TRIWAVE

for as long as power is applied to the circuit.

The time T that is required for one cycle is determined by the resistances in the circuit, and by the value of the capacitor:

$$T = 2 \times R1 \times C1 \times \ln\left(1 + \frac{2R2}{R3}\right)$$

In that equation, T is specified in seconds, C1 is specified in farads, and all resistors are specified in ohms; ln again signifies use of the natural logarithm.

By making the value of R2 equal to that of R3, we can simplify the equation to:

$$T = 3.2 \cdot R1 \cdot C1$$

Solving for the resistance,

$$R1 = T / (3.2\ C1)$$

To work in frequency rather than period, recall that $T = 1/f$. Then we can substitute:

$$1/f = 3.2 \cdot R1 \cdot C1$$

or

$$f = 1/(3.2 \cdot R1 \cdot C1)$$

Now let's work a practical example. Calculate the values of the components needed to build a 1500-Hz oscillator. Assume we'll use a 0.001-µF capacitor.

$$R1 = T / (3.2\ C1)$$

$$R1 = (0.00067) / (3.2 \times 10^{-9})$$

$$R1 = 209{,}375\ \text{ohms}$$

The duty cycle of the squarewave circuit in Fig. 3 is 50 percent; in other words, the output is high for the same amount of time that it is low. However, we don't always want a 50 percent duty cycle; sometimes we need the high portion of the waveform to be shorter than the low portion, or vice versa. There are several circuits that will yield different high and low times.

One alternative is shown in Fig. 5. That circuit uses different timing resistors for

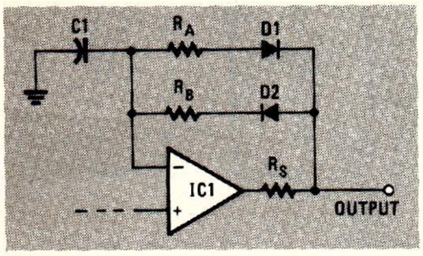

FIG. 5—TO OBTAIN UNEQUAL DUTY CYCLE in the squarewave oscillator, use two different timing resistors. Resistor R_B controls the positive half-cycle, and R_A controls the negative half-cycle.

the high and the low portions of the cycle; the diodes switch R_A or R_B into the circuit at the appropriate time. When the output is high, D2 is forward-biased, so R_B controls timing. Similarly, when the output is low, D1 is forward-biased, so R_A controls timing.

LISTING 2—TRIANGLE-WAVE CALCULATIONS

```
100 REM Triangle wave generator
110 FOR I=1 TO 30
120 PRINT
130 NEXT I
140 PRINT "Fixed or Variable?"
150 PRINT
160 PRINT "1. Fixed
170 PRINT "2. Variable
180 PRINT
190 INPUT "Choice: ",A
200 IF A > 2 THEN GOTO 140
210 GOSUB 1100
220 ON A GOTO 230, 480
230 PRINT
240 PRINT "Fixed Frequency."
250 PRINT
260 INPUT "Frequency in Hz: ",F
270 PRINT
280 PRINT
290 INPUT "Capacitor in uF: ",C
300 C = C/(10^6)
310 IF K = 1 THEN R = .25/(F*C)
320 IF K = 2 THEN GOSUB 940
330 R = INT(R)
340 C = C*10^6
350 PRINT
360 PRINT "Fixed frequency ";
370 PRINT "component values:"
380 PRINT
390 PRINT "Frequency=";F;" Hz"
400 PRINT "Capacitor=";C;" uF"
410 PRINT "Resistor =";R;" Ohms"
420 IF K<>2 THEN 450
430 PRINT "RI =";R1;" Ohms "
440 PRINT "R2 =";R2;" Ohms"
450 PRINT
460 PRINT
470 GOTO 820
480 PRINT "Variable Frequency
490 PRINT
500 PRINT "Enter upper and lower"
510 PRINT "frequency limits in Hz"
520 PRINT
530 INPUT "Lower Limit: ",FL
540 PRINT
550 INPUT "Upper Limit: ",FH
560 PRINT
570 INPUT "Capacitor in uF: ",C
580 C = C/10^6
590 IF K = 2 THEN GOSUB 1020
600 IF K = 1 THEN RL = .25/(FL*C)
610 IF K = 1 THEN RH = .25/(FH*C)
620 C = C*10^6
630 RL = INT(RL)
640 RH = INT(RH)
650 PRINT "Variable frequency
660 PRINT "component values
670 PRINT
680 PRINT "Frequency range:";
690 PRINT FL;" to ";FH;" Hz"
700 PRINT "Capacitor=";C;" uF"
710 PRINT "Resistor =";RH;
720 PRINT " to ";RL;" Ohms"
730 PRINT
740 IF K <> 2 THEN 770
750 PRINT "R1 =";R1;" Ohms, "
760 PRINT "R2 =";R2;" Ohms"
770 GOTO 820
780 INPUT "Choice: ",W
790 IF W > 2, THEN GOTO 780
800 ON W GOTO 810,240
810 RETURN
820 PRINT
830 PRINT "What's next?"
840 PRINT
850 PRINT "1. The same again"
860 PRINT "2. Options menu"
870 PRINT "3. Quit"
880 PRINT
890 INPUT L
900 IF L > 3, THEN GOTO 820
910 ON L GOTO 220,140,920
920 PRINT "PROGRAM ENDED"
930 GOTO 1210
940 PRINT
950 INPUT "Value of R1: ",R1
960 PRINT
970 INPUT "Value of R2: ",R2
980 PRINT
990 R = R1/(4*R2*C*F)
1000 R = INT(R)
1010 RETURN
1020 PRINT
1030 INPUT "Value of R1: ",R1
1040 PRINT
1050 INPUT "Value of R2: ",R2
1060 PRINT
1070 RH = R1/(4*R2*C*FH)
1080 RL = R1/(4*R2*C*FL)
1090 RETURN
1100 PRINT
1110 PRINT "Select One:"
1120 PRINT
1130 PRINT "1. Standard Version ";
1140 PRINT "(R1=R2)"
1150 PRINT "2. Custom Values ";
1160 PRINT "(you enter R1 and R2)"
1170 PRINT
1180 INPUT "Select One: ",K
1190 IF K > 2, THEN GOTO 1110
1200 RETURN
1210 END
```

Another method of obtaining a nonsymmetrical waveform is shown in Fig. 6. In that circuit we bias the timing capacitor

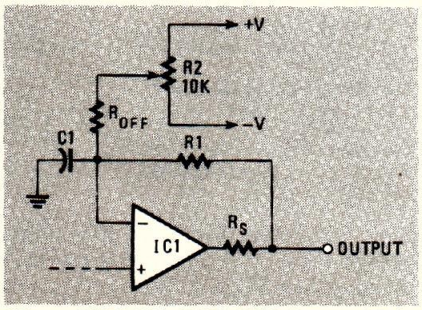

FIG. 6—UNEQUAL DUTY CYCLE may also be obtained by biasing the timing capacitor (C1) positive or negative through R_{OFF} and R2.

either positive or negative by the actions of potentiometer R2 and R_{OFF}. The polarity of the bias voltage is determined by the setting of R2; that voltage can vary anywhere from −V through zero to +V.

Triangle-wave oscillators

There are numerous ways of designing a triangle-wave oscillator, but few have the simplicity of a squarewave oscillator followed by a Miller integrator. The latter is shown in Fig. 7; its timing diagram is shown in Fig. 8.

The slope of the waveform in the lower trace depends on the R1C1 time constant. When that time constant is long compared with the period of the squarewave input, a

continued on page 79

$+V_Z$ because D2 clamps the voltage to about 0.7 volts).

However, the output voltage is $-V_Z$, so the charge across C2 will begin to approach that potential. It will never reach it, however, because the noninverting input of the op-amp is biased to a fraction of the output voltage, B, as determined by the voltage divider composed of R6 and R7. When the voltage across C2 exceeds BV_O, the output of the op-amp will snap back to the stable (high) state.

The refractory period

The period immediately after the output returns to the stable state is called the refractory period. The circuit will not respond to trigger inputs during that period. To understand why that is the case, first assume that R4 and D3 are not present. Then C2 can discharge only through R3, and that takes a long time. However, by including R4 and D3, we can shorten the refractory period. If the resistance of R4 is much less than that of R3, then the circuit will discharge much faster than it will charge. Diode D3 ensures that current flows through R4 only during discharge. The lower curve in Fig. 2 indicates the different discharge times with and without those components.

The duration T of the output pulse is given approximately by this equation:

$$T = R3 \cdot C2 \cdot \ln [1/(1-B)]$$

In that equation, T is given in seconds, R3 is in ohms, C2 is in farads, ln denotes the use of the natural logarithm, and B is the feedback factor. B is determined from the voltage-divider equation: $B = R6/(R6+R7)$.

That timing equation is derived from the time it takes C2 to charge from +0.7 volts to voltage BV_O. We can simplify the equation by making B a constant. For example, if the values of the resistors are equal, then $B = R/(R+R) = 0.500$, so the equation can be simplified as follows:

$$T = R3 \cdot C2 \cdot \ln [1/(1-B)]$$

$$T = R3 \cdot C2 \cdot \ln [1/(0.500)]$$

$$T = R3 \cdot C2 \cdot \ln [2]$$

Therefore,

$$T = R3 \cdot C2 \cdot 0.693$$

If $R6 = 2R7$, then $B = R/(R+2R) = R/3R = 0.333$. In that case we can simplify the timing equation as follows:

$$T = R3 \cdot C2 \cdot \ln [1/(1-0.333)]$$

$$T = R3 \cdot C2 \cdot \ln [1.500]$$

$$T = R3 \cdot C2 \cdot 0.406$$

B is often given a value of 0.632. Doing so allows us to reduce the timing equation to

$$T = R3 \cdot C2$$

Since $R7/(R6+R7) = 0.632$, we can do a little algebra and find that $R6 = 0.582\ R7$.

In practical terms, we usually select a capacitor and then calculate resistor values, since there are fewer standard values of capacitance.

Automatic calculations

Listing 1 contains a BASIC program that will calculate component values for the one-shot multivibrator. The program is written for the dialect of BASIC used in the IBM-PC (and compatibles), but it should run on many other machines as-is, and it should be easy to translate into other dialects of BASIC, if necessary.

When you run the program it asks you for the duration of the pulse (in milliseconds) and a value of capacitance (in µF). The program then calculates the required resistance, and reports it. At that point you can either run the program again, or exit.

Squarewave oscillators

As you can see in Fig. 3, an op-amp-based squarewave generator is relatively simple. The timing diagram of that circuit is shown in Fig. 4. Refer to both during the discussion that follows.

LISTING 1—
ONE-SHOT CALCULATIONS

```
100 REM Monostable Multivibrator
110 FOR I=1 TO 30
120 PRINT
130 NEXT
140 PRINT " Monostable
150 PRINT "Multivibrator
160 PRINT "  Circuit
170 PRINT "  Design
180 PRINT
190 PRINT
200 PRINT
210 INPUT "Pulse duration in ms: ",T
220 T = T/1000
230 INPUT "      Capacitor in uF: ",C
240 PRINT
250 C = C/10^6
260 R = T/(.693*C)
270 R = INT(R)
280 C = C*10^6
290 T = T*1000
300 PRINT "For a pulse duration of:"
310 PRINT
320 PRINT T;"milliseconds"
330 PRINT "     use a
340 PRINT R;"ohm resistor"
350 PRINT "     and a
360 PRINT C;"uF capacitor."
370 PRINT
380 PRINT
390 PRINT "What Now?"
400 PRINT
410 PRINT "1. Do another"
420 PRINT "2. Quit
430 PRINT
440 INPUT "Choose one: ",D
450 IF D = 1 THEN GOTO 200
460 END
```

In contrast to the one-shot, the squarewave oscillator is called an astable oscillator, because it has no stable output state. In other words, its output snaps back and forth between the high ($+V_Z$) and low ($-V_Z$) states.

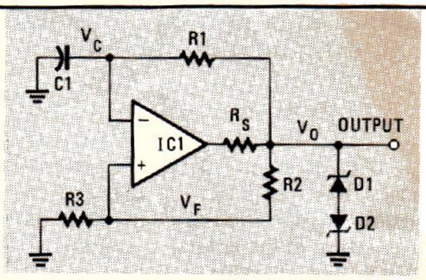

FIG. 3—THIS SQUAREWAVE OSCILLATOR'S frequency of oscillation is given by $f = 1/(3.2\ R1\ C1)$.

The noninverting input of the op-amp is biased by a fraction of the output voltage, as determined by the R2/R3 network; the inverting input is biased by the voltage (V_C) across capacitor C1. That voltage is determined by V_O and by the R1C1 time constant.

When the circuit is initially turned on, the capacitor has no charge, so the inverting input has no potential with respect to ground. Therefore the output will be high. The capacitor will begin to charge toward $+V_O$ at a rate that is determined by the product of the values of R1 and C1.

When that voltage reaches the bias

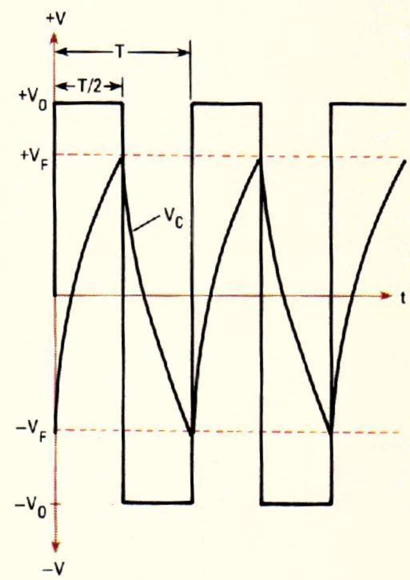

FIG. 4—THE VOLTAGE ACROSS C1 (in Fig. 3) varies between $+V_F$ and $-V_F$.

point of the noninverting input ($+V_F$), the output will snap low. At that point the charging of the capacitor reverses, and the voltage will discharge from $+V_F$ toward zero, and then toward $-V_F$. When it reaches that negative voltage, the output again snaps high, the capacitor begins to discharge toward zero and then toward $+V_F$. That oscillating cycle will continue