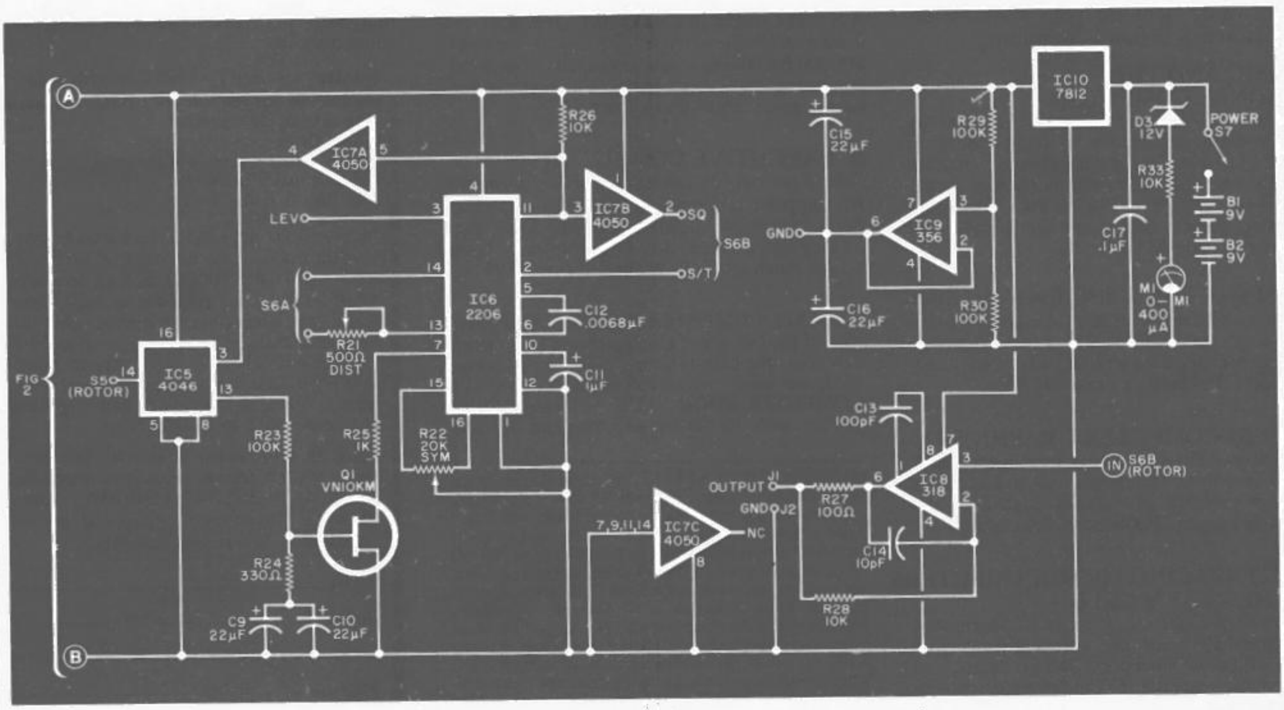


Fig. 3. Shown here are the second PLL and the power supply.

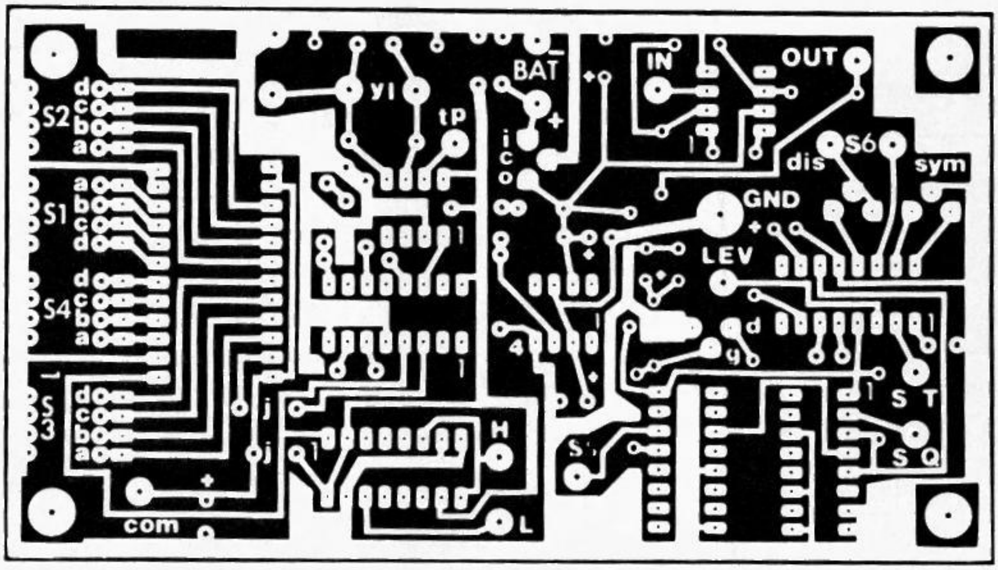


Fig. 4. Full-size etching and drilling guide for pc board.

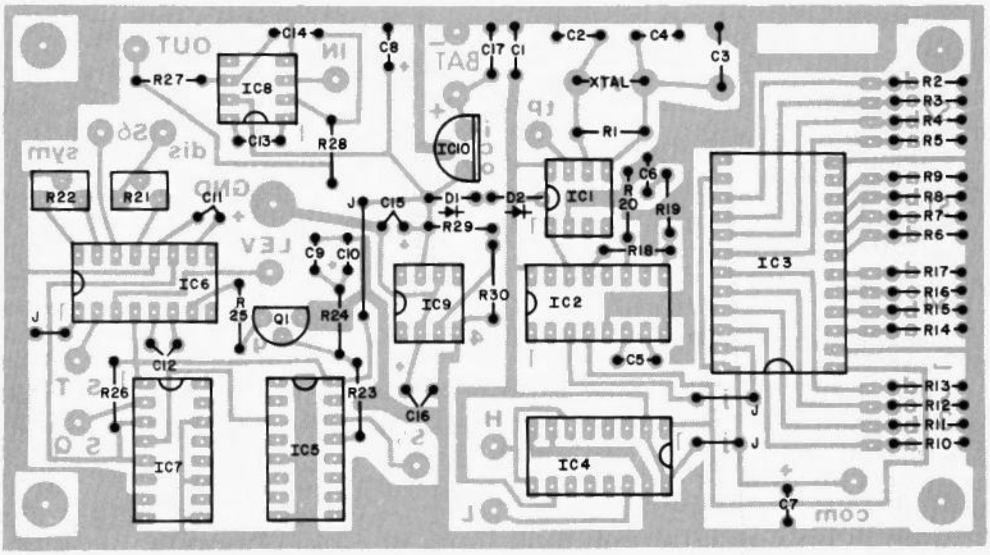


Fig. 5. Locations and orientations of the components on the pc board.

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

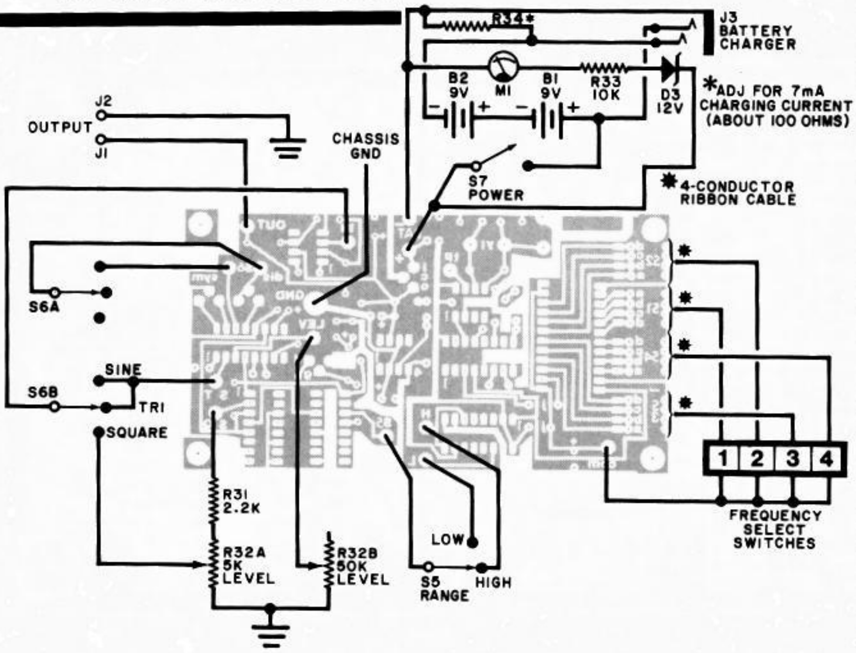


Fig. 6. Connection of off-board components to the pc assembly.

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

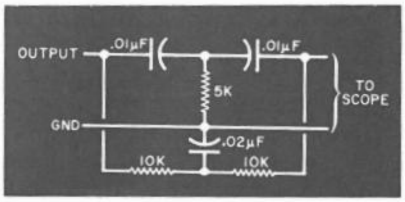


Fig. 7. Filter to be used in viewing project output on scope.

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*. ◇

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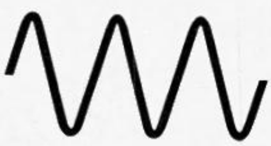
BUILD THIS

Synthesized Function Generator



A function generator is one of the most useful pieces of equipment you can own. This synthesized unit offers professional performance at a reasonable price.

GARY McCLELLAN

THE FUNCTION GENERATOR IS A RELAtively recent piece of equipment (since the early 1960's) and has found its way to the average hobbyist's workbench. These devices are really handy for checking out audio gear, servicing other equipment, and just plain experimenting. But unfortunately, progress seems to have ignored the function generator. The generators you see today are great, but all still have crudely calibrated tuning dials that are hard to read, and most generators have some frequency drift. That may be acceptable for most purposes, but try to work with the new active filters, tone decoders, and phase-locked loops. It's tough to do if you don't have good control over the function generator's frequency, which can drift out of the passband of these devices.

Enter our SFG-or *S*ynthesized *F*unction *G*enerator project. This device is a radical departure from conventional function generators in many important ways. As you can see from the photos, gone is the squinty analog tuning dial that you always had to fiddle with. And gone, too, is the drift of conventional function generators that can cause so much aggravation when working with sharp filters. And there are other innovations, too, like the absence of a range switch—that feature is done automatically by the panel switches. And there is also a switchable digital output of different frequencies on the rear

R-E TESTS IT

LEN FELDMAN
CONTRIBUTING HI-FI EDITOR

THE SYNTHESIZED FUNCTION GENERATOR was tested in our laboratory. As expected, signal frequencies were totally accurate, thanks to the quartz crystal frequency synthesis method used in the circuitry of the device. Maximum peak-to-peak signal amplitude observed was 15 volts for the sinewave output—somewhat lower for the triangular and squarewave outputs.

As is true of most other function generators, distortion of the sinewave output was quite high. Our measured results are as follows:

Frequency	Harmonic Distortion
100 Hz	2.5%
2 kHz	2.0%
10 kHz	3.0%
100 kHz	1.3% (Bandwidth limit of analyzer)

Accordingly, we would not recommend the use of the sinewave output for distortion evaluations of audio equipment, but rather as a highly accurate source of desired audio (and super-audible) frequencies. The

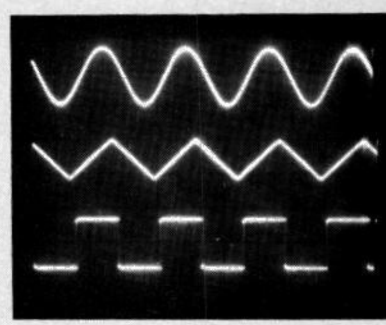


FIG. 1

sinewave source *may* be used for measuring frequency response of audio equipment, however, since levels remain constant over the entire bandwidth of the instrument. The TTL compatible signal outputs on the rear of the unit were also checked and were found to be in accordance with the author's claims and suitable for driving external logic circuitry.

Waveform outputs from the SFG were photographed in a composite photo, as shown in Fig. 1. The frequency selected for this scope photo was approximately 2 kHz.

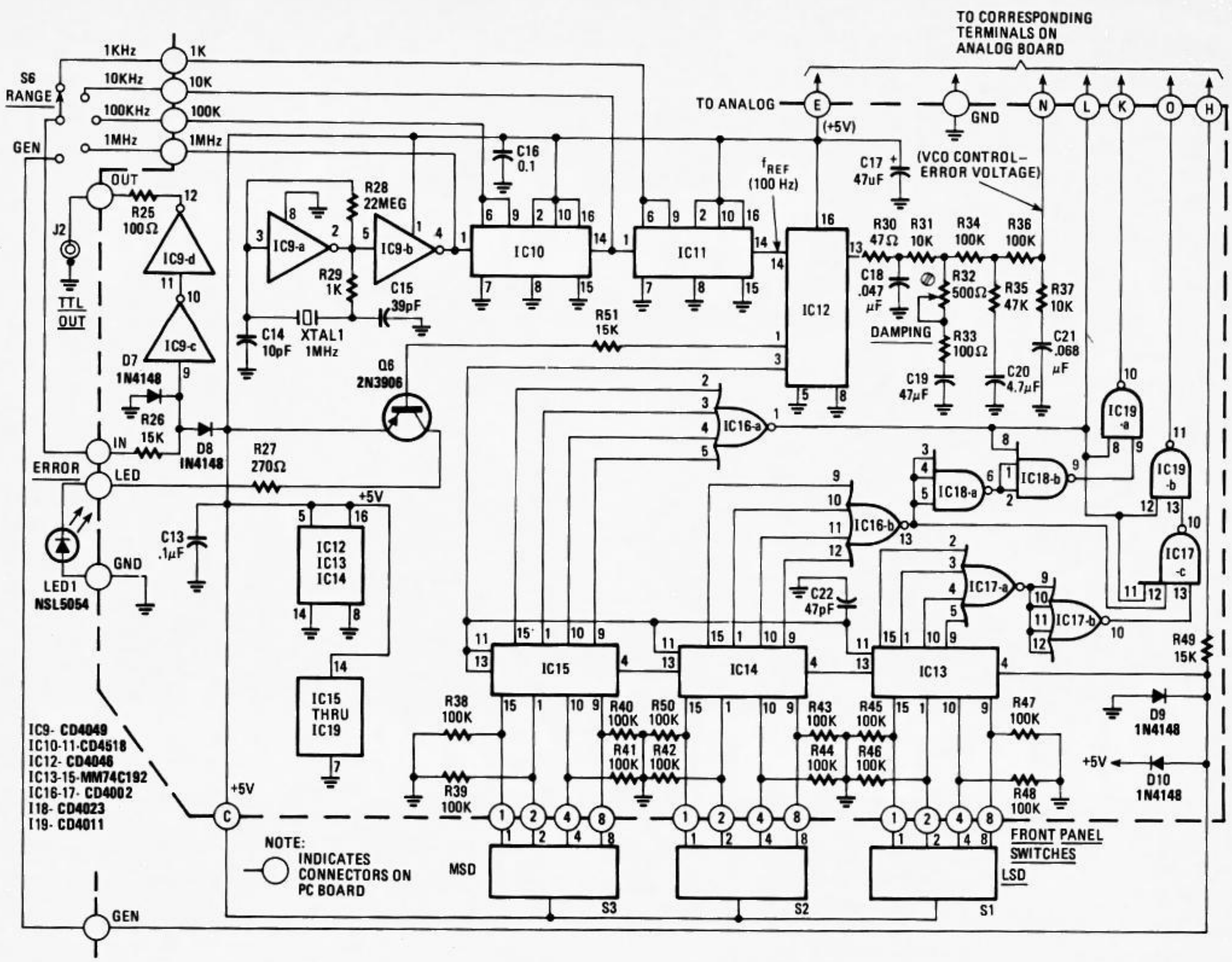


FIG. 1—SCHEMATIC DIAGRAM of the digital circuitry used in the SFG. The many output frequencies are all derived from the 1-MHz crytal and a series of programmable frequency dividers.

panel for use in running digital circuitry *independent* of the frequency the unit is set to. And if that isn't enough, this generator is crystal controlled.

You'll like the performance features of the SFG, too. All you have to do is set the desired frequency with the front-panel thumbwheel switches, select the type of waveform, and adjust the output level. There's a frequency vernier control that allows you to "fine tune" your frequency with minimal (if any) drift, too. (The photos show four thumbwheel switches. Only three are used in the SFG because output waveforms suffer when programmable output is pushed to 1 MHz.) The maximum output frequency is 100 kHz. There's an error indicator that alerts you if for some reason your frequency is off.

Not to be forgotten are two other important requirements of a function generator—namely the output waveforms and output impedance. This project offers high-quality sine, square, and triangular waveforms, plus TTL level signals from 1 kHz to 1 MHz in decade steps. The output is 50 ohms as found in the highest quality function generators. It can swing up to a 10-volt peak-to-peak signal into a 50-ohm load. If you are looking for an advanced, high-quality function generator, you are bound to like this project!

The performance of the SFG rates well with other function generators. In addition to its superior frequency stability, it produces a low distortion (adjustable to 0.5% THD) sinewave. It also generates triangular and squarewave signals on a par with the better generators. As mentioned earlier, this project features a low-impedance output (50 ohms) that is ideal for driving low-impedance loads. In fact, you can drive a speaker if desired! And with a maximum output of 10 volts peak-to-peak into 50 ohms, there should still be plenty of signal delivered to that 4-ohm speaker.

Although this is an advanced project, the cost and construction features have been optimized to make it as easy as possible to own this instrument. The cost is lower than most less-sophisticated function generators, and far lower than the least expensive commercial equivalent. In fact, the nearest commercial unit costs about $800, and this project was built for 15% of that. Wouldn't you like to have the SFG for about $60?

Inside the SFG

This project is built on two PC boards to make assembly and testing easier. Let's begin with the digital board, whose schematic is shown in Fig. 1. The signal starts with crystal XTAL1, which generates a 1-MHz reference with the aid of inverter IC9-a and IC9-b. Since the frequency of this signal is too high for the rest of the SFG, it is divided down to 100 Hz by IC10 and IC11. Each of those IC's contains a dual CMOS decade counter. In addition, the outputs of each decade are tapped off, buffered by IC9-c and IC9-d, and appear on a rear-panel switch and TTL-OUTPUT jack J2. Those signals are handy for other digital testing. Meanwhile, the 100-Hz output of IC11 drives the reference input of IC12, a CMOS phase detector. That device compares the phase of two signals and gives an output if they are different. In this case, the original signal is the 100-Hz reference from IC11, and the unknown signal derives from IC15.

When the SFG has reached the frequency it is set to, the synthesizer is said to be in "lock", and both input frequencies will be 100 Hz. Let's look closer at IC13 to IC15. Those devices are the programmable dividers that accept inputs from the front panel switches (S1–S3) and divide the signal from the VCO by the same number. Thus, if the switches are set for 100, and the VCO generates a

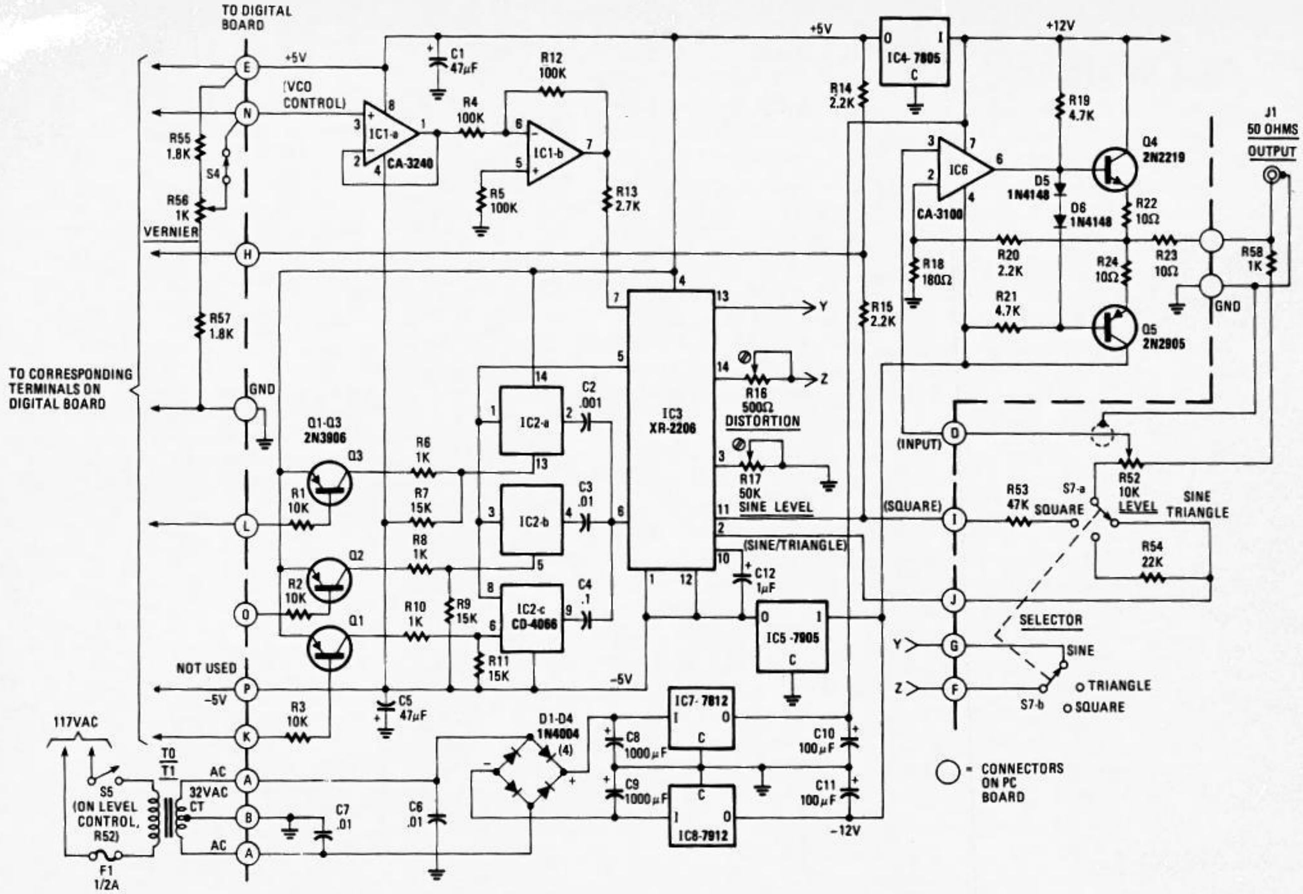


FIG. 2—THE ANALOG CIRCUITS are designed around IC3, the heart of the function generator. Output frequency is determined by a DC voltage from the digital section. Range switching is automatic.

PARTS LIST

Resistors ¼ watt, 5% unless otherwise noted
R1-R3—10,000 ohms
R4, R5, R12, R34, R36, R38-R48, R50—100,000 ohms
R6, R8, R10, R29, R58—1000 ohms
R7, R9, R11—15,000 ohms
R13—2700 ohms
R14, R15, R20—2200 ohms
R16—500 ohm trimpot
R17—50,000 ohms, trimmer (Jim-pak 840-50K or equal)
R18—180 ohms
R19, R21—4700 ohms
R22-R24—10 ohms, ½ watt
R25, R33—100 ohms
R26, R49, R51—15,000 ohms
R27—270 ohms
R28 —22 megohms
R30—47 ohms
R31, R37—10,000 ohms
R32—500 ohm trimpot
R35, R53—47,000 ohms
R52—10,000 ohms, linear-taper pot with SPST switch
R54—22,000 ohms
R55, R57—1800 ohms
R56—1000 ohms, linear-taper pot with SPST switch

Capacitors
C1, C5, C17—47 μF, 6 volts, electrolytic, PC mount
C2—0.001 μF, 100 volts, Mylar
C3, C6, C7—0.01 μF, 100 volts, Mylar
C4—0.1 μF, 50 volts, Mylar
C8, C9—1000 μF, 25 volts, electrolytic, PC mount
C10, C11—100 μF, 16 volts, electrolytic, PC mount
C12—1 μF, 16 volts, tantalum
C13, C16—0.1 μF, 25 volts, ceramic disc
C14— 10 pF mica
C15—39 pF mica
C18—0.047 μF, 100 volts, Mylar*
C19—47 μF, 6 volts, tantalum*
C20—4.7 μF, 6 volts, tantalum*
C21—0.068 μF, 100 volts, Mylar*
C22—47 pF ceramic disc
***Do not substitute.**

Semiconductors
D1-D4—1N4004
D5-D10—1N4148
IC1—CA3240AE dual BiMOS op-amp
IC2—CD4066 quad analog switch
IC3—XR 2206 function generator (EXAR)
IC4—7805 or LM340T-5 +5-volt regulator
IC5—7905 or LM320T-5 −5-volt regulator
IC6—CA3100EM wideband op-amp
IC7—7812 or LM340T-12 +12-volt regulator
IC8—7912 or LM320-12 −12-volt regulator
IC9—CD4049 CMOS hex inverter
IC10, IC11—CD4518 CMOS dual BCD up-counter
IC12—CD4046 CMOS Micropower phase-locked loop
IC13-IC15—MM74C192 CMOS BCD up/down counter
IC16, IC17—CD4002 dual 4-input NOR gates
IC18—CD4023 CMOS triple 3-input NAND gates
IC19—CD4011 CMOS quad 2-input NAND gates
Q1-Q3, Q6—2N3906
Q4—2N2219
Q5—2N2905
LED1—NSL5054 LED and holder

Miscellaneous
XTAL1—crystal, 1 MHz, 32 pF parallel mode, HC-6/U case
S1-S3—BCD thumbwheel switch (C&K Type 332110000, Cherry Switch Type T35-02A3 (Herbach & Rademan) or Unimax Type SF-21X3 or equal approximately $10.00 completely assembled.
S4, S5—SPST, on R52 and R56
S6—rotary switch, 1 pole, 5 positions
S7—rotary switch, 2 poles, 3 positions
I1—power transformer, 32 volts, CT, 1 amp
J1, J2—BNC connectors
F1—fuse, 0.5A with holder
IC sockets: two 8-pin, eight 16-pin, five 14-pin
Heatsinks: two TO-220, two TO-5

PC boards and plans are available. If desired, the plans can be ordered separately or combined with a set of boards. Here's how to order: SFG-1 complete set, $12.00 postpaid in U.S.A.

SFG-2 plans only, $5.00 postpaid in U.S.A.

California residents add sales tax. Foreign residents add $3.00 for shipping and handling. No COD's or foreign currency, please. Order from Technico Services, PO Box 20HC, Orangehurst, Fullerton, CA 92633

10-kHz signal, the output will, of course, be 100 Hz.

The output of IC15 drives the phase detector input, completing the programmable divider chain. Notice the 4-input NOR gates tied to IC13 to IC15? They serve as a *priority decoder*, and act as an automatic range switch, controlling the output frequency of the instrument. The outputs of NOR gates, IC16-a, IC16-b and IC17-a go low any time a non-zero number is selected by its corresponding switch. These signals then drive inverter IC17-b and gates IC18 and IC19, generating a logic output at terminals L, K and O, corresponding to the most significant digit selected. These outputs are used to select a range capacity on the analog board, which will be described shortly. Finally, back to IC12. The output of the phase detector drives a rather extensive R-C network. That network is a "loop filter" that smooths the pulses coming out of IC12 to a DC voltage in order to drive the VCO.

The reason for the complexity of the loop filter is that it not only filters, but controls the performance of the SFG. It determines how long it takes to lock on a new signal, and how stable the output signal will be. In short, it's important. A pot adjustment is provided for "damping" or for minimizing the jitter in the output as the loop tries to lock. If you are concerned about the difficulty of making this adjustment, don't worry—it takes only a moment to make with a triggered-sweep oscilloscope. That takes care of the SFG digital board.

The second half of the SFG is the analog board. Refer to the schematic in Fig. 2. Although there are fewer IC's on this board, the larger number of discrete components make it seem "busier" than the digital board. Actually, the circuitry is easy and straightforward enough to understand quickly. The DC control signal from the loop filter goes to the input (pin 3) of IC1-a, a CMOS op-amp. That device provides the high-input impedance required to minimize loading on the loop filter. You should know that any loading on the loop filter causes damping problems—jitter—making a CMOS device ideal for this application.

The second half of IC1 serves as an inverter with a gain of one. That converts the +1.5–3-volt input from the loop filter to a *minus* value of the *same* magnitude. This is necessary to operate the function generator IC3 properly. Also, another input is provided on pin 3 of IC1-a. It is used for a frequency vernier control, or for an external FM input.

Now on to IC3. This device is a standard function generator. It generates an especially high quality sine-square-triangle wave output. The sine and triangle outputs appear on pin 2, with the type of waveform selected by closing the switch between pot R16 and pin 13. This switch is part of S7, the SINE-TRIANGLE-SQUARE SELECTOR. In the sine mode (switch closed), trimmer pot R16 adjusts the shape of the waveform for minimum distortion, while trimmer R17 sets the maximum output level. Both adjustments are easy to make with an oscilloscope.

Moving on, the squarewave output appears on pin 11. Note the pull-up resistors, R14 and R15. The voltage tapped off these resistors drives IC12 on the digital board. In order to set the output frequency, three different timing capacitors (C2, C3, C4) are used, allowing IC3 to cover 10 kHz to 100 kHz, 1 kHz to 10 kHz, and 100 Hz to 1 kHz, respectively. An analog switch (IC2) selects the appropriate capacitor. Since the switch is powered by ±5-volt supplies, some logic conversion is necessary. Transistors Q1 through Q3 provide that function, and interface the outputs from the priority decoder gates to the analog switch. Next, there's a power-amplifier circuit on board to boost the signal of the function generator IC to useful levels. That's the job of IC6, a 15-MHz op-amp, and transistors Q4 and Q5. Finally, the balance of the board consists of the power supply. Standard three-terminal regulators provide a stable source of ±12 volts and ±5 volts for the circuitry. That takes care of the analog board.

SUGGESTED PARTS SUPPLIERS

IC's:
Tri-Tek, Inc.
7808 N. 27th Ave.
Phoenix, AZ 85021
(602) 995-9352

Jameco Electronics
1021 Howard Ave.
San Carlos, CA 94070
(415) 592-8097

Misc. Parts:
Digi-Key Corp.
PO Box 677
Hiway 32 South
Thief River Falls, MN 56701
1-800-346-5144

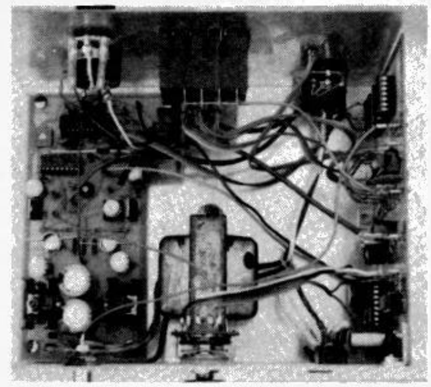
T1:
B&F Enterprises
119 Foster St.
Peabody, MA 01911

Signal Transformer
500 Bayview Ave.
Inwood, NY 11696
(516) 239-7200

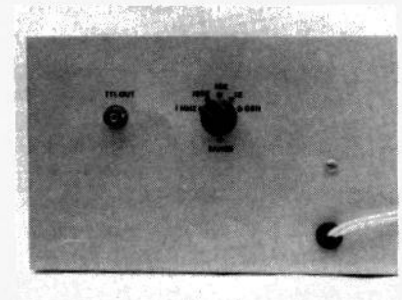
Thumbwheel switches:
C & K
15 Riverdale Ave.
Newton, MA 02158
(617) 964-6400

Jameco Electronics
1021 Howard Ave.
San Carlos, CA 94070
(415) 592-8097

Herbach & Rademan
401 E. Erie Ave.
Philadelphia, PA 19134



INTERIOR VIEW of the Synthesized Function Generator shows board and parts placement and point-to-point wiring.



REAR APRON of the SFG contains the jack for providing TTL-level signal output and rotary range switch.

The cabinet houses a few minor bits of circuitry besides the power transformer, controls, and connectors. You'll be able to see those next month when you wire up the two boards. All that the circuitry consists of is a vernier pot and switch which supply a bias voltage to the op-amp on the analog board. The pot allows adjustment of the SFG to frequencies not selectable by the switches—a handy feature. Also, there are several resistors on the SINE-TRIANGLE-SQUARE switch. Their purpose is to make the output levels of the different waveforms equal in peak-to-peak values, reducing the need to adjust the level control.

Construction

As you should know, this project consists of two PC boards and the case. So building the SFG will consist of stuffing each of the boards first, then connecting them together in the case. The work is easy if you know what you are doing and take your time to do the job.

This month we'll present the necessary information to get you started on the SFG, by assisting in the ordering of the parts and preparation of the circuit-boards. Then next month we'll describe the actual construction.

The first thing you can do on this project is to make or buy the PC boards. For your convenience, foil patterns have been provided in Figs. 3 and 4 so you can duplicate the boards. Or if desired, you can order the board set that is being made available to **Radio-Electronics** readers. Simply refer to the parts list for the name and address of the supplier. As a bonus,

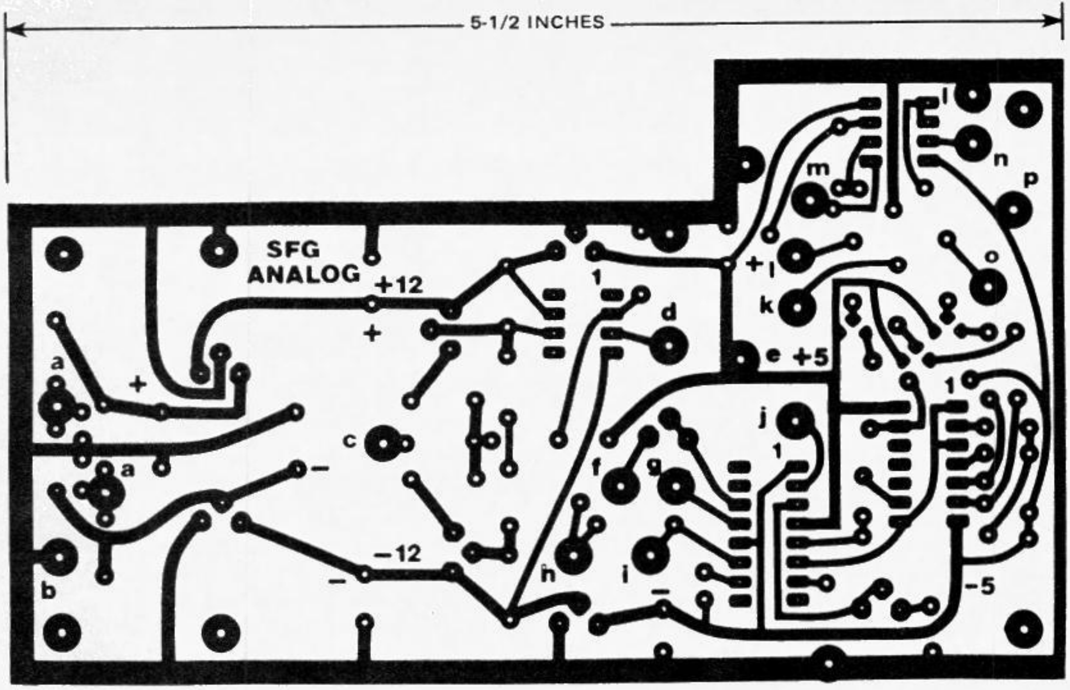


FIG. 3—FOIL PATTERN for the analog circuit board.

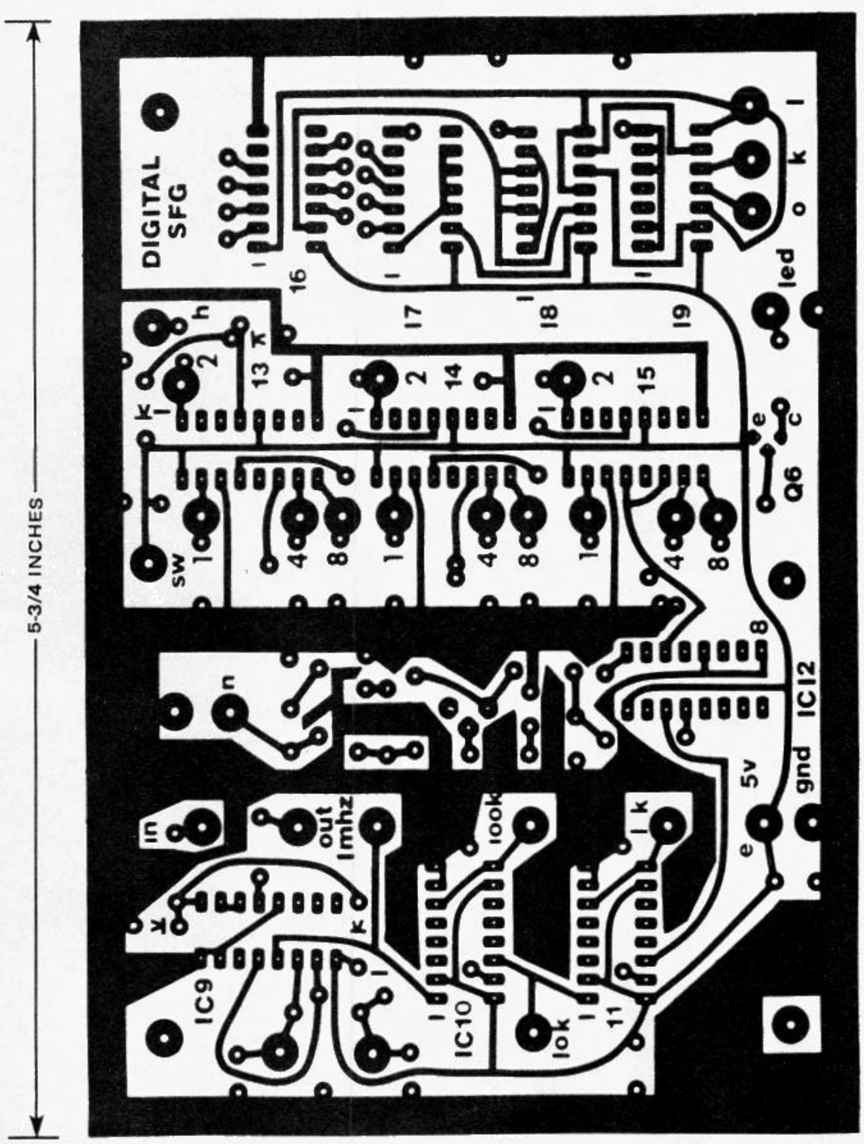


FIG. 4—FOIL PATTERN for the digital circuit board. Etched and drilled boards are available at a nominal cost. See parts list.

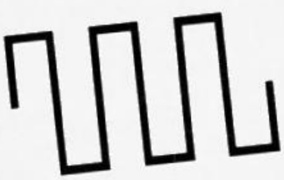
you'll receive a copy of instruction plans, plus operating and troubleshooting information. At any rate, the choice is yours!

The next step is to obtain the parts. That should be a fairly easy job in that no special "synthesizer products" were used in the design. All IC's are standard CMOS, with the exception of the bipolar function-generator IC. Some good parts sources are listed at the end of this article. Or, if you prefer, choose other suppliers from the classified section of this magazine, or raid your junkbox.

Now let's look at some of the parts themselves, as a few might be confusing at the store. The function generator, IC3, is from EXAR and is often seen blister-packed in stores carrying the *Jim-pak* or *CALECTRO* product lines. So you might try your local dealer for it. Power transformer, T1, may throw you at first, but it is actually one of those units used in "drugstore" stereo receivers, so you may be able to scrounge one at home. If not, try Signal Transformer, 500 Bayview Ave., Inwood, NY 11696, for a usable unit. The secondary voltage should run from 30 to 36 volts center-tapped with no load, and be capable of at least a half amp. The frequency-setting switches, S1–S3, are readily available in surplus; try a computer store. Be sure that you get one with BCD coded (e.g. C, 1, 2, 4 and 8 connections) outputs. There are plenty of those switches available from many sources if you just take time to look. As far as the rest of the parts are concerned, there should be no problems obtaining them. Just be sure to get quality devices and you'll be all set.

Next month the construction of the SFG continues with the board stuffing and installation data. The project will be rounded out with the adjustment procedure, and a "how to use it" guide. **R-E**

Synthesized Function Generator



GARY McCLELLAN

Part 2—Here are complete instructions for building and using the Synthesized Function Generator.

LAST MONTH YOU STARTED OBTAINING the parts and PC boards for the SFG. We hope that you were successful and are now ready to start building. The first thing to do is to "stuff" the two PC boards; then you wire the case. Take your time and this should be an easy project.

Before starting with the construction, first take a look at Figs. 5 and 6 which are the parts-placement diagram and photo of the analog board. Study the parts locations carefully, then start construction of the analog board. Install an 8-pin socket at the IC1, IC6 locations, a 14-pin socket at IC2, and a 16-pin socket at IC3. Do not install the IC's themselves until after all assembly has been completed.

Next, install the voltage-regulator IC's–IC4, IC5, IC7 and IC8. Note that heatsinks are required for IC7 and 8 only; they are small ones and mount directly on the board with the IC's. Now install the two jumpers in the lower left corner of the board. Those are the only jumpers to be installed. Continue by installing the electrolytic capacitors. Start with C8 and C9 (1000 μF), then move left and install C10 and C11 (100 μF). Be sure to watch the polarity of those capacitors; for your convenience it is printed on the foil side of the PC board. Continue by installing C1 and C5 (47 μF); and, finally, install C12 (1 μf tantalum) next to C5.

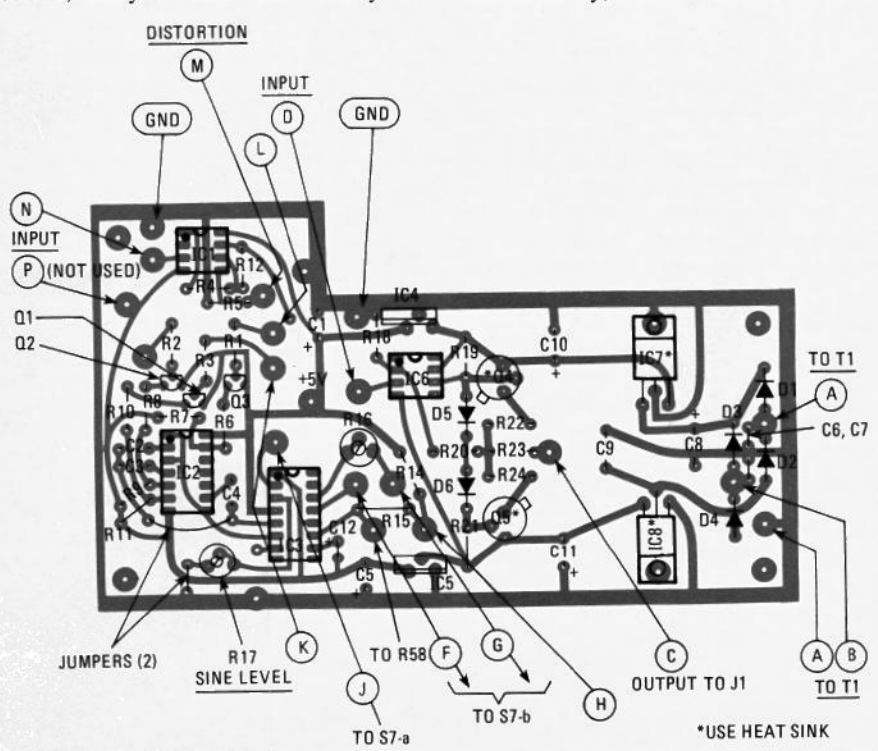


FIG. 5—PARTS PLACEMENT on the analog board. Don't overlook the jumpers, watch the polarity of the electrolytic capacitors, and be sure that the semiconductors are properly oriented.

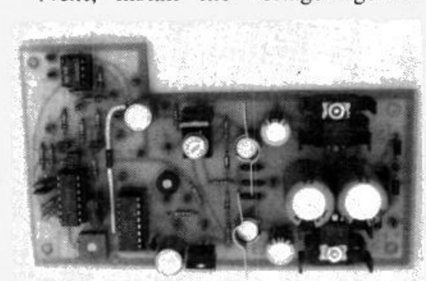


FIG. 6—TOP VIEW of the analog board. Study this carefully before you begin "stuffing" the board. Note the heatsinks on IC7, IC8, Q4 and Q5.

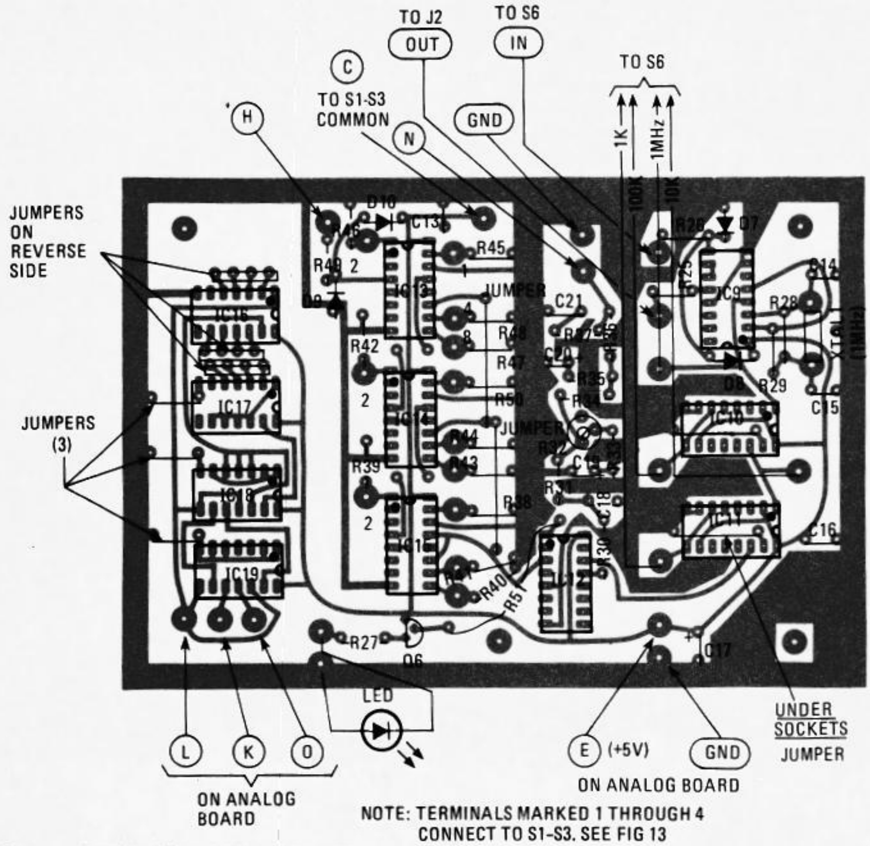


FIG. 7—HOW PARTS ARE POSITIONED on the digital board. Follow text for wiring sequence for easier assembly. Don't forget the jumpers that are on the foil side of the board.

At this point you have the major components installed and should be able to see that the board has taken shape and looks like Fig. 6. Continue by installing diodes D1–D4 (1N4004's) near the edge of the board, then install D5–D6 (1N4148's) in the spaces near the center. After you finish, recheck the diodes for proper installation. Now the resistors can be installed. Start with R22, R23, R24 (10 ohms, ½ watt), which mount in the center of the board; then jump left and install R19 and R21 (4.7K). Next, add R20 (2.2K) in the middle of the board. Go left still farther and install two 2.2K resistors at R14 and R15; then install pot R16 (500 ohm) and R18.

Stop for a moment and check carefully to be sure that the resistors are in the proper places and all connections are soldered properly. Now move left across the board still farther and install R12, R4, and R5 (100K). Next, go down and install R1, R2, and R3 (10K). Continue with R6 (1K) and R7 (15K). Move left slightly and install R8 and R10 (1K). Move down and install R9 and R11 (15K). Then jump right and install pot R17 (50K). Finish up by installing R13 (2.7K), noting that it stretches between two widely separated points on the board. Use spaghetti tubing on the exposed leads to insure that there are no shorts with adjacent components.

Take a short breather and continue with the transistors. Install Q4 (2N2219) first, then slip a heatsink over the case. Now install Q5 (2N2905) and slip another heatsink over the case. **Be sure that the two sinks don't touch after they are installed.** Then move to the left of the board and install Q1, Q2, and Q3. Note that the flat spot on each case faces to the top of the board. Complete construction by installing the remaining capacitors. Start at the right of the board with C6 and C7 (0.01 μF) which go between the diodes. Then go left and install C4 (0.1 μF Mylar) next to the 14-pin IC socket. Move to the other side of the socket and install C2 (0.001 μF Mylar) and C3 (0.01 μF Mylar). Finish up the board by installing the IC's.

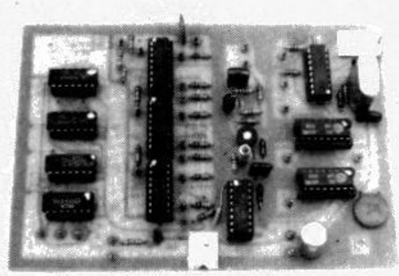


FIG. 8—TOP VIEW of the digital board. The white pieces at bottom center and top right corner are metal mounting brackets.

That completes the construction of the analog board. Be sure to check for proper parts placement and to be certain that all solder connections are good before going any farther. Make any corrections necessary, then set the board aside until later.

Wiring the digital board

Now you can stuff the digital board. First, refer to Fig. 7 for parts placement; start construction when you are reasonably familiar with that drawing. Position the board as shown with the large foil block in the top left-hand corner. Now you are all set to begin construction. Start with the wire jumpers on the component side. Note that there are a total of seven. Begin by installing the two in the IC10 and IC11 spots, noting that they run between the IC's and ground. It is important to install them now, as IC sockets will be installed over them shortly. Then move to the center of the board and install the two long jumpers as shown. They link the pin-11 terminals on IC13, IC14 and IC15, and are important. Next, go over to the left edge of the board and install the three jumpers next to IC's 17, 18 and 19. That takes care of the component side jumpers.

Now install the sockets. If desired, start by installing a 16-pin unit at IC9, IC10, and IC11. Then move to the bottom center of the board and install the socket for IC12. Now install the remaining 16-pin sockets at IC13, IC14, and IC15. Stop for a moment to recheck all solder connections (it's easy to miss one!), then continue with the 14-pin sockets. Install one at IC16, IC17, IC18 and IC19. Recheck your solder connections and take a short breather.

The next step is to continue with the resistors. Note that most of them are of 100K value on this board. We'll get to them shortly, but first let's install R28 (22 megs) next to IC9. Then install R29 (1K) adjacent to it. Move up to the top of the board and install R26 (15K) on the other side of IC9, then go below it and install R25 (100 ohms). Install R36 (100K), then R37 (10K) next. Move down a little more and install R35 (47K) and R34 (100K), which are next to each other. Continue with R33 (100 ohms) and R31 (10K) which are at right angles to each other. Then install R30 (47 ohms) and R51 (15K) on either side of IC12. Use spaghetti tubing on R51's leads to avoid shorts.

Stop for a moment and recheck all resistors for proper placement. Then continue by starting at the top center of the board. Install 100K resistors in the following places: R45, R48, R47, R50, R44, R43, R38, R41 and R40. Be sure not to miss soldering any of the leads. Then jump over IC15 and install the remaining 100K resistors at R39, R42, and R46. Finish up by installing a 15K resistor at R49 and trimpot R32. **Be sure not to get the R46 and R49 positions mixed up!** Take a breather and recheck your work, making any corrections necessary.

Resume construction by installing crystal XTAL1, next to IC9. Use the soldering iron sparingly to avoid overheating and damaging the crystal. Then install the diodes. Note the position of the banded ends as you install them. First, install D7 and D8 (1N4148) at the ends

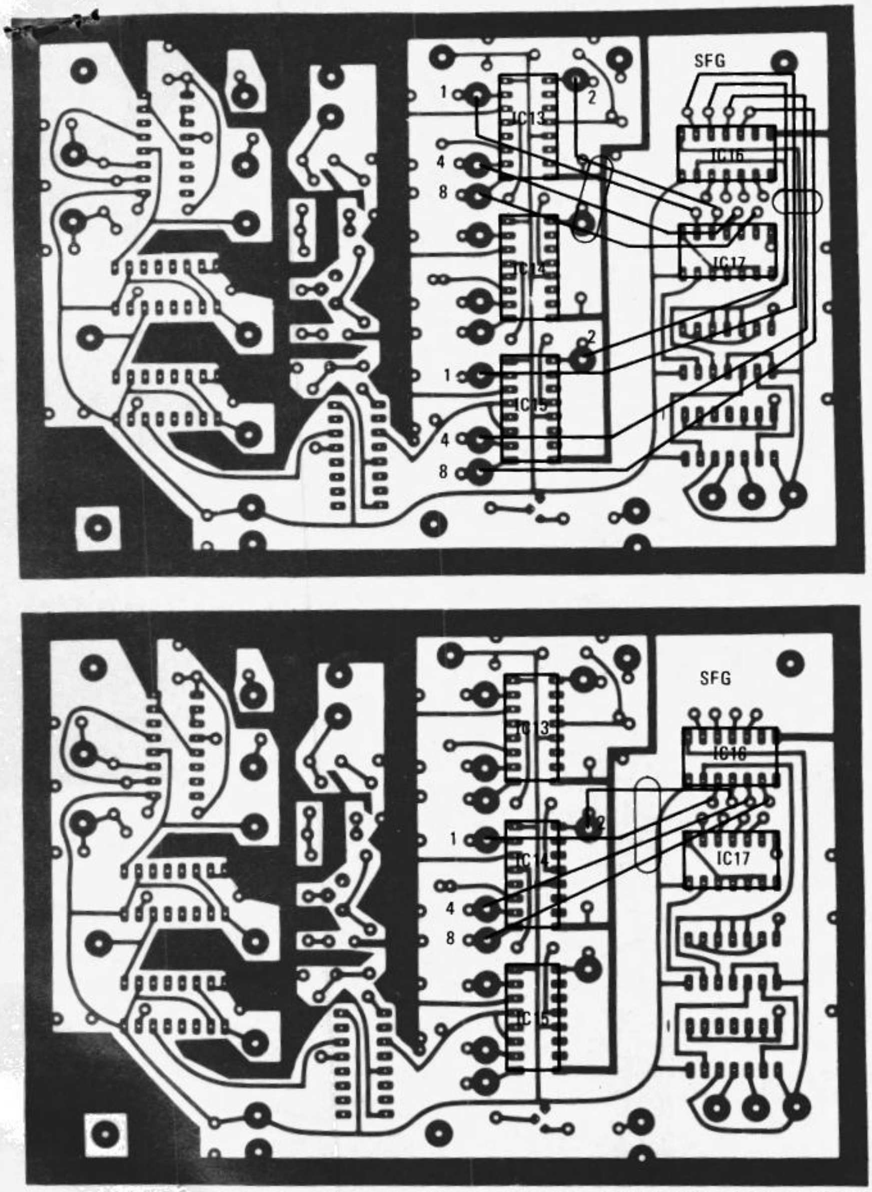


FIG. 9—TWO DIAGRAMS showing placement of the jumpers on the foil side of the digital board. Flat, color-coded cable can be used for the jumpers.

of IC9, and move over to IC13. Then add D9 and D10 (1N4148) as shown. Move down to the bottom of the board and install Q6 (2N3906) with the flat spot in the case pointing to the left. At the same time, install R27 (270 ohms) next to Q6 if you haven't done so yet.

The last components to be installed are the capacitors, so start with C14 (10 pF) and C15 (39 pF) first. Then add C16 (0.1 μF) below them. Move to the bottom of the board and install C17 (47 μF), being sure to observe polarity. Now go to the top center of the board and install C13 (0.1 μF) next to IC13. Then move to the right and install C21 (0.068 μF Mylar). Next, install C20 (4.7 μF tantalum), being sure to watch the polarity. Move down farther and install C19 (47 μF tantalum), watching the polarity. And finally, install C18 (0.047 μF Mylar) as shown. That finishes the component installation on the digital board. Stop and check your wiring carefully for bad solder joints, then correct any you find. Your

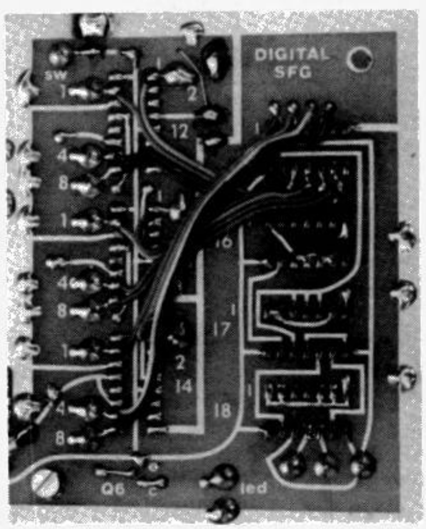


FIG. 10—FOIL SIDE of the digital board shows wire jumpers as they appear when formed from flat cable.

digital board should now look like that in Fig. 8.

The remaining wiring on the digital board consists of connecting some jumpers on the foil side. Fig. 9 shows the details, so look it over first before starting the wiring. As you can see, the jumpers connect the "1", "2", "4", "8" inputs on IC13–IC15 to the inputs of gates IC16 and IC17. Use short pieces of ribbon cable for the connections. Start with the inputs off IC16, pins 2–5. Cut a short length of 4-conductor cable and connect the ends as shown to IC15 first, then IC16. Cut another piece of cable and connect it as shown between pins 2–5 of IC17 and the inputs of IC13. Finally, repeat the process with a short piece of cable between pins 9–12 of IC16. Finish up by checking for shorts, inserting the ICs. Compare your board with Fig. 10 then set the board aside temporarily.

Final assembly

The last thing to do with the SFG is to prepare the case and install the PC boards in it. The photos of the project readily show how this can be done. Start by preparing the cabinet (drilling the holes, painting, and labelling it) to suit your requirements or else to match the prototype. Next, mount the front-panel devices like the switches, pots, and connector; then mount transformer T1, the fuseholder, jack J2 and the switch on the back of the cabinet. Now you are all set to mount the analog and digital boards. Use 4-40 threaded ¼-inch spacers to mount the analog board temporarily on the bottom of the cabinet; then mount the digital board "standing up" as shown in Fig. 12 using two aluminum "L" brackets and 4-40 hardware to hold it in place. That should take care of the mechanical construction of the project.

The next thing to do is wire the boards together and to the components in the box. The drawing in Fig. 11 and photo in Fig. 12 show how. To make working with the boards easier, push-on connectors were obtained from AMP Electric. However, since those connectors aren't readily available, low-cost Molex connectors may be used instead. Start by wiring the power connections first to T1, then continue by connecting the secondary leads to the analog board. Next, start wiring the front panel pots, connector, and switch to the board. Be sure to use shielded cable for the LEVEL pot to minimize noise pickup. Use subminiature coaxial cable such as RG-174 for the connections. Finally, connect the ground pad on the circuitboard to the case ground.

It is rather important to note that there is only one ground point in this project. Having several grounds might introduce noise in the output signal, so you don't have to make any more ground connections other than this one. Next, the digital board is wired. A good place to start is by making the connections between it and the analog board—and that includes the lone ground connection as shown in Fig. 11. As you did for the LEVEL control, be

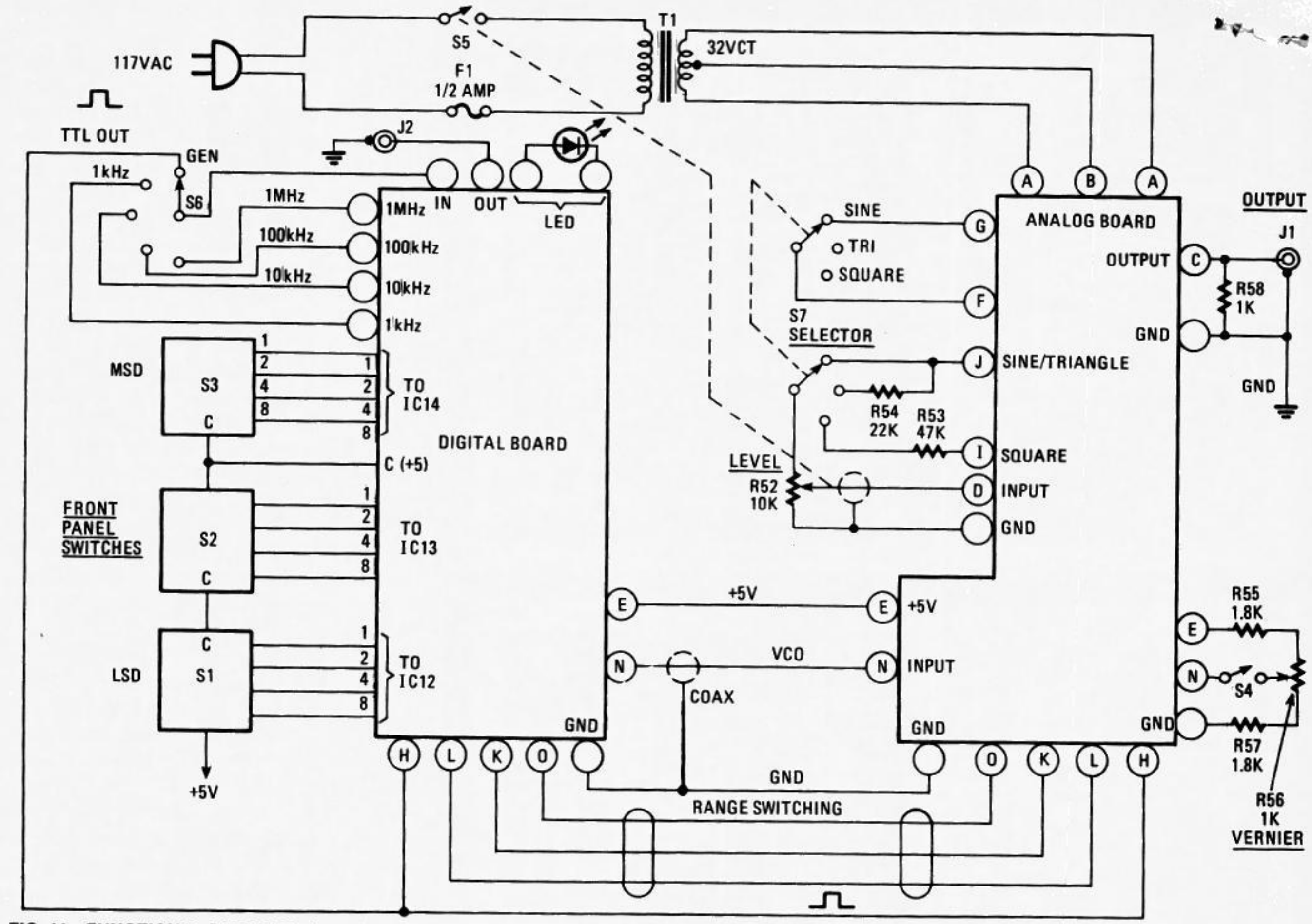


FIG. 11—FUNCTIONAL DIAGRAM shows how the boards connect together and to off-board components.

sure to use coax cable for the VCO line (pin "N"); that will reduce noise on the output signal. Note that the cable is grounded *only* at the digital board end; that minimizes noisy groundloops. The next step is to connect up the frequency switches. Tie all the "C" terminals together with a piece of bus wire, and bring out a short piece of wire for connection to the +5-volt supply. Then get some 4-conductor ribbon cable and cut it into three pieces of about 6 inches each. Solder the wires of each cable to the "1" "2" "4" "8" terminals on each switch deck. After that, connect each wire to the corresponding pad near IC13–IC15 (74C192) on the digital board. Finally, finish up the wiring by hooking up switch S7 and jack J2 on the rear panel. For a neater appearance you can use a short length of six-conductor ribbon cable for those connections. That takes care of the cabinet wiring. Be sure to give it a quick once-over to check for errors, and correct any you find.

At this point you are all set to try the project out, calibrate it, and then put it to good use.

Calibration

To calibrate this project effectively, and get maximum performance out of it, you'll need a few pieces of test equipment. At the least, obtain an oscilloscope with triggered sweep. A distortion analyzer (THD type) would be desirable for adjusting the sine distortion. However, you can do a good job with just the oscilloscope.

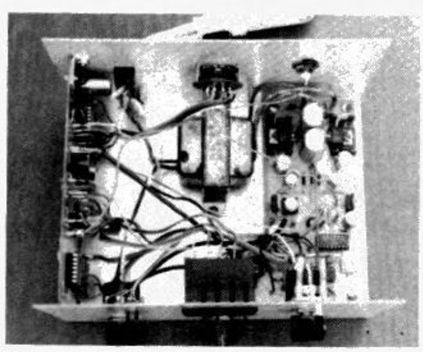


FIG. 12—INTERIOR VIEW of the instrument shows how the boards and off-board parts are positioned.

Start calibration by setting the frequency switches for 010 (1 kHz), VERNIER OFF, and the selector for a sinewave. Connect the scope across the output jack and apply power to both the project and the scope. Moving inside the cabinet, carefully set all three pots to the center of their ranges.

Note that the ERROR light is out or possibly blinking very slowly. If it is blinking, adjust DAMPING pot R32 carefully until it stops. When that light is out, the project is both working properly and in frequency calibration. If it won't go out, there's a problem and you should see the Troubleshooting section. Once that is taken care of, advance the LEVEL control and look at the sinewave on the scope. Next, adjust R16, DISTORTION, on the analog board until you get a smooth-looking sinewave. Expand the scope sweep to be sure that the top and bottom of the sinewave are nicely rounded. Then adjust the SINE LEVEL pot, R17, for maximum output without clipping (flattening). Back it off slightly to be safe. Now switch to the TRIANGLE position and note the peak-to-peak value of the waveform. Switch back to the SINE position and adjust R17 so that the peak values are approximately equal. That takes care of the sinewave calibration. If desired, switch to 99.9 kHz and then 100 Hz to check the quality of the waveform. A slight adjustment may be necessary to give good performance over the frequency range. Or, better yet, connect a THD distortion analyzer and adjust for the lowest distortion.

The last adjustment is the DAMPING adjustment. You may already have performed that adjustment to extinguish the ERROR indicator, but let's do it right. Switch to 100 Hz and view the squarewave output. There may be a little side-to-side jitter on your triggered sweep oscilloscope. If so, slowly adjust R32 (DAMPING) until it stops or is at a minimum. Be sure not to go too far or the waveform will sweep violently back and

PARTS LIST

Resistors ¼ watt, 5% unless otherwise noted
R1-R3—10,000 ohms
R4, R5, R12, R34, R36, R38-R48, R50—100,000 ohms
R6, R8, R10, R29, R58—1000 ohms
R7, R9, R11—15,000 ohms
R13—2700 ohms
R14, R15, R20—2200 ohms
R16—500 ohm, trimmer pot
R17—50,000 ohms, trimmer (Jim-pak 840-50K or equal)
R18—180 ohms
R19, R21—4700 ohms
R22-R24—10 ohms, ½ watt
R25, R33—100 ohms
R26, R49, R51—15,000 ohms
R27—270 ohms
R28—22 megohms
R30—47 ohms
R31, R37—10,000 ohms
R32—500 ohm, trimmer pot
R35, R53—47,000 ohms
R52—10,000 ohms, linear-taper pot with SPST switch
R54—22,000 ohms
R55, R57—1800 ohms
R56—1000 ohms, linear-taper pot with SPST switch

Capacitors
C1, C5, C17—47 µF, 6 volts, electrolytic, PC mount
C2—0.001 µF, 100 volts, Mylar
C3, C6, C7—0.01 µF, 100 volts, Mylar
C4—0.1 µF, 50 volts, Mylar
C8, C9—1000 µF, 25 volts, electrolytic, PC mount
C10, C11—100 µF, 16 volts, electrolytic, PC mount
C12—1 µF, 16 volts, tantalum
C13, C16—0.1 µF, 25 volts, ceramic disc
C14— 10 pF mica
C15—39 pF mica
C18—0.047 µF, 100 volts, Mylar*
C19—47 µF, 6 volts, tantalum*
C20—4.7 µF, 6 volts, tantalum*
C21—0.068 µF, 100 volts, Mylar*
C22—47 pF ceramic disc
***Do not substitute.**

Semiconductors
D1-D4—1N4004
D5-D10—1N4148
IC1—CA3240AE dual BiMOS op-amp
IC2—CD4066 quad analog switch
IC3—XR 2206 function generator (EXAR)
IC4—7805 or LM340T-5 +5-volt regulator
IC5—7905 or LM320T-5 −5-volt regulator
IC6—CA3100EM wideband op-amp
IC7—7812 or LM340T-12 +12-volt regulator
IC8—7912 or LM320-12 −12-volt regulator
IC9—CD4049 CMOS hex inverter
IC10, IC11—CD4518 CMOS dual BCD up-counter
IC12—CD4046 CMOS Micropower phase-locked loop
IC13-IC15—MM74C192 CMOS BCD up/down counter
IC16, IC17—CD4002 dual 4-input NOR gates
IC18—CD4023 CMOS triple 3-input NAND gates
IC19—CD4011 CMOS quad 2-input NAND gates
Q1-Q3, Q6—2N3906
Q4—2N2219
Q5—2N2905
LED1—NSL5054 LED and holder

Miscellaneous
XTAL1—crystal, 1 MHz, 32 pF parallel mode, HC-6/U case
S1-S3—BCD thumbwheel switch (C&K Type 332110000, Cherry Switch Type T35-02A3 (Herbach & Rademan) or Unimax Type SF-21X3 or equal approximately $10.00 completely assembled.
S4, S5—SPST, on R52 and R56
S6—rotary switch, 1 pole, 5 positions
S7—rotary switch, 2 poles, 3 positions
T1—power transformer, 32 volts, CT, 1 amp
J1, J2—BNC connectors
F1—fuse, 0.5A with holder
IC sockets: two 8-pin, eight 16-pin, five 14-pin
Heatsinks: two TO-220, two TO-5

PC boards and plans are available. If desired, the plans can be ordered separately or combined with a set of boards. Here's how to order: SFG-1 complete set, $12.00 postpaid in U.S.A.
SFG-2 plans only, $5.00 postpaid in U.S.A.
California residents add sales tax. Foreign residents add $3.00 for shipping and handling. No COD's or foreign currency, please. Order from Technico Services, PO Box 20HC, Orangehurst, Fullerton, CA 92633

forth. Back off on the pot and try again. After that adjustment is made at 100 Hz, switch to 99.9 kHz and repeat the process. A slight compromise may be necessary in order to get best results over the frequency range.

That completes calibration of the SFG, and it is now ready to use. If you have any problems with calibration, read over the next section on troubleshooting before going any farther.

Troubleshooting

Servicing the SFG has been made easier by several built-in features. For one thing, the board connections have been designed so that a wrong wiring connection is less likely to damage parts. And, as a bonus, this project has built-in diagnostics! Since the diagnostics is the most important feature, let's discuss it. The front panel ERROR indicator will tell you if there are any problems. If it lights, the synthesizer loop is out of lock; and most likely the problem is on the digital board. So if you have problems and the indicator stays lit, check the digital board. On the other hand, if it goes out after a frequency is selected, check the analog board. Now you know where to look for the trouble in a general way.

Finding the exact cause of the problem can be confusing if you have never worked with a synthesizer before. That is because any defect in the loop circuitry will cause it to stop working. Here's an effective procedure to isolate the problem quickly. Only an oscilloscope and voltmeter are required for troubleshooting, although a frequency counter would be helpful to check the accuracy of the 1-MHz reference. Start troubleshooting by checking the power-supply voltages. Check the 12- and 5-volt supplies on the analog board first, then check for +5 volts on the digital board. If those are OK, check to see that the digital board is grounded, and that the analog board is grounded to the case.

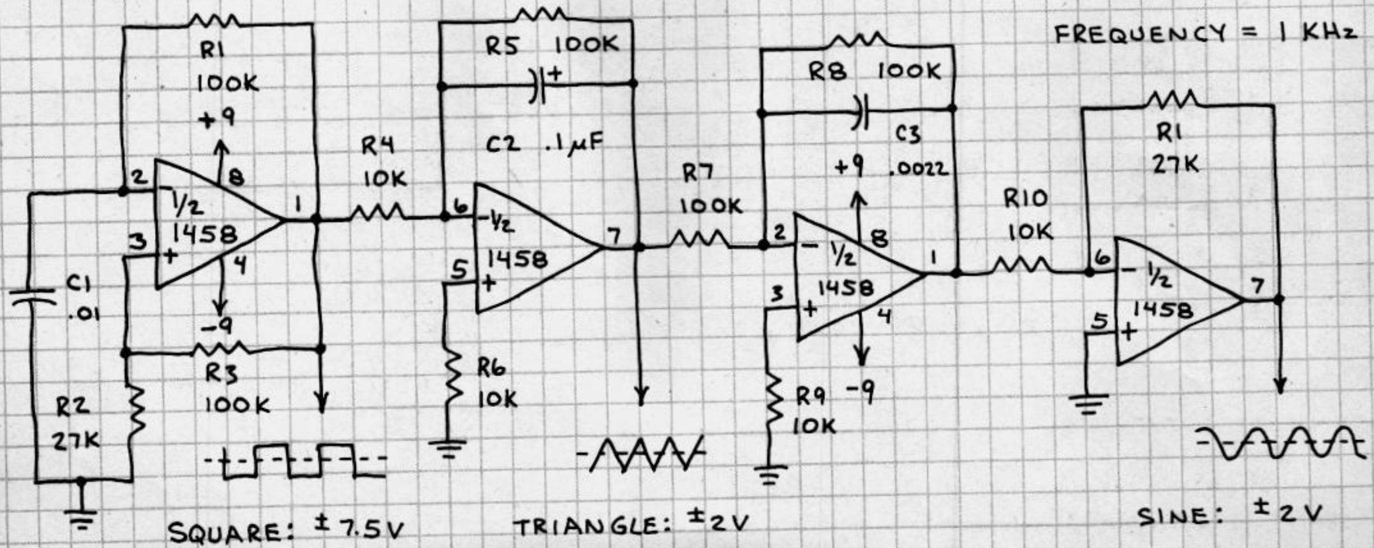
In all likelihood, correcting any power-supply defects will cause the project to begin normal operation. If not, connect the scope to the high end of the LEVEL control and look at the output. You should be able to select sine, triangle and square waveforms. If the same signal isn't present on the output jack, troubleshoot everything after the LEVEL control. If there is no signal present, the ERROR indicator won't be lit. Turn to the digital board and use the scope to see if there is a 100-Hz signal at pin 14 of IC11 (CD4518) and going to pin 14 of IC12 (CD4046). If not, check the IC9–12 circuitry. Use a counter, if available, to verify that the output of IC9 is 1 MHz.

Those checks will probably solve most of the tougher problems, if experience is any indication. In the event you are still not getting results, check the performance of the function generator IC circuitry on the analog board. That is easy to do, but requires an adjustable 1.5- to 4-volt DC power source and a few clip leads. Disconnect the VCO cable from point "N" on the digital board, and disconnect the leads from "O", "K", and "L" as well. Ground point "L" with a cliplead, and ground the minus terminal of the power supply as well. Then set the supply voltage to zero, and connect the output terminal to point "N". If everything's working on the analog board, you should get an output as you adjust the power supply from about 1.5 volts to 4.0 volts. This indicates that there is a problem on the digital board with IC13–19, so check. On the other hand, if you can't get a signal out, check IC1–3. That takes care of troubleshooting.

Using the SFG

Putting the SFG to work on your testbench is a snap. Just select the type of waveform to suit your job, and set the desired frequency on the switches. The ERROR indicator will blink a few times, and go out. Whenever that indicator is out, you are locked on frequency, and are all set to do your job. Simply adjust the output level to suit your application. That's all there's to it! **R-E**

FUNCTION GENERATOR



SPECIAL FM TUNERS BUYERS GUIDE

Radio-Electronics

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THE MAGAZINE FOR NEW IDEAS IN ELECTRONICS

COVER STORY

FUNCTION GENERATOR

Sine, square and triangular waveforms from 2 Hz to over 200 kHz plus external sweep mode makes this a great addition to your workbench. Turn to page 37.

BURGLAR ALARM

Protect your home and family with this feature-packed perimeter alarm. Construction starts on page 41.

FREQUENCY PROBE

Using special construction techniques, a complete frequency counter built into a probe. Story starts on page 67.

CASES AND CABINETS

Save these handy charts and use them to select the best enclosure for your next project. Turn to page 45.

VIDEO RECORDERS

Buying, installing and using VTR's. What you should know starts on page 60.

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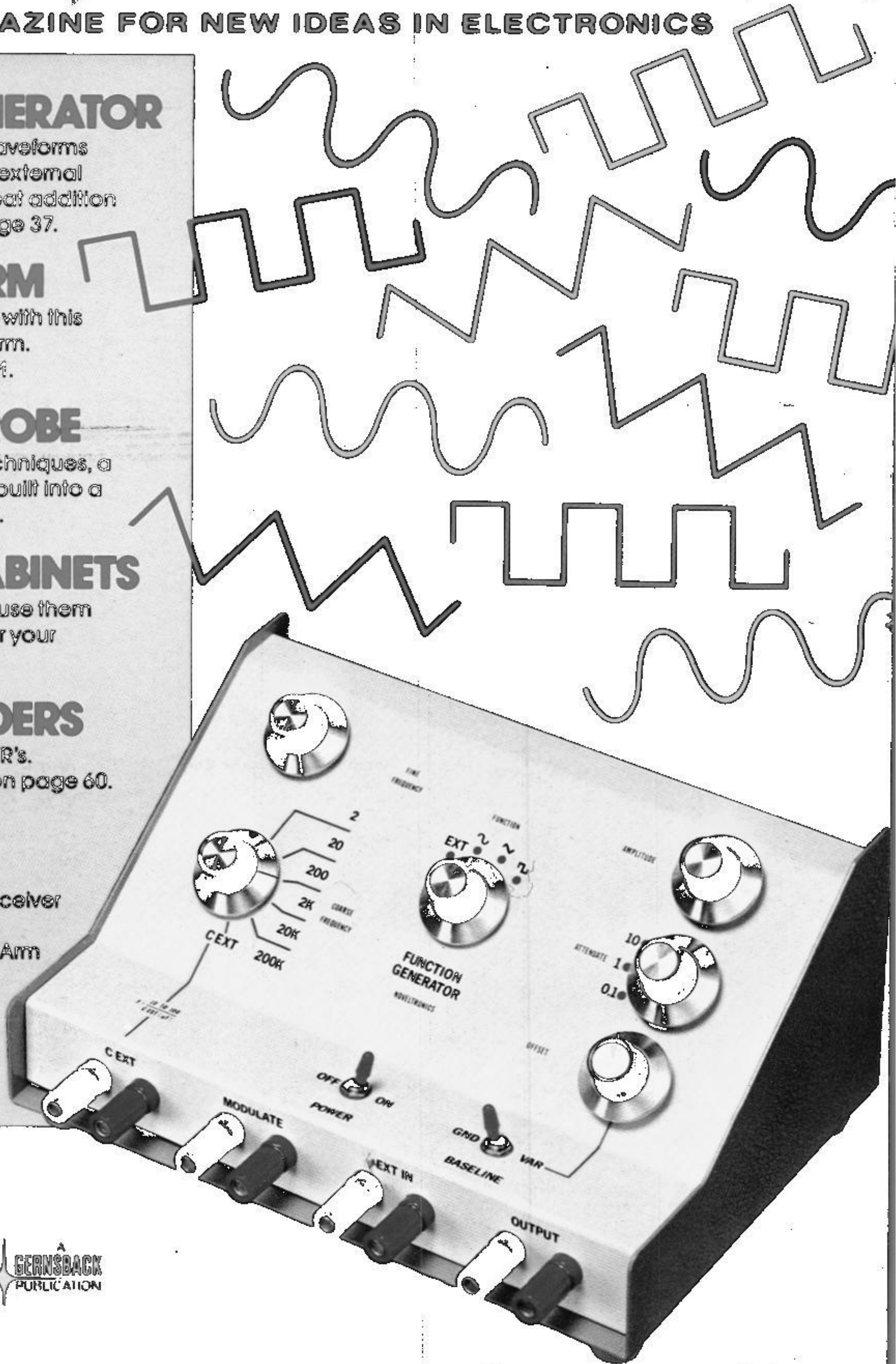

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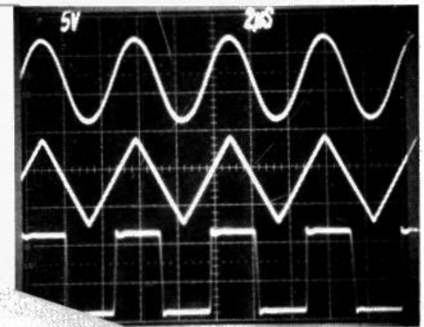
BUILD THIS

2-200,000 Hz Function Generator



Designed around the latest state-of-the-art waveform generator IC, this function generator delivers sine, square and triangle waves with precision and features not possible a few years ago.

DOUG FARRAR

THE AVAILABILITY OF LOW-COST WAVEform generator integrated circuits now makes it fairly simple to put together a function generator (see "Build 3-way IC Function Generator," **Radio-Electronics,** November, 1974). However, these waveform generator IC's suffer from a number of deficiencies that can make the resulting system "not quite good enough" for serious use. Specific complaints are: High-impedance outputs, high distortion and lack of amplitude control.

The function generator described here overcomes these deficiencies and adds features that you won't find on most other commercially available units. Its highlights are:

- Sine, square and triangle wave outputs with a frequency range of 2 to 200 kHz in decade steps.
- Output buffer amplifier puts out a 10-volt P-P signal into a 600-ohm load with rise and falltimes of less than 200 nS.
- Three-step output attenuator for 10, 1 and 0.1-volt P-P maximum output signal, variable down to zero.
- Front-panel connection for an external timing capacitor, permitting a center-frequency different from that built into the unit. It also allows the generator to measure capacitance.
- DC frequency modulation input for extremely slow frequency-sweep capability.
- The unit's 1.5-MHz buffer amplifier is front-panel available for external signal buffering.
- Built-in duty-cycle calibrator eliminates the need for an oscilloscope for minimizing waveform distortion.
- Variable-output baseline means that the function generator can be used as a pulse generator for digital circuits.

An added plus is that all of the IC's used in the generator are available in the back pages of **Radio-Electronics** as "surplus" items, which keeps the cost low. You'll also find that the mechanics of the unit minimizes the wiring nightmare often associated with a project of this size, because all pots and rotary switches mate directly to the printed-circuit board. Even the power supply is totally contained on a PC board—transformer and heat sink included!

Circuit operation

The heart of the function generator is the popular 8038 waveform generator IC. For a detailed explanation of its operation, refer to the description of the 8038 waveform generator contained in the box elsewhere in this article. Tracking current sources are required for the function generator IC (not necessarily equal, but tracking). Op-amp controlled circuitry is used to perform the trick. The additional IC's go beyond the manufacturer's recommendations but contribute to an overall performance improvement.

Referring to the schematic in Fig. 1, pot R5 taps a voltage between 0.4 and 9.1 volts which is buffered by IC1-b. This output is passed through resistors R7 and R8 to the IC1-c—Q1 level shifter. Thus, the ground-referenced current-source voltage developed by R5 is now referenced to the artificial supply voltage (V1 on the schematic). Voltage V1, about 3

FUNCTION GENERATOR SPECIFICATIONS

Output Waveforms: Sine, Square, Triangle
Frequency Range: 2—200,000 Hz in 5 decade ranges
Output Amplitude: Specified into a 600-ohm load, 3 variable ranges:
0 to 10 volts
0 to 1.0 volt } short-circuit protected
0 to 0.1 volt
Output Offset: ± 6 volts (signal plus offset ≤ 10 volts)
Sine Distortion: ≤1% (typ) to 100 kHz
Squarewave Rise/Falltimes: <200 ns
Squarewave Symmetry: Within 1% of 50% using built-in calibrator
Front-Panel Inputs:
External Timing Capacitor: 200 pF minimum, 16-volt rating
Frequency Modulate: linear sweep, DC-coupled. 10,000-ohm impedance
External Signal Input: DC to 1.5-MHz amplifier, gain of 2.
100,000-ohm impedance

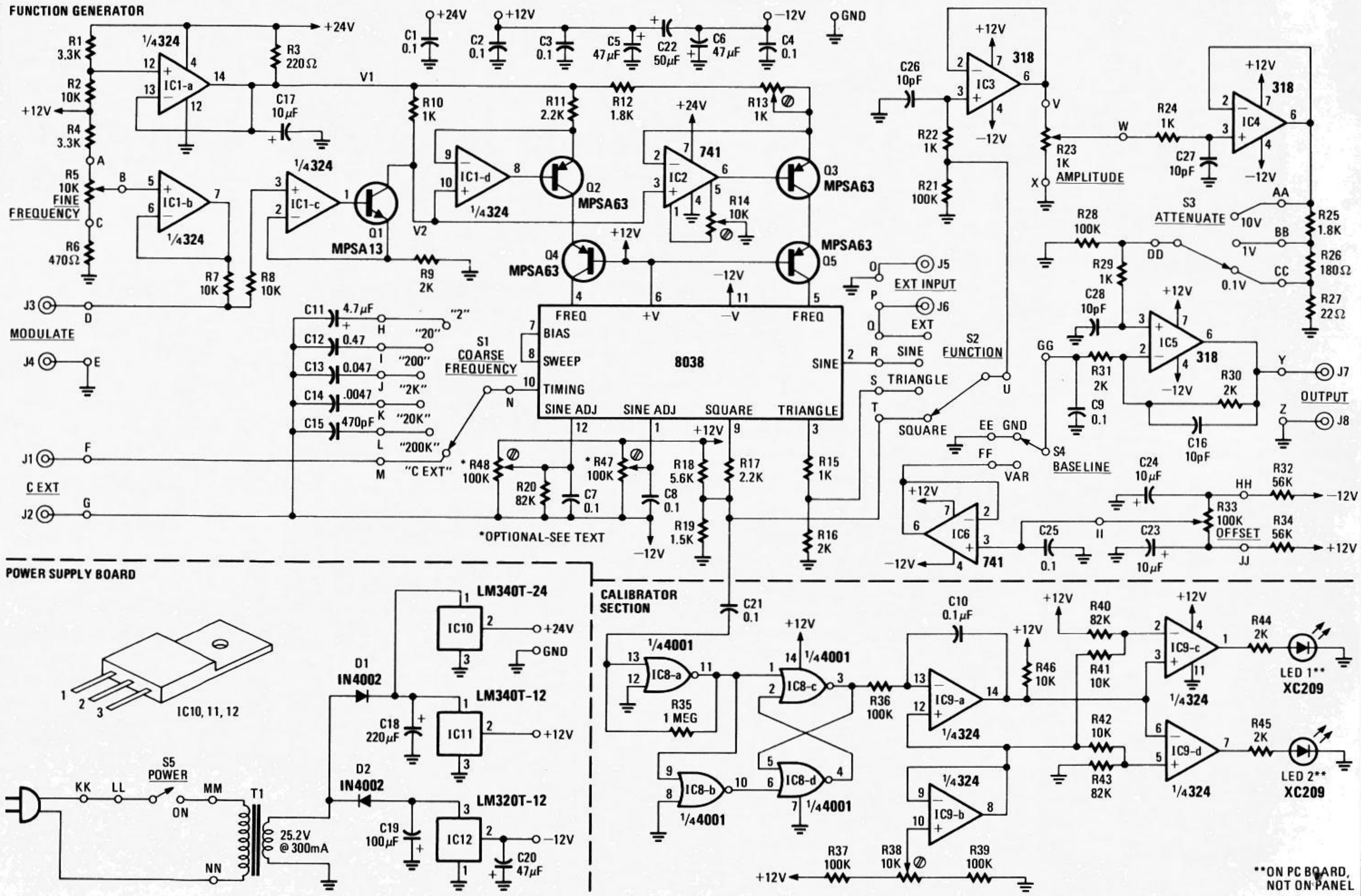


FIG. 1—COMPLETE SCHEMATIC of the function generator. Don't look for the two LED's on the panel. They're on the main board and are used only during the calibration process.

PARTS LIST

Resistors ¼ watt, 5% unless otherwise noted
R1, R4—3300 ohms
R2, R7, R8, R41, R42, R46—10,000 ohms
R3—220 ohms
R5—10,000 ohms, potentiometer, linear taper (Centralab HMP-10K)
R6—470 ohms
R9, R16, R30, R31, R44, R45—2000 ohms
R10, R15, R22, R24, R29—1000 ohms
R11, R17—2200 ohms
R12, R25—1800 ohms
R13—1000 ohms, printed circuit trimmer
R14, R38—10,000 ohms, printed circuit trimmer
R18—5600 ohms
R19—1500 ohms
R20, R40, R43—82,000 ohms
R21, R28, R36, R37, R39—100,000 ohms
R23—1000 ohms, potentiometer, linear taper (Centralab HMP-1000)
R26—180 ohms
R27—22 ohms
R32, R34—56,000 ohms
R33—100,000 ohms, potentiometer, linear taper (Centralab HMP-100K)
R35—1 megohm
R47, R48—100,000 ohms, printed circuit trimmer (optional, see text).

Capacitors
C1-C4, C7-C10, C21, C25—0.1 µF, 50V, Mylar
C5, C6, C20, C22—47 µF, 35V, radial electrolytic
C11—4.7 µF, 25V, 10% tantalum
C12—0.47 µF, 25V, 10% tantalum
C13—.047 µF, 25V, 10% Mylar
C14—.0047 µF, 25V, 10% Mylar
C15—470 pF, 25V, 10% ceramic
C16, C26, C28—10 pF, 25V, ceramic
C17, C23, C24—10 µF, 25V, radial electrolytic
C18—220 µF, 50V, radial electrolytic
C19—100 µF, 50 V, radial electrolytic

D1, D2—1N4004, 100V, 1A diode
IC1, IC9—LM324 quad op-amp
IC2, IC6—LM341CN op-amp
IC3-IC5—LM318CN high-speed op-amp
IC7—8038 waveform generator (Intersil, Lithic Systems)
IC8—4001 CMOS quad NOR gate
IC10—LM340T-24, +24V regulator
IC11—LM340T-12, +12V regulator
IC12—LM320T-12, −12V regulator
LED1, LED2—XC209 (or equal) LED lamp
Q1—MPSA13, NPN Darlington
Q2-Q5—MPSA63, PNP Darlington
S1—1-pole 6-position miniature rotary switch (CTS T-206)
S2—1-pole 4-position miniature rotary switch (CTS T-206)
S3—1-pole 3-position miniature rotary switch (CTS T-206)
S4—SPDT miniature toggle switch
S5—SPST miniature toggle switch
T1—power transformer, 25.2-VAC 300-mA secondary, PC mount (Triad type F-148XP or Radio Shack 273-1386)
Miscellaneous—LMB 007-946 case, ½-inch aluminum angle bar, 6-32 × ½" bolts with hex nuts' ⅜" × 32 nuts, ⅜" lockwashers. Binding posts (J1-J8), power cord, strain relief, hookup wire.

A complete kit of parts including all components, and undrilled and unlabeled cabinet is available for $79.95. Etched, drilled and silk-screened PC boards $11.00. Full-size photo-negative of PC pattern $3.50. Available postpaid from Noveltronics, PO Box 4044, Mountain View, CA 94040. California residents add state and local taxes as applicable. Foreign readers add 5% for extra postage and handling.

THE 8038 WAVEFORM GENERATOR

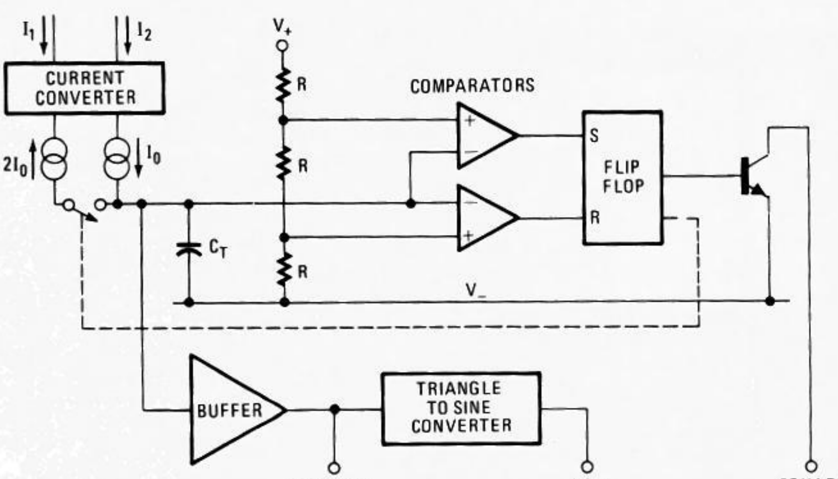
The function generator IC used here is the 8038. A block diagram of the IC is shown. Timing capacitor C_T is alternately charged and discharged by a current sink/source network. Assuming $I_1 = I_2 = I_0$, the resulting voltage across the capacitor is a triangle wave with a 50% duty cycle. The triangle wave is fed to a comparator network that sets and resets a flip-flop. When the triangle waveform reaches a voltage of $2/3(V_+ - V_-)$ the upper comparator sets the flip-flop and the $2I_0$ current source is enabled. The voltage ramps down until it reaches $1/3(V_+ - V_-)$ when the lower comparator turns the $2I_0$ current source off.

The period of oscillation is thus:

$$t = 2 \times \frac{C_T \times 1/3\,(V_+ - V_-)}{I_0} = \frac{2}{3} \times \frac{C_T}{I_0} \times (V_+ - V_-)$$

or

$$f = \frac{3}{2} \times \frac{I_0}{C_T} \times \frac{1}{(V_+ - V_-)}$$



The timing capacitor waveform is buffered, brought out as an output, and applied to a triangle-to-sine converter network. The relatively high-impedance sinewave output is another output. The flip-flop is a transistor whose open collector is used as the squarewave output.

volts below the +24-volt supply line, is generated by IC1-a and is necessary to keep the working voltages within the operating range of IC1-d and IC2. Current-source voltage V2 is fed to the current-source networks IC1-d—Q2—R11 and IC2—Q3—R12—R13.

Each op-amp—transistor pair forces V2 across its respective resistor. The transistor, a high-current-gain Darlington PNP, passes virtually all of the current from its emitter to its collector, so we now have two near-ideal current sources at the collectors of Q2 and Q3. Trimmer pots R13 and R14 allow the Q3 current source to be adjusted to meet the calibration needs of the waveform generator, IC7.

High-frequency switching transients appear at the current inputs of the 8038. If these voltage spikes were applied to the collectors of Q2 and Q3, they would couple into the current-regulating network via the collector-base capacitance and create a noisy current-source pair. Series-pass transistors Q4 and Q5 are therefore used to couple most of the transients into the +12-volt supply.

Switch S1, the COARSE FREQUENCY control, selects one of five timing capacitors to be applied to the 8038. A sixth switch position allows an external timing capacitor at the front panel to be used. The current sources are then switched in and out of the selected timing capacitor by the generator IC.

The three waveform outputs of the function generator IC are of different amplitudes, but the triangle and squarewave signals are attenuated to about the same amplitude as the sine output with resistors R15—R16 (triangle) and R17—R18—R19 (square). One of the

R-E TEST REPORT

LEN FELDMAN

THIS COMPACT (9 W × 4¼ H × 6¼-inches D) all-purpose function genrator is extremely well designed, relatively easy to assemble and produces sine, square and triangle waveforms. Although frequency sweep is not included internally, it is possible to sweep frequencies of the three available waveforms over a 10:1 range by applying a ramp (or any other varying) voltage at the external modulation terminals. The front-panel controls permit manual frequency adjustment from 2 Hz to 200 kHz in 5 decade ranges.

We measured the frequency ranges available and found that any frequency between 3 Hz and 264,600 Hz was obtainable over the five ranges, with a good deal of overlap, as follows:

"2" range: 3 Hz to 28 Hz
"20" range: 13 Hz to 292 Hz
"200" range: 113 Hz to 2.660 kHz
"2K" range: 1.073 kHz to 27 kHz
"20K" range: 11.9 kHz to 264.6 kHz

Maximum amplitude of the sinewave output measured 3.45 volts RMS, which corresponds to a peak-to-peak value of just under 10 volts, the same value obtained for the triangular and square waveforms. The output amplitude is virtually constant from under 10 Hz to the frequency limit of the generator. As is typical of this type of generator (in which the sinewave output is derived or shaped from the basic flip-flop circuit squarewave, harmonic distortion was fairly high, measuring 2.5% at 20 Hz, 2.0% at 1 kHz and 1.5% at 20 kHz. (The author has subsequently modified the prototype to improve the performance on the 0.1-volt output range. These changes reduce the noise and, therefore, the distortion on this range. Also, squarewave overshoot is reduced. However, we have not had time to test the modified circuit—*Editor*)

Rise and falltime (for 90% of full amplitude) of the squarewave measured 175 ns, well within the 200-ns claimed specification. Figure 1 shows the full amplitude squarewave outputs from the function generator at frequencies of 10 Hz (Fig. 1-a), 1 kHz (Fig. 1-b) and 20 kHz (Fig. 1-c). Figure 2 shows the triangular waveform obtained from the generator, while Fig. 3 is a scope photo of a 1-kHz sinusoidal output obtained from the generator.

Considering the price of most commercially available function generators having similar capabilities, this unit represents extremely good value. Our estimate of construction time, working with the supplied complete kit including etched and drilled PC board, would be one evening or even less.

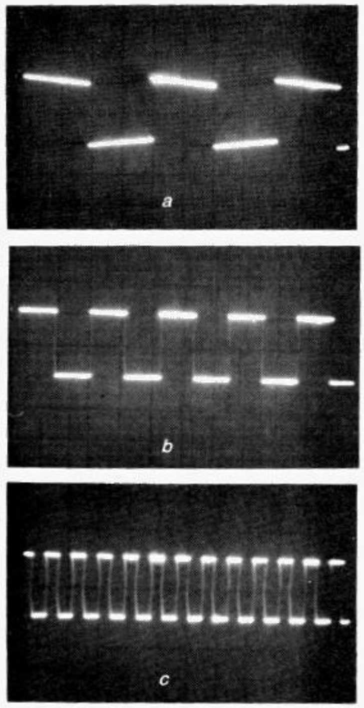


FIG. 1

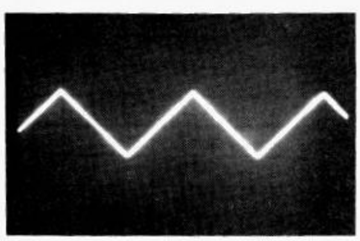


FIG. 2

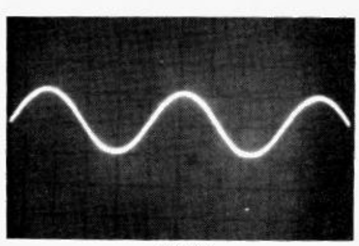


FIG. 3

three (now-equal amplitude) waveforms or the external input waveform is switched by FUNCTION switch S2 into the buffer amplifier network consisting of op-amps IC3, IC4 and IC5. These amplifiers feature extremely high slew rates (50 V/μs), necessary for minimum signal distortion.

The first op-amp, IC3, provides high-impedance buffering between the generator outputs and AMPLITUDE pot R23. The pot output is buffered by IC4, whose output feeds resistor attenuator network R25—R26—R27. The ATTENUATE switch, S3, selects the attenuated signal and routes it to IC5, a noninverting buffer with a gain of 2. If point "GG" on the PC board (and schematic) is switched to ground by BASELINE switch S4, then the waveform output of IC5 will be symmetrical about ground. However, by applying a DC voltage at this point, the output waveform will be offset by an amount equal to the *opposite* of the voltage. That is, by applying −5 volts to "GG" the output will swing around a DC voltage of +5 volts. This variable offset voltage is generated by IC6, adjusted by R33 and selected by switch S4.

The waveform IC's output amplitude is approximately 5 volts P-P. With switch S3 in the 10-volt position the output of IC5 will be about 10 volts P-P. The offset feature allows this signal to be DC-shifted ±6 volts, but signal plus offset cannot exceed ±10 volts without clipping.

To calibrate the function generator for a 50% waveform duty cycle would normally require an oscilloscope. For those without one, this design includes a built-in duty-cycle calibrator; calibration requires nothing more than a voltmeter.

The calibrator consists of squaring circuit IC8 and integrator/comparator network IC9. The waveform IC's squarewave is capacitively applied to IC8-a, which converts the ground-symmetrical voltage to a swing between +12 volts and ground. The rest of IC8 squares the waveform. The output of the shaping circuit is applied to integrator IC9-a. *In theory, if the applied squarewave had a duty cycle of exactly 50%, the integrator output would be a triangle waveform centered around the +12-volt supply divided by 2.* The triangle amplitude is a function of the input frequency and the integrator values. This design develops a 1.5-volt P-P signal for a 200-Hz input.

However, a duty cycle greater than 50% causes the integrator output to drift up to its positive supply value; less than 50% forces it down to its negative-voltage level. So by comparing the integrator's output to see if its voltage swing stays in the middle of its active range, we can tell when we have a 50% duty cycle. Comparators IC9-c and IC9-d do this. When they detect a voltage above 6.7 volts or below 5.3 volts, they turn on their respective light-emitting diodes, LED1 and LED2. Thus, calibration requires adjusting the current-source trimmer pots until both LED's are off. Voltage-follower IC9-b applies the reference voltage to the comparators and the integrator.

The power supply consists of three monolithic voltage regulators, IC10, IC11 and IC12, that deliver +24, +12, and −12 volts, respectively. The 24-volt supply is necessary for the current-source network, while the ±12-volt supplies handle everything else. Inclusion of bypass capacitor C20 is absolutely essential to prevent IC12 from oscillating. Use only the value shown.

continued next month

FUNCTION GENERATOR

IT IS NOT AN UNREASONABLE prediction to say that this circuit will find great usage as a general servicing implement. It produces greater test flexibility than the usual sine-wave signal injector, providing 1kHz square and triangle waves as well, and is both cheap and simple to build.

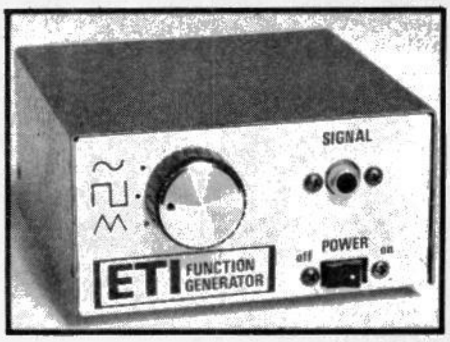
As it stands the output is around 3V ptp on square wave, and 2V r.m.s. on the sine-wave. A switched attenuator could easily be added should you wish to be kinder to the circuit you're testing, but being heartless to electrons, we haven't included one! Operation is from a PP6 battery which should last you as long as it would on the shelf!

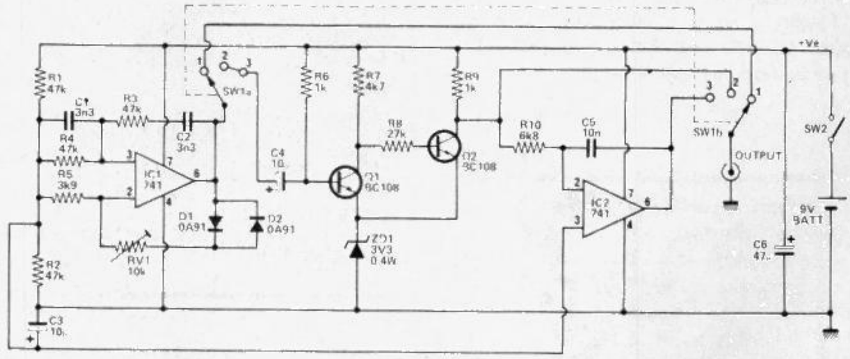
CONSTRUCTION

Assemble the components onto the PCB as shown in the overlay, and watch the orientation of the zener, electrolytics and ICs. To set up the circuit, simply adjust RV1 until the sine-wave is just *below* clipping level. This gives you the best sine-wave from the oscillator. The square and triangle do not need any further setting-up.

How it works

IC1 is set up as a Wien bridge running at 1kHz. Amplitude control is provided by the diodes D1 and D2. The output from this IC is switched through either to the output socket or to the squaring circuit. This is coupled to SW1a via C4 and is a Schmidt trigger (Q1-Q2). The zener ZD1 forms a 'hysterisis-free' trigger. The integrator of IC2, C5 and R10 produces the triangular wave from the input square wave.





Circuit Diagram of the Generator

Parts List

RESISTORS

R1,2,3,4	47k
R5	3k9
R6,9	1k
R7	4k7
R8	27k
R10	6k8

All ¼W 5% H.S.

CAPACITORS

C1,2	3n3 polystyrene
C3,4	10u10V electrolytic
C5	10n ceramic
C6	47u 16V electrolytic

SEMICONDUCTORS

IC1,2	741 8-pin DIL
Q1,2	BC108 or similar
D1,2	OA91 diodes
ZD1	3V 3/4W zener

POTENTIOMETER

VR1	10k vertical miniature trim

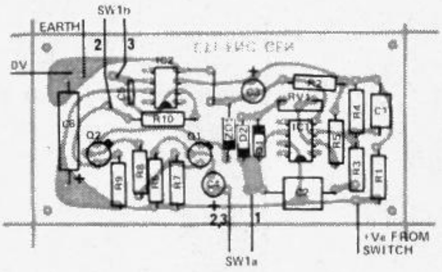
SWITCHES

SW1 a/b	2-pole 3 way rotary
SW2	Single pole off-on rocker

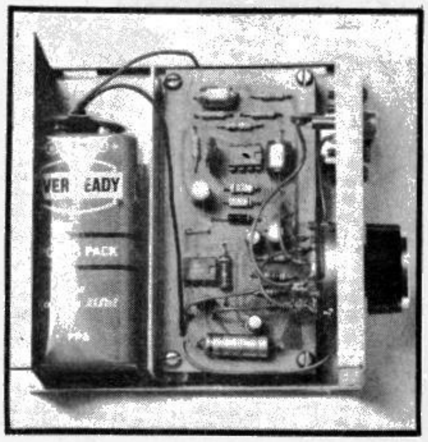
MISCELLANEOUS
Phono socket, knob, board spacers, nuts, bolts, etc. P.P.6 battery, P.P.6 battery clip.

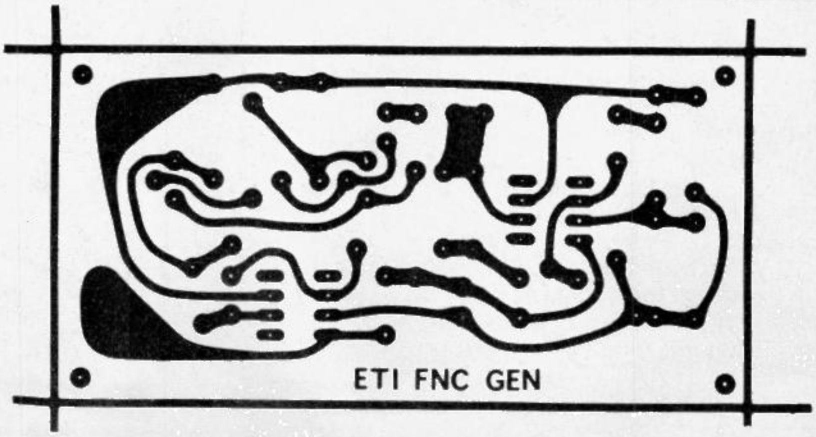
CASE
Samos: S2 Doram 984 - 447.

COST
£4.77 inc. VAT, battery, + board.

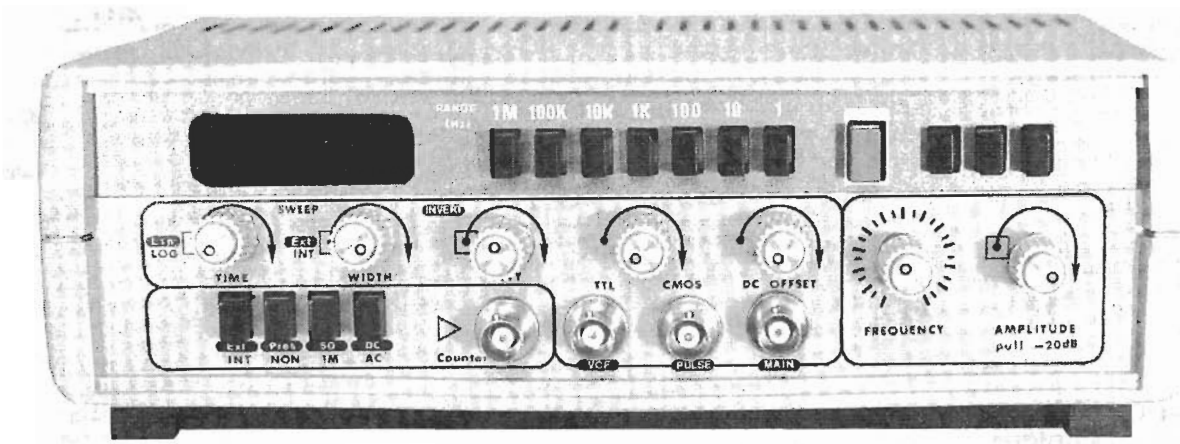


PCB Overlay For The Function Generator





PCB Foil Pattern — Full Size



SWEEP/FUNCTION GENERATOR

Build this sweep/function generator and frequency counter and add to your bench-top instrument collection.

MICHAEL A. LASHANSKY

IF YOU'RE AN ELECTRONIC PROFESsional or advanced hobbyist, you know the value of a well-equipped workbench. An important piece of basic equipment is a function generator and frequency counter. Although few professionals are missing one from their bench, many hobbyists can't justify the expense of quality commercial units. If you're one of those who has put off buying such an instrument, we can show you how to build one that produces up to a 2.5-MHz square, triangle, or sine-wave output with a 1 to 20-volt peak-to-peak amplitude and a 20-dB attenuator. This instrument also has a TTL or CMOS 0.5- to 15-volt peak output as well as a sweep generator and frequency counter that can read up to 150 MHz. All of these features are combined in a single bench-top unit, for a price of $300.

Overview

Our function generator and counter produces a square, triangle, or sine-wave output with a continuously variable amplitude of one volt to 20 volts peak-to-peak. A 20-dB attenuator allows smaller amplitude signals to be generated. A variable 0.5 to 15-volt peak TTL or CMOS pulse output is also available. You can vary the DC-level content, duty cycle, or invert any of those signals.

The output frequency covers seven decades, ranging from 0.1 Hz up to 2.5 MHz. (A higher frequency limit can be attained by making some potentiometer adjustments, but at the expense of a degraded amplitude and waveform shape, which we will discuss in our next article.) Fine adjusting is achieved through a linear dial. A six-digit LED indicates the output frequency of the generator, or it can be used to display the frequencies of external signals.

Using the sweep generator, any of the output waveforms can be swept linearly or logarithmically by selecting the sweep width and/or speed with the front panel controls. You can also sweep the selected waveform under the control of an external voltage, which is useful for frequency modulation generation techniques.

The frequency-counter section can either give a readout of the frequency being generated or it can measure external signals. The counter's range is from DC to 150 MHz with an input sensitivity of 20 millivolts. Input signals can be DC or AC coupled and the input impedance is switchable between 50 ohms and 1 megohm. A prescale/non-prescale function is provided to make maximum use of the six-digit LED to display high-frequency counts. The gate time of the counter is controlled by the frequency decade switches and offers gate times of 10, 1, 0.1, and 0.01 seconds.

Theory of operation

All low- to mid-end function generators—including this one—use a similar technique for generating a waveform. A basic triangle wave is first generated, then massaged into a sine wave and a square wave. The block diagram of Fig. 1 shows the basic workings of the main board. A frequency-controlled multivibrator drives two current switches, which alternately charge and discharge a capacitor through a resistor. The resulting triangle wave is fed either through a sine-shaper circuit, a square-wave amplifier, or straight out to the output amplifier section.

The output of the square-wave amplifier controls the polarity of the charging voltage of the capacitor. The capacitor will charge to positive, then to negative and back again to positive, thereby creating a triangle wave with an amplitude of 2 volts peak-to-peak. The waveform frequency is controlled by the RC time constant and the amount of negative voltage applied to the multivibrator. We will explore that in more detail later.

The output of the square-wave amplifier is also used to drive a TTL gate and CMOS level-shifter gate combination, which allows both TTL- and CMOS-level pulse outputs.

The sweep-generator section is made up of a voltage controlled multivibrator with a long time constant. That produces a DC voltage that varies according to the voltage applied. The output can be routed to a logarithmic amplifier to create both linear and log outputs. The signal is then fed to a buffer/level control amplifier which is then coupled to the voltage-control input of the function generator's main multivibrator.

The frequency-counter section is made up of an input-amplifier signal-conditioning circuit, a divide-by-100 prescaler, an Intersil 7216B frequency-counter chip, and a six-digit LED. Signals are routed through the front panel for measuring. Prescaling decreases the resolution of the display but allows 150 MHz to be displayed with six digits. The decimal point on the LED indicates that the display is read in kHz.

Triangle-wave generation

Figure 2 shows the schematic of the current switch and the triangle/square-wave generator. The combination of IC1–IC4 and Q1–Q4 makes up the main voltage-controlled multivibrator. A negative voltage is applied to the inverting input of IC1, which

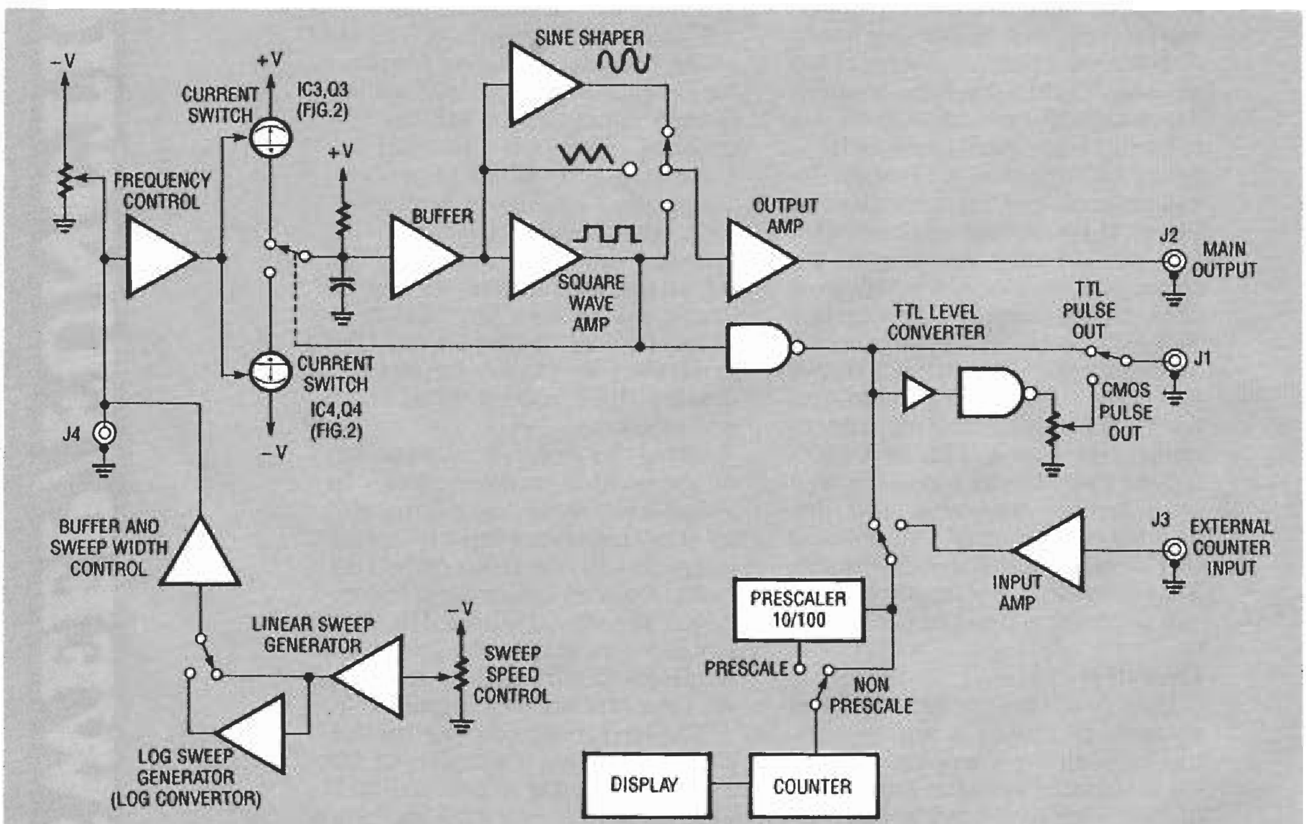


FIG. 1—BLOCK DIAGRAM OF THE FUNCTION GENERATOR. Note how the square-wave output is continuously fed back into the current-switch input. That is done to precisely align the triangle and square wave output through the hysteresis loop to prevent crossover distortion.

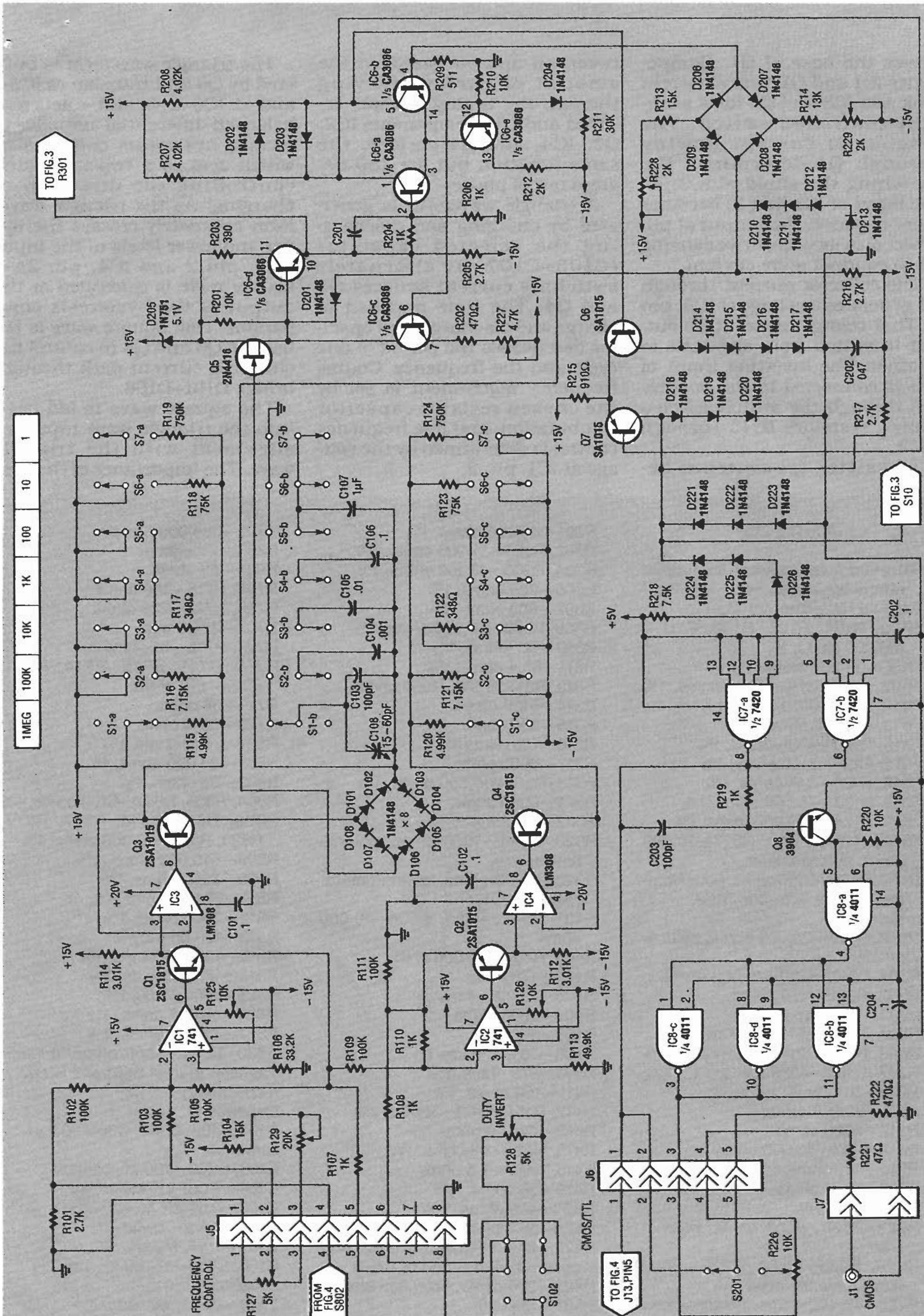


FIG. 2—CURRENT SWITCH, TRIANGLE/SQUARE-WAVE GENERATOR schematic. The triangle waveform is generated by alternately switching current sources Q3 and Q4, thereby charging and discharging C103–C107. As the triangle wave crosses the upper and lower levels of IC3's input, a square wave is generated at the output of hysteresis comparator IC6.

drives the base of Q1. Components IC1 and Q1 form a current sink and IC3 and Q3 form a current-controlled switch. The amount of current flowing through Q1 determines the switching threshold of IC3. As the input of IC1 (pin 2) becomes more negative, the output at pin 6 becomes more positive causing Q1 to conduct more current.

The collector current through Q1 generates a voltage at IC3, pin 3. That voltage causes IC3's output to switch from one state to another. The inverting input of IC3 is connected to the positive rail through the switch-selected timing resistors R115 through R119.

Transistor Q3 switches between on and off based on the amount of current flowing through the timing resistor selected and Q1. Components IC2, Q2, IC4, and Q4 perform the same function but are 180 degrees out of phase.

A triangle waveform is generated by charging and discharging the selected capacitor (C103–C107) by alternately switching current sources Q3 and Q4. The time required to charge and discharge the capacitor determines the period of one cycle and the frequency. Course frequency adjustment is set by the chosen resistor-capacitor combination, and fine frequency control is determined by the voltage at IC1, pin 2.

The triangle waveform is buffered by Q5 and transistors IC6-*c* and -*d*. IC6-*a*, -*b*, and -*e* acts as a balanced differential amplifier to form a hysteresis comparator which acts as a two-state latch controlling the direction of charging. As the triangle waveform alternately crosses the upper and lower levels of the input (IC3, pin 2 and IC4, pin 2), a square wave is generated at the output of the hysteresis comparator. That square wave is fed back to Q3 and Q4 to control the charging current path through bridge D101–D108.

The square wave is fed back into the triangle wave input for alignment with the triangle wave. The importance of the hys-

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise indicated.

R101—2700 ohms, 1%
R102, R104, R105, R109, R111—100,000 ohms, 1%
R106—33,200 ohms, 1%
R107, R108, R110—1000 ohms, 1%
R112, R114—3010 ohms, 1%
R113—49,900 ohms, 1%
R115, R120—4990 ohms, 1%
R116, R121—7150 ohms, 1%
R117, R122—348 ohms, 1%
R118, R123—75,000 ohms, 1%
R119, R124—750,000 ohms, 1%
R125, R126, R826, R827—10,000 ohms, potentiometer
R127, R128—5000 ohms, potentiometer (part of S101 and S102, respectively)
R129, R825—20,000 ohms, potentiometer
R201, R210, R220—10,000 ohms
R202, R222—470 ohms
R203—390 ohms
R204, R206, R219–1000 ohms
R205, R216, R217—2700 ohms, 1%
R207, R208—4020 ohms, 1%
R209—511 ohms
R211—30,000 ohms
R212—2000 ohms
R213, R214—13,000 ohms
R215—910 ohms, 1%
R218—7500 ohms
R221—47 ohms
R223, R828—5000 ohms, potentiometer
R224, R225, R228, R229—2000 ohms, potentiometer
R226—10,000 ohms, potentiometer (part of S201)
R227—4700 ohms, potentiometer
R301—49,900 ohms, 1%
R302, R303—11,300 ohms, 1%
R304, R306—12,100 ohms, 1%
R305—309 ohms, 1%
R307—200 ohms, 1%
R308, R309—24,900 ohms, 1%
R310—127 ohms, 1%
R311—63.4 ohms, 1%
R312, R313, R320—1000 ohms
R314—5100 ohms
R315—680 ohms
R316—150 ohms
R317—6800 ohms
R318, R319—10,500 ohms, 1%
R321—2000 ohms
R322—12 ohms
R323, R324—1000 ohms, potentiometer
R325—5000 ohms, potentiometer (part of S301)
R401, R402, R503, R504—10,000 ohms
R403, R404—22,000 ohms
R405—170 ohms, 1%
R406—12,000 ohms
R407—1200 ohms
R408—2000
R409—18,200 ohms 1%
R410—270 ohms, 1%
R411—100 ohms, 1%
R412, R414, R502—3000 ohms
R413—24,300 ohms, 1%
R415, R418—47 ohms, 1W
R416, R417—7.5 ohms
R419—50 ohms, ½W
R420—499 ohms, ½W
R421—56.2 ohms, 1%
R422, R424—10,000 ohms, potentiometer (R424 is part of S401)
R423—200 ohms, potentiometer
R501—100,000
R505—10 megohms
R701—10,000 ohms
R702—100,000 ohms
R703—1 megohm
R704—50 ohms
R705, R718—150 ohms
R706, R712—220 ohms
R707—470 ohms
R708, R715—51 ohms
R709–R711, R713, R714, R716, R717—510 ohms
R719—36 ohms
R720—1000 ohms
R801—7500 ohms, 1%
R802—33,000 ohms, 1%
R803—33 ohms, 1%
R804, R805, R807—5100 ohms, 1%
R806, R810, R816, R817, R819, R820, R822—10,000 ohms, 1%
R808—510,000 ohms, 1%
R809—2200 ohms, 1%
R811—22,000 ohms, 1%
R812—2400 ohms, 1%
R813—100 ohms, 1%
R815—150,000 ohms, 1%
R818—15,500 ohms, 1%
R821—2000 ohms, 1%
R823—15,000 ohms, 1%
R824—18,000 ohms, 1%
R830, R831—5000 ohms, potentiometer (part of S801 and S802, respectively)

Capacitors

C101, C102, C204, C205—0.1 µf ceramic
C103, C203—100 pF, ceramic
C104—0.001 µF, Mylar
C105—0.01 µF, Mylar
C106—0.1 µF, Mylar
C107—1 µF, Mylar
C108, C504—15–60 pF, variable capacitor
C201—68 pF, ceramic
C202—0.047 µF, ceramic
C301, C303—0.1 µF, ceramic

teresis loop (IC6 pin 4) is to ensure that the triangle and square wave are perfectly timed to avoid any crossover distortion.

The collector of Q7 is clipped to approximately 3 volts by D218–D226 and fed to IC7, pins 1 and 9. IC7 is a dual four-input AND gate, which logically AND's the input square wave with a logic high to produce a TTL-level square wave output. The outputs of the two gates are tied together for increased current drive, and fed to the pulse-output control circuitry. The TTL square wave is level shifted by Q8 to 15-volt CMOS levels, were it is NANDed with 15 volts in IC8-*a*. The output of the gate is fed in parallel to IC8-*b*, -*c*, and -*d*, where they are also NANDed with 15 volts.

The outputs of IC8-*b*, -*c*, and -*d* are connected in parallel for greater drive capability and routed through S201, a 10K potentiometer with a SPDT switch, which controls the pulse output mode. With the potentiometer in the OFF position, a TTL-level output is available. Turning the potentiometer throws the switch, which routes the CMOS output to the BNC connector J1. The 10K potentiometer controls the amount of signal available to J1 and will vary the amplitude of the signal from 0.5 volts to 15 volts.

Figure 3 shows the schematic of the sine shaper and output amplifier. Sine-wave generation is accomplished by taking the triangle wave from IC6-*d* and feeding it through the nonlinear network made up of D301–D312 and resistors R301–R310. The circuit attenuates the input triangle wave according to its level, producing a sine-wave equivalent. The output of the sine shaper is fed through a high-pass filter to the input of IC9, a CA3030 op-amp. Zener diodes D313 and D314 drop the 15-volt supply voltage to ±11.3 volts to accommodate the ±12-volt requirements of the IC. The gain of IC9 is about 10, and can be adjusted by potentiometer R323. The CA3030 is an inexpensive wide-band op-amp but requires some frequency compensation to work over its entire bandwidth.

C302, C304, C502—39 pF, ceramic
C305, C401—4.7 pF, ceramic
C307—15 pF, ceramic
C308, C408—5-35 pF, variable capacitor
C402—120 pF, ceramic
C403—2.2 pF, ceramic
C404, C406—6.8 µF, tantalum, 20 volts
C405, C407—0.047 µF, ceramic
C501—33 pF, ceramic
C503—10 pF, ceramic
C601, C602—1000 µF, electrolytic, 50 volts
C603, C604—100 µF, electrolytic, 50 volts
C605—1 µF, tantalum, 20 volts
C701, C704–C706—0.1 µF, ceramic
C702, C707—100 pF, ceramic
C703 10u tantalum 16 volts C801—22 µF, tantalum, 16 volts
C802, C803—220 pF, ceramic
C804, C805—100 pF, ceramic
C806—500 pF, ceramic

Semiconductors

D101–D108, D201–D204, D206–D226, D301–D312, D315–D318, D401, D402, D701, D702, D801—1N4148 diode
D205—1N751, 5.1-volt Zener diode
D313, D314–1N746, 3.3-volt Zener diode
BR1—W02M bridge diode
Q1, Q4, Q12, Q13, Q21—2SC1815 or MPSA05 NPN transistor
Q2, Q3, Q6, Q7, Q11, Q19, Q20—2SA1015 or 2N4403 PNP transistor
Q5, Q17—2N4416, N-channel FET
Q8—2N3904, NPN transistor
Q9, Q10, Q14—2SC1923 or MPSH34, NPN transistor
Q15—2N2219, NPN transistor
Q16—2N2905, PNP transistor
Q18—PN5139, PNP transistor
IC1, IC2—LM741, op-amp
IC3, IC4—LM308, op-amp
IC5, IC6, IC20—CA3086, NPN five-transistor IC (Harris)
IC7—7420, dual 4-input AND gate
IC8—4011, quad NAND gate
IC9—CA3030, op-amp
IC10—4066, CMOS quad bilateral switch
IC11—7216B, frequency counter and LED driver (Intersil)
IC12—7815, +15-volt voltage regulator
IC13—7805, +5-volt voltage regulator
IC14—7915, −15-volt voltage regulator
IC15—MC10116, ECL triple-line receiver with Schmitt trigger (Motorola)
IC16—SP8629, prescaler (Plessy)
IC17—LM324, quad op-amp
IC18—MC1458, dual op-amp
IC19—CA3140, op-amp (Harris)
SR801—1000 ohms, thermistor
DISP1–DISP6—common-cathode LED (FND357)

Other components

S1–S7—4PDT-D switch
S8—DPDT switch
S9–S11—DPDT-D switch
S12–S14—DPDT-I switch
S15—DPDT on/off switch
S101—DTDP switch used with R127 (5K potentiometer)
S102—DTDP switch used with R128 (5K potentiometer)
S201—SPDT switch used with R226 (10K potentiometer)
S301—DPDT switch used with R325 (5K potentiometer)
S401—SPDT switch used with R424 (10K potentiometer)
S801—DPDT switch used with R830 (5K potentiometer)
S802—DPDT switch used with R831 (5K potentiometer)
J1–J4—BNC panel mount connector
J5, J14—8-position female/male, 0.1-inch centers
J6—5-position female/male, 0.1-inch centers
J7, J12—2-position female/male, 0.1-inch centers
J8, J13—6-position female/male, 0.1-inch centers
J9–J11, J15, J16—4-position female/male, 0.1-inch centers
XTAL1—10-MHz AT/CUT crystal
T1—115/40 volts AC, 0.5-amp transformer
F1—0.5-amp fuse

Miscellaneous: Case (CTP-1 by Global Specialties), three 1.75-inch standoffs, two T0-5 heatsinks, three T0-220 heatsinks, three PC boards, internal wiring, fuseholder, 3-conductor 18-gauge power-supply cord and strain relief.

Note: The following items are available from Tristat Electronics, Inc., 66A Brockington Cres., Nepean, Ontario, Canada, K2G 5L1, (613) 228-7223:

- **A set of three etched, drilled and plated-through PC boards—$76.**
- **All components without the PC board and case—$250.**
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- **Cut and silk-screened front panel—$10.**

Add $17 for shipping and handling. Send check or M.O.

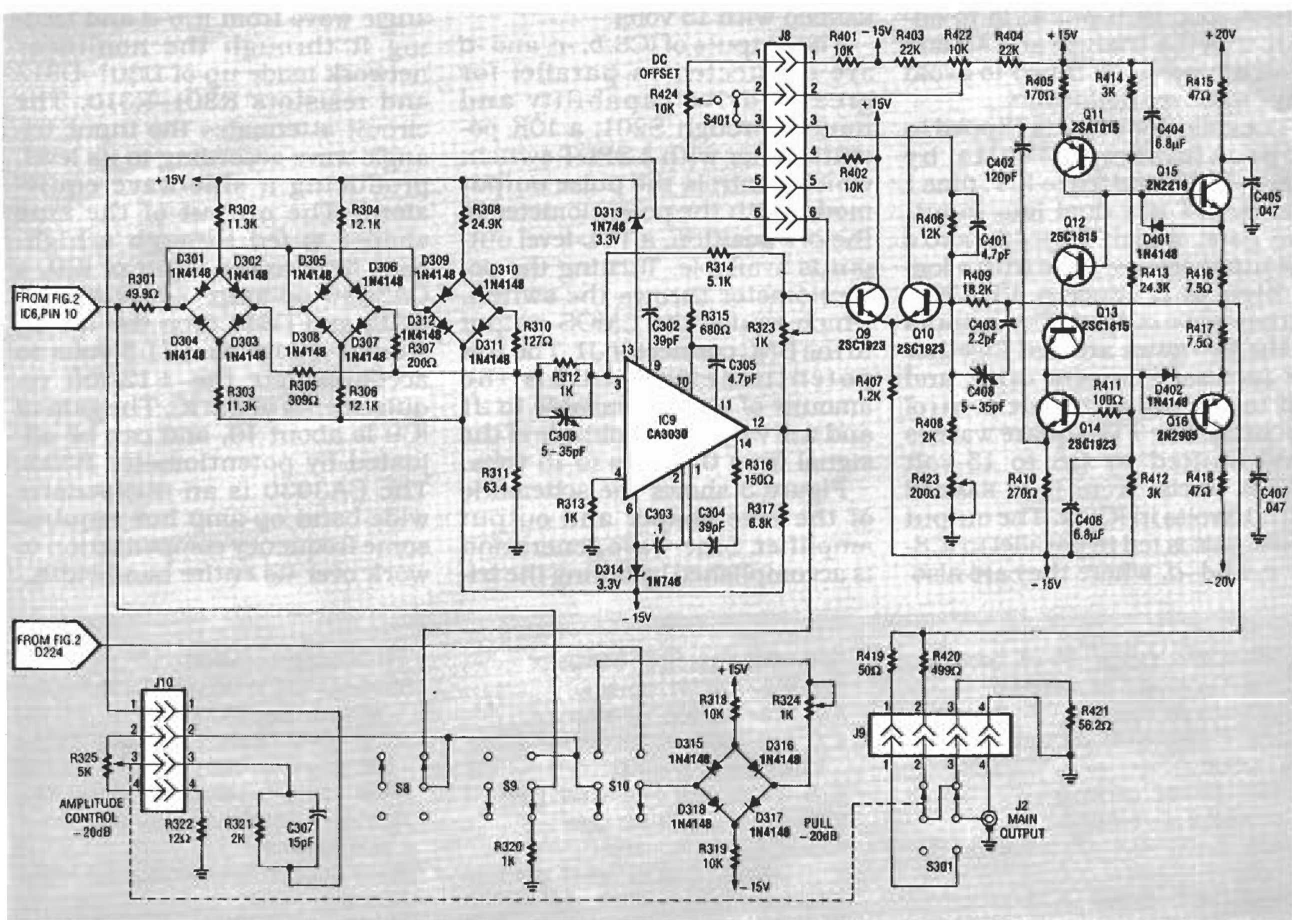


FIG. 3—SINE SHAPER AND OUTPUT AMPLIFIER schematic. The triangle wave from IC6-*d* is fed to a nonlinear network made up of D301–D312 and R301–R310. The triangle wave is attenuated according to its level, producing a sine-wave equivalent.

The main output amplifier consists of Q9 and Q10 configured as an unbalanced differential pair and transistors Q11–Q16 configured as a complementary symmetry push-pull amplifier. A differential amplifier amplifies the difference between the signals present at the base of each transistor. The input signal is fed into the base of Q9 and the output of the push-pull amplifier is fed back through the attenuating circuit of R409, C403, and C408 and coupled to the base of Q10. The output of the differential pair, Q9 and Q10, is taken from the collector of Q10 with the gain of that signal controlled by R408 and R423, which shunts the input signal to ground.

The DC content of the output signal is determined by the DC bias voltage at the base of Q10 (that value is set by potentiometer R422 and should be adjusted to give a 0-volt DC level). Panel-mounted switch/potentiometer S401 allows the user to adjust the DC base bias of Q10, which causes the output signal to ride on a DC voltage from −10 volts to +10 volts depending on the potentiometer setting.

The output of Q10 is connected to the emitters of Q11 and Q14 through DC blocking capacitor C402. Transistors Q11 and Q14 are used in the common-base mode with the input signal fed into the emitters and the outputs taken from the collectors. Transistors Q12 and Q13 are used as diodes to connect the collectors of Q11 and Q14. The output of Q11 is fed to the base of Q15, which amplifies the positive half of the signal. The output of Q14 is fed into the base of Q16 which amplifies the negative excursion of the signal. Switch S301 controls the amount of signal entering the amplifier section through the use of a potentiometer. When the ganged DPDT switch is left in its normal IN position, the output will swing 20 volts peak-to-peak (open circuit). Pulling the switch attenuates the signal by 20 dB. Output impedance is approximately 600 ohms in the normal switch position and 50 ohms in the 20-dB position.

The frequency-counter and sweep-generator circuits are shown in Fig. 4. The sweep generator consists of IC17–IC20. The potentiometer section of S801 applies a negative voltage to the inverting input of integrator IC17-*a*. The input signal is inverted and charges C801 until it reaches the switching threshold of comparator IC17-*b*. When the switching threshold is reached the output will go high, forward biasing Q21 which discharges C801 to ground through R806. The output at IC17-*a* pin 7 is a positive-going ramp and is routed through the linear/log selection switch S801 to either the output buffer amp or the logarithmic ramp generator.

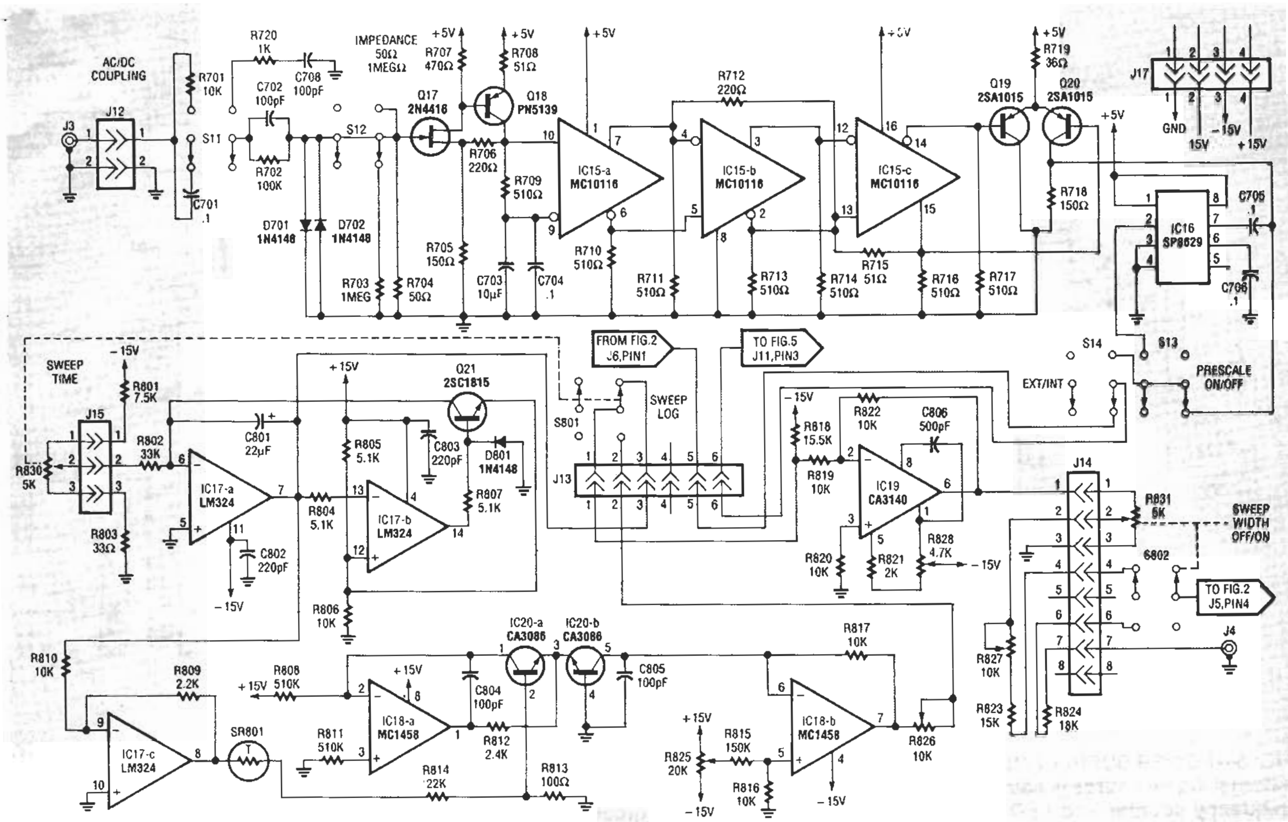


FIG. 4—SWEEP GENERATOR AND SIGNAL ROUTING. Potentiometer R830 applies a negative voltage to IC17-*a*; C801 charges until it reaches the switching threshold of IC17-*b*, which then forward biases Q1. The output at IC17, pin 7 is a positive-going ramp which is routed through the linear/log selection switch S801 to the output buffer amp or log ramp generator. IC16 is a prescaler chip used to downscale frequencies greater than 10 MHz.

An anti-log generator circuit is made up of IC17-*c*, IC18-*a*, -*b*, IC20-*a*, and -*b*, which performs an X^2 function. IC17-*c* acts as an input buffer and attenuator. IC18-*a* and IC20-*a* drives the emitter of IC20-*b* in proportion to the input voltage at the base of IC20-*a*. The collector current of IC20-*b* varies exponentially with the emitter-base voltage. The current is then converted to a voltage by amplifier IC18-*b*. Potentiometer R825 sets the balance of IC18-*b*'s output between a linear and exponential function while potentiometer R826 controls the output signal level. Thermistor SR801 is necessary to compensate for temperature drift because the output of the circuit is directly proportional to the anti-log of the input voltage, and the coefficient of the log term is directly proportional to absolute temperature. Without compensation, the scale factor would also vary directly with temperature. Constant gain is achieved by making the voltage at the base of IC20-*a* directly proportional to temperature.

The linear and logarithmic positive-going ramps are buffered by IC19, a CA3140 op-amp, and are converted to a negative-going ramp. That signal is then fed into IC1 pin 2 through R102. Switch-potentiometer S802-R831 controls the negative voltage that is coupled to IC1 pin 2 when it is in the normal IN position. IC1 is controlled by the main frequency-adjust potentiometer S101, which consists of R127 unconnected to S101.

With S802 in the OUT position, the output of IC19 will be present at IC1. Potentiometer S802 sets the level of the ramp and controls the sweep width. It should be noted that IC1 pin 2 is a summing point and the voltage present from the main frequency control and the sweep generator adds together. The sweep generator starts its sweep at the point determined by the initial voltage at pin 2. For maximum sweep control, the main frequency adjust potentiometer should be turned to its minimum level.

Frequency counter

The power supply and frequency counter circuit is shown in Fig. 5. The frequency counter can count either signals generated internally or measure external signals. The external signal is switch coupled through S11 directly through R701, or capacitively coupled through C701, as shown in Fig. 4. When the input signal is directly coupled, the low-pass filter of C708 and R720 is present. Capacitively-coupled signals by-pass the low-pass filter and pass through a high-pass filter. Diodes D701 and D702 clamp the input to protect Q17. Switch S12 selects the gate resistor and sets the input impedance of the circuit. Transistors Q17 and Q18 provide amplification and impedance matching for IC15, an MC10116 ECL triple-line receiver with Schmitt trigger. Differential amplifier Q19 and Q20 provide a single-ended output from the dif-

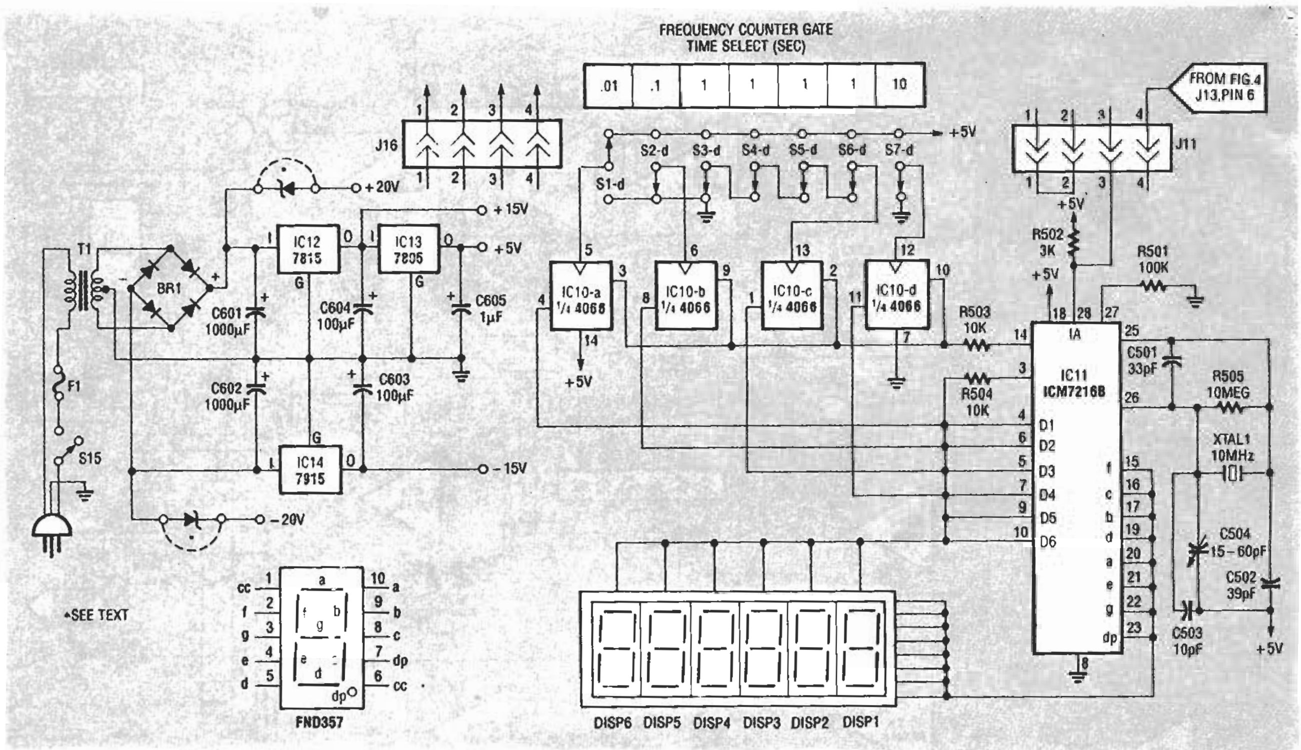


FIG. 5—POWER SUPPLY AND FREQUENCY COUNTER schematic. Either an internal or external signal source is selected via S14 (Fig. 4). Both signal sources are fed to IC11, a frequency counter and LED driver chip. For input frequencies greater than 10 MHz, prescaling is needed

ferential outputs of IC15 Switch S13 controls whether the input signal is fed directly from the input amplifier or from the divide-by-100 prescaler to the counter section.

The counter section can take its input from the internal source or from an external source via S14. The internal signal represents the output frequency of the frequency generator and is taken from the junction of D221 and D224. Both signal sources are pulled up to CMOS levels by R502 and fed into IC11, an Intersil frequency counter and LED driver chip. The chip combines a high-frequency oscillator, decade timebase counter, an 8-decade data counter and latches, 7-segment decoder, digit multiplexes, and 8-segment and 8-digit drivers, which directly drive multiplexed LED's. The input frequency of the chip is limited to 10 MHz so prescaling of the input is required to measure higher frequency signals. The 7216B is a multifunctional chip, performing many useful measuring tasks.

A 10-MHz crystal, XTAL1 with components C501–C504 and R505 set the internal timebase to 10 MHz. That configuration works well with our divide-by-100 prescaler because the timebase can remain the same, only the decimal point takes on a different meaning. In non-prescaled operation, the decimal point on the LED indicates the reading is in kHz, when the input is prescaled, the decimal point indicates the display is read as ×10 kHz. We'll discuss more about that later.

Gate-time selection is controlled by the main frequency selection switches S1-*d* through S7-*d*. They are configured to give gate times of 0.01 seconds in the 1-MHz range, 0.1 seconds in the 100-kHz range, 1 second in the 10-kHz through 10-Hz ranges, and 10 seconds in the 0.1-Hz range. The gate time select (IC11 pin 14) must be connected to the appropriate digit driver to select the required time.

Gate-time selection is achieved by applying 5 volts DC from one of the switches S1-*d* though S7-*d* to the control input of one of the quad-bilateral switches of IC10. Each of the bilateral switches of IC10 controls the digit driver that is connected to the gate-select input. Because switches S1-*d* through S7-*d* are dependent (only one can be engaged at any one time) only one of the bilateral switches will have 5 volts on its control input, all the others will be at ground. Resistor R504 hardwires the function select to implement the frequency measuring mode only. Both R504 and R503 are required to reduce ringing at the input, which could result in false selections.

The power supply is fairly straightforward. AC line current is switch-connected through S15 to fuse F1 to the primary of T1. The transformer is center tapped with a secondary voltage of 40 volts and full load current of 0.5 amps. Diode bridge BR1 rectifies the AC secondary voltage and it is filtered by capacitors C601 and C602. Voltage regulators, IC12–IC14, provide +15, +5, and −15 volts DC. The ±20 volts DC is taken right from the bridge circuit. If a 40-volt AC secondary transformer cannot be found, Zener diodes can be used to drop a high secondary voltage down to the ±20-volt range. Next time we'll discuss how to build and test the function generator. **R-E**

MICHAEL A. LASHANSKY

SWEEP/FUNCTION GENERATOR

Let's build our benchtop function generator and frequency counter!

LAST MONTH WE INTRODUCED YOU to our professional-quality 2.5-MHz function generator and frequency counter that can read up to 150 MHz. This month we'll show you how to build, test, and properly use this essential test instrument.

Construction

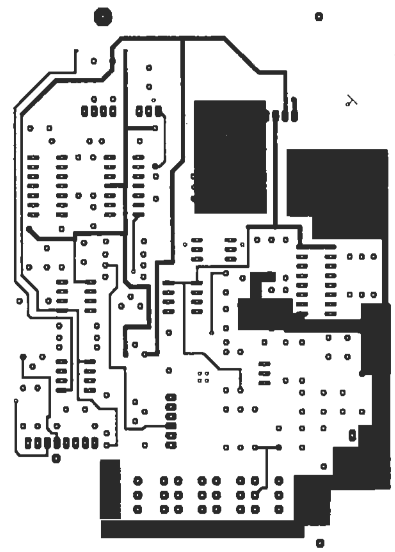
The function generator circuitry is mounted on three PC boards; the mother board, daughter board, and LED display board. The PC boards are available from the source mentioned in the parts list. Foil patterns are provided here if you wish to make your own boards, however the artwork was designed for nonplated holes. In places where it is impossible to solder both sides of a component, such as in the switch arrays, vias are provided for wire connections from one side of the board to the other. If you do make your own board, you'll have to solder some wires from the top of the switch arrays to points on the board. That is not necessary if you use the boards supplied with the kit.

Figures 6 and 7 show internal photographs of the author's prototype. Solder all diodes and resistors first, followed by the capacitors and then the IC's. IC sockets are not required, but they may make life a lot easier in the event of trouble.

It's best to build and test functional blocks as you go rather than building the whole unit all at once. First, start by constructing all the cable assemblies as indicted in Fig. 8. Start with the power-supply section, and verify that the output voltages are correct. The AC power cord routes through a strain relief in the back panel, and one side is soldered to the top of switch S15 (pole a). The other AC lead is soldered to the pad connected to fuse F1.

Next, build the triangle and square-wave generator sections. Those sections consist of components with the 1XX and 2XX component numbering scheme. A parts placement diagram of those sections, located on the main board, is shown in Fig. 9. You will need an oscilloscope to verify that a triangle wave of about two volts peak-to-peak is present at the gate of Q5, and a one-volt peak-to-peak square wave is present at the collector of Q6. If those two waveforms are not present, go back and check your solder joints and component orientations.

Potentiometers R125 and R126 set the symmetry of the waveform and should be adjusted to give a triangle wave with equal slopes. R129 sets the upper frequency limit and should be adjusted to give your desired high frequency for a given range. That is done with the course frequency-adjust potentiometer S101 in its maximum position. As a general guide, set R129 for a maximum frequency of 2.5 MHz, with the 1-MHz range switch engaged. Potentiometer R223 sets the zero balance of the triangle wave and is adjusted to give a centered signal. Square-wave balance is achieved through potentiometers R224 and R225. You can now check the pulse output for TTL levels and a variable CMOS level. With the basic gen-



COMPONENT SIDE DAUGHTER BOARD foil pattern.

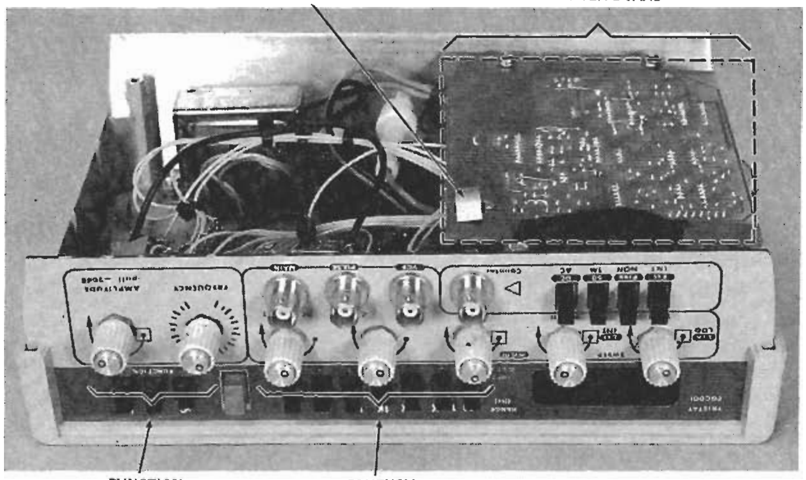
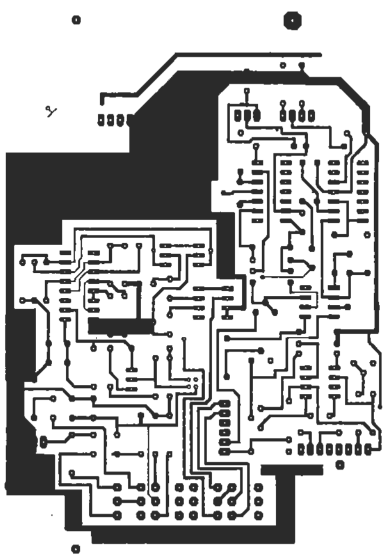


FIG. 6—INSIDE VIEW OF the author's prototype. A transparent red acrylic sheet was used for the front panel. A copper tab is soldered to the ground plane of the daughter board and contacts a 9½ by 3½-inch conductive shield, which is glued to the inside of the bottom case (not shown).



SOLDER SIDE DAUGHTER BOARD foil pattern.

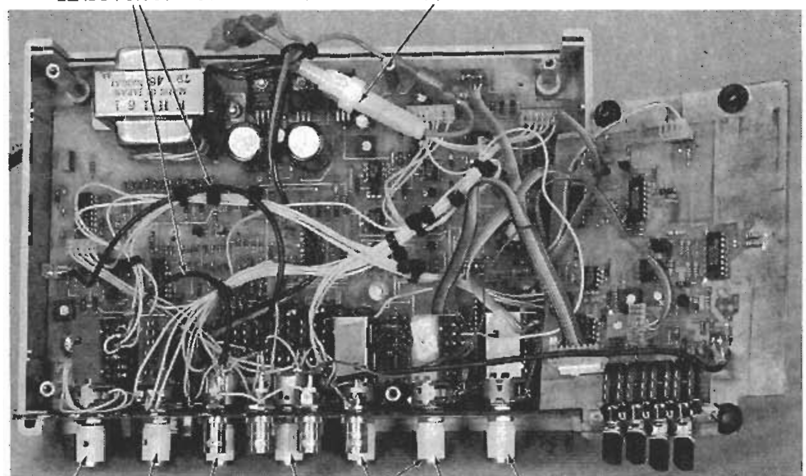


FIG. 7—INTERNAL PHOTO OF the author's prototype. Start construction by connecting all cable assemblies to switch-potentiometers mounted on the front panel.

erator now functioning, build the sine-shaper circuit (component numbers 3XX) and verify a sine wave at the output of IC9.

Adjust R323 for a two-volt peak-to-peak sine-wave output at IC9 pin 12. The amplitude of the square wave is controlled by R324, which should be set to give a clean square wave without any overshoot or rounding on the edges.

The output amplifier should be built next. That section uses the 4XX numbering scheme. Set to R423 to its center position and adjust it only if there is no output. Next, put your oscilloscope on DC coupling and observe the DC level of the output, adjust R422 until the output waveform is centered around zero. Verify the open-circuit signal swing of 20 volts peak-to-peak and the −20-dB attenuator switch.

The last work on the mother board is to build the frequency-counting section and to mount the display board. The six display LED's are soldered to the display board, which is connected to the motherboard by a 90-degree, 14-pin strip header. With the display and components in place, observe the display. Select the MHz range and make sure that all the digits are functioning. If not, go back and double check the circuit. Use a frequency counter or scope to calibrate the counter by adjusting C504 so that the display reading is the correct frequency selected.

The daughter board, which holds the counter input amplifier and sweep generator is as-

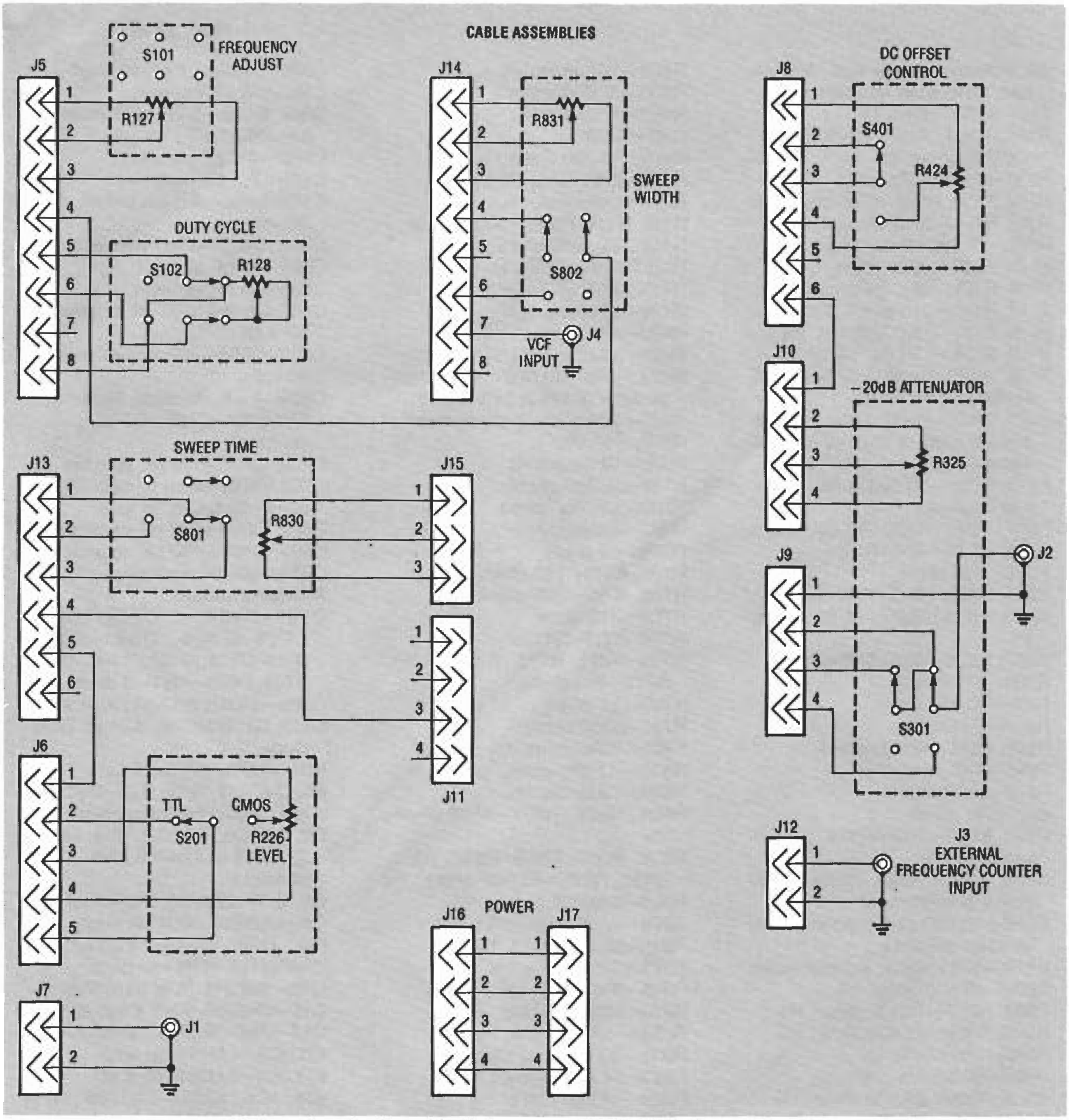


FIG. 8—CABLE ASSEMBLIES show the potentiometers that are connected to each of the function switches.

sembled next. That parts-placement diagram is shown in Fig. 10. The frequency-counter input circuit must be tested with an external signal or by selecting the external-signal source function and jumping the generator output to the counter input. Testing consists of verifying the operation of the switches, S11–S14 and the input amplifier.

The input amplifier can be tested by varying the amplitude of an input signal from about 25 millivolts to 50 volts peak-to-peak (if no test signal is available, use the generator itself) and observing the frequency reading on the display. The frequency should remain the same for all amplitude conditions. When selecting the prescale function, the display should shift two decimal places to the right if working correctly.

All the boards were designed to use transistors with an emitter-collector-base pin arrangement, and the rectangular pads are configured to accept that. If you choose to use the alternate transistors indicated in the parts list, they are American made, and use an emitter-base-collector pin arrangement. When the substitutes are used, a small circular pad is placed between the emitter and collector of the rectangular pads. This circular pad is used for the base pin and the collectors and emitters remain connected to the rectangular pads.

All resistors are ¼-watt, 5% unless otherwise indicated.
R101—2700 ohms, 1%
R102, R104, R105, R109, R111—100,000 ohms, 1%
R106—33,200 ohms, 1%
R107, R108, R110—1000 ohms, 1%
R112, R114—3010 ohms, 1%
R113—49,900 ohms, 1%
R115, R120—4990 ohms, 1%
R116, R121—7150 ohms, 1%
R117, R122—348 ohms, 1%
R118, R123—75,000 ohms, 1%
R119, R124—750,000 ohms, 1%
R125, R126, R826, R827—10,000 ohms, potentiometer
R127, R128—5000 ohms, potentiometer (part of S101 and S102, respectively)
R129, R825—20,000 ohms, potentiometer
R201, R210, R220—10,000 ohms
R202, R222—470 ohms
R203—390 ohms
R204, R206, R219–1000 ohms
R205, R216, R217—2700 ohms, 1%
R207, R208—4020 ohms, 1%
R209—511 ohms
R211—30,000 ohms
R212—2000 ohms
R213, R214—13,000 ohms
R215—910 ohms, 1%
R218—7500 ohms
R221—47 ohms
R223, R828—5000 ohms, potentiometer
R224, R225, R228, R229—2000 ohms, potentiometer
R226—10,000 ohms, potentiometer (part of S201)
R227—4700 ohms, potentiometer
R301—49,900 ohms, 1%
R302, R303—11,300 ohms, 1%
R304, R306—12,100 ohms, 1%
R305—309 ohms, 1%
R307—200 ohms, 1%
R308, R309—24,900 ohms, 1%
R310—127 ohms, 1%
R311—63.4 ohms, 1%
R312, R313, R320—1000 ohms
R314—5100 ohms
R315—680 ohms
R316—150 ohms
R317—6800 ohms
R318, R319—10,500 ohms, 1%
R321—2000 ohms
R322—12 ohms
R323, R324—1000 ohms, potentiometer
R325—5000 ohms, potentiometer (part of S301)
R401, R402, R503, R504—10,000 ohms
R403, R404—22,000 ohms
R405—170 ohms, 1%
R406—12,000 ohms
R407—1200 ohms
R408—2000
R409—18,200 ohms 1%
R410—270 ohms, 1%
R411—100 ohms, 1%
R412, R414, R502—3000 ohms
R413—24,3000 ohms, 1%
R415, R418—47 ohms, 1W
R416, R417—7.5 ohms
R419—50 ohms, ½W
R420—499 ohms, ½W
R421—56.2 ohms, 1%
R422, R424—10,000 ohms, potentiometer (R424 is part of S401)
R423—200 ohms, potentiometer
R501—100,000
R505—10 megohms
R701—10,000 ohms
R702—100,000 ohms
R703—1 megohm
R704—50 ohms
R705, R718—150 ohms
R706, R712—220 ohms
R707—470 ohms
R708, R715—51 ohms
R709–R711, R713, R714, R716, R717—510 ohms
R719—36 ohms
R720—1000 ohms
R801—7500 ohms, 1%
R802—33,000 ohms, 1%
R803—33 ohms, 1%
R804, R805, R807—5100 ohms, 1%
R806, R810, R816, R817, R819, R820, R822—10,000 ohms, 1%
R808—510,000 ohms, 1%
R809—2200 ohms, 1%
R811—22,000 ohms, 1%
R812—2400 ohms, 1%
R813—100 ohms, 1%
R815—150,000 ohms, 1%
R818—15,500 ohms, 1%
R821—2000 ohms, 1%
R823—15,000 ohms, 1%
R824—18,000 ohms, 1%
R830, R831—5000 ohms, potentiometer (part of S801 and S802, respectively)

Capacitors
C101, C102, C204, C205—0.1 µF ceramic
C103, C203—100 pF, ceramic
C104—0.001 µF, Mylar
C105—0.01 µF, Mylar
C106—0.1 µF, Mylar
C107—1 µF, Mylar
C108, C504—15–60 pF, variable capacitor
C201—68 pF, ceramic
C202—0.047 µF, ceramic
C301, C303—0.1 µF, ceramic
C302, C304, C502—39 pF, ceramic
C305, C401—4.7 pF, ceramic
C307—15 pF, ceramic
C308, C408—5–35 pF, variable capacitor
C402—120 pF, ceramic
C403—2.2 pF, ceramic
C404, C406—6.8 µF, tantalum, 20 volts
C405, C407—0.047 µF, ceramic
C501—33 pF, ceramic
C503—10 pF, ceramic
C601, C602—1000 µF, electrolytic, 50 volts
C603, C604—100 µF, electrolytic, 50 volts
C605—1 µF, tantalum, 20 volts
C701, C704–C706—0.1 µF, ceramic
C702, C707—100 pF, ceramic
C703 10u tantalum 16 volts C801—22 µF, tantalum, 16 volts
C802, C803—220 pF, ceramic
C804, C805—100 pF, ceramic
C806—500 pF, ceramic

Semiconductors
D101–D108, D201–D204, D206–D226, D301–D312, D315–D318, D401, D402, D701, D702, D801—1N4148 diode
D205—1N751, 5.1-volt Zener diode
D313, D314–1N746, 3.3-volt Zener diode
BR1—W02M bridge diode
Q1, Q4, Q12, Q13, Q21—2SC1815 or MPSA05 NPN transistor
Q2, Q3, Q6, Q7, Q11, Q19, Q20—2SA1015 or 2N4403 PNP transistor
Q5, Q17—2N4416, N-channel FET
Q8—2N3904, NPN transistor
Q9, Q10, Q14—2SC1923 or MPSH34, NPN transistor
Q15—2N2219, NPN transistor
Q16—2N2905, PNP transistor
Q18—PN5139, PNP transistor
IC1, IC2—LM741, op-amp
IC3, IC4—LM308, op-amp
IC5, IC6, IC20—CA3086, NPN transistor IC (Harris)
IC7—7420, dual 4-input AND gate
IC8—4011, quad NAND gate
IC9—CA3030, op-amp
IC10—4066, CMOS quad bilateral switch
IC11—7216B, frequency counter and LED driver (Intersil)
IC12—7815, +15-volt voltage regulator
IC13—7805, +5-volt voltage regulator
IC14—7915, −15-volt voltage regulator
IC15—MC10116, ECL triple-line receiver with Schmitt trigger (Motorola)

IC16—SP8629, prescaler (Plessy)
IC17—LM324, quad op-amp
IC18—MC1458, dual op-amp
IC19—CA3140, op-amp (Harris)
SR801—1000 ohms, thermistor
DISP1–DISP6—common-cathode LED (FND357)

Other components

S1–S7—4PDT-D switch
S8—DPDT switch
S9–S11—DPDT-D switch
S12–S14—DPDT-I switch
S15—DPDT on/off switch
S101—DTDP switch used with R127 (5K potentiometer)
S102—DTDP switch used with R128 (5K potentiometer)
S201—SPDT switch used with R226 (10K potentiometer)
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S802—DPDT switch used with R831 (5K potentiometer)
J1–J4—BNC connector
J5, J14—8-position female/male, 0.1-inch centers
J6—5-position female/male, 0.1-inch centers
J7, J12—2-position female/male
J8, J13—6-position female/male
J9–J11, J15, J16—4-position female/male, 0.1-inch centers
XTAL1—10-MHz AT/CUT crystal
T1—115/40 volts AC, 0.5-amp transformer
F1—0.5-amp fuse

Miscellaneous: Case (CTP-1 by Global Specialties), three 1.75-inch standoffs, four 2-inch standoffs, two T0-5 heatsinks, three T0-220 heatsinks, three PC boards, internal wiring, fuseholder, 3-conductor 18-gauge power-supply cord, and strain relief.

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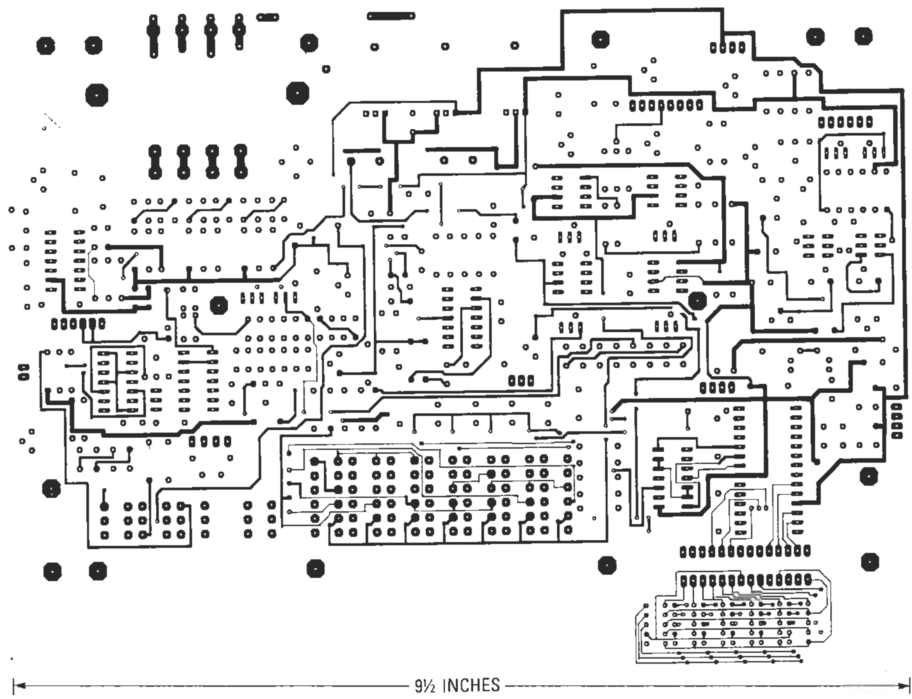
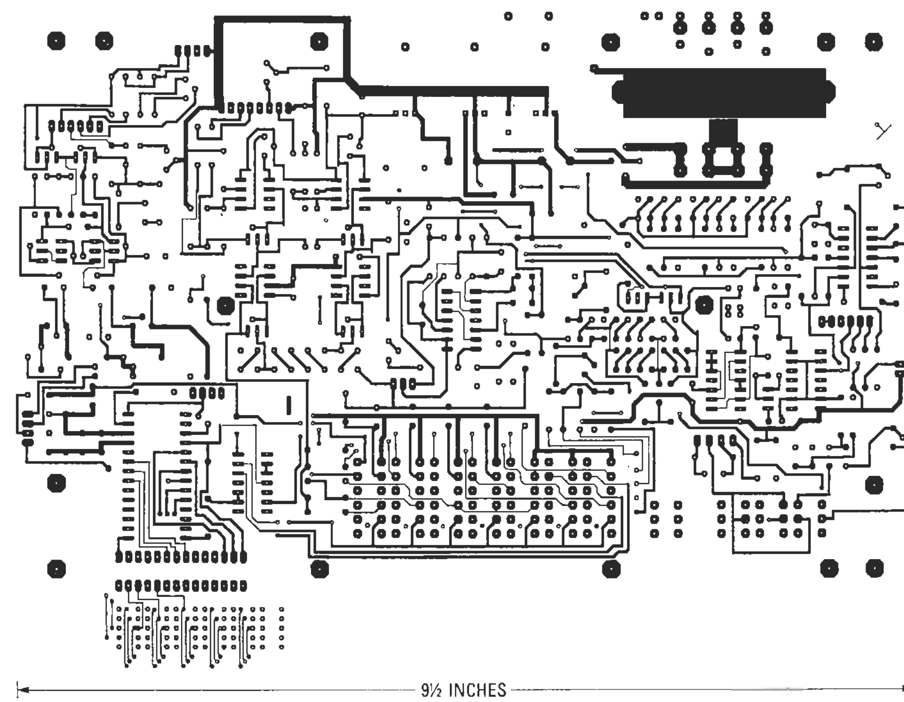


COMPONENT SIDE FOIL pattern of the mother board.



SOLDER SIDE FOIL PATTERN of the mother board.

The sweep generator is built next. If you're using the boards supplied with the kit, mount potentiometers R825–R828 to the solder side of the board. That will make adjustments easier when the unit is assembled. If you're making your own boards, place the potentiometers on the component side and make your adjustments before the board is connected to the mother board.

Once again you'll need an oscilloscope to verify proper alignment. Set R828 to its midpoint,

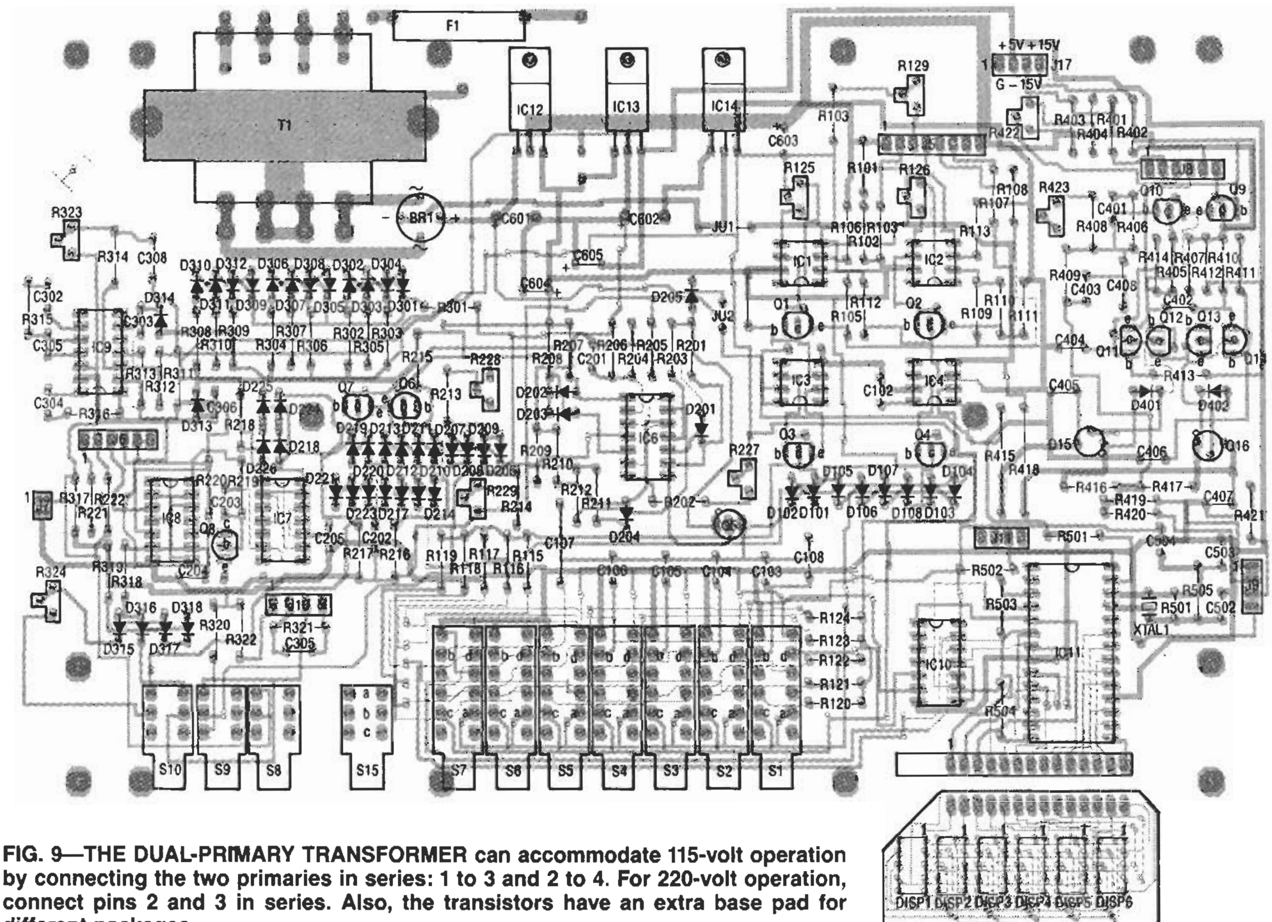


FIG. 9—THE DUAL-PRIMARY TRANSFORMER can accommodate 115-volt operation by connecting the two primaries in series: 1 to 3 and 2 to 4. For 220-volt operation, connect pins 2 and 3 in series. Also, the transistors have an extra base pad for different packages.

and adjust R825 to give a good log output (when selected) and a linear output. Adjust R826 to achieve a good input signal to IC19 pin 2 and R827 will set the maximum sweep width. If a scope is not available, most potentiometers can be set to their center position and adjustments can be made by observing the LED display with the counter set to the internal-count mode.

If everything is working properly, you can install the completed boards into the case. The top of the case uses four 2-inch standoffs. The front and back panels supplied with the case are of 0.065-inch aluminum and are not recommended for use as a front panel. A complete cut and silk-screened panel is available from the source mentioned in the parts list, or you can make your own using transparent red acrylic. Secure the mother board in place (top half of case) and finally install the daughter board uses three 1¾-inch standoffs. You're now ready to power up and use your combination function generator and frequency counter.

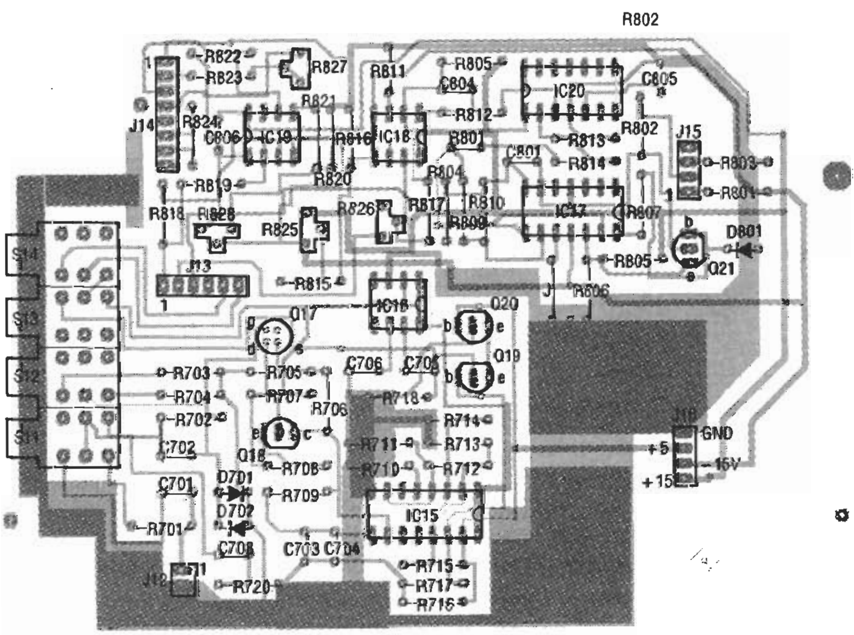


FIG. 10—PARTS PLACEMENT OF DAUGHTER BOARD holds the input amplifier and sweep generator circuit.

Using your unit

Table 1 shows a complete list

TABLE 1—FUNCTION GENERATOR SPECIFICATIONS

FUNCTION	MIN	MAX	UNITS
Sine Wave	0.1	2.5 Mega	Hz
Triangle Wave	0.1	2.5 Mega	Hz
Square Wave	0.1	2.5 Mega	Hz
Pulse	0.1	2.5 Mega	Hz
Ampitude			
Main Output	3.0	20	Vp-p
−20dB	0.5	6	Vp-p
TTL Pulse	50	5	Vp
CMOS Pulse	0.5	15	Vp
Duty Cycle	10	90	%
DC Offset	−10	+10	VDC
Sweep Generator			
Sweep Width	1	1000	X Initial Freq.
Sweep Time	1	20	Seconds
Frequency Counter			
Input Sensitivity	20	100	Vp-p
Input Range	0.1	150 Mega	Hz
Input Impedance	50	1 Mega	Ohms
Gates Times	.01	10	Seconds
Error	±LSD		
Stability	50ppm/°C		

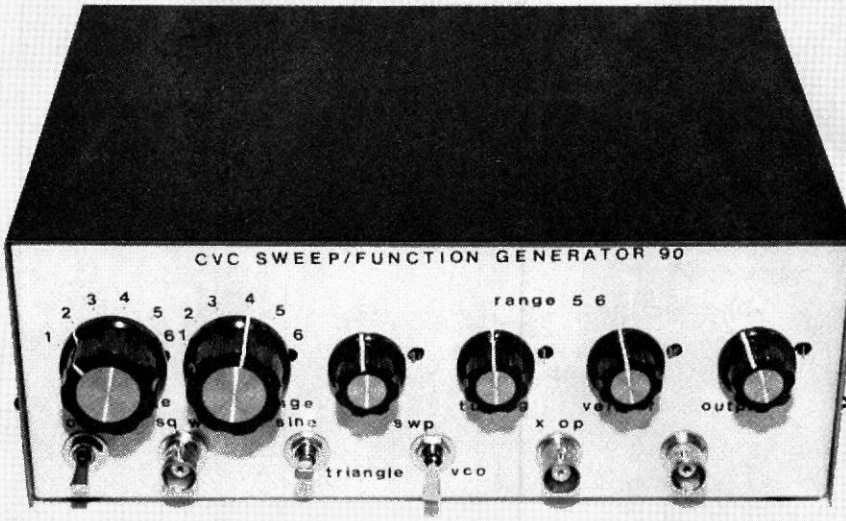
of functions and specifications of the unit.

The square wave output is in phase with the sine wave and the triangle wave, but is 180 degrees out phase with the TTL and CMOS pulse outputs. That feature is useful for creating a two-phase clocking system if you happen to be working with digital equipment. The unit is calibrated to give a frequency range of 0.1 Hz to 2.5 MHz. The upper frequency limit can be extended by adjusting variable capacitor C108 and/or R129. With the component values that we have given, the upper frequency limit can reach as high as 4 MHz.

Changing the values of the timing resistors R115–R119 and R120–R124 will produce output frequencies as determined by the formula 1/RC. That method will achieve a maximum sine-wave output of 10 MHz with an amplitude of 1 volt peak-to-peak above 2 MHz. **R-E**

C.V. CARLSON

SWEEP/FUNCTION GENERATOR



Build this sweep generator to create sine, triangle, and square waves and provide a horizontal sweep for an oscilloscope

FUNCTION GENERATORS ARE VERY important and versatile test instruments capable of providing a variety of waveforms over a wide frequency range. The most common output waveforms are ·sine, square, triangular, and ramp. Most popular function generators have a frequency range that extends from tens of hertz to hundreds of kilohertz.

The function generator featured in this article meets all of these basic requirements, and it has a frequency range of 10 Hz to 800 kHz, making it a valuable addition to your workshop's suite of test and measurement instruments. In addition, the output can automatically sweep between two user-defined frequencies. The generator is based on two monolithic Exar XR2206 function generators. One produces the sine, triangle and square waveforms. The other is configured as a voltage-controlled oscillator (VCO) that sweeps the selected waveform between two frequency limits.

The sine, square, and triangular waveforms generated by this instrument can be used in verifying the design of prototype or brassboard circuits, and they can also be used in the diagnosis and servicing of consumer and industrial electronics products. The swept output, when displayed on an oscilloscope, can provide a way to measure a circuit's frequency response.

Front panel controls

The following are the manually operated front-panel controls of the sweep/function generator:

- SWEEP RATE rotary switch S5
- FREQUENCY rotary switch S2
- VCO control R30
- TUNING tuning control R28
- VERNIER tuning control R27
- OUTPUT level control R29
- ON-off switch S1
- SINE/TRIANGE switch S3
- SWEEP/VCO switch S4

Three coaxial output jacks are also located on the front panel:

- SQUARE-wave output J3
- HORIZ sweep output J2
- TRIANGLE output J4

Circuit description

Refer to Fig. 1, the schematic for the sweep/function generator. Both IC2 and IC4 are Exar XR2206 monolithic function generators; IC4 functions as a ramp generator, and IC2 functions as a generator of of sine, triangular and square waveforms. Dual operational amplifier IC1 produces a scaled, level-shifted ramp output that is capable of deflecting an oscilloscope's horizontal sweep. This ensures that the sweep generator and the oscilloscope's sweep circuit are always properly synchronized.

Any frequency of interest along the horizontal axis of an oscilloscope that is coupled to this function generator can be measured with an external frequency counter by manually tuning the function generator's VCO instead of sweeping it. The performance characteristics of the sweep/function generator are summarized in Table 1.

The generator's sweep rate and frequency can be set by front-panel rotary six-position switches, SWEEP RATE switch S5 and FREQUENCY switch S2. The VCO control R30 manually tunes the VCO. Table 2 lists the sweep ranges of the function generator. Sweep ranges not covered in ranges 1 to 4 can be set up as required on positions 5 and 6. Selecting the VCO setting on the front panel toggle switch S4 permits tuning any fixed frequency within the total frequency range of the instrument with both the FREQUENCY switch S2 and VCO control R30.

Sweep operation on the SWEEP/VCO setting for oscilloscope display and frequency measurement are explained later in this article.

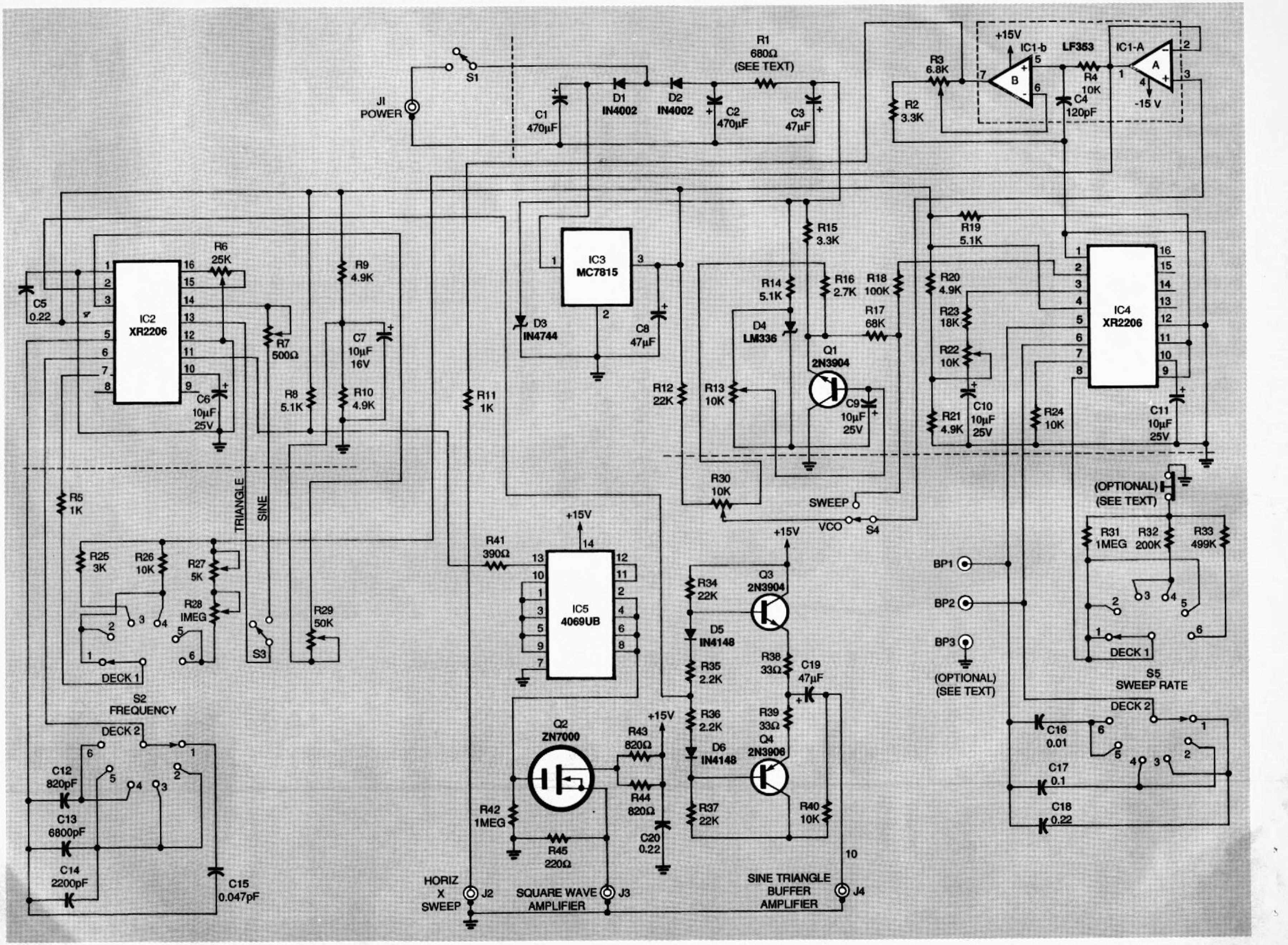


FIG. 1—SCHEMATIC FOR THE SWEEP/FUNCTION GENERATOR. The dotted lines separate circuitry on the board from that on the front and back panels of the case. Two Exar XR2206 monolithic function generators are included in the circuit.

TABLE 1
FUNCTION GENERATOR CHARACTERISTICS

Waveform output	Maximum P-to-P	Frequency	Conditions
Sine (1)	5V	10 Hz-100 kHz	1 V@800 kHz
Triangle (1)	8 V	10 Hz- 50 kHz	1 V>500 kHz
Square (2)	5 V		Positive output DC-coupled, ground ref: rise/fall >50 ns
Ramp (3)			Descending, 6 rates

(1) Output level variable frim min. to max.
(2) Output level not adjustable.
(3) X and Y amplitude internally adjustable.

TABLE 2
SWEEP RANGES OF THE FUNCTION GENERATOR

Switch	Condition	Frequency range
1	Preset	20Hz to >2kHz
2	Preset	<400Hz to >10kHz
3	Preset	<1kHz to >25kHz
4	Preset	5kHz to >100kHz
5*	Resistance tuned	2kHz to 100kHz
	Resistance & VCO tuned	<10Hz to >100kHz
6*	Resistance tuned	<40kHz to >800kHz
	Resistance & VCO tuned	<100Hz to >800kHz

* Ranges show for positions 5 and 6 represent the total tuning range of the function generator and do not imply one continuous sweep.

The sweep rate or duration of the sweep ramp is selected by the rotary six-position SWEEP RATE switch S5. Table 3 lists the sweep rate durations for each of the six positions. Longer periods should be used for lower frequency sweeps.

TABLE 3
SWEEP RATE OR DURATION

Sweep position	Period (milliseconds)
1	~130
2	~ 60
3	~ 30
4	~ 15
5	~ 6
6	~ 3

Sine-triangle amplifier

A sine-triangle buffer amplifier amplifies the sine and triangle waveforms so that the sweep generator can drive an output load as low as 50 ohms, with reduced output. The nominal load would be 1000 ohms. The amplifier consists of complementary symmetry NPN transistor Q3 and PNP transistor Q4. Resistors R34, R35, R36, and R37, in series with diodes D4 and D5, form the bias network.

Emitter resistors R38 and R39 bias NPN transistor Q3 and PNP transistor Q4. Aluminum electrolytic capacitor C19 and resistor R40 reference the output of the complementary pair to ground.

The amplifier has rise and fall times of 300 nanoseconds. As a result, the output is slew-rate limited above 100 kHz on the SINE setting of S3 and above 50 kHz on the TRIANGLE setting of S3 to about 1 volt at its highest frequency.

Squarewave amplifier

The squarewave amplifier consists of MOSFET transistor Q2 and peripheral resistors and a capacitor. The rise and fall output times of an Exar XR 2206 are unequal, so this amplifier conditions the signal to correct that condition. A CD4069UB CMOS hex inverter, IC5,drives transistor Q2 to produce rise and fall times at the output with durations of less than 50 nanoseconds at 5 volts. The squarewave output becomes less symmetrical above 100 kHz, but it retains its fast rise and fall times.

The input to the squarewave amplifier MOSFET transistor Q2 (which has a relatively large and dynamically variable input capacitance) is conditioned by IC5. The input to pin 13 is squared up by the cascaded inverter sections IC5-e and IC5-f, and their output drives four paralleled inverter sections IC5-a, IC5-b, IC5-c, and IC5-d. The output at pin 8 of IC5 feeds the gate of MOSFET transistor Q2.

The output of Q2 is taken from the source across R45 to give a ground-referenced, DC-coupled signal. A complementary output of 9 volts appears at the drain. Capacitor C20 bypasses AC for Q2.

Theory of operation

Refer to the schematic Fig. 1. Resistors R20 and R21, peripheral to IC4, and R9 and R10, peripheral to IC2, divide the voltage between the regulated +15 volts and ground for IC2 and IC4. The junction between the resistors is bypassed by aluminum electrolytic capacitor C10 for IC4, and C7 for IC2. Trimmer potentiometer R22 and resistor R23 set the voltage ramp output at pin 3 of IC4, as shown in Fig. 2, the functional block diagram of the XR2206.

Resistors R17 and R18 attenuate the ramp which is level-shifted by the negative bias voltage present at the emitter of Q1, the bias regulator. This voltage will be set to −2.5 volts during calibration by trimmer potentiometer R13. The negative bias voltage is developed across Zener diode D4 (an LM336 2.5-volt precision voltage reference IC in a three-pin plastic TO-92 package) by the current through R14 from the −15 volts developed across the 1N4744 Zener diode D3.

The resulting bias at the emitter of Q1 is more negative than the voltage set by R13. The negative voltage at Zener diode D3 for the dual operational amplifier IC1 is filtered by electrolytic capacitor C3. Resistor R1 in the filter sets the operating current through Zener diode D3. Capacitor C9 bypasses AC at the base of Q1 to ground, and ceramic disc capacitor C5 bypasses AC to ground between pins 1 and 4 of IC2.

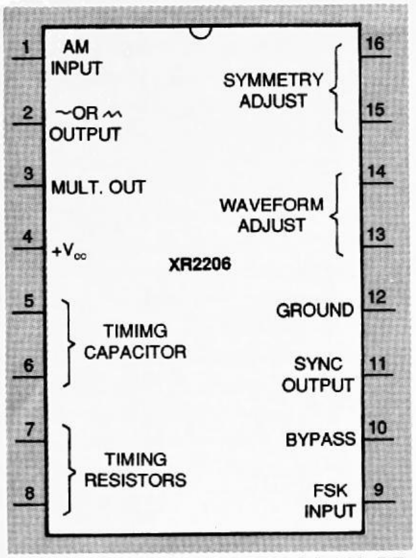


FIG. 2—FUNCTIONAL DIAGRAM OF XR2206. It can produce sine, square, triangle, ramp, and pulse waveforms. This project contains two XR2206s.

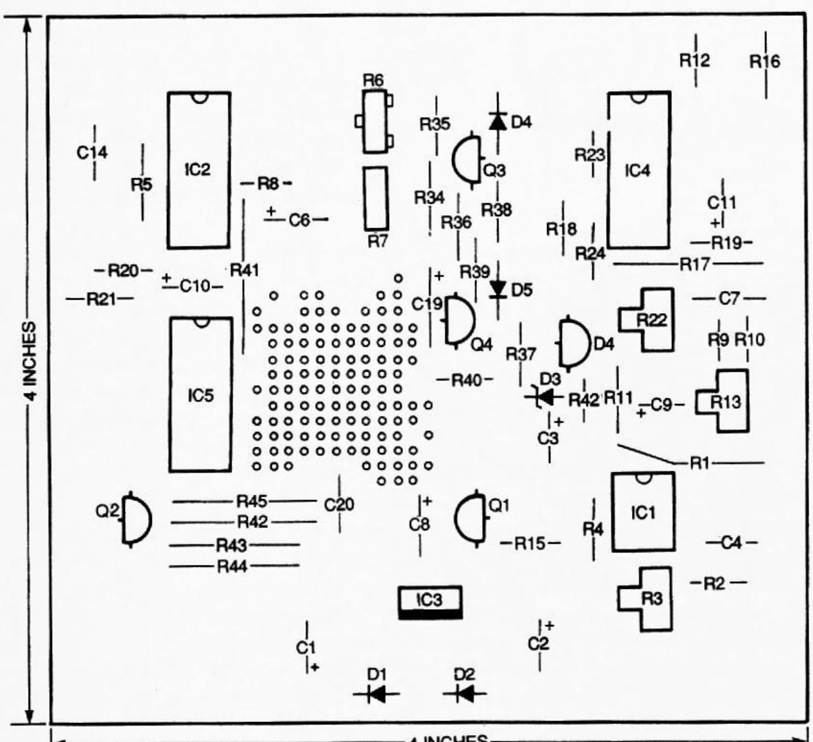


FIG. 3—PARTS LAYOUT FOR POINT-TO-POINT WIRING. Position the components in the general locations shown to minimize wire lengths. All DIP-packaged ICs are mounted in sockets.

The attenuated and level-shifted sweep-ramp voltage modulates the frequency output of IC2 linearly from low to high frequency. A network of one series and three parallel capacitors determines frequency. The output frequency of IC2 is determined by networks of capacitors and resistors connected between pins 5 and 6 and to pin 7, respectively. The timing networks are selected by switch S2, which provides six operating frequency ranges.

The frequency selected by the timing components can be modulated with another signal. Here, the frequency is controlled by applying the control voltage to pin 7. That control voltage is derived from IC4 through IC1-a.

Operational amplifier IC1-a is organized as a voltage follower to form a low-resistance current sink for the timing current. Non-inverting amplifier IC1-b provides a horizontal sweep output for an oscilloscope display. Trimmer R3 at output pin 7 sets the gain of IC1-b.

Resistor R4 (between the output of IC1-a and non-inverting pin 5 of IC1-b) and capacitor C4 form a low-pass filter to reduce any noise developed across the output impedance of IC1-a by internal timing current switching in IC2.

The sweep rate of ramp generator IC4 is determined by resistors R31, R32, and R33 as selected by two-pole, six-position rotary SWEEP RATE switch S5.

Resistor R32 has a value of 200 kilohms and R24 has a value of 10 kilohms. As a result, the flyback period will be between a maximum of 5% and a minimum of 1% of the period of the ramp. The ramp signal is repetitive and produces a continuous sweep output from IC1 except when VCO is selected by switch 4.

Resistor R11, trimmer potentiometer R30, and R15 form a voltage divider between the +15-volt supply and the negative bias at the emitter of transistor Q1. The voltage-controlled oscillator (VCO) voltage across R11 simulates the sweep ramp voltage. It can be adjusted to set any frequency within the range selected by switch S2 and potentiometer controls R27 and R28, when S4 is moved from SWEEP to VCO.

The horizontal sweep output also tracks the VCO setting so that a frequency of interest on a swept oscilloscope display can be read from an external frequency counter connected to squarewave amplifier output jack J3. The output of a circuit under test will remain visible as a vertical deflection at the same point on the oscilloscope display. It can be be fine tuned for peaks or nulls with the panel-mounted knob of the VCO linear control R30.

The frequency sweep produced by the function generator is linear, not logarithmic. Consequently, a sweep display can be positioned so that each horizontal sweep graticule division on the oscilloscope screen represents a frequency span of 1 kHz, 10 kHz, or more, depending on the sweep range selected.

The knob of VCO linear control R30 and the knob of panel OUTPUT linear control R29 adjust waveform symmetry, and internal trimmer potentiometer R6 can be adjusted to minimize distortion.

Load resistor R8 produces the squarewave input for the square-wave amplifier. Alumi-

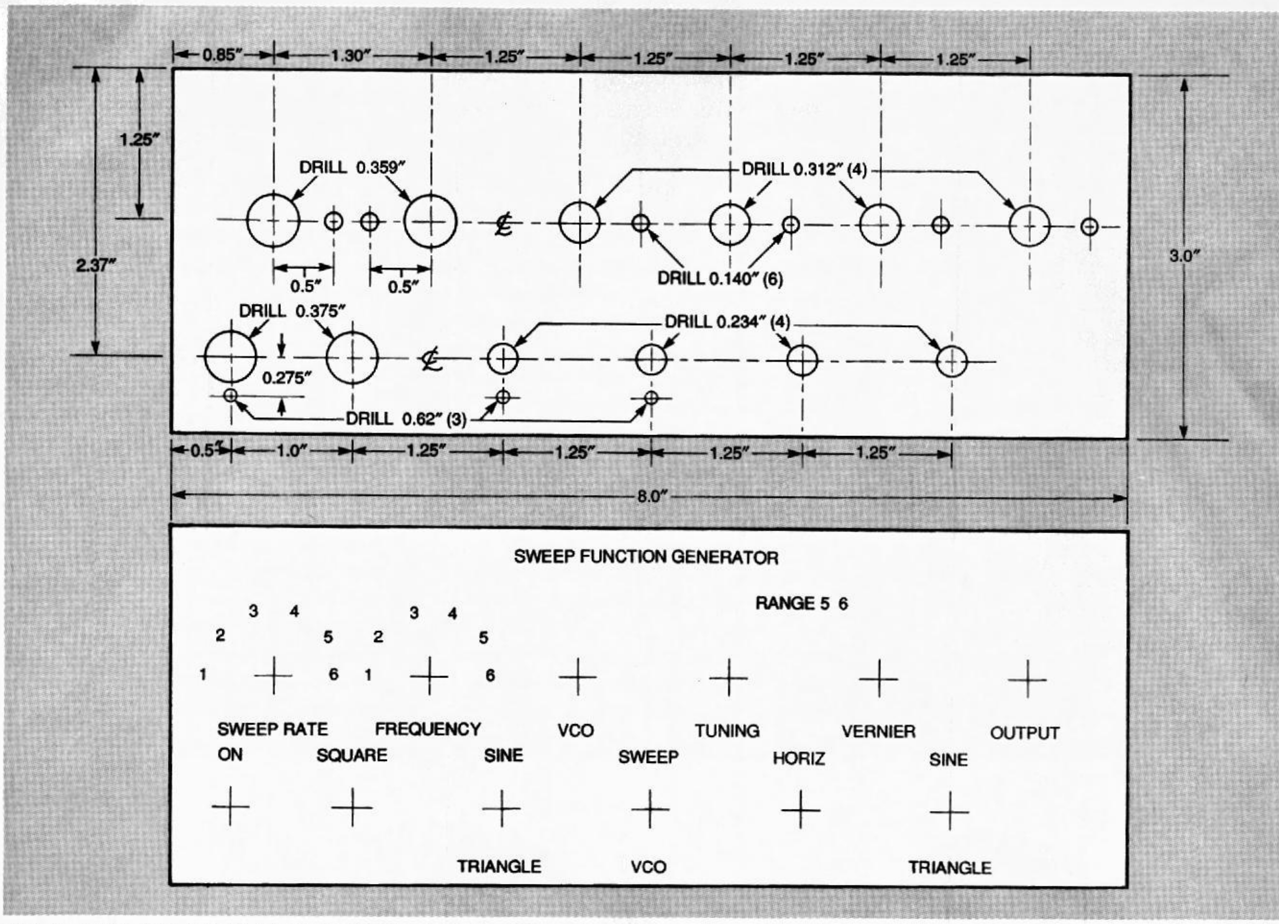


FIG. 4—HOLE FORMING AND LABEL INSTRUCTIONS. Drill all holes as shown in (*a*) and apply function labels as shown in (*b*)

num electrolytic capacitors C6 and C11 bypass the internal voltage references of IC2 and IC4, respectively.

Power supply

The AC input is supplied by a 120-volt AC to 15-volt DC wall-outlet adapter. Diodes D1 and D2 in the power supply section provide both positive and negative outputs, which are filtered by aluminum electrolytic capacitors C1 and C2.

The positive 15 volt supply is regulated by a IC3, which is an MC7815 voltage regulator. The regulated +15 volts is filtered by aluminum electrolytic capacitor C8. Transistor Q1, functioning as the bias regulator, absorbs sweep modulation of the bias voltage.

NOTE: If your local utility does not provide adequate line-voltage regulation, obtain an 18-volt AC to DC adapter. Increase the value of R1 from 680 ohms to 820 ohms.

Building the generator

The prototype sweep/function generator is housed in a two-piece metal project case that measures 8×6×3 inches. The sheet metal of the baseplate is folded at right angles to form the front and back panels. The metal of the cover is bent to form the two side panels, and it is fastened to the baseplate with sheet metal screws.

The circuit board in the prototype instrument was also a stock item with parallel edge contacts so that it could plug into a mating cardedge connector. This circuit board can be easily removed for maintenance, but any 4-inch square of 0.1×0.1-inch grid perforated circuit board material is also suitable for this project. Before mounting any components, drill holes in each of the four corners of the board so that it can be mounted on the base of the case with screws and insulating standoffs.

All of the electronic components with the exception of the Exar XR2206 function generator ICs are standard items readily available from most electronics retail stores or mail-order distributors. The Exar devices can be purchased in small quantities from Bell Account Development Group, Los Angeles, CA 90049 (1-800 289 2355).

All resistors specified in the parts list have 1 % tolerance because they are recommended for building precision instruments. Trimmer potentiometers R3, R13, and, R22 are circuit-board mounting, single-turn units.

Parts placement

Refer to the parts placement diagram Fig. 3 for the general placement of all components on the perforated circuit board. Perform the wiring by point-to-point method, making use of the component leads, where practical, to interconnect other components.

Position the IC sockets in the locations shown in Fig. 3. Next, insert and solder the five trimmer potentiometers. Install the capacitors and other components, and bend the leads to assure that the components are positioned snugly against the component side of the board before soldering them on the solder side.

Refer to the schematic Fig. 1, and be sure to observe the polarities of all polarized electrolytic capacitors and the positions of the cathodes of all silicon and Zener diodes. Install the TO-220 packaged, three-leaded MC7815 regulator IC2 and bias regulator transistor Q1 and make all connections. Note that effective Zener diode D4 is actually an integrated circuit in a three-pin TO-92 plastic transistor package.

Solder all leads and trim excess lead lengths. Check to be sure that you have not made any inadvertent solder bridges or cold solder joints, and repair any that you find.

Case hole drilling

Figure 4-a is the pattern for drilling the holes in the front panel of the project case. This pattern can be enlarged to full size on a copying machine and taped or pasted to the panel. Follow standard practice in centerpunching the holes in the sheet metal before drilling.

Cut out a square hole in the back panel of the case for mounting the power jack J1 approximately 1 inch above the base and 1 inch in from the edge for mounting the AC to DC adapter power jack J1. Drill the three holes for the three optional binding posts only if you intend to install them on the back of the case. These were drilled on the left side of the back panel of the prototype case.

Drill four holes in the baseplate with the same spacing as the holes drilled in the corners of the circuit board for mounting the completed circuit board on insulating standoffs above the base. After drilling all holes, deburr them.

Figure 4-b shows the positioning of the legends on the front panel of the project case. The legends can be applied to the front panel with water-soluble transfer lettering obtained from a stationery store or the labels can be embossed with a labeling machine on plastic adhesive-backed tape and fastened to the front panel in the appropriate locations with their adhesive.

Mount the BNC connectors in

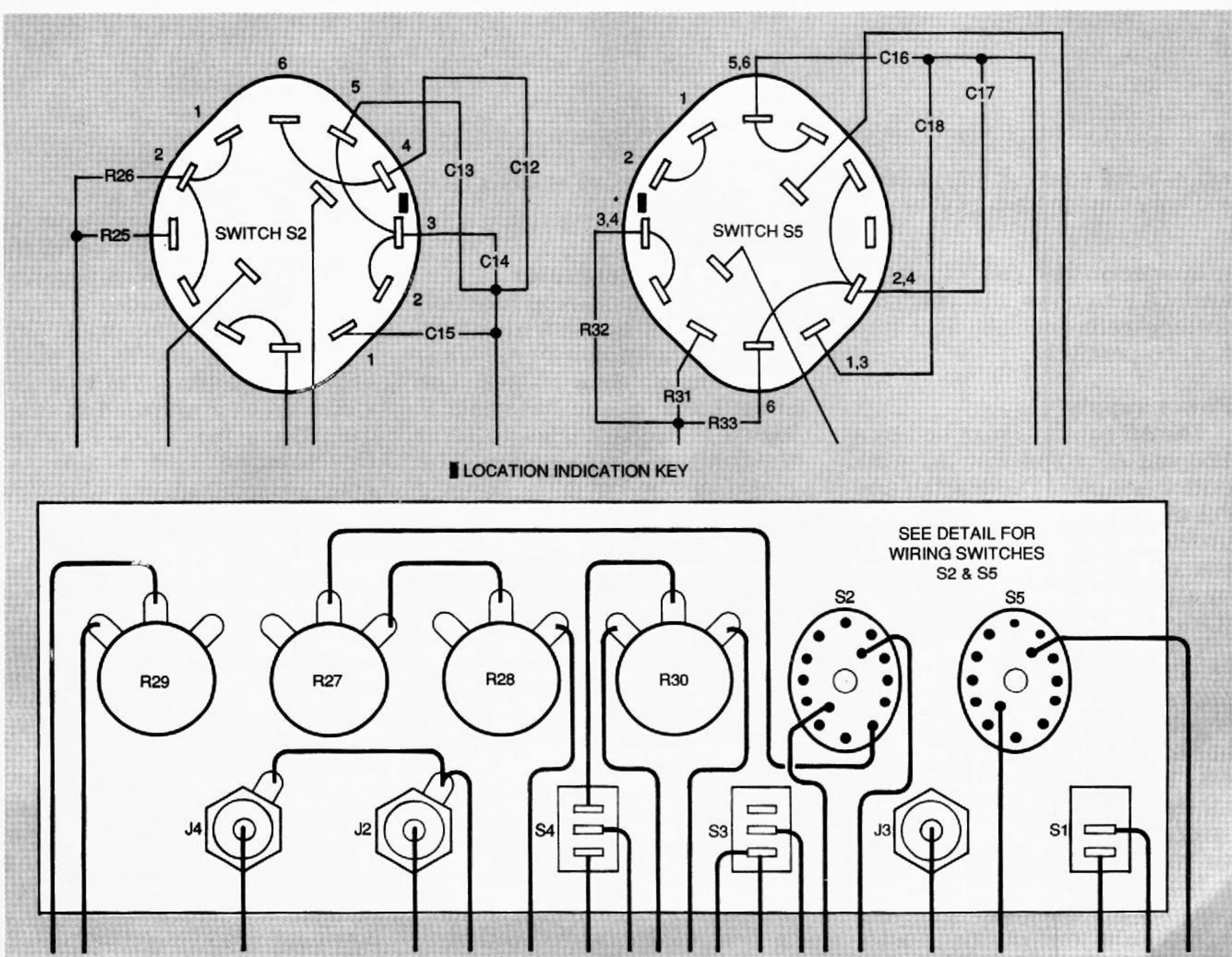
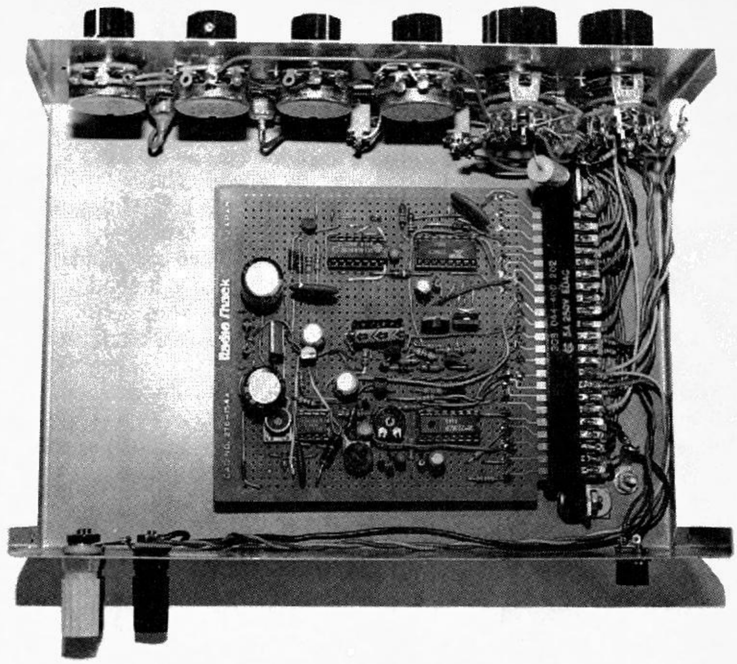


FIG. 5—WIRING FOR FRONT-PANEL-MOUNTED COMPONENTS. Wiring for rotary, two-pole switches S2 and S5 (*a*) and wiring for other controls, switches and jacks.(*b*)

the holes marked in Fig. 3-b with the ground lug and nut supplied. Mount the toggle switches in the holes with the keyed washer in front. Attach the power jack with the hardware provided. If you want to install binding posts in the drilled holes, install them at this time.

Form a wire ground from the BNC jack ground lugs to the cabinet ground lug, near the front mounting bracket. Perform all internal wiring not performed with component leads with No. 22 AWG insulated, stranded hookup wire. Make ground connections from No. 20 AWG bare solid or stranded copper wire to the closest case ground lug.

Form twisted pairs for wiring between the power jack J1, ON switch and the connections from FREQUENCY switch S2 and SWEEP RATE switch S5.



INSIDE VIEW OF SWEEP/FUNCTION GENERATOR. Connections between board and panel circuitry were made with an edge connector in the prototype.

Back-panel wiring

The wiring of the switches, potentiometers and coaxial jacks that are mounted on the back of the panel of the project case is shown in Fig. 5. Complete this wiring before mounting the switches to the panel of the project case. Cut excess lengths from the shafts of all panel potentiometers as necessary to permit the knobs to fit close to the ring nuts on the front face of the panel.

Position all bare wire jumpers and resistors, and solder the wires and resistors in place. Make the leads from the switches back to the circuit board from No. 22 AWG insulated stranded wire long enough to reach the connector terminals or controls.

Test and checkout

Test the power supply by connecting 15-volt DC on the circuit board. To test the voltages for the integrated circuits that are not yet installed, measure the voltages at the socket pins that correspond to the DIP package pins. The output voltages should be as shown in test voltages Table r:

If the measured voltages agree with those listed in Table 4, disconnect the power supply. Transistor Q4 is a 2N7000 MOSFET. Keep the terminals of MOSFET Q2 shorted together until it is soldered in place. Complete any other wiring or assemble any parts not yet installed.

Set trimmer potentiometer R22 to its midpoint, and monitor pin 2 of IC4 with an oscilloscope. Restore power and look for a negative sloping waveform with an amplitude of 6 to 9 volts peak-to-peak on all positions of SWEEP RATE control S5. Turn off the power, and insert the dual operational amplifier IC1 in its socket.

Restore power and monitor the output on coaxial connector J2 for the SWEEP RAMP output of 2 to 3 volts peak-to-peak. Set the horizontal sweep output of trimmer potentiometer R3 to its midpoint. The final adjustment of R3 will depend on the horizontal deflection sensitivity of the oscilloscope. This will be discussed under function generator sweep.

Set switch S4 to VCO and SINE-TRIANGLE buffer amplifier switch S4 to SINE. With power off, insert IC3. Select range 1 on the FREQUENCY switch S2, and observe the output of the sine/triangle buffer amplifier. Tune the output to 1 kHz with the VCO trimmer potentiometer control R30. Adjust trimmer potentiometer R6 for minimum sine wave distortion by visual examination.

Set trimmer potentiometer R5 with switch S3 set for TRIANGLE, and adjust for balanced rise and fall times on the waveform. Some compromise might be required here to avoid distorting the output.

The VCO tuning can be observed on each of the six ranges of FREQUENCY switch S2. However, expect the oscillator to stop oscillating at some position of counter-clockwise rotation of the rotary control. This is a normal condition, and it indicates the lowest frequency that can be tuned on that specific range. The lowest frequencies on ranges 5 and 6 are controlled by the setting of trimmer potentiometer R28 and, to a lesser extent, by vernier fine-tuning trimmer potentiometer R27.

The frequency range attained by the prototype was stated at the beginning of this article. However, because of variations in different XR2206 monolithic function generators, not all results will agree with the ranges stated. The output level can be adjusted with the OUTPUT panel control potentiometer R29.

PARTS LIST

All resistors are ¼-watt, 1% unless otherwise specified
R1—680 or 820 ohms, ½watt (see text)
R2, R15—3,300 ohms
R3—6,800 ohms, trimmer potentiometer, PCB, horizontal slot
R4, R24, R40—10,000 ohms
R5,R11—1000 ohms
R6—25,000 ohms,trimmer potentiometer, PCB, vertical mount
R7—500 ohms, trimmer, PCB, vertical mount, Allen Bradley D or equiv.
R8, R14, R19—5,100 ohms
R9, R10, R20, R21—4,900 ohms
R12, R34, R37—22,000 ohms
R13—10,000 ohms, trimmer, PCB, vertical mount Allen Bradley D or equiv.
R16—2,700 ohms
R17—68,000 ohms
R18—100,000 ohms
R22—10,000 ohms, trimmer potentiometer, PC, horizontal mount
R23—18,000 ohms
R25—3,000
R26—10,000 ohms
R27—5,000 ohms, linear control, Radio Shack 271-1714 or equiv.
R28—1 megohm, linear control, Radio Shack 271-211 or equiv.
R29—50,000 ohms, linear control, Radio Shack 271-1716 or equiv.
R30—10,000 ohms, linear control, Radio Shack 271-1715 or equiv.
R31—1 megohm
R32—200,000 ohms
R33—499,000 ohms
R35, R36—2,200 ohms
R38, R39—33 ohms
R41—390 ohms
R42—1 Megohm
R43, R44—820 ohms
R45—220 ohms

Capacitors
C1, C2—470 µF, 35 volt, aluminum electrolytic
C3, C8—47µF µF, 25 volt, aluminum electrolytic, radial- leaded
C4—120 pF ceramic disc
C5, C20—0.22 µF, 16 volt, ceramic disc
C6, C9, C11—10 µF, 25 volt, aluminum electrolytic, radial leaded
C7, C10,—10 µF, 16 volts, tanatalum electrolytic, radial leaded, dipped
C12—820 pF, polypropylene film
C13—6800 pF, polypropylene film
C14—2200 pF, polypropylene film
C15—0.047 pF, polypropylene film
C16—0.01 µF, 100 volt, polypropylene film
C17—0.1 µF, 100 volt,polypropylene film
C18—0.22 µF, 100 volt, polypropylene film
C19—47µF, 25 volt, aluminum electrolytic, radial-leaded

Semiconductors
D1, D2—1N4002 diode, silicon rectifier
D3—1N4744, Zener diode, 15 volt, 1 watt
D4—LM336, 2.5 volt reference diode (Zener), National Semiconductor or equiv.
D5, D6—1N4148/1N914 silicon diode
Q1, Q3—2N3904 NPN bipolar transistor
Q2—2N3906 PNP bipolar transistor
Q4—2N7000 MOSFET transistor
IC1, IC4—XR2206 function generator, Exar
IC2—MC7815 positive fixed voltage regulator, Motorola or equiv.
IC3—LF353 dual JFET operational amplifier, National Semiconductor or equiv.
IC5—CD4069UB CMOS hex inverter, Harris or equiv.

Other components
S2, S5—switch, rotary 2-pole, 6-position, Radio Shack 275-1386 or equiv.
S3, S4—switch, miniature flat-lever toggle, 6 A, SPDT, Radio Shack 275-635 or equiv.
S5— switch, miniature toggle, 6 A SPST, Radio Shack 275-634 or equiv.
J2, J3, J4—BNC coaxial jack, panel mount, Radio Shack 278-415 or equiv.
J1—jack, AC to DC adapter, coaxial, Radio Shack 274-1565 or equiv.

Miscellaneous: AC-to-DC wall outlet adapter, 120-V AC to 15-V DC (see text); perforated circuit board, 0.1×0.1 inch hole spacing, 4×4-inches; metal project case, two-part, 8×6×3-inches,(see text); six panel control knobs in two sizes; four IC DIP sockets: two 16-pin, one 14-pin, one 8-pin; binding posts (optional, see text); No. 22 AWG insulated hookup wire; No. 22 AWG bare tinned copper hookup wire, solder

If all electrical measurements of the sweep/function generator are within the limits specified, and the circuit has responded correctly to all adjustments, start the procedure for calibrating the instrument with your oscilloscope.

Function generator sweep

Set bias-trimming potentiometer R13 for −2.5 volts at the emitter of transistor Q1. Select Range 3 on FREQUENCY switch S2 and positions 1 or 2 on SWEEP RATE switch S5. Connect the HORIZONTAL output jack J2 of the sweep/function generator to the horizontal sweep input jack on the oscilloscope, and set the oscilloscope to EXTERNAL INPUT.

Set SWEEP-VCO switch S4 to SWEEP and SINE/ TRIANGLE buffer amplifier switch S3 to SINE. Connect the SINE/TRIANGLE output jack J4 to the oscilloscope's vertical or Y-axis input jack, either with a probe or with a properly terminated coaxial cable.

Adjust OUTPUT panel potentiometer R29 for a Y deflection of 1 to 2 volts peak-to-peak on the oscilloscope screen. Center the band of horizontal X deflection with the oscilloscope's horizontal X-position control, and adjust trimmer potentiometer R3 at the output of operational amplifier IC1, the X deflection trimmer potentiometer for full (typically 10 division) oscilloscope deflection.

Adjust trimmer potentiometer R22 (adjacent to IC4) for maximum X deflection until the Y output ceases at the left edge of the oscilloscope screen because the sine oscillator has turned off. Back off trimmer potentiometer R22 until the oscillator starts to oscillate.

Readjust all the controls related to the X display to produce a band of sweep output that fills the full ten-division graticule width. Index the rotary SWEEP RATE switch S5 through all six positions to verify that the oscillator operates for the full sweep. (Its ability to do this could be limited by minor variations in the ramp output.)

If the SWEEP RATE switch does not perform correctly, readjust trimmer potentiometer R22 as previously described to produce the maximum sweep frequency width obtainable without stopping the oscillator.

Oscillation ceases when the most positive point on the sweep ramp reaches the nominal bias of +3 volts on pin 10 of IC2, preventing the flow of timing current. It might be necessary to set the sweep on one position of switch S5 and avoid sweep-rate positions 3 and 4 where oscillation is most likely to stop.

One or more horizontal lines at the left side of the oscilloscope screen indicate that oscillation has ceased. Maximum sweep width is achieved if this condition is avoided because some hysteresis exists between the stop and restart settings of the oscillator.

The sweep-frequency range obtained on positions 1 to 4 of FREQUENCY switch S2 can now be measured by setting the SWEEP/VCO switch S4 to VCO. Set VCO control potentiometer R30 so that the vertical deflection visible on the oscilloscope screen is on the first (left hand) graticule line.

The frequency measured by an external counter is the lowest frequency of the sweep, while the frequency measured on the extreme right graticule line of the VCO setting is the highest frequency. The frequency anywhere within the area bounded by the graticule can be read the same way.

Set the upper frequency on one of the first four ranges by adjusting trimmer potentiometer R13 and setting range 2 to 10 kHz or range 4 to 100 kHz. One setting affects all ranges.

Set the FREQUENCY range on positions 5 and 6 of rotary FREQUENCY switch S2 by adjusting front-panel TUNING control R28 or VERNIER tuning control control R27 to set the highest frequency. Set SWEEP/VERNIER switch S4 as described earlier with the trace on the right side graticule line.

TABLE 4
TEST VOLTAGES

Location	Volts ±10%
D1, cathode side of D1	+25
D2, anode side of D2	−25
IC1, pin 4 (1)	−15
IC1, pin 8	+15
IC2, IC4, pin 4	+15
Q1, emitter (2)	
R9-R10 function	+7.5
R20-R21 junction	+7.5

(1) With R1 installed.
(2) Depends on setting of trimmer R13

VCO control

The adjustment range of the VCO control R30 slightly exceeds the voltage change of the sweep ramp. Slightly higher or lower frequencies can be set with switch S4 on the VCO setting than on the SWEEP setting without stopping the oscillator.

The VCO control can tune any single frequency within each of the six ranges of the sweep-function generator with simultaneous adjustment of TUNING control R28 and VERNIER control R27 on ranges 5 and 6.

The sweep can be offset to the left with the osilloscope's X-position control to put a selected frequency such as 1kHz on the left graticule line. Then the sweep can be adjusted to display a 1-kHz change on each following graticule line. This response can be demonstrated on SWEEP RATE range 2.

The sweep/function generator was designed for use with an oscilloscpe that has no horizontal gain control. To compensate for this, a negative ramp signal of about 4 volts for ten division deflection is required. If your oscilloscope has an X gain control, it can set sweep deflection, and trimmer potentiometer R3 at pin 7 of IC1 need not be adjusted. Once calibrated, the sweep performance shown on ranges 1 to 4 is repeatable without further manual adjustment.

If you intend to use the sweep/function generator with an X-Y or chart recorder, its sweep rate can be slowed with an external non-polarized aluminum electrolytic capacitor connected across pins 5 and 6 of IC4. A 100 microfarad, 15-volt capacitor will provide a range of sweep durations with SWEEP RATE switch S5 various positions:

- 68 seconds in positions 1, 2, and 5
- 14 seconds in positions 3 or 4
- 33 seconds in position 6

The output cuts off for several seconds after flyback because of longer than normal sweep. This can be minimized by readjusting trimmer potentiometer R22. A low-frequency sweep of 20 to 300 Hz can be obtained by selecting sweep range 5 and setting tuning and vernier controls for maximum resistance.

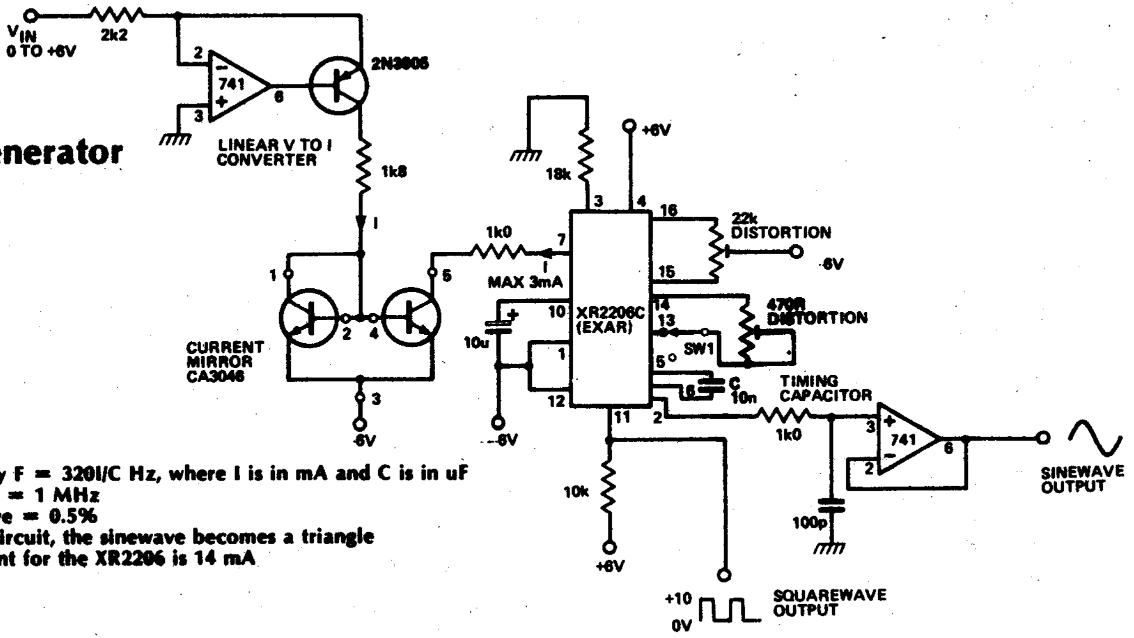
The sweep can be started at the same instant as the X-Y chart recorder by connecting the common lead to ground from resistors R31, R32, and R33 through a normally closed (NC) pushbutton switch shown on schematic Fig. 1. Connect a closed-circuit miniature phone jack, a plug, and cable to the pushbutton switch. Press the pushbutton and hold it as soon as the retrace is complete, and it will stop the sweep until you are ready to start recording.

The X-Y recorder will follow the sweep. Give the pen down command at the same time the pushbutton is released. Retrace will sweep in about 1 second. An AC voltmeter with a calibrated DC output (or other peak or envelope detector) will be required for X-Y or chart recording.

The squarewave output of the sweep/function generator is a useful signal source for bench or development tests on transistor-transistor logic devices or 5-volt CMOS logic devices. Clamp the input of those devices with a switching diode—anode to the input, cathode to supply voltage (V_{CC} = 5 volts) to absorb any overshoot that might occur at the end of an unterminated coaxial cable when fast-switching input signals are applied.

The XR2206 is a versatile monolithic function generator, but its squarewave output is degraded at frequencies in excess of 100 kHz by a rise time of 250 nanoseconds and a fall time of 50 nanoseconds. The squarewave amplifier will provide some compensation for this shortcoming, but it will not correct the loss of symmetry. Ω

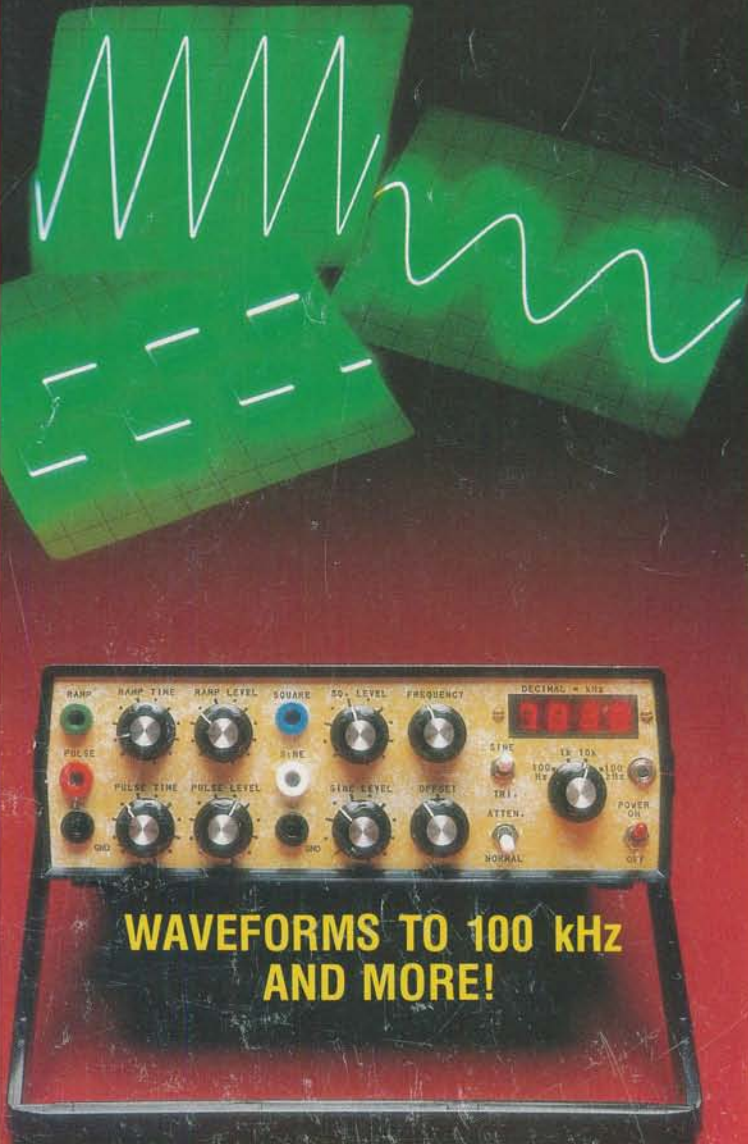
27
Function Generator



Oscillation frequency F = 320I/C Hz, where I is in mA and C is in uF
Maximum frequency = 1 MHz
Best THD of sinewave = 0.5%
When SW1 is open-circuit, the sinewave becomes a triangle
Typical supply current for the XR2206 is 14 mA

BUILD THIS FUNCTION GENERATOR

A "MUST-BUILD" PROJECT FOR EVERY ELECTRONICS WORKBENCH



WAVEFORMS TO 100 kHz AND MORE!

This versitile signal generator can provide simultaneous square/triangle or square/sine output signals.

VERSATILE FUNCTION GENERATOR

JOHN WANNAMAKER

THERE WAS A TIME WHEN A SIMPLE SINE OR square wave signal was all that was needed to test electronic equipment. Today, we need many more kinds of test signals, as well as specific control over such things as their duration, shape, and duty cycle. Basically, what's needed is a laboratory-grade multifunction signal generator, such as the one described in this article. Using readily available parts, the signal generator provides a square wave output, with simultaneous triangle, and sine wave outputs; it can also supply variable duty-cycle pulses and a more-or-less conventional linear-sawtooth ramp.

All outputs have level controls, and the sine/triangle function makes provision for a fixed amount of attenuation. There's also a front-panel OFFSET control for the sine and triangle waveforms that provides ±1.5 volts into a 600-ohm load, or 3 volts into an open load. Other waveforms are unipolar and may be used with CMOS and TTL circuits.

The variable duty-cycle output pulse, which has a timing value of 1–50 ms can sink more than 20 TTL loads. The linear output ramp is similarly variable. A built-in frequency counter monitors the output frequency using four decaded ranges of 100, 1000, 10,000, and 100k Hz.

Although the time-base accuracy and stability of the internal counter are exceptionally good, it would be fairly easy to add an external jack that switches out the internal monitoring and accepts a signal from the outside world. A 0–1-volt pulse is adequate input from 5 Hz to 2 MHz, but the four-digit counter and display can only handle up to 99.99 kHz.

The circuits

The signal generator is divided into three sections: (1) the sine/triangle/square wave generator; (2) the counter; (3) the pulse/ramp.

As shown in Fig. 1, IC3, an Exar *XR2206* Function Generator integrated circuit, provides the sine, triangle, and square waves. Normally, IC3's frequency adjustment is a 0.2–2-megohm variable resistor connected from pin 7 to ground, but that kind of adjustment often proves to be critical because only conventional single-turn potentiometers are normally available in such large values. In our prototype, however, the *XR2206* is used as a voltage-controlled oscillator, and frequency-adjustment control R25 is a 10K 10-turn potentiometer. Adjusting the output frequency to within one cycle out of a thousand takes only a modest degree of dexterity.

Values other than 10K may be used if fixed-resistor R16 is changed. For a 2K potentiometer, R16 = 4.7K. For 5K, R16 = 20K. For 20K, R16 = 82K. Try to stay within that range, or the low-frequency adjustment trimmer may become ineffective.

The sine/triangle circuit is also unusual in that, unlike some commercial circuits, attenuation switch S3 affects only the signal amplitude and not the value of any offset voltage. You decide how much fixed attenuation the circuit is to have (up to -20 dB; a 10:1 voltage ratio) by making R26 larger than necessary, and then trimming its value by connecting another fixed resistor (R27) in parallel. If that method is too cumbersome, the two resistors can be replaced by a multi-turn trimmer resistor. (Although the trimmer is more costly, it's a great deal easier to use.)

Output impedance

A sine or triangle output is selected by switch S2. Emitter-follower Q8 has an output impedance of about 20 ohms, which can supply a 1.5-volt p-p waveform into an 8-ohm speaker, or about twice that amount into 16 ohms. That holds true from 10 Hz to frequencies that are far above the audio range. (It's important to adjust for zero offset if testing speakers in that manner.)

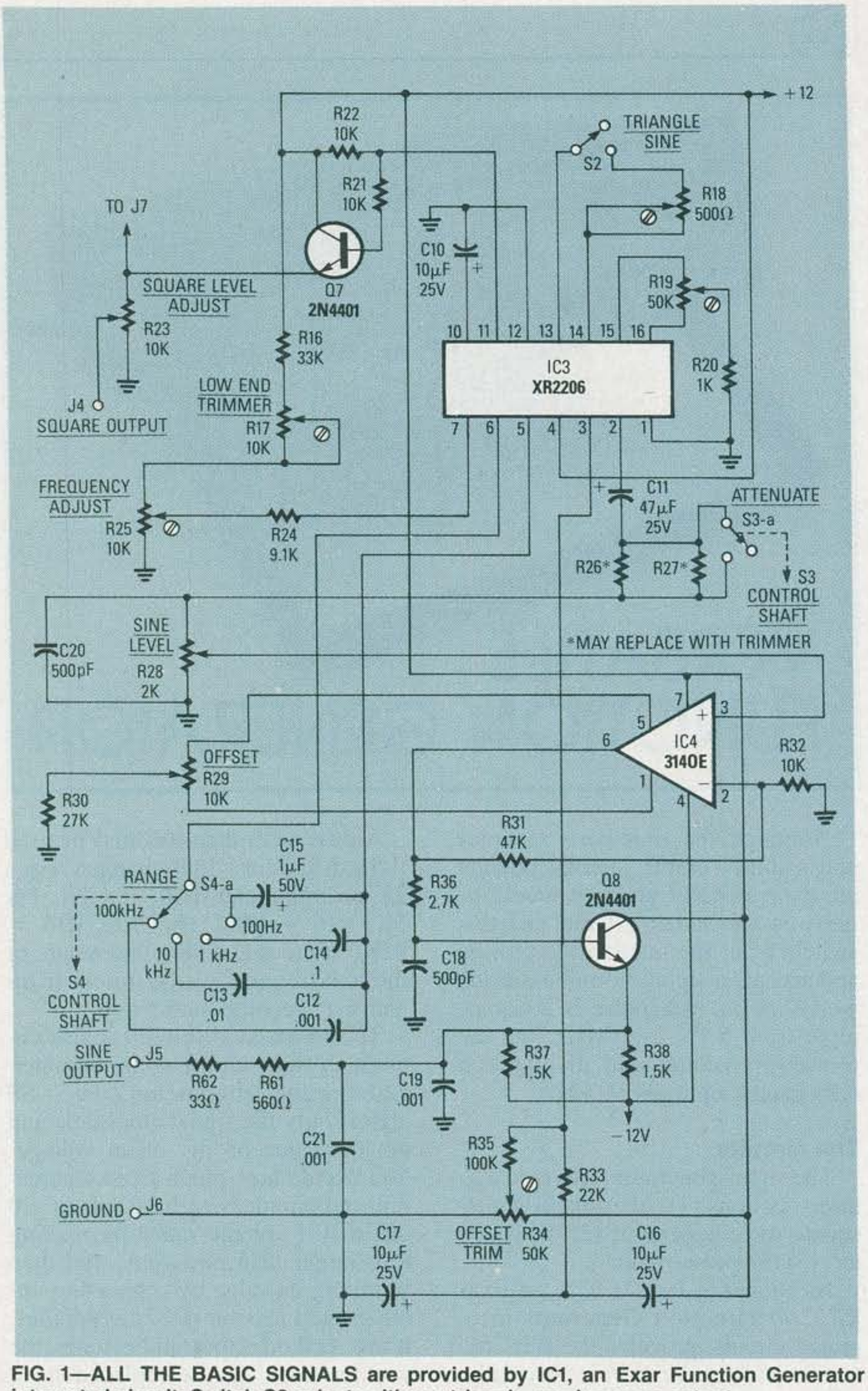


FIG. 1—ALL THE BASIC SIGNALS are provided by IC1, an Exar Function Generator integrated circuit. Switch S2 selects either a triangle- or sine-wave output.

Normally, the low impedance is attained when resistors R61 and R62 are replaced by a jumper wire. The resistors are used only if you prefer the generator to have a 600-ohm output impedance.

A switching arrangement to change the output impedance from 20 to 600 ohms is not suggested, because the additional wiring might result in noise pickup that would be added to the output signal.

The counter section, shown in Fig 2, is unique in that it mates IC6, an Intersil 7207A time-base device with IC5, a 74C926 counter. Since counter IC5 doesn't have built-in sampling or gating, the timing pulses from IC5 are used to alternately short circuit the counter input pulses to ground and then allow them to pass for precise 1-second or 0.1-second intervals.

The counter display dims when attenuation switch S3 is set for ATTENUATE because S3 also inserts a 330 ohm resistor, R60, in series with the 5-volt regulator that services the counter section. The regulator loses its control and the voltage drops to about 3 volts, causing the output current to drop to about one-third of its normal value. That causes both time-base IC's to operate at a voltage below the manufacturer's recommended values. While that is not an admirable practice, as long as R60's value did not exceed 1000 ohms, no ill results were noticed when several sets of IC's were tested in the circuit.

The reason for reducing the voltage applied to the counter circuit below the recommended minimum values is to attenuate the multiplexing noise that leaks into the sine-wave output when the circuit voltage is the usual +5 volts.

Dual one-shots

The pulse/ramp circuit, shown in Fig. 3, uses a *4538* CMOS IC that contains two monostable multivibrators, or one-shots. Each is triggered into its ON state by the negative-going edge of the other's Q output. The circuit is activated by a kick-start via C1 when power is first applied. Since the pulse width of each one-shot is determined by an independent time constant, the overall duty-cycle variation is unusually large. Using the values shown, the duty-cycle is variable from 2–98%.

The time constant of IC1-a is modified so that its timing capacitor charges through constant-current transistor Q1, which creates a straight-line voltage rise across the capacitor. The input resistance of op-amp IC2 buffers the capacitor voltage from loading effects and also provides an output impedance of less than 100 ohms.

The pulse output at J2, which is derived from IC1, can sink a 100-mA, 50% duty-cycle current.

Since the ramp is the time-constant voltage for one of the multivibrators, it is therefore locked in step with the pulse from the other multivibrator. When the pulse is on, the ramp is off, and vice versa.

The oscilloscope photographs shown in Figs. 4–6 show the kind of outputs you can get. Figure 4 shows a 50% duty-cycle square wave on the bottom and its simultaneous triangle wave at the top. Figure 5 shows the same 50% duty-cycle square wave at the bottom and the simultaneous sine-wave output at the top. Figure 6 shows

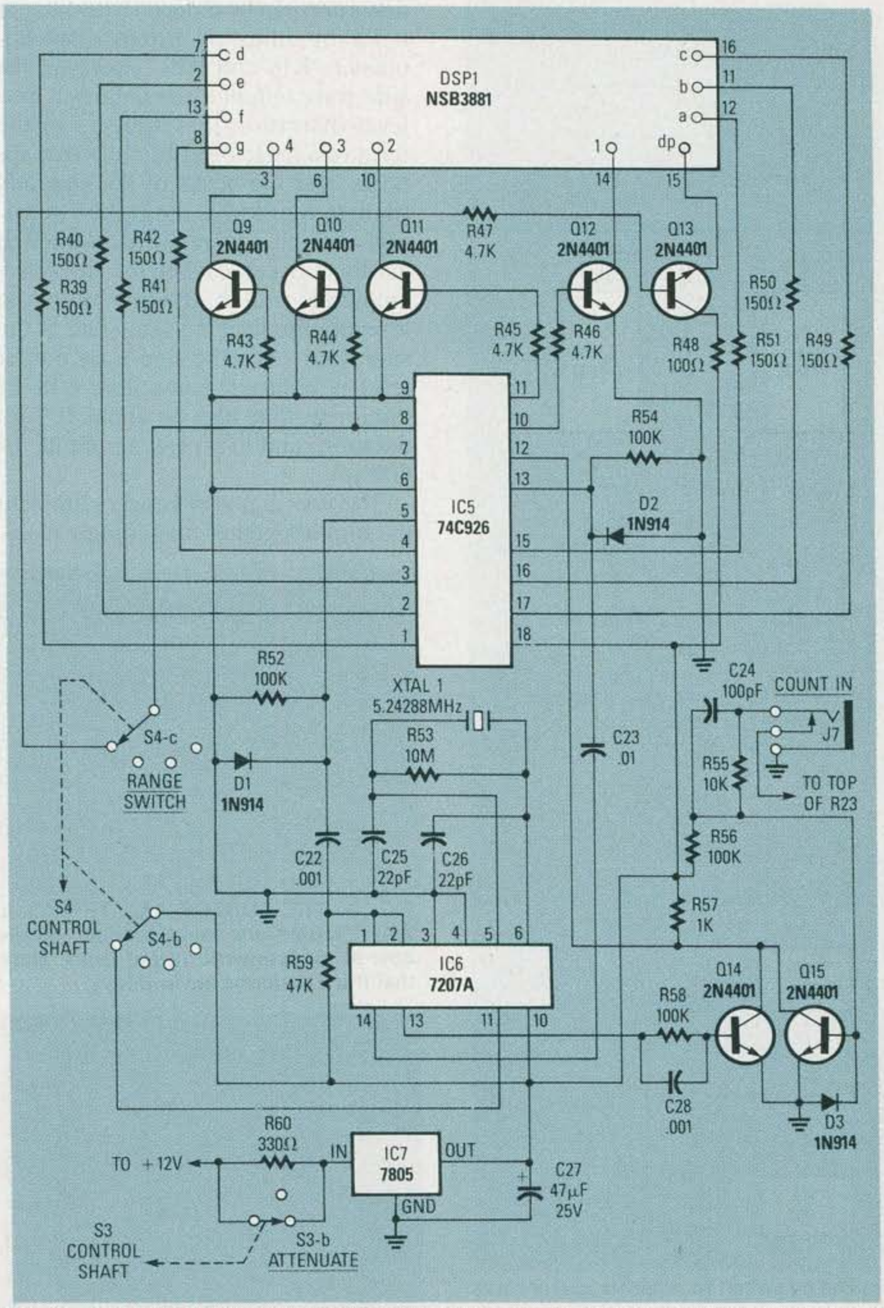


FIG. 2—THE FREQUENCY-COUNTER SECTION can be used independently by applying an external signal via jack J7. In typical operation, J7's normal-through connection connects J7 to the the square-wave output from Q7.

a 26% duty-cycle ramp at the bottom and its corresponding square-wave output at the top.

Construction

The unit is assembled on a 3 × 6-inch printed-circuit board. The template for the board is provided in PC Service. Alternately, a pre-drilled PC board can be purchased from the source given in the Parts List.

The component layout and interconnections for the PC-board are shown in Fig. 7. Be sure to use sockets for all IC's except the voltage regulators. Although the board's component density is about six parts per square inch, except for rectifier diodes D4 and D5 all components are mounted flat on the board. Although that degree of compactness suggests that a small but well-ventilated metal case would be a suitable enclosure, the LED display, jacks, and the operating controls occupy a relatively large area of panel space. Therefore, those components become a controlling factor in the size of the housing. The enclosure used for the prototype shown is the series *570 Desktop Enclosure* by Amerex. But regardless of what you use for an enclosure, make certain that there are adequate ventilation holes for air circulation.

Because it lends itself to neat groupings of associated wires by splitting off appropriate lengths of whatever number of conductors are required, stranded multiconductor ribbon cable should be used for connections between the PC board and the panel-mounted components. At the very least, wire having ribbon cable's flexibility should be used to connect the LED display to the PC board.

The gold-plated foil on the display's own PC board is fragile, and mechanical abuse or too much heat will cause it to peel off. For those connections, the stranded wires should be prepared prior to installation by stripping about ⅛ inch of insulation and tinning the bare ends of the wires. Then insert the tinned wires through the holes from the display's back so that they are just flush with the opposite side of the board; than solder them carefully from the back, using as little solder as is possible. Take particular care when connecting wires to the LED display, because not all the holes on the display are used.

To accommodate either in-line or offset center-pin units using 0.1-inch pin spacing, an extra solder pad has been provided wherever trimmer potentiometers are to be mounted on the PC board. Trimmers R17 and R34 may be either laydown or upright types, ⅜-inch square, having either a side or a top adjustment. Due to space limitations, trimmers R18 and R19 must be upright types that measure no more than about 0.2-inch wide. If the attenuation resistors, R26 and R27, are to be replaced with a trimmer potentiometer, it, too, must be an upright type. A top-adjust multi-turn unit is suggested.

The front panel should have enough bare metal on its inner surface to electrically connect all potentiometer cases. The GROUND jack in the center of the panel (J6) should connect to the panel with a short length of bare wire wrapped under its retaining nut. Use a grounding lug if you have the appropriate size on hand. Resistor R30 should be similarly grounded around the bushing of R29, the front panel OFFSET potentiometer. (The other leg of R30 is soldered to R29's wiper terminal.) Attempting to ground R30

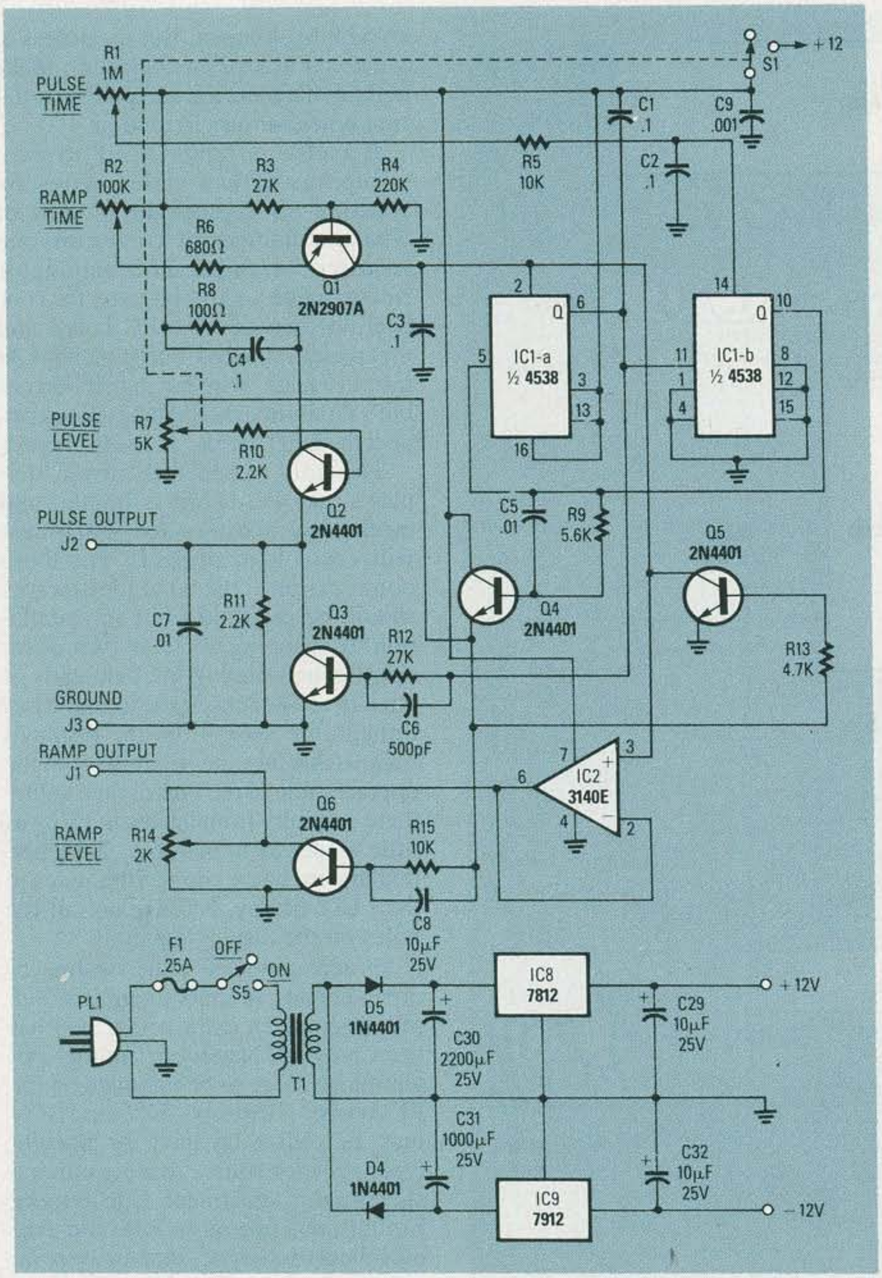


FIG. 3—THE RAMP/PULSE SECTION can be disabled by switch S1, which is part of PULSE-LEVEL control R7.

in a different way might increase noise on the sine-wave output.

Since the sine-wave output can be adjusted to a very low level, it is important to minimize the resident noise level on the output line. The use of wide foil in the power-supply circuit, plus a short length of hookup wire used as a supplemental ground bus, keeps powerline-related noise to about 200 μV p-p. We found that grounding the resistor in the OFFSET circuit to the front panel instead of to the ground foil on the PC-board made a significant reduction in random noise, again proving that all grounds are not equal. Noise spikes caused by the counter's multiplexing (or pulse transitions) are suppressed by either removing power or reducing power to the offending area. The counter/display current is reduced by one section of attenuator-switch S3. Although that causes the readout to dim, it is still usable. The pulse/ramp circuitry may be switched off entirely by switch S1, which is part of PULSE LEVEL control R7. The overall noise is about 250 μV p-p into a 600-ohm load, and about twice that value into an open circuit.

Low distortion

The sine-wave output's harmonic distortion can be reduced to as little as 0.5% by adjusting trimmer potentiometers R18 and R19. However, the sine-wave output also contains a low-level distortion that appears in the form of a tenacious little blip that appears near the peaks of the sine and triangle waveforms during the transitions of the square wave. Although hardly noticeable when the sine-wave amplitude is high, the blip refuses to lose amplitude at the same rate as the sine wave when the sine-wave output level is reduced. Capacitors C18–21 minimize that blip to about 0.5-μs duration, and to a peak amplitude of 400 μV.

The user can very nearly eliminate the blip altogether by adding capaci-

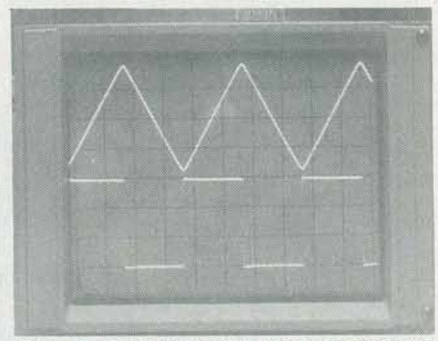


FIG. 4—THE SQUARE AND TRIANGLE WAVEFORMS are simultaneously available at independent output jacks. Note that the waveforms are in-phase.

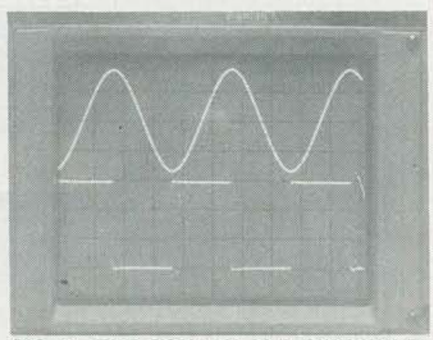


FIG. 5—THE SQUARE AND SINE WAVEFORMS are also in-phase and simultaneously available at independent output jacks.

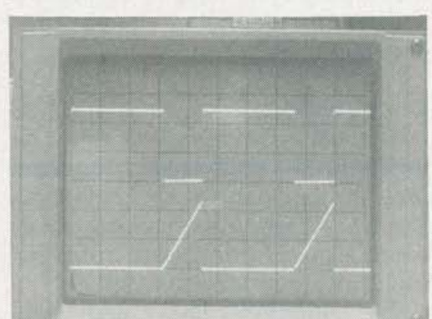


FIG. 6—THE RAMP OUTPUT OCCURS during the negative-going part of the square-wave's duty-cycle.

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.
R1—1 megohm, linear potentiometer
R2—100,000 ohm, linear potentiometer
R3, R12, R30—27,000 ohms
R4—220,000 ohms
R5, R15, R21, R22, R32, R55—10,000 ohms
R6—680 ohms
R7—5000 ohm, potentiometer with switch
R8—100 ohms, 2 watts
R9—5600 ohms
R10, R11—2200 ohms
R13, R43–47—47000 ohms
R14, R23, R28—2000 ohm, linear potentiometer
R16—33,000 ohms
R17—10,000-ohm trimmer potentiometer
R18—500 or 1000 ohm, trimmer potentiometer
R19—50,000 ohm, trimmer potentiometer
R20, R57—1000 ohms
R24—9100 ohms
R25—10,000 ohms, 10-turn potentiometer (see text)
R26, R27—selected, see text
R29—10,000 ohms, linear potentiometer
R31, R59—47,000 ohms
R33—22,000 ohms
R34—50,000 ohms, trimmer potentiometer
R35, R52, R54, R56, R58—100,000 ohms
R36—27,000 ohms
R37, R38—1500 ohms
R39–42, R49–51—150 ohms
R48—100 ohms
R53—10 megohms
R60—330 ohms

Capacitors
C1, C4—0.1 µF, ceramic disc
C2, C3—0.1 µF, Mylar
C5, C7, C23—0.01 µF, ceramic disc
C6, C18, C20—500 pF, ceramic disc
C8, C24—100 pF, ceramic disc
C9, C10, C16, C17, C29, C32—10 µF, 25-volts, electrolytic
C11, C27—47 µF, 25 volts, electrolytic
C12—.001 µF, Mylar, 1%
C13—.01 µF, Mylar, 1%
C14—0.1 µF, Mylar, 1%
C15—1 µF,, 50 volts, electrolytic
C19, C21, C22, C28—.001 µF, ceramic disc
C25, C26—22 pF, ceramic disc
C30—2200 µF, 25 volts, electrolytic
C31—1000 µF, 25 volt, electrolytic

Semiconductors
IC1—CD4538 or MC14538 dual monostable
IC2, IC4—CA314OE op-amp
IC3—XR2206 function generator
IC5—74C926 counter
IC6—ICM7207A time base
Q1—2N2907A PNP transistor
Q2–Q15—2N4401 NPN transistor
D1–3—1N914 small signal diode
D4, D5—1N4401 silicon rectifier

Other components
F1—0.25-amp fuse
DSP1—NSB3881 Four-Digit display (National)
J1–J6—Insulated banana jack
J7—Miniature phone jack
PL1—Powerline plug
S1—SPST, part of R7
S2, S5—SPST switch
S3—DPST switch
S4—3-pole, 4-position rotary switch
T1—Power transformer; 117-volt primary; 12.6-volt, 1-amp secondary
XTAL1—5.24288-MHz crystal
Miscellaneous: PC-board, IC sockets, enclosure, wire, solder, etc.
Note: An etched and drilled printed-circuit board is available for $17 postpaid (includes postage and handling) from John Wannamaker, Route 4, Box 550, Orangeburg, SC 29115. South Carolina residents must add appropriate sales tax.

tance between the terminal and ground, although the cost of the extra capacitance is a rounding of the triangle-waveform's peaks. (With the built-in capacitors, that becomes objectionable only on the highest range.) The capacitance also causes 4-dB attenuation at 100 kHz. If that seems too stiff a price to pay for a clean low-level signal, simply remove the aforementioned capacitors, but expect a little rounding of the high-frequency triangle peaks anyway.

Since it is known that the square-wave output contributes significantly to the unwanted blip on the sine wave, the square-wave's output line should be kept short, and (it really hurts to say this) it should be shielded.

The 330-ohm current-limiting resistor for the counter section, R60, should be mounted directly between the terminals of the appropriate section of the DPST (or DPDT) ATTENUATE switch. Other front-panel mounted components are C20 (500 pF), which should be soldered across the outboard terminals of the SINE-LEVEL potentiometer, and C21 (.001 µF), which should be soldered between the SINE output jack and the nearby front-panel GROUND jack. (Separate GROUND jacks should be provided for the pulse/ramp signals and the sine/triangle signals.)

If the SINE output is to provide maximum current, wire it directly to its PC-board solder pad. If a 600-ohm output is desired, use a string of ¼-watt resistors with a nominal resistance of about 580 ohms in place of the direct wire connection. When the resistance value is just right, an open-circuit sine wave of any value will drop to exactly half of that value when a precise 600-ohm load is connected between the SINE and GROUND jacks.

Even though the PC board has two foils connecting the power-supply ground to the long ground foil on the "output" side of the board, there is sufficient inherent impedance to create some hum at the SINE output. To minimize the induced hum, solder a short—approximately 3 inches—insulated jumper between the ground foils, under the board. Solder one end to the wide foil where C30 is grounded; solder the other end to the foil near the two ground pads on the opposite side of the board.

Mounting

Each corner of the board has room for a 4–40 machine screw mounting hole. Be careful to not let a metal spacer under the board short to a nearby foil; or even better, use insulated spacers. It would be wise to pass the screws through the bottom of the cabinet so that the retaining nuts are on top of the board.

The LED-display assembly can be held in place by either 2–56 or 4–40 machine screws that extend through the front panel on each side of the display. They should pass through some kind of improvised insulated retaining bar across the back of the display. Take care, when installing the display, that its solder terminals do not short to the panel. Since the recommended display has a built-in red filter, no additional filter is necessary.

When mounting the power transformer, make provision for two lugs under one of the mounting screws.

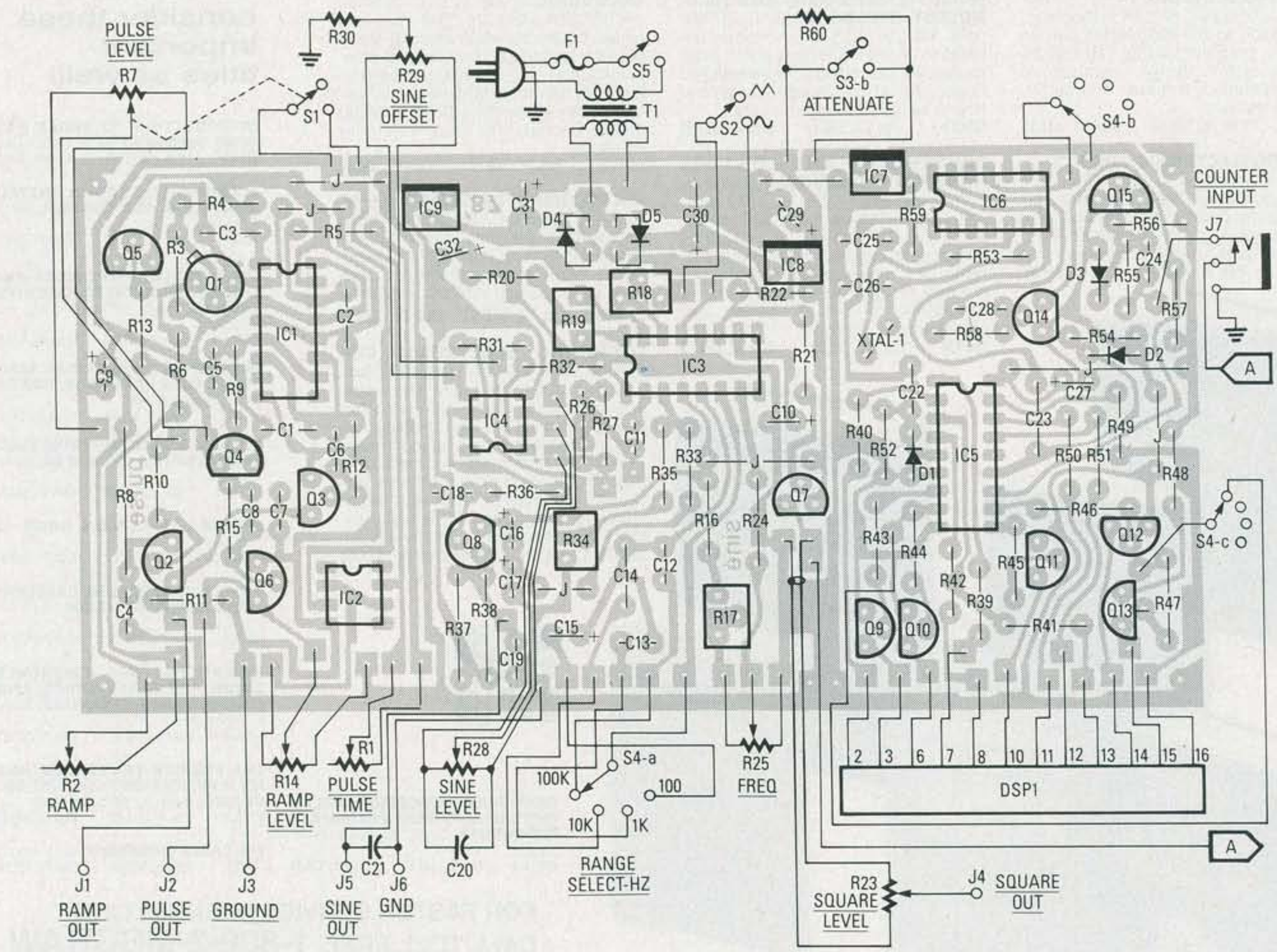


FIG. 7—THE PARTS PLACEMENT FOR THE PRINTED-CIRCUIT BOARD. Notice that not all of the 16 connections on display DSP1 are used.

Attach one to the green ground wire of the three-conductor line cord. The other should attach to an insulated wire to the PC-board's ground in the power-supply area. That has to be brought out from beneath the board and may be fairly long to allow the board to be turned over. Use stranded wire for its flexibility.

Jack J7, which is shown in Fig. 2, is needed only if you want to be able to measure the frequency of an externally generated external to the signal generator. If the feature isn't needed, using Fig. 4 as a reference, simply eliminate the jack and connect the wire going to J7's "hot" terminal to the PC-board terminal having the A-flag, which actually is a connection to the top of R23.

Checkout

Don't install the IC's. Begin with the soldered-in voltage regulators. Using an oscilloscope, check each power source for proper voltage and polarity. Looking at the plastic front of the regulators, the rightmost pin is the regulated output of both the positive and negative units. There should be no ripple. If everything checks out, unplug the power cord and let the voltages decay before inserting any IC's.

Plug in the IC5 and IC6 and apply power. The display should indicate 0000 for the three lowest frequency positions of the range switch, and 00.00 for the highest position. If counter is set for SINE ATTENUATE, the display will be very dim. Without any attenuation all digits will be bright.

A single dim digit can be due to insufficient multiplexing drive; check the 4700-ohm resistors at the bases of Q9–Q13. If the same segment of all digits is dim or will not light, check connections through to the display, particularly the 150-ohm resistors. At this point, of course, the middle bar cannot light. Once checked out, unplug power and allow time for voltages to decay.

To check out and adjust the sine/triangle/square circuit, initially adjust all trimmer resistors and the front-panel potentiometers to mid position. The FREQUENCY control should be rotated five turns into its range. Select the highest frequency range with the RANGE switch and turn off any attenuation. Insert IC3 and IC4, then apply power. The counter should indicate a frequency of approximately 40 kHz. If not, check pin 11 of IC3 with an oscilloscope: You should measure a 12-volt square wave, which means that the IC is oscillating. Trace the signal through to the counter's input. If no problem is found along the route, the problem is most likely to be in the counter.

Adjust the FREQUENCY control to observe that the readout changes, updating every 0.2 seconds (2 seconds on the three lower ranges). Adjust for the lowest frequency on a particular range. Observe the readout while adjusting the low-end trimmer, R17, for a reading of approximately 9.40 kHz. You can then check each range for at

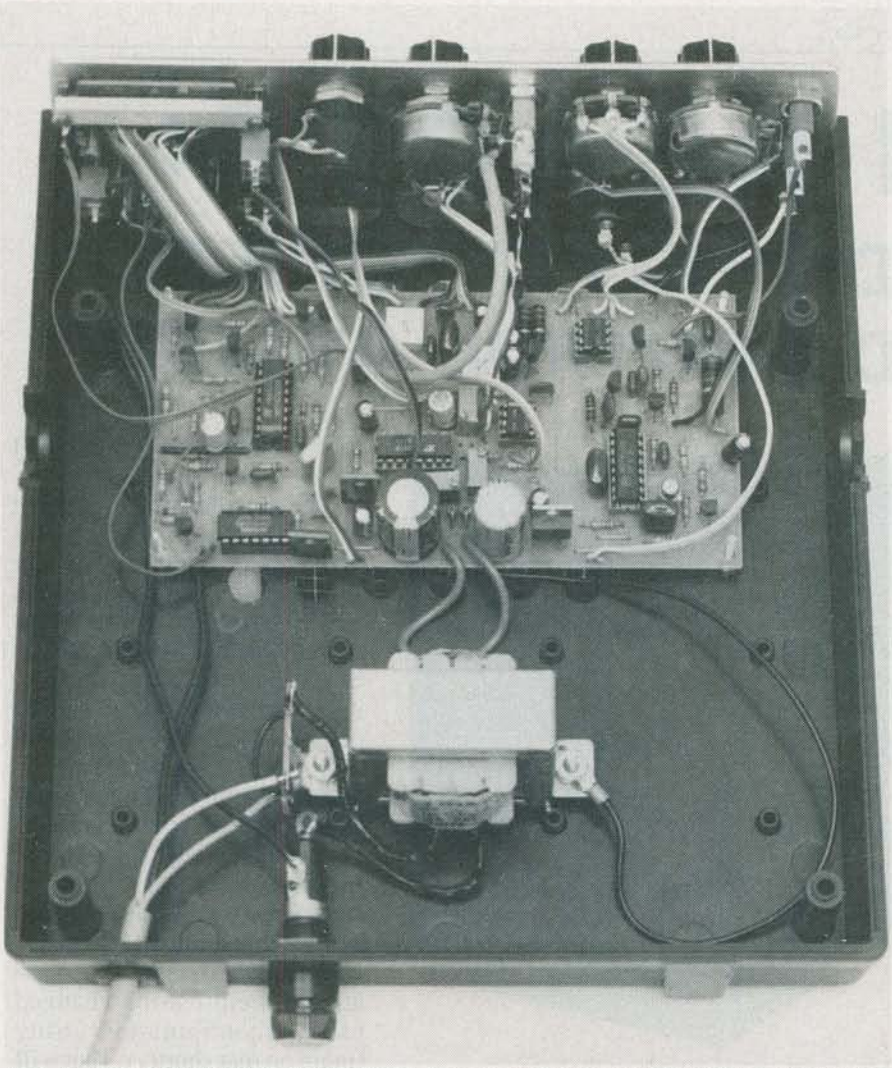


FIG. 8—THE COMPLETED PROTOTYPE. To reduce the possibility of hum pickup, the power transformer, T1, is located a considerable distance from the printed-circuit board. The ribbon cable at the upper left connect the display unit to the PC board.

least a 1:10 frequency variation: 10 Hz to 100 Hz; 100 Hz to 1000 Hz, etc. Of course, where a five-digit figure is given, the most significant digit is missing from the display. Correct the adjustment of R17 on any range that does not go down to, or below, the expected low value. If the highest range will not quite reach 100 kHz, it will be due to stray capacitance that parallels C12. You might try finding a capacitor with a slightly lower value, but a quick fix is to insert a 470-ohm resistor at the RANGE switch in series with the wire from S4 to C12.

Use the scope to check the square-wave output at J4. The SQUARE LEVEL control should vary the amplitude from near zero to 10 volts p-p. If there is a problem, trace the signal from pin 11 of IC3.

Set the frequency to 1000 Hz and select the triangle waveform. Observe the output at the SINE OUTPUT, J5. Adjust the SINE-LEVEL control for minimum (zero) output. Set the scope for measuring 2-volts DC per division and a time base of 0.2-ms/division. Position the trace so that the zero-volt line is across the center of the CRT. The front panel OFFSET adjustment should be able to create a variable output of approximately ±3 volts.

Adjust the SINE-LEVEL control to mid-position and check for a triangle-like waveform of approximately 8 volts p-p (no attenuation). Either the top or the bottom of the waveform may be clipped. Adjust the internal OFFSET trimmer potentiometer, R34, to remove the clipping. Continue increasing the sine level and adjusting R34 until you get the maximum non-clipped waveform. A clean 16 volts p-p should be possible.

Sine shaping

Select and observe the SINE output. When the sine-shaping adjustments are completed, the sine wave's amplitude will be about half of that of the triangle wave. Shaping trimmers R18 and R19 interact, so alternate between the two until the scope displays the best shape. Consider that a perfect sine wave has equal areas above and below the zero line, and both peaks should have the same amount of rounding. Low distortion is definitely possible and if not attained, check your circuit, especially for improper trimmer values.

If you substitute a trimmer potentiometer for attenuating resistors R26 and R27, make the adjustment this way: With no attenuation, adjust the front panel SINE-LEVEL control for an output of precisely 8 volts p-p. Switch the attenuation in and adjust the trimmer potentiometer for whatever loss you want, up to −20 dB (10:1).

If you decided to use the fixed attenuating resistors, then solder in a value for R26 based on the following: 4.7K = −6 dB (2:1), 10K = −12 dB (4:1), 27K = −20dB (10:1). Resistor R27 is used as a fixed-value trimmer to bring the attenuation more nearly on target, and its value is either selected by trial and error, or it is "empirically" selected, depending on your particular view of reality. Start with a value ten times that of R26. The trimmer resistor must be tack soldered in place when determining its value to avoid introducing hum.

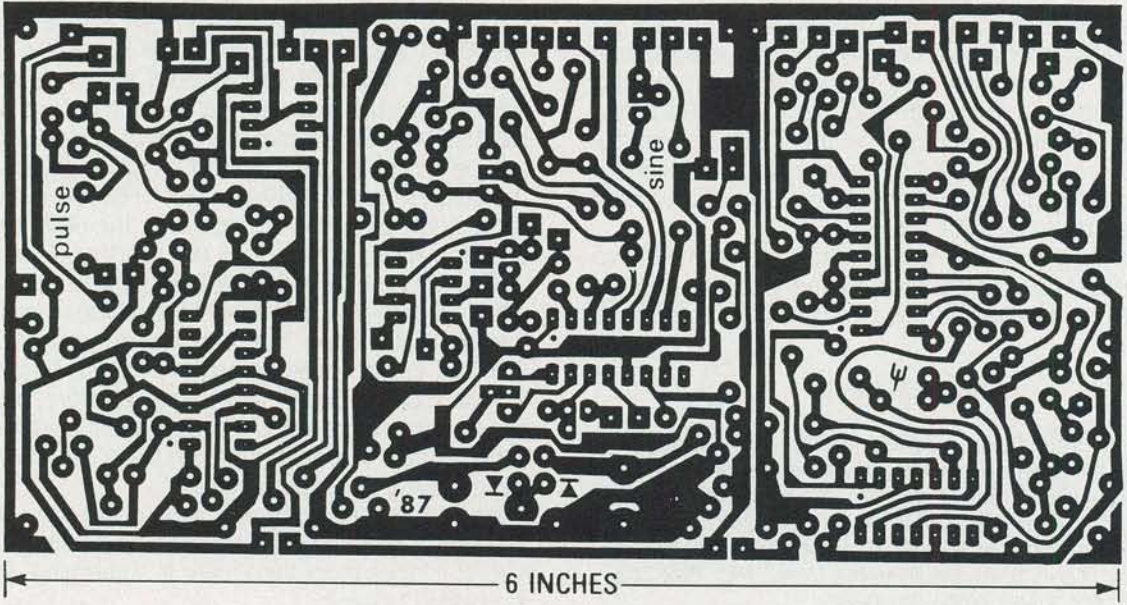
The ramp

The remaining task is to check out the pulse/ramp circuit. Unplug the unit's power cord, insert IC1 and IC2, and set all pulse/ramp controls to mid range; then apply power.

View the pulse output at J2 with the scope's time-base initially at 20-ms/division. The pulse amplitude should be more than 3 volts p-p.

The PULSE-LEVEL control should allow varying the amplitude from near zero to more than 7 volts p-p. The PULSE-TIME control should vary the pulse width from 1 ms to more than 50 ms. The RAMP-TIME control determines the pulse's off time.

Observe the ramp output at J1. The RAMP LEVEL varies the ramp output from zero to +7 volts. The RAMP-TIME control adjusts the duration of the ramp, which is equal to the off-time of pulse output. Switch S1, which is part of the PULSE-LEVEL control should kill both the pulse and ramp outputs. **R-E**



PC-BOARD PATTERN for the Versatile Function Generator.

FUNCTION GENERATOR

"Build This Function Generator" (Radio-Electronics, May 1988) caught my eye because the discrete-components-based function generator I am presently using shows signs of impending death. Mr. Wannamaker's project appears to be a versatile, precise piece of equipment.

However, I am troubled by the grounding. The schematics show the utility ground (green wire in the cord) and the analog ground (one terminal of T-1) connected to the same point. That seems to invite unnecessary ground-loop noise and hum.

Generally, the only reason to connect the utility ground to the box is to protect personnel from an accidental shock if the 120-volt line shorts to the chassis. The power-supply secondary is connected to a ground plane, or to the chassis, to reduce stray capacitive coupling within the circuit by providing lower-impedance capacitive coupling to ground.

On a metal chassis, both grounds are usually the same. Your photographs, however, seem to show a plastic case with a metallic front panel. If the power switch and fuse holder are moved to the back panel, and the leads kept properly short, there is no danger from an electrified case except through the transformer-mounting screws. Those can be connected to the green wire, but kept separate from the analog-circuit ground.

If the project is built in a two- or three-part metal enclosure, and R30 is connected to the front panel as suggested, a noisy output may result from imperfect contact between the painted enclosure parts. That connection is in the ground circuit, bypassed only by the relatively high-impedance wires to the ground jacks.

When a plastic case is used, a

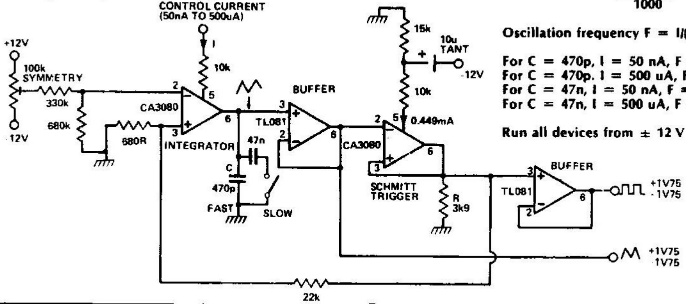
capacitive ground environment can be created by mounting grounded sheet metal on standoffs immediately adjacent to the circuit board. Better yet, a ground plane can be designed into the circuit board, to be connected to the case and to the utility ground, or not, as the designer chooses

The second problem with the article is that you have edited out almost all of the circuit description, and much of what remains is confusing. Of course, I can puzzle out most of the circuit for myself, and Exar can provide a data sheet for the XR2206, but I have come to expect better from Radio-Electronics. I realize it was a long article; I wish you had opted to spread it out over two issues.

DAVID MARSHALL
El Cerrito, CA

The project, with the grounding shown, worked fine. We saw no reason to change the author's design.—Editor

39
Linear VCO/Function Generator



Schmitt levels $= \frac{R \times 0.449}{1000} = 3.9 \times 0.449 = \pm$ 1V75

Oscillation frequency $F = I/(C \times 4 \times 1.75) = I/7C$ Hz

For C = 470p, I = 50 nA, F = 15 Hz
For C = 470p, I = 500 uA, F = 150 kHz
For C = 47n, I = 50 nA, F = 0.015 Hz
For C = 47n, I = 500 uA, F = 150 Hz

Run all devices from ± 12 V

VERSATILE FUNCTION GENERATOR

This versitile signal generator can provide simultaneous square/triangle or square/sine output signals.

JOHN WANNAMAKER

THERE WAS A TIME WHEN A SIMPLE SINE OR square wave signal was all that was needed to test electronic equipment. Today, we need many more kinds of test signals, as well as specific control over such things as their duration, shape, and duty cycle. Basically, what's needed is a laboratory-grade multifunction signal generator, such as the one described in this article. Using readily available parts, the signal generator provides a square wave output, with simultaneous triangle, and sine wave outputs; it can also supply variable duty-cycle pulses and a more-or-less conventional linear-sawtooth ramp.

All outputs have level controls, and the sine/triangle function makes provision for a fixed amount of attenuation. There's also a front-panel OFFSET control for the sine and triangle waveforms that provides ±1.5 volts into a 600-ohm load, or 3 volts into an open load. Other waveforms are unipolar and may be used with CMOS and TTL circuits.

The variable duty-cycle output pulse, which has a timing value of 1–50 ms can sink more than 20 TTL loads. The linear output ramp is similarly variable. A built-in frequency counter monitors the output frequency using four decaded ranges of 100, 1000, 10,000, and 100k Hz.

Although the time-base accuracy and stability of the internal counter are exceptionally good, it would be fairly easy to add an external jack that switches out the internal monitoring and accepts a signal from the outside world. A 0–1-volt pulse is adequate input from 5 Hz to 2 MHz, but the four-digit counter and display can only handle up to 99.99 kHz.

The circuits

The signal generator is divided into three sections: (1) the sine/triangle/square wave generator; (2) the counter; (3) the pulse/ramp.

As shown in Fig. 1, IC3, an Exar *XR2206* Function Generator integrated circuit, provides the sine, triangle, and square waves. Normally, IC3's frequency adjustment is a 0.2–2-megohm variable resistor connected from pin 7 to ground, but that kind of adjustment often proves to be critical because only conventional single-turn potentiometers are normally available in such large values. In our prototype, however, the *XR2206* is used as a voltage-controlled oscillator, and frequency-adjustment control R25 is a 10K 10-turn potentiometer. Adjusting the output frequency to within one cycle out of a thousand takes only a modest degree of dexterity.

Values other than 10K may be used if fixed-resistor R16 is changed. For a 2K potentiometer, R16 = 4.7K. For 5K, R16 = 20K. For 20K, R16 = 82K. Try to stay within that range, or the low-frequency adjustment trimmer may become ineffective.

The sine/triangle circuit is also unusual in that, unlike some commercial circuits, attenuation switch S3 affects only the signal amplitude and not the value of any offset voltage. You decide how much fixed attenuation the circuit is to have (up to -20 dB; a 10:1 voltage ratio) by making R26 larger than necessary, and then trimming its value by connecting another fixed resistor (R27) in parallel. If that method is too cumbersome, the two resistors can be replaced by a multi-turn trimmer resistor. (Although the trimmer is more costly, it's a great deal easier to use.)

Output impedance

A sine or triangle output is selected by switch S2. Emitter-follower Q8 has an output impedance of about 20 ohms, which can supply a 1.5-volt p-p waveform into an 8-ohm speaker, or about twice that amount into 16 ohms. That holds true from 10 Hz to frequencies that are far above the audio range. (It's important to adjust for zero offset if testing speakers in that manner.)

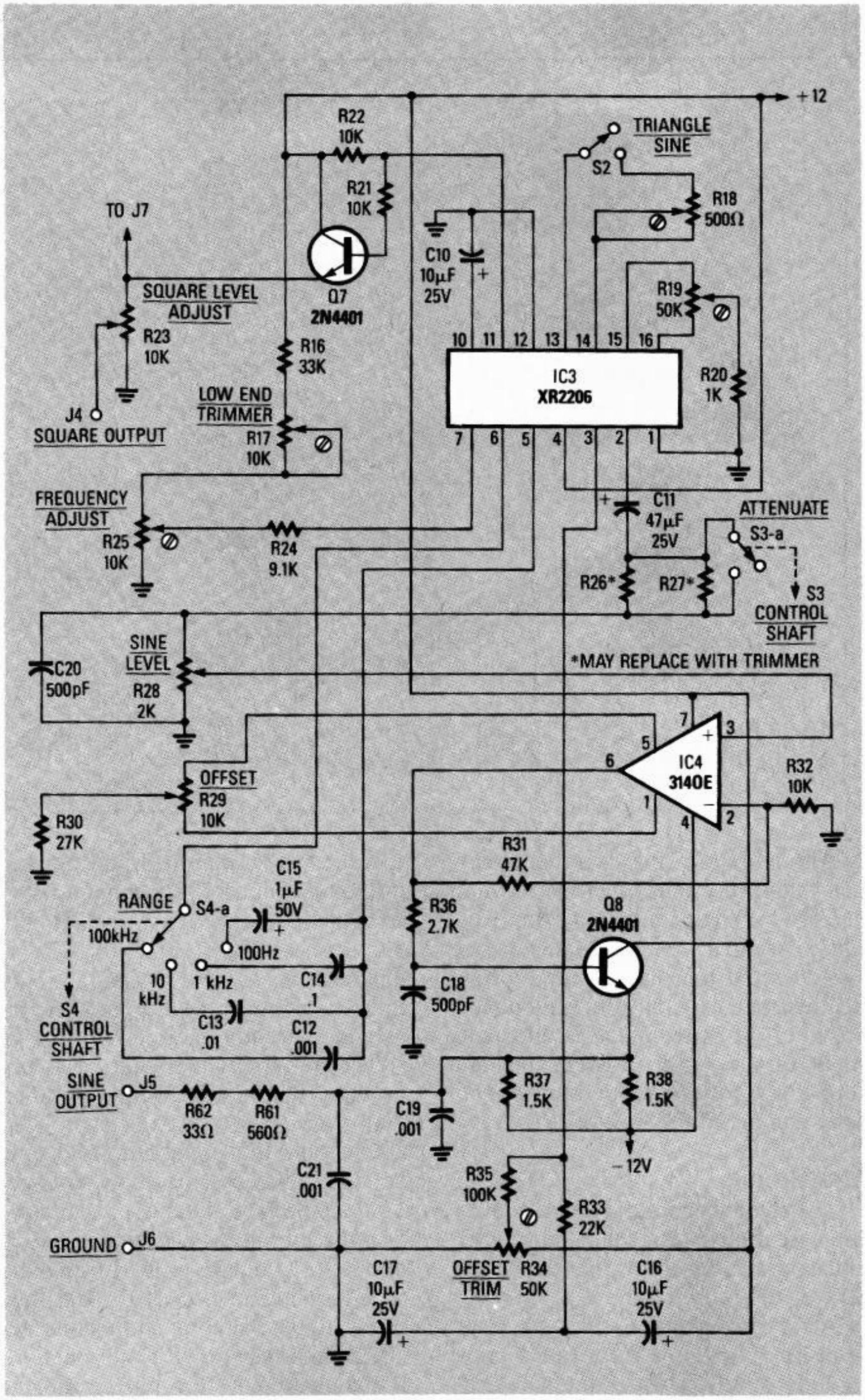


FIG. 1—ALL THE BASIC SIGNALS are provided by IC1, an Exar Function Generator integrated circuit. Switch S2 selects either a triangle- or sine-wave output.

Normally, the low impedance is attained when resistors R61 and R62 are replaced by a jumper wire. The resistors are used only if you prefer the generator to have a 600-ohm output impedance.

A switching arrangement to change the output impedance from 20 to 600 ohms is not suggested, because the additional wiring might result in noise pickup that would be added to the output signal.

The counter section, shown in Fig 2, is unique in that it mates IC6, an Intersil 7207A time-base device with IC5, a 74C926 counter. Since counter IC5 doesn't have built-in sampling or gating, the timing pulses from IC5 are used to alternately short circuit the counter input pulses to ground and then allow them to pass for precise 1-second or 0.1-second intervals.

The counter display dims when attenuation switch S3 is set for ATTENUATE because S3 also inserts a 330 ohm resistor, R60, in series with the 5-volt regulator that services the counter section. The regulator loses its control and the voltage drops to about 3 volts, causing the output current to drop to about one-third of its normal value. That causes both time-base IC's to operate at a voltage below the manufacturer's recommended values. While that is not an admirable practice, as long as R60's value did not exceed 1000 ohms, no ill results were noticed when several sets of IC's were tested in the circuit.

The reason for reducing the voltage applied to the counter circuit below the recommended minimum values is to attenuate the multiplexing noise that leaks into the sine-wave output when the circuit voltage is the usual +5 volts.

Dual one-shots

The pulse/ramp circuit, shown in Fig. 3, uses a *4538* CMOS IC that contains two monostable multivibrators, or one-shots. Each is triggered into its ON state by the negative-going edge of the other's Q output. The circuit is activated by a kick-start via C1 when power is first applied. Since the pulse width of each one-shot is determined by an independent time constant, the overall duty-cycle variation is unusually large. Using the values shown, the duty-cycle is variable from 2–98%.

The time constant of IC1-a is modified so that its timing capacitor charges through constant-current transistor Q1, which creates a straight-line voltage rise across the capacitor. The input resistance of op-amp IC2 buffers the capacitor voltage from loading effects and also provides an output impedance of less than 100 ohms.

The pulse output at J2, which is derived from IC1, can sink a 100-mA, 50% duty-cycle current.

Since the ramp is the time-constant voltage for one of the multivibrators, it is therefore locked in step with the pulse from the other multivibrator. When the pulse is on, the ramp is off, and vice versa.

The oscilloscope photographs shown in Figs. 4–6 show the kind of outputs you can get. Figure 4 shows a 50% duty-cycle square wave on the bottom and its simultaneous triangle wave at the top. Figure 5 shows the same 50% duty-cycle square wave at the bottom and the simultaneous sine-wave output at the top. Figure 6 shows

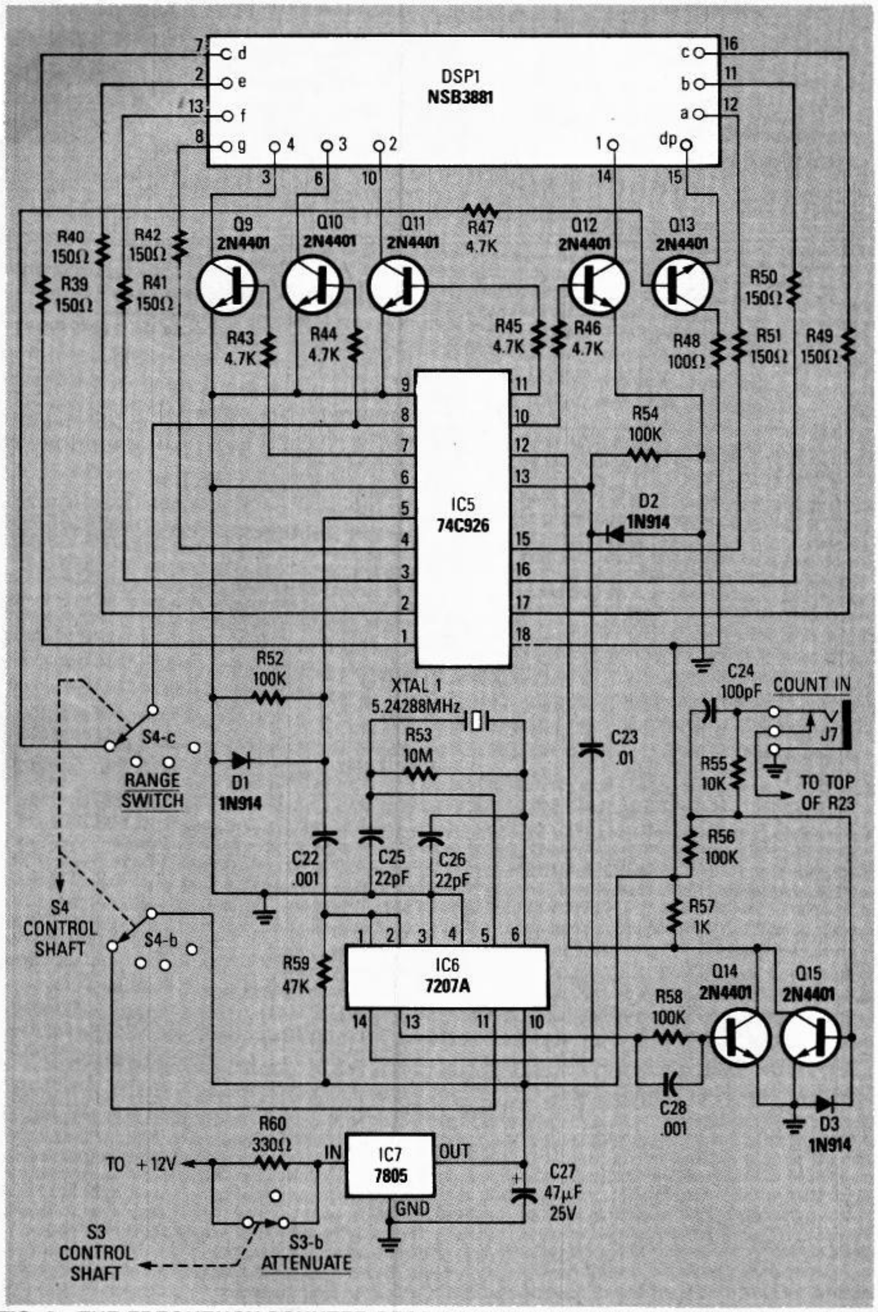


FIG. 2—THE FREQUENCY-COUNTER SECTION can be used independently by applying an external signal via jack J7. In typical operation, J7's normal-through connection connects J7 to the the square-wave output from Q7.

a 26% duty-cycle ramp at the bottom and its corresponding square-wave output at the top.

Construction

The unit is assembled on a 3 × 6-inch printed-circuit board. The template for the board is provided in PC Service. Alternately, a pre-drilled PC board can be purchased from the source given in the Parts List.

The component layout and interconnections for the PC-board are shown in Fig. 7. Be sure to use sockets for all IC's except the voltage regulators. Although the board's component density is about six parts per square inch, except for rectifier diodes D4 and D5 all components are mounted flat on the board. Although that degree of compactness suggests that a small but well-ventilated metal case would be a suitable enclosure, the LED display, jacks, and the operating controls occupy a relatively large area of panel space. Therefore, those components become a controlling factor in the size of the housing. The enclosure used for the prototype shown is the series *570 Desktop Enclosure* by Amerex. But regardless of what you use for an enclosure, make certain that there are adequate ventilation holes for air circulation.

Because it lends itself to neat groupings of associated wires by splitting off appropriate lengths of whatever number of conductors are required, stranded multiconductor ribbon cable should be used for connections between the PC board and the panel-mounted components. At the very least, wire having ribbon cable's flexibility should be used to connect the LED display to the PC board.

The gold-plated foil on the display's own PC board is fragile, and mechanical abuse or too much heat will cause it to peel off. For those connections, the stranded wires should be prepared prior to installation by stripping about ⅛ inch of insulation and tinning the bare ends of the wires. Then insert the tinned wires through the holes from the display's back so that they are just flush with the opposite side of the board; than solder them carefully from the back, using as little solder as is possible. Take particular care when connecting wires to the LED display, because not all the holes on the display are used.

To accommodate either in-line or offset center-pin units using 0.1-inch pin spacing, an extra solder pad has been provided wherever trimmer potentiometers are to be mounted on the PC board. Trimmers R17 and R34 may be either laydown or upright types, ⅜-inch square, having either a side or a top adjustment. Due to space limitations, trimmers R18 and R19 must be upright types that measure no more than about 0.2-inch wide. If the attenuation resistors, R26 and R27, are to be replaced with a trimmer potentiometer, it, too, must be an upright type. A top-adjust multi-turn unit is suggested.

The front panel should have enough bare metal on its inner surface to electrically connect all potentiometer cases. The GROUND jack in the center of the panel (J6) should connect to the panel with a short length of bare wire wrapped under its retaining nut. Use a grounding lug if you have the appropriate size on hand. Resistor R30 should be similarly grounded around the bushing of R29, the front panel OFFSET potentiometer. (The other leg of R30 is soldered to R29's wiper terminal.) Attempting to ground R30

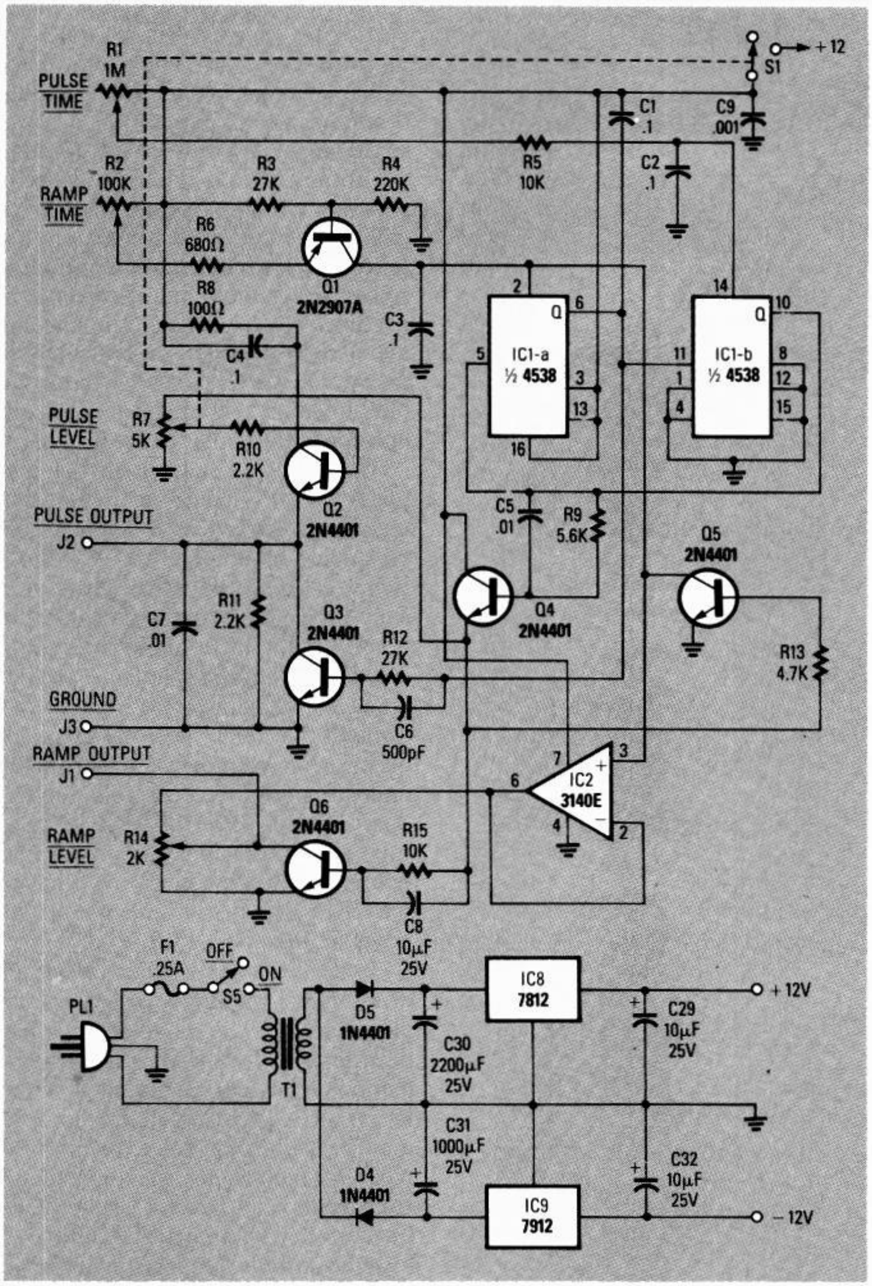


FIG. 3—THE RAMP/PULSE SECTION can be disabled by switch S1, which is part of PULSE-LEVEL control R7.

in a different way might increase noise on the sine-wave output.

Since the sine-wave output can be adjusted to a very low level, it is important to minimize the resident noise level on the output line. The use of wide foil in the power-supply circuit, plus a short length of hookup wire used as a supplemental ground bus, keeps powerline-related noise to about 200 μV p-p. We found that grounding the resistor in the OFFSET circuit to the front panel instead of to the ground foil on the PC-board made a significant reduction in random noise, again proving that all grounds are not equal. Noise spikes caused by the counter's multiplexing (or pulse transitions) are suppressed by either removing power or reducing power to the offending area. The counter/display current is reduced by one section of attenuator-switch S3. Although that causes the readout to dim, it is still usable. The pulse/ramp circuitry may be switched off entirely by switch S1, which is part of PULSE LEVEL control R7. The overall noise is about 250 μV p-p into a 600-ohm load, and about twice that value into an open circuit.

Low distortion

The sine-wave output's harmonic distortion can be reduced to as little as 0.5% by adjusting trimmer potentiometers R18 and R19. However, the sine-wave output also contains a low-level distortion that appears in the form of a tenacious little blip that appears near the peaks of the sine and triangle waveforms during the transitions of the square wave. Although hardly noticeable when the sine-wave amplitude is high, the blip refuses to lose amplitude at the same rate as the sine wave when the sine-wave output level is reduced. Capacitors C18–21 minimize that blip to about 0.5-μs duration, and to a peak amplitude of 400 μV.

The user can very nearly eliminate the blip altogether by adding capaci-

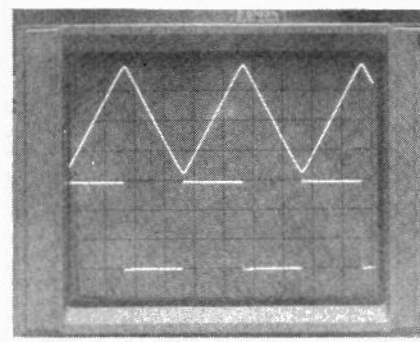


FIG. 4—THE SQUARE AND TRIANGLE WAVEFORMS are simultaneously available at independent output jacks. Note that the waveforms are in-phase.

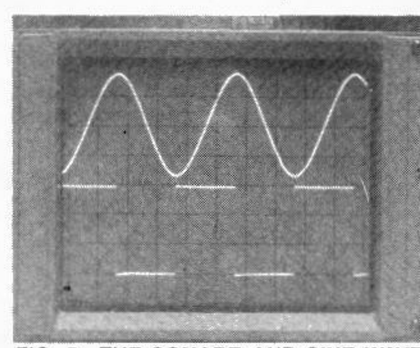


FIG. 5—THE SQUARE AND SINE WAVEFORMS are also in-phase and simultaneously available at independent output jacks.

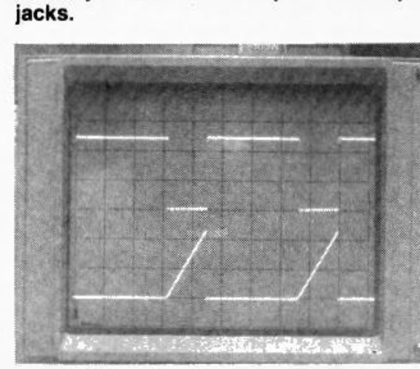


FIG. 6—THE RAMP OUTPUT OCCURS during the negative-going part of the square-wave's duty-cycle.

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.
R1—1 megohm, linear potentiometer
R2—100,000 ohm, linear potentiometer
R3, R12, R30—27,000 ohms
R4—220,000 ohms
R5, R15, R21, R22, R32, R55—10,000 ohms
R6—680 ohms
R7—5000 ohm, potentiometer with switch
R8—100 ohms, 2 watts
R9—5600 ohms
R10, R11—2200 ohms
R13, R43–47—47000 ohms
R14, R23, R28—2000 ohm, linear potentiometer
R16—33,000 ohms
R17—10,000-ohm trimmer potentiometer
R18—500 or 1000 ohm, trimmer potentiometer
R19—50,000 ohm, trimmer potentiometer
R20, R57—1000 ohms
R24—9100 ohms
R25—10,000 ohms, 10-turn potentiometer (see text)
R26, R27—selected, see text
R29—10,000 ohms, linear potentiometer
R31, R59—47,000 ohms
R33—22,000 ohms
R34—50,000 ohms, trimmer potentiometer
R35, R52, R54, R56, R58—100,000 ohms
R36—27,000 ohms
R37, R38—1500 ohms
R39–42, R49–51—150 ohms
R48—100 ohms
R53—10 megohms
R60—330 ohms

Capacitors
C1, C4—0.1 μF, ceramic disc
C2, C3—0.1 μF, Mylar
C5, C7, C23—0.01 μF, ceramic disc
C6, C18, C20—500 pF, ceramic disc
C8, C24—100 pF, ceramic disc
C9, C10, C16, C17, C29, C32—10 μF, 25-volts, electrolytic
C11, C27—47 μF, 25 volts, electrolytic
C12—.001 μF, Mylar, 1%
C13—.01 μF, Mylar, 1%
C14—0.1 μF, Mylar, 1%
C15—1 μF., 50 volts, electrolytic
C19, C21, C22, C28—.001 μF, ceramic disc
C25, C26—22 pF, ceramic disc
C30—2200 μF, 25 volts, electrolytic
C31—1000 μF, 25 volt, electrolytic

Semiconductors
IC1—CD4538 or MC14538 dual monostable
IC2, IC4—CA314OE op-amp
IC3—XR2206 function generator
IC5—74C926 counter
IC6—ICM7207A time base
Q1—2N2907A PNP transistor
Q2–Q15—2N4401 NPN transistor
D1–3—1N914 small signal diode
D4, D5—1N4401 silicon rectifier

Other components
F1—0.25-amp fuse
DSP1—NSB3881 Four-Digit display (National)
J1–J6—Insulated banana jack
J7—Miniature phone jack
PL1—Powerline plug
S1—SPST, part of R7
S2, S5—SPST switch
S3—DPST switch
S4—3-pole, 4-position rotary switch
T1—Power transformer; 117-volt primary; 12.6-volt, 1-amp secondary
XTAL1—5.24288-MHz crystal
Miscellaneous: PC-board, IC sockets, enclosure, wire, solder, etc.
Note: An etched and drilled printed-circuit board is available for $17 postpaid (includes postage and handling) from John Wannamaker, Route 4, Box 550, Orangeburg, SC 29115. South Carolina residents must add appropriate sales tax.

tance between the terminal and ground, although the cost of the extra capacitance is a rounding of the triangle-waveform's peaks. (With the built-in capacitors, that becomes objectionable only on the highest range.) The capacitance also causes 4-dB attenuation at 100 kHz. If that seems too stiff a price to pay for a clean low-level signal, simply remove the aforementioned capacitors, but expect a little rounding of the high-frequency triangle peaks anyway.

Since it is known that the square-wave output contributes significantly to the unwanted blip on the sine wave, the square-wave's output line should be kept short, and (it really hurts to say this) it should be shielded.

The 330-ohm current-limiting resistor for the counter section, R60, should be mounted directly between the terminals of the appropriate section of the DPST (or DPDT) ATTENUATE switch. Other front-panel mounted components are C20 (500 pF), which should be soldered across the outboard terminals of the SINE-LEVEL potentiometer, and C21 (.001 μF), which should be soldered between the SINE output jack and the nearby front-panel GROUND jack. (Separate GROUND jacks should be provided for the pulse/ramp signals and the sine/triangle signals.)

If the SINE output is to provide maximum current, wire it directly to its PC-board solder pad. If a 600-ohm output is desired, use a string of ¼-watt resistors with a nominal resistance of about 580 ohms in place of the direct wire connection. When the resistance value is just right, an open-circuit sine wave of any value will drop to exactly half of that value when a precise 600-ohm load is connected between the SINE and GROUND jacks.

Even though the PC board has two foils connecting the power-supply ground to the long ground foil on the "output" side of the board, there is sufficient inherent impedance to create some hum at the SINE output. To minimize the induced hum, solder a short—approximately 3 inches—insulated jumper between the ground foils, under the board. Solder one end to the wide foil where C30 is grounded; solder the other end to the foil near the two ground pads on the opposite side of the board.

Mounting

Each corner of the board has room for a 4–40 machine screw mounting hole. Be careful to not let a metal spacer under the board short to a nearby foil; or even better, use insulated spacers. It would be wise to pass the screws through the bottom of the cabinet so that the retaining nuts are on top of the board.

The LED-display assembly can be held in place by either 2–56 or 4–40 machine screws that extend through the front panel on each side of the display. They should pass through some kind of improvised insulated retaining bar across the back of the display. Take care, when installing the display, that its solder terminals do not short to the panel. Since the recommended display has a built-in red filter, no additional filter is necessary.

When mounting the power transformer, make provision for two lugs under one of the mounting screws.

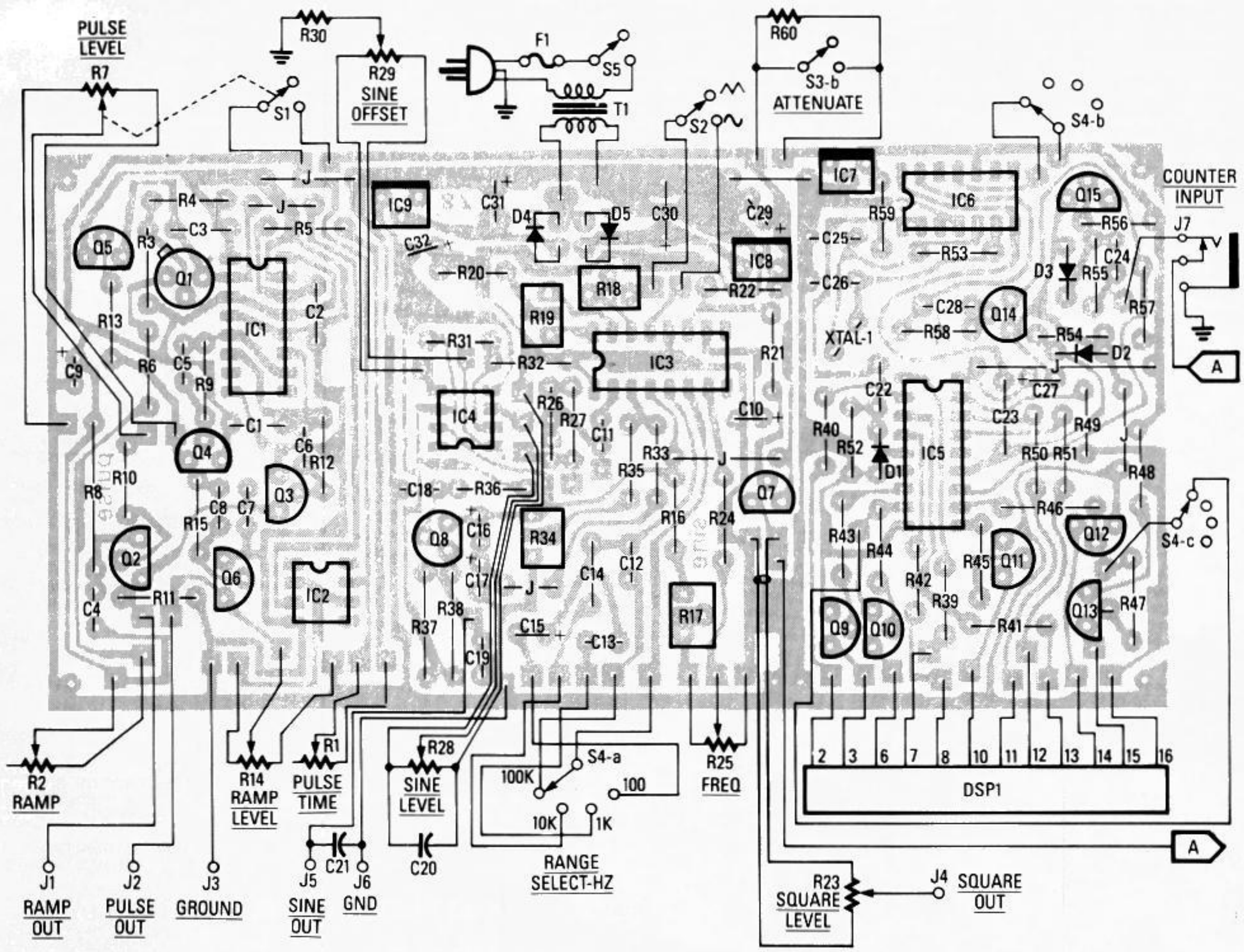


FIG. 7—THE PARTS PLACEMENT FOR THE PRINTED-CIRCUIT BOARD. Notice that not all of the 16 connections on display DSP1 are used.

Attach one to the green ground wire of the three-conductor line cord. The other should attach to an insulated wire to the PC-board's ground in the power-supply area. That has to be brought out from beneath the board and may be fairly long to allow the board to be turned over. Use stranded wire for its flexibility.

Jack J7, which is shown in Fig. 2, is needed only if you want to be able to measure the frequency of an externally generated external to the signal generator. If the feature isn't needed, using Fig. 4 as a reference, simply eliminate the jack and connect the wire going to J7's "hot" terminal to the PC-board terminal having the A-flag, which actually is a connection to the top of R23.

Checkout

Don't install the IC's. Begin with the soldered-in voltage regulators. Using an oscilloscope, check each power source for proper voltage and polarity. Looking at the plastic front of the regulators, the rightmost pin is the regulated output of both the positive and negative units. There should be no ripple. If everything checks out, unplug the power cord and let the voltages decay before inserting any IC's.

Plug in the IC5 and IC6 and apply power. The display should indicate 0000 for the three lowest frequency positions of the range switch, and 00.00 for the highest position. If counter is set for SINE ATTENUATE, the display will be very dim. Without any attenuation all digits will be bright.

A single dim digit can be due to insufficient multiplexing drive; check the 4700-ohm resistors at the bases of Q9–Q13. If the same segment of all digits is dim or will not light, check connections through to the display, particularly the 150-ohm resistors. At this point, of course, the middle bar cannot light. Once checked out, unplug power and allow time for voltages to decay.

To check out and adjust the sine/triangle/square circuit, initially adjust all trimmer resistors and the front-panel potentiometers to mid position. The FREQUENCY control should be rotated five turns into its range. Select the highest frequency range with the RANGE switch and turn off any attenuation. Insert IC3 and IC4, then apply power. The counter should indicate a frequency of approximately 40 kHz. If not, check pin 11 of IC3 with an oscilloscope: You should measure a 12-volt square wave, which means that the IC is oscillating. Trace the signal through to the counter's input. If no problem is found along the route, the problem is most likely to be in the counter.

Adjust the FREQUENCY control to observe that the readout changes, updating every 0.2 seconds (2 seconds on the three lower ranges). Adjust for the lowest frequency on a particular range. Observe the readout while adjusting the low-end trimmer, R17, for a reading of approximately 9.40 kHz. You can then check each range for at

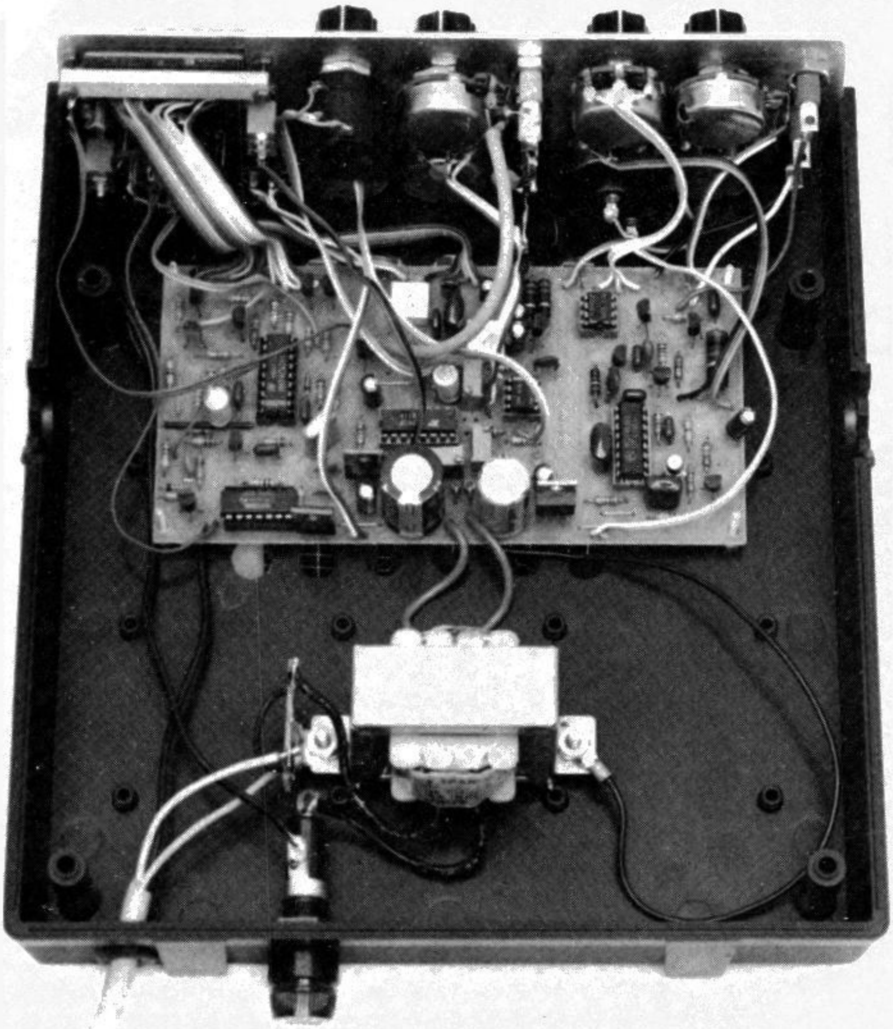


FIG. 8—THE COMPLETED PROTOTYPE. To reduce the possibility of hum pickup, the power transformer, T1, is located a considerable distance from the printed-circuit board. The ribbon cable at the upper left connect the display unit to the PC board.

least a 1:10 frequency variation: 10 Hz to 100 Hz; 100 Hz to 1000 Hz, etc. Of course, where a five-digit figure is given, the most significant digit is missing from the display. Correct the adjustment of R17 on any range that does not go down to, or below, the expected low value. If the highest range will not quite reach 100 kHz, it will be due to stray capacitance that parallels C12. You might try finding a capacitor with a slightly lower value, but a quick fix is to insert a 470-ohm resistor at the RANGE switch in series with the wire from S4 to C12.

Use the scope to check the square-wave output at J4. The SQUARE LEVEL control should vary the amplitude from near zero to 10 volts p-p. If there is a problem, trace the signal from pin 11 of IC3.

Set the frequency to 1000 Hz and select the triangle waveform. Observe the output at the SINE OUTPUT, J5. Adjust the SINE-LEVEL control for minimum (zero) output. Set the scope for measuring 2-volts DC per division and a time base of 0.2-ms/division. Position the trace so that the zero-volt line is across the center of the CRT. The front panel OFFSET adjustment should be able to create a variable output of approximately ±3 volts.

Adjust the SINE-LEVEL control to mid-position and check for a triangle-like waveform of approximately 8 volts p-p (no attenuation). Either the top or the bottom of the waveform may be clipped. Adjust the internal OFFSET trimmer potentiometer, R34, to remove the clipping. Continue increasing the sine level and adjusting R34 until you get the maximum non-clipped waveform. A clean 16 volts p-p should be possible.

Sine shaping

Select and observe the SINE output. When the sine-shaping adjustments are completed, the sine wave's amplitude will be about half of that of the triangle wave. Shaping trimmers R18 and R19 interact, so alternate between the two until the scope displays the best shape. Consider that a perfect sine wave has equal areas above and below the zero line, and both peaks should have the same amount of rounding. Low distortion is definitely possible and if not attained, check your circuit, especially for improper trimmer values.

If you substitute a trimmer potentiometer for attenuating resistors R26 and R27, make the adjustment this way: With no attenuation, adjust the front panel SINE-LEVEL control for an output of precisely 8 volts p-p. Switch the attenuation in and adjust the trimmer potentiometer for whatever loss you want, up to −20 dB (10:1).

If you decided to use the fixed attenuating resistors, then solder in a value for R26 based on the following: 4.7K = −6 dB (2:1), 10K = −12 dB (4:1), 27K = −20dB (10:1). Resistor R27 is used as a fixed-value trimmer to bring the attenuation more nearly on target, and its value is either selected by trial and error, or it is "empirically" selected, depending on your particular view of reality. Start with a value ten times that of R26. The trimmer resistor must be tack soldered in place when determining its value to avoid introducing hum.

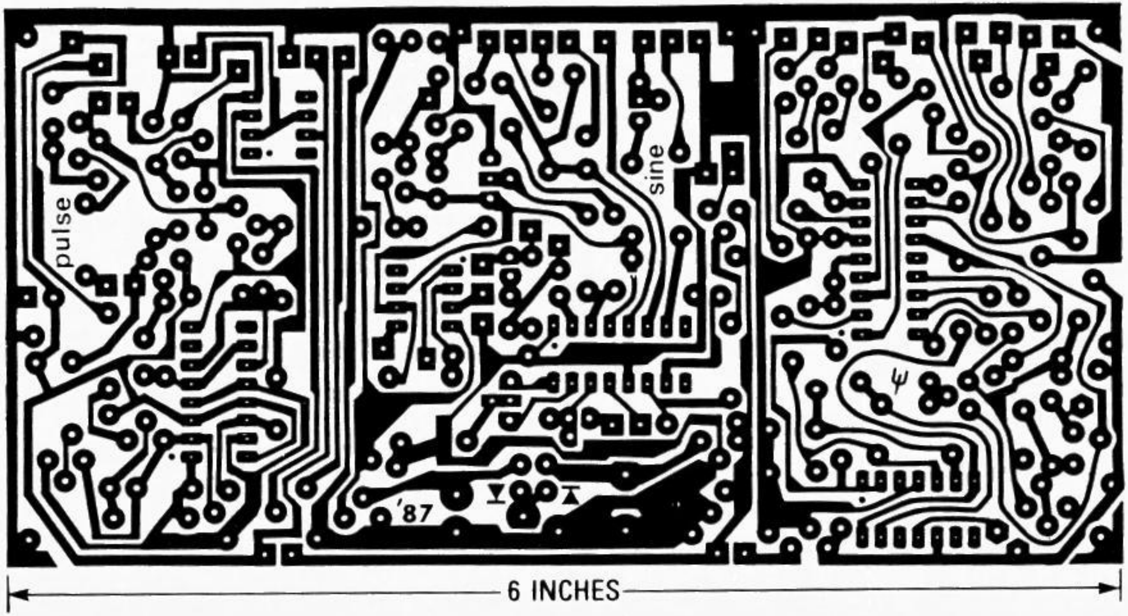
The ramp

The remaining task is to check out the pulse/ramp circuit. Unplug the unit's power cord, insert IC1 and IC2, and set all pulse/ramp controls to mid range; then apply power.

View the pulse output at J2 with the scope's time-base initially at 20-ms/division. The pulse amplitude should be more than 3 volts p-p.

The PULSE-LEVEL control should allow varying the amplitude from near zero to more than 7 volts p-p. The PULSE-TIME control should vary the pulse width from 1 ms to more than 50 ms. The RAMP-TIME control determines the pulse's off time.

Observe the ramp output at J1. The RAMP LEVEL varies the ramp output from zero to +7 volts. The RAMP-TIME control adjusts the duration of the ramp, which is equal to the off-time of pulse output. Switch S1, which is part of the PULSE-LEVEL control should kill both the pulse and ramp outputs. **R-E**



PC-BOARD PATTERN for the Versatile Function Generator.

LETTERS

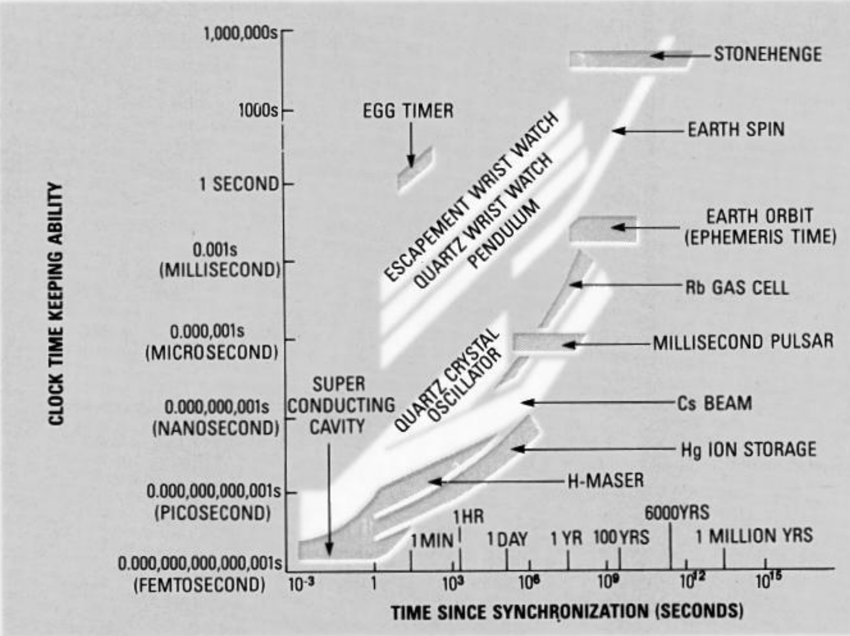


FIG. 1

KEEPING TIME

"All About Calibration" (**Radio-Electronics**, June 1988) contains some errors in relation to time standards. The article states, as a general rule, that "universal time (UTO, UT1, UT2) is accurate to within 3 ms in 1 day." That yields a factor of about 3.5×10^{-8} accuracy. The Ephemeris time value of 50 ms in 9 years yields a factor of about 1.8×10^{-10} accuracy. That is OK too. However, the atomic time of 0.1 μs in 1 minute only yields a factor of 16.7×10^{-10}. That is less than what is stated for Emphemeris time. I believe that what you wanted was something like 0.1 μs in 1 day, which yields a factor of 1.16×10^{-12}.

STEPHEN L. COAN
Beaverton, OR

Mr. Coan, you are absolutely correct. As the Time Chart shows, some Cesium-beam atomic clocks are accurate to 1 ns in 1 day, or an accuracy factor of 1.16×10^{-14}. See Fig. 1.—Editor

RS-232 CORRECTION

*It has come to our attention that there were a couple of errors in the article "RS-232 Monitor/Control System" (**ComputerDigest**, August 1988). The voltage supplied to IC3 can range from 4.5–18.0 volts, not 4.5–8.0 volts, as the article indicated. The equation for the time it takes to transmit data from the same node twice should read: (1/4800) × 11 bits/byte × 8 bytes. We apologize for any inconvenience caused by those mistakes.*—Editor.

VERSATILE FUNCTION GENERATOR

If you are building the "Versatile Function Generator" (**Radio-Electronics**, May 1988), please note that the timing IC (IC6) **must** have an "A" suffix. Do not try to use an ICM7207IPD in place of an ICM7207AIPD. Someone has been advertising the IC with the "A" suffix, but sending the wrong one, so check carefully before using it.

A few minor errors appeared in the article. On the Parts Placement diagram, IC9, the negative regulator, is oriented backward. The tab side should face the middle of the board—just the opposite of the two positive regulators. The ramp output and the pulse output are reversed. In the schematics, R23 should be a 2K linear potentiometer, C8 should be 100 pF, and C9 should be 10μF, 25 volts. The two rectifier diodes, D4 and D5, should have been labeled 1N4001, not 1N4401. Any diode with at least 1-amp/50- volt rating will do. In the Parts List, R36 should be 2.7K, and R13 and R43–R47 should be 4.7K instead of 47K.

JOHN WANNAMAKER
Orangeburg, SC

AMATEUR COMPUTERISTS CLUB

In May 1966, Stephen B. Gray formed the Amateur Computer Society for people who were interested in building their own computers. By sharing their experiences and problems, Gray believed that hobbyists could reduce the frustration and isolation of working on their own to build a computer. Ned Wadsworth's *Scelbi-8H*, Jonathan Titus' *Mark-8*, and Ed Roberts' *Altair 8800* were the practical results of many years of effort to develop a personal computer.

While personal computers are now readily available, there is an increasing emphasis on business uses and software appropriate for

Featuring discrete devices and conventional IC's, the wide-range function generator in Fig. 4 offers serious experimenters more of a challenge than do simplified designs using special-purpose devices, such as the XR-2206. It is described by Robert C. Dobkin in Application Note AN-115, published by the National Semiconductor Corporation (2900 Semiconductor Drive, Santa Clara, CA 95051). The instrument is capable of supplying sine, square and triangular waveforms at amplitudes up to ±10 V from 10 Hz to 1 MHz *without band switching*. Usable outputs are available to as high as 2 MHz, but of reduced amplitude and waveform quality. It requires three IC's, a dual pnp transistor, two dual npn transistors, two conventional npn transistors, and seven standard diodes. With both trigger and signal outputs, the instrument has two semi-fixed adjustments and three operating controls in addition to its power switch: a three-position FUNCTION switch, a FREQUENCY control, and an AMPLITUDE control.

The basic generator comprises an LM319 dual voltage comparator, current-source switching transistors *Q1-Q2* and *Q3-Q4*, timing capacitor *C1*, and an LH-0033C FET-input voltage follower buffer amplifier. A triangular signal waveform is generated by alternately charging and discharging timing capacitor *C1* through switching current-source transistors *Q1-Q2* and *Q3-Q4* and diodes *D1* and *D2*. The resulting signal is amplified by the LH0033C voltage follower and coupled back through voltage-divider *R8-R9-R10* as inputs to the LM319 dual voltage comparator which forms part of the feedback network. The triangular signal also is applied to function switch *S1* through series isolating resistor *R18*. Control dc voltages obtained from voltage-dividers *R20-R32* and *R23-R31* set the threshold at the other inputs of the voltage comparators, thus establishing the peak-to-peak amplitudes of the comparator outputs. Connected in parallel, the comparator output signals are applied to emitter follower *Q5*, which serves both to supply a square-wave output signal to function switch *S1* through series isolating resistor *R24* and to provide a drive signal to the current-source switching transistors, *Q1-Q2* and *Q3-Q4*.

The generator's frequency of operation depends on *C1*'s charge and discharge currents. Ranging from 5 nA to 5 mA, these are controlled by the emitter bias applied to the switch-

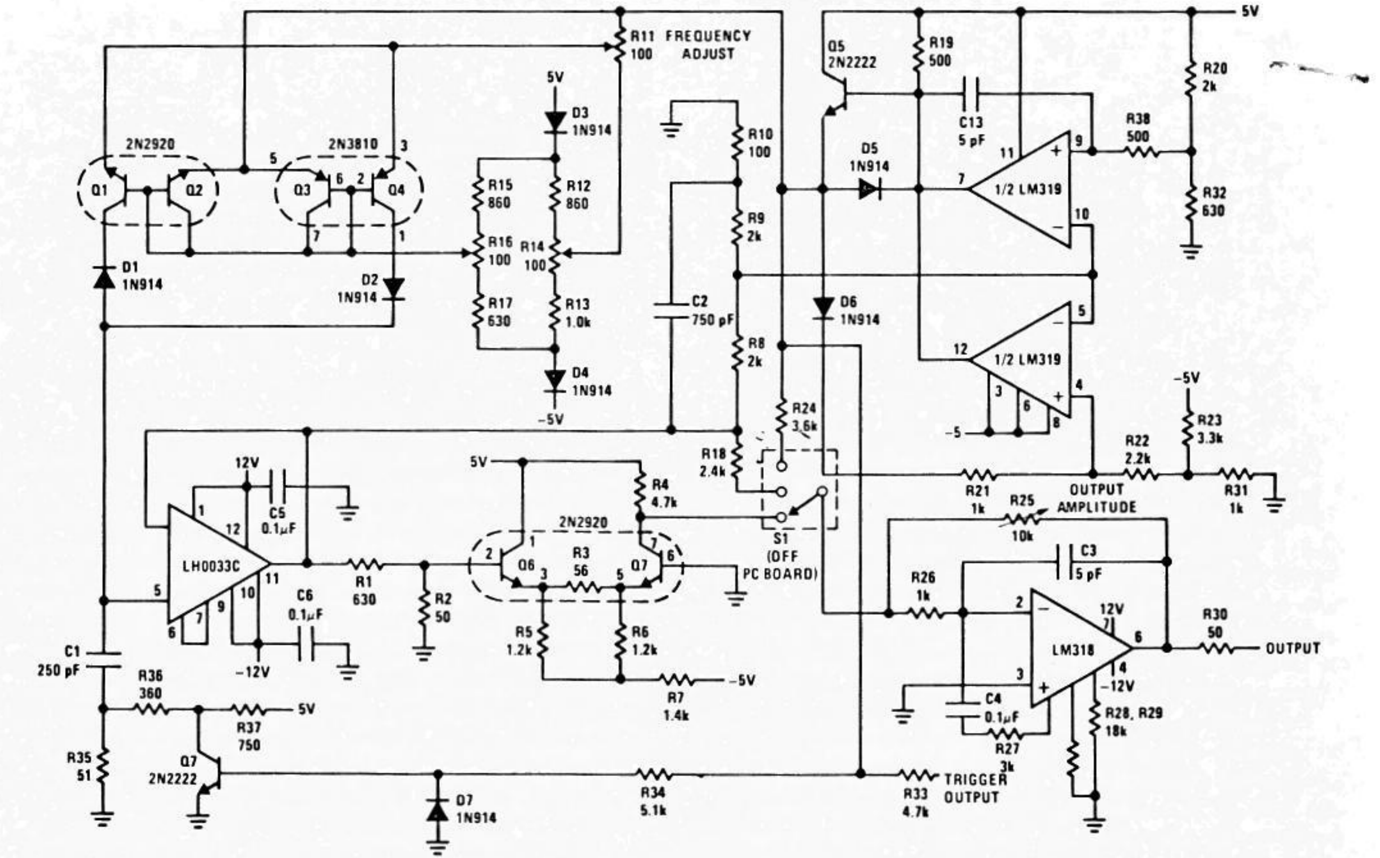


Fig. 4. National Semiconductor's wide-range function generator circuit.

ing transistors through frequency control *R11*. Differential amplifier *Q6-Q7*, operated with degenerative emitter feedback, serves to modify the triangular signal delivered by the buffer amplifier through voltage-divider *R1-R2*. This develops a close approximation to a sine wave across output load *R4* which is applied directly to function switch *S1*. From *S1*, the selected signal waveform is coupled through series resistor *R26* to the LM318 serving as the output amplifier. The output amplitude is controlled by *R25*, which provides inverse feedback across the op amp.

The function generator requires regulated dual ±5- and ±12-volt dc sources for proper operation. Suggested by National Semiconductor in its Application Note, the ac line operated power supply in Fig. 5 will provide the correct voltages. A conventional design, it comprises a spst ON-OFF switch, fuse, 24-volt step-down transformer, bridge rectifier, two filter capacitors (*C7* and *C8*), positive and negative 5- and 12-volt regulator IC's, and four bypass capacitors (*C9, C10, C11* and *C12*). All of the regulators are standard 3-terminal devices.

Though standard parts are specified in the instrument's design, some care must be exercised in the choice of components to insure optimum performance. A standard potentiometer may be used for frequency control *R11*, for example, but a vernier type or 10-turn pot is preferred due to the unit's six-decade frequency coverage. The output level control, *R25*, can be a standard potentiometer, with trimmer types used for semi-fixed adjustments *R14* and *R16*. All fixed resistors may be either quarter- or half-watt types, but should have a 5% tolerance rating except for *R1, R2, R5, R6* and *R7*, which should carry a 1% tolerance. Good quality ceramic or plastic film capacitors should be used in the generator circuit, 25-volt electrolytics as power supply filters *C7* and *C8*, and solid tantalum types for the power supply bypass units (*C9, C10, C11* and *C12*). Function switch *S1* is a 3-position, single-pole, non-shorting rotary switch.

If a separate power supply is used, bypass capacitors *C9* through *C12* should be wired within the function generator. However, with careful planning the entire circuit, including the power supply (except for the power transformer and ac line components), can be assembled on a single pc board. A common heat sink should be used to couple switching transistors *Q1-Q2* and *Q3-Q4* to insure thermal tracking. After assembly and check-out, two simple adjustments are required. With the function switch in mid-position (triangular wave output), *R11* is set for a 1-MHz signal and *R16* is adjusted for perfect waveform symmetry. Next, *R11* is set for a 10-Hz output and *R14* is adjusted for perfect symmetry. ◇

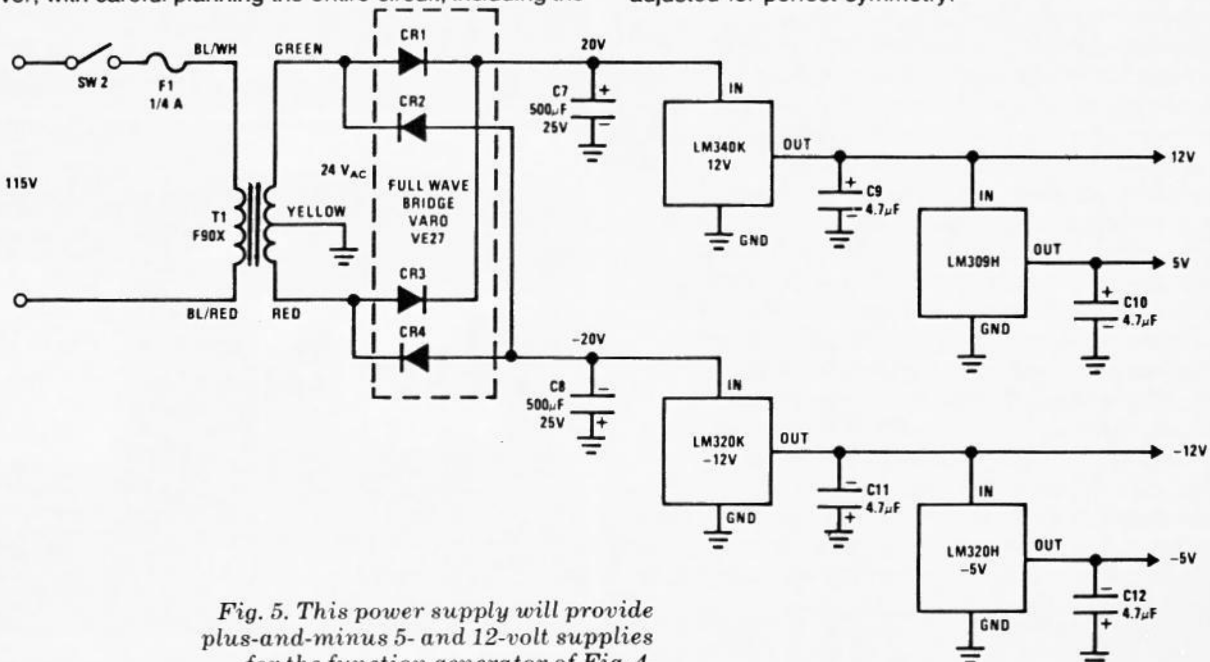


Fig. 5. This power supply will provide plus-and-minus 5- and 12-volt supplies for the function generator of Fig. 4.