We note there are three outputs available. A ramp output from Q4, an out-of-phase ramp output from Q3 and a square wave from Q6. If we take the Q6 output, we have our square wave. If we take either the Q3 or Q4 output, we have our ramp. Now, if we take the *difference* between Q3 and Q4, we get a triangle wave. And finally, if we take the difference between Q3 and Q4 and round off the sharp corners, we come up with a sinewave.

Changing frequency

We can obviously change frequency by changing capacitor values, for the charging time for a constant current is directly proportional to how big a capacitor you hang on the circuit. So, looking at Fig. 3, we switch select a series of capacitors that are decade multiples (10X) of each other. This takes care of range switching.

To get a 10:1 vernier range, we have to somehow change the value of the current source at the bottom of the circuit. We can't change what's inside an IC, but we can add to or subtract from this current by sourcing or sinking some extra current at pin 13. We do this with an external potentiometer and current-limiting resistor. In the middle of the range, the pot does nothing. Make it more negative, and it *adds* to the available circuit current, and thus *increases* frequency. Make it more positive, and it steals some of the available current, leaving *less* for the circuit and *lowering* the frequency. We get a 10:1 operating range with reasonable care, and, except for some pot loading, the voltage versus frequency curve is very linear.

We can also shunt some current around Q1 and Q2 and get some added features. Normally the currents through Q1 and Q2 are very nearly 50-50, but they can go one way or the other by a few percent. This makes the square wave slightly asymmetrical, which isn't too bad. Trouble is that when we get to the sinewave output, anything but a 50-50 duty cycle will give us a bunch of second harmonic distortion in a hurry. So, we set up a high impedance pot and some big resistors (R21,R22,R23 of Fig. 6) around Q1 and Q2 to give us a symmetry control that lets us touch things up to an exactly 50-50 duty cycle.

If we shunt a bunch of current around one side, we get a very low duty cycle. This is how we get our pulse waveform. Weusethesquare-waveoutput, but we unbalance things badly enough to get a 1:5 or 20:80 dutycycle. By the way, this also changes frequency, so the dial readings for the pulse output will be around half the actual pulse repetition rate.

So, the wave generator directly generates a square wave and a pair of out-of-phase ramp waveforms. If we take the difference between the ramps, we get a triangle wave. If we polish the tops of the triangle wave, we get a sinewave. Finally, if we pick the squarewave and unbalance the symmetry, we get a pulse output.

Wave shaping

The shaping circuit of Fig. 5-b is called a *variable-gain differential amplifier*. The gain is controlled by resistor R_x, and the *difference* between the two input signals gets amplified and appears as an output. A differential amplifier is a linear amplifier for small input signals or low gains. Its also a limiter or clipper for large input signals or high gains, for you can get no more current out than is available at the bottom of the circuit, nor less than zero. Converted to voltages across the load resistor, this means you get a smooth clipping or clamping action for high input levels or high gains.

So, we change both the gain and drive level to improve upon our basic waveforms. Triangle and ramp are sent through at low level and low gain; they come out the way they went in. The differential amplifier nicely converts the two out-of-phase ramps into a uniform triangular wave. For square and pulse, we heavily overdrive the differential amplifier and run the gain up very high. This gives us a constant amplitude, lots of output, and sharp rise and fall times for these waveforms.

For the sine wave, we use a moderate amount of gain and start with a triangle wave generated as the difference between the two ramps. What this

FUNCTION GENERATOR

source that generates sine, triangle, waveforms from 1 Hz to 1 MHz.

by DON LANCASTER

does is knock the sharp corners off the triangle waveshape, giving us the familiar sinewave shape, with a distortion typically around 2%. This technique is far simpler than those normally used in function generators, and this level of distortion is not even noticeable for anything but critical audio testing.

Biasing is critical on any differential amplifier. Both *inputs must be returned to the same dc level,* or the circuit goes into limiting and ignores the input signal due to the unbalance in currents caused by improper biasing.

There are two ways we use the differential amplifier in the **Radio-Electronics** function generator. For triangle and sine, we connect the inputs directly to the ramp and out-of-phase ramp outputs. These are both at the same dc level and thus give us proper bias. At the same time, the differential amplifier takes the *difference* between these two waveforms, generating a triangle wave at low gain and a rounded top triangle approximation to a sine wave at higher gain.

The rest of the waveshapes must be capacitor-coupled. To do this, we return both inputs of the differential amplifier to ground and bypass one input. This gives us a single-ended amplifier into which we can couple these square, pulse, and ramp inputs. We run the ramp at low gain, so the same signal comes out we put in. In square and pulse, we run very high gain by shorting R_x. This gives us a bigger output with completely flat tops and fast risetimes. Two small refinements complete the square and pulse coupling. The coupling capacitor is a compromise, since one that gives no droop on the 1-Hz range also gives objectionably long transients on the higher ranges as frequency is suddenly changed. To beat this, we use a relatively small coupling capacitor C6 for the higher ranges and switch in a larger C10 for the 1-Hz range. The pulse waveform has a large dc component due to its duty cycle. If we capacitor-couple, we end up with linear amplification on the bottom of the pulse and limiting on the top. This reduces pulse amplitude, but worse yet, it makes the bottom noisy and rounds the edges of the rise and fall times. To beat this, we purposely unbalance the differential amplifier slightly with R27, but *only during pulse operation.* This nicely limits both the bottom and the top of the pulse, giving us an output as big and as clean as the square-wave.

Amplitude compensation

There is a slight change of wave generator output amplitude when we operate over a 10:1 current range. Most obvious is a dropoff at the high current, high frequency and caused by larger drops in Q3 and Q4. The high-end voltage drop gets eliminated automatically in the square and pulse modes since the shaper heavily limits, and you get a constant output level. The problem isn't too bad in triangle and ramp, but in the sine position, the waveshape changes pretty drastically as you reduce the amplitude, giving you "pointy" sinewaves at the high end of any frequency range. To beat this, we raise the gain of the shaper slightly at the far end of the frequency pot. The drop in input amplitude gets made up by the increase in shaper gain, and the output sine wave amplitude and waveshape stays constant over the pot's range.

Since the pot's going the wrong

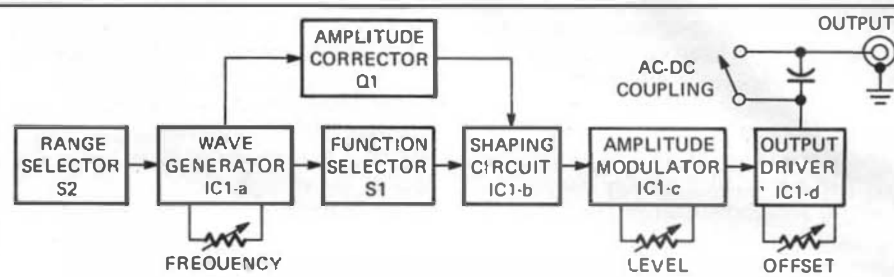
SPECIFICATIONS

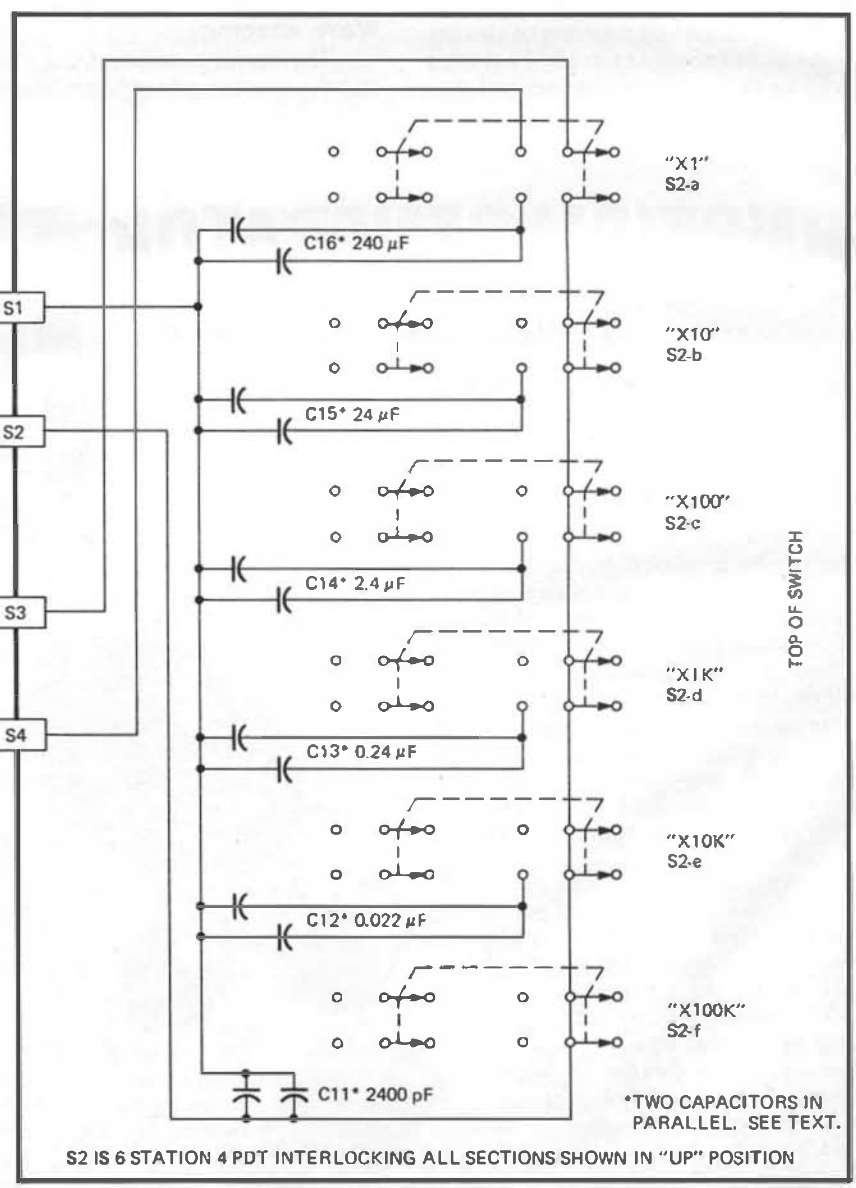
FREQUENCY RANGE: 1 Hz to 1 Mhz, pushbutton selected by decades and vernier adjusted over any one decade. Overall accuracy 2-5%

FUNCTIONS: Sine, Triangle, Square, Pulse, and Ramp

AMPLITUDE: Variable 0-2 volts Sine, Square, Pulse; 0-1.75 volts Triangle and Ramp. TTL compatable output using + 0.6-volt baseline offset.

OFFSET: In DC Mode, adjustable from -2 to +2 volts giving high, centered, or low baseline. Capacitor coupled in ac mode.





SPECIFICATIONS

DISTORTION: Single frequency sine wave, less than 2%; 3% over vernier range.

DUTY CYCLES: Pulse 20% typical; Square adjustable to 50%. Dial calibration not accurate on pulse range.

OUTPUT IMPEDANCE: 70 Ohms, Zener protected

SIZE: 2½" x 5" x 6½"; grey impact plastic case.

WEIGHT: 2 pounds

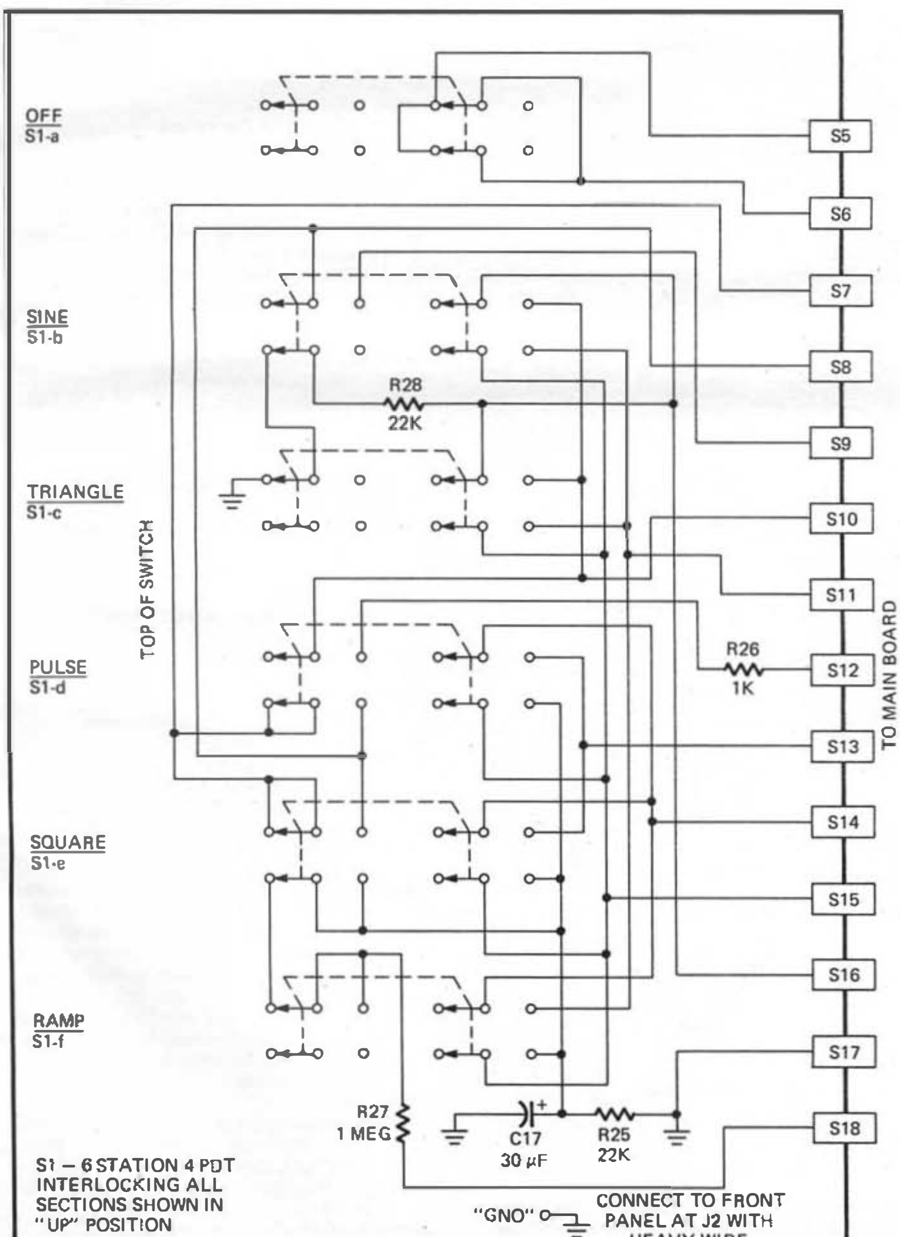
MODULATION: None in basic unit; AM, FM, VCO, remote gain, keying, etc. are easily added to the basic circuit.

way to do us any good, we invert it with a transistor and use this control voltage to steal a small amount of the shaper's current source. This increases the shaper gain as R_x is now smaller with respect to the circuit currents than it was before. By keeping the transistor saturated for part of the pot's range, we don't start any correction till we need it. More and more gain is added as we get to the end of the pot. Looking ahead at Fig. 6, we see that R31 and R32 decide *how much* gain we add at the high end, while the *ratio* of R29 to R30 decides *when* in the pot's rotation the gain correction is to begin.

FIG. 2—(left) BLOCK DIAGRAM OF GENERATOR gives an overall look at how the unit operates. The one IC does the lion's share of the work.

FIG. 3—(bottom left) RANGE-SWITCHING CIRCUIT is on a separate printed-circuit board. An interlocking push-button switch, that mounts on this board, is used.

FIG. 4—(below) FUNCTION-SELECTOR SWITCH forms another subassembly on a separate circuit board. Again an interlocking pushbutton switch is used and is mounted on the board.



We control the gain with an electronic modulator as shown in Fig. 5-c. We can also inject signals here for amplitude modulation, remote volume control, keying, etc. If we like. The circuit is a true multiplier, which means it doubles as a balanced modulator. The circuit works by letting both the input and the control provide only a fraction of the available current to the output. Since the two fractions are cascaded, the *product* of the input and control appears at the output. Polarity may be controlled by reversing the difference in voltage on the control inputs. Zero difference gives zero gain, and one volt gives full gain, the polarity of the input determining which side of the waveshape ends up on top. The electronic gain control is internally directly connected to the shaper; all we have to do is connect up an external gain control or signal. Note that no waveforms have to travel through the pot and we can easily and safely use long leads without worryingabout high frequency response falling off and causing misleading conclusions from the tests you are performing.

Output buffer

A Darlington differential amplifier converts the output signal to one with enough current drive to handle a short circuit or another low-impedance load without damage. To adjust the offset, or how much dc we get out in addition to the waveshape, we capacitor-couple the buffer's input and add a variable bias that we control with the offset potentiometer. We also provide an output coupling capacitor that we short out when we want variable offset and insert for ac work.

Circuit of the generator

The complete schematic is shown in Figs. 3, 4 and 6. Capacitors C11 to C16 select the decade frequency ranges, while R17 selects the vernier frequency and drives amplitude compensator Q1. Pots R9 and R11 put limits on the frequency control, so we can calibrate the upper and lower frequencies on the dial. Selector S1 picks the function we want and controls power to the +10,−10 volt conventional Zener supply.

R19 controls the triangle waveshape, while R19 and R20 together control the sine waveshape. R21 to R23 provide the symmetry control, while R13 controls offset. Square, pulse, and ramp coupling is handled by C6, helped along C10 on the 1-Hz range. R27 switches in only during pulse operation to give a good pulse waveform.

The switching may seem complicated, but its really simple, particularly since the switches mount directly on the board, S1-a controls the ac power. If this button is *up*, the power is on. S1-b handles the sine wave. It first connects the shaper differentially to the

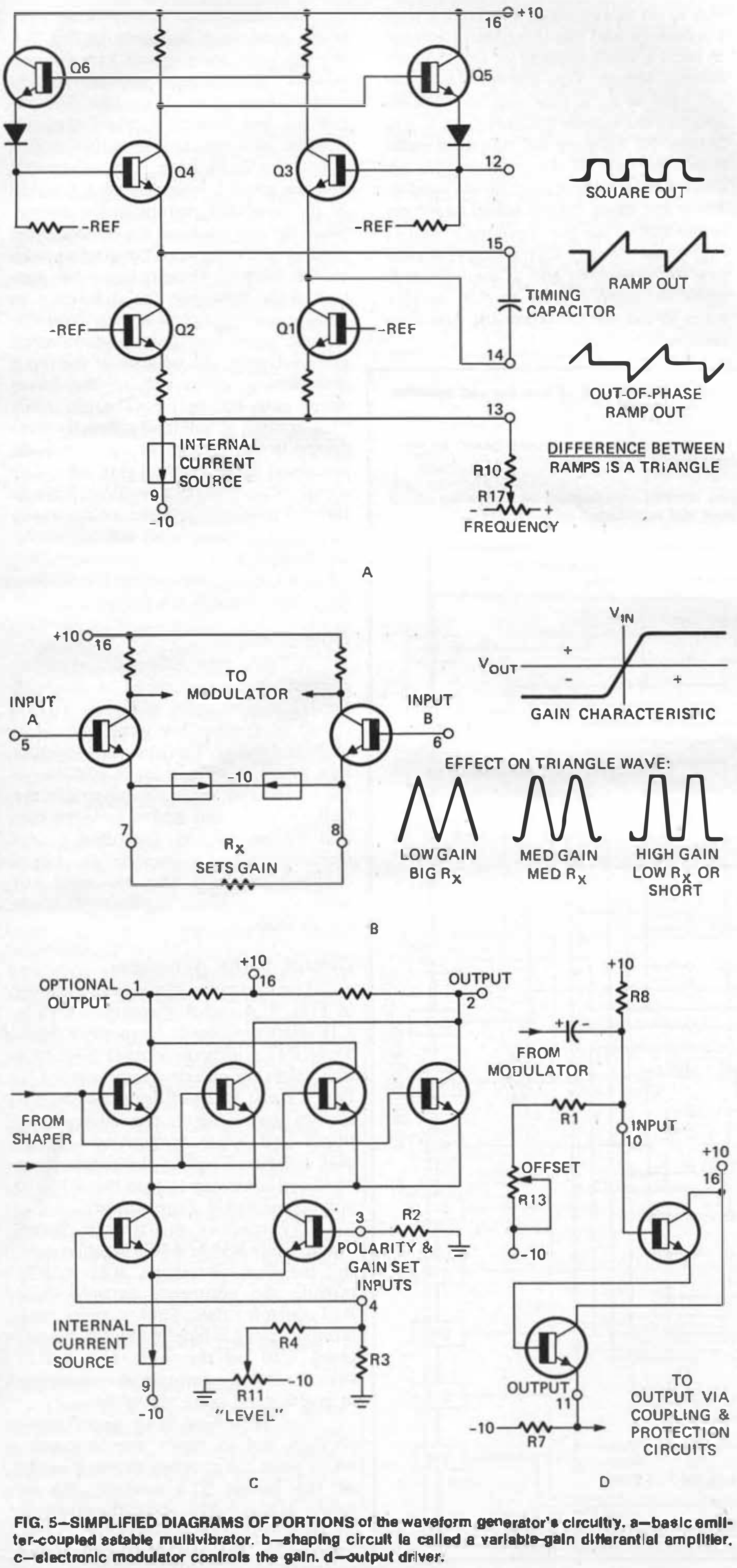


FIG. 5—SIMPLIFIED DIAGRAMS OF PORTIONS of the waveform generator's circuitry. a—basic emitter-coupled astable multivibrator. b—shaping circuit is called a variable-gain differential amplifier. c—electronic modulator controls the gain. d—output driver.

ramp and out-of-phase ramp outputs to generate a triangle wave. Then it switches in enough gain increase in the shaper with R20 to give the sine wave output. Finally, it *prevents* R22 from getting into the circuit. R22 is used to bias the shape.

That's all we have room for in this issue. Next month we will conclude the story by presenting the remaining text on construction and operation along with a complete set of circuit-board patterns, both foil and parts placement diagrams.

R-E

PARTS LIST

C1—1 μF, 400 volts, mylar
C2,C7—0.22 μF, mylar
C3,C9—500 μF, 12-volt electrolytic
C4,C5—1000 μF, 25-volt electrolytic
C6—3 μF, 6-volt tantalum
C8—6000 μF, 10-volt electrolytic
C10—50 μF, 6-volt tantalum
C11—Two parallel capacitors, 2400 pF, 2%
C12—Two parallel capacitors, .022 μF, 2%
C12—Two parallel capacitors, 0.24 μF, 2%
C14—Two parallel capacitors, 2.4 μF, 2%
C15—Two parallel capacitors, 24 μF, 2%
C16—Two parallel capacitors, 240 μF, 2%
C11—C16 Value shown is total capacitance
See October issue for capacitor selection details
C17—30-μF, 12-volt electrolytic
C18—0.1 μF, disc ceramic
D1,D2—Silicon power diode, 1 amp, 50 PIV, 1N4001 or equiv.
D3,D4—10-volt Zener, 1N4740 or equivalent
D5—16- to 20-volt Zener, 1N4744 or equivalent
F1—0.1-ampere fuse
IC1—XR-205 Function Generator IC (Exar)
J1,J2—5-way binding posts, 1 black, 1 blue
Q1—2N5129 transistor, silicon npn
R1,R25,R28—22,000 ohms, ¼ watt
R2,R3,R29—4700 ohms
R4,R31,R32—47,000 ohms
R5,R21,R22,R30—10,000 ohms
R6,R24—12 ohms
R7—1500 ohms
R8—33,000 ohms
R9—1000 ohms upright PC potentiometer
R10—680 ohms, ¼ watt
R11—1000 ohms upright PC potentiometer
R12,R18—330 ohms, ¼ watt
R13—50,000 ohms linear potentiometer with spst pull switch
R14—5000 ohms linear potentiometer
R15,R16—100 ohms, ½ watt
R17—1000 ohms linear potentiometer
R19—5000 ohms upright PC potentiometer
R20—5000 ohms upright PC potentiometer
R23—250,000 upright PC potentiometer
R26—1000 ohms, ¼ watt
R27—1 megohm, ¼ watt
S1,S2—six station, 4PDT interlocking
S3—spst pull switch on R13
T1—Power transformer: 20 Vct @ 60 mA, PC mount, *Signal* PC-20-60

MISC: Main, Selector, and Range PC boards, punched front panel; impact plastic case; line cord; ¾" knobs (2); skirted 2¼" knob with special calibration; flat cable or wiring harness; capacitor clip; no skid feet; fuse clips; PC terminals; angle brackets (4); mounting hardware; plastic machine screws for front panel; mylar button callouts; ground lug; wire; sleeving; solder.

NOTE: The following are available from Southwest Technical Products, 219 West Rhapsody, San Antonio, Texas, 78216
Set of three PC boards, etched and drilled FGb, $8.25
Complete kit of all above parts FG.1, $39.95

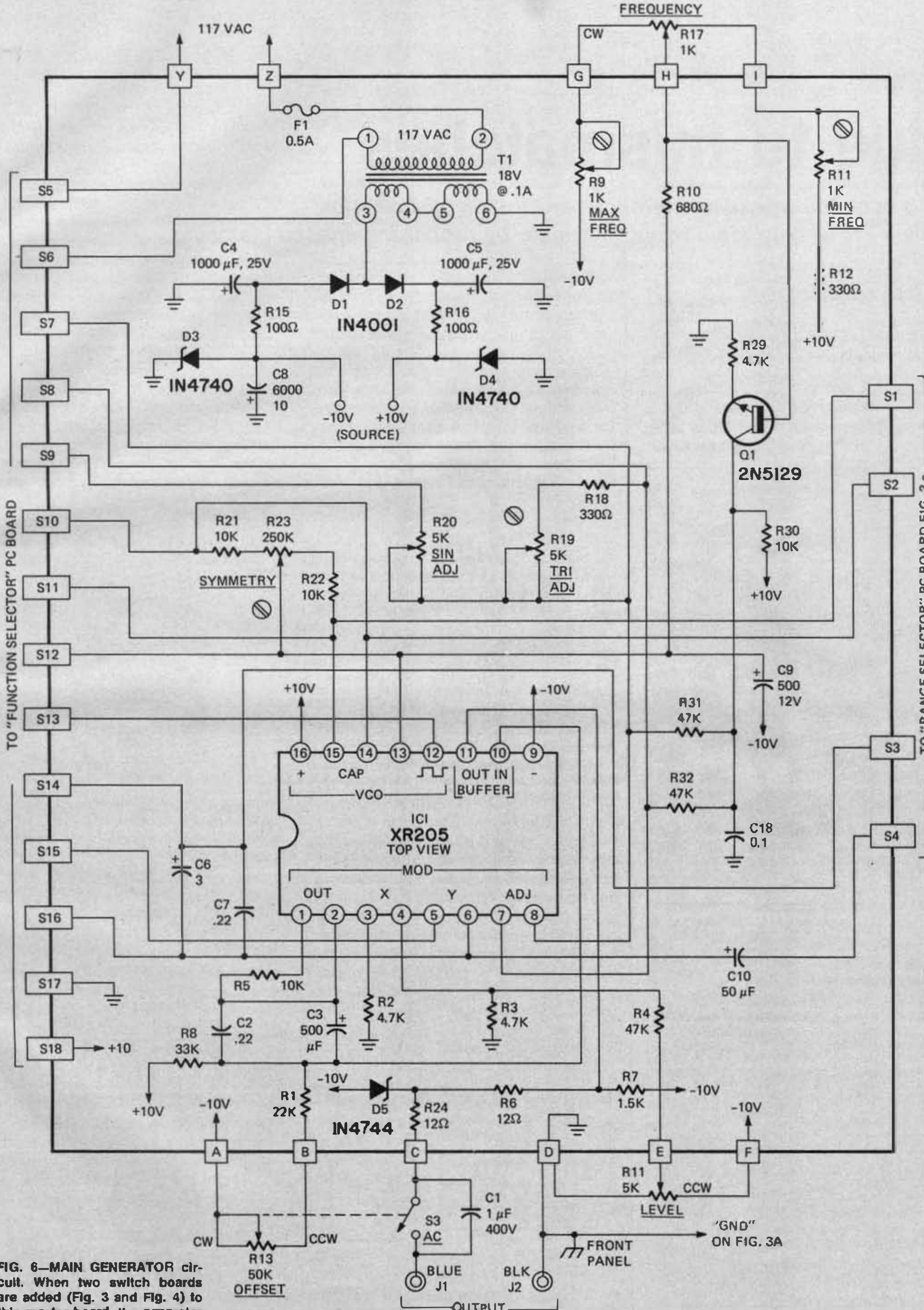


FIG. 6—MAIN GENERATOR circuit. When two switch boards are added (Fig. 3 and Fig. 4) to this master board, the generator is complete.