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. We use the square-wave output, but we unbalance things badly enough to get a 1:5 or 20:80 duty cycle. 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 sine-wave. Finally, if we pick the square-wave 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 Rx, 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
does is knock the sharp corners off the
triangle waveshape, giving us the famil-
iliar 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 differen-
tial amplifier. Both inputs must be re-
turned 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 dif-
ferential amplifier in the Radio-Elec-
tronics function generator. For triangle
and sine, we connect the inputs directly
to the ramp and out-of-phase ramp out-
puts. 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
Rs. This gives us a bigger output with
completely flat tops and fast risetimes.
Two small refinements complete the
square and pulse coupling. The cou-
ping 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 fre-
quency 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 volt-
age drop gets eliminated automatically
in the square and pulse modes since the
shaper heavily limits, and you get a con-
stant output level. The problem isn't too
bad in triangle and ramp, but in the sine
position, the waveshape changes pretty
dramatically 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 compatible 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.

S2 IS 6 STATION 4 PDT INTERLOCKING ALL SECTIONS SHOWN IN "UP" POSITION
**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.

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 half wave rectifier. 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 wave- shape ends up on top. The electronic gain control is internally directly connected to the waveform. 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 safely use long leads without worrying about 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 in addition to the wave- shape, 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 waveform, while R19 and R20 together control the sine waveform. R21 to R23 provide the symmetry control, while R13 controls offset. Square 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.

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 full and parts placement diagrams.

PARTS LIST

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>1 µF, 400 volts, mylar</td>
</tr>
<tr>
<td>C2, C7</td>
<td>0.02 µF, mylar</td>
</tr>
<tr>
<td>C3, C9</td>
<td>500 µF, 12-volt electrolytic</td>
</tr>
<tr>
<td>C4, C5</td>
<td>1000 µF, 25-volt electrolytic</td>
</tr>
<tr>
<td>C6</td>
<td>3 µF, 6-volt tantalum</td>
</tr>
<tr>
<td>C8</td>
<td>10,000 µF, 10-volt electrolytic</td>
</tr>
<tr>
<td>C10</td>
<td>50 µF, 6-volt tantalum</td>
</tr>
<tr>
<td>C11</td>
<td>Two parallel capacitors, 2400 µF, 2%</td>
</tr>
<tr>
<td>C12</td>
<td>Two parallel capacitors, 0.22 µF, 2%</td>
</tr>
<tr>
<td>C14</td>
<td>Two parallel capacitors, 2.4 µF, 2%</td>
</tr>
<tr>
<td>C15</td>
<td>Two parallel capacitors, 24 µF, 2%</td>
</tr>
<tr>
<td>C16</td>
<td>Two parallel capacitors, 240 µF, 2%</td>
</tr>
<tr>
<td>C17</td>
<td>Internal source current modulator sets gain</td>
</tr>
</tbody>
</table>

NOTE: The following are available from Southwest Technical Products, 219 West Rhapsody, San Antonio, Texas, 78218

Set of three PC boards, etched and drilled Fgb, $8.25

Complete kit of all above parts FG.1, $38.95
FIG. 6—MAIN GENERATOR circuit. When two switch boards are added (Fig. 3 and Fig. 4) to this master board, the generator is complete.