GENERATING SQUARE WAVES

WITH ANY FREQUENCY AND DUTY CYCLE

By Mark McWilliams

EXPERIMENTERS often need to generate square waves for test circuits and other applications. A simple way to do this is with a 555-timer IC operating in the astable mode. Most manufacturers' spec sheets include graphs to help you choose the resistor values needed to obtain a desired frequency with a given capacitance. The only drawback of this method is that you can't maintain control over the duty cycle of the square wave. This article presents simple formulas and plots for selecting resistor values to control both frequency and duty cycle.

Figure 1 shows the circuit commonly used to produce a 555 astable waveform such as that shown in Fig. 2. In Fig. 1, the output voltage at pin 3 will be high or *on* during the charging of capacitor C through R_A and R_B. The output will be low or *off* or near ground potential during the discharging cycle. The *on* time is designated as T_1

Fig. 1. Standard 555 square-wave generator.

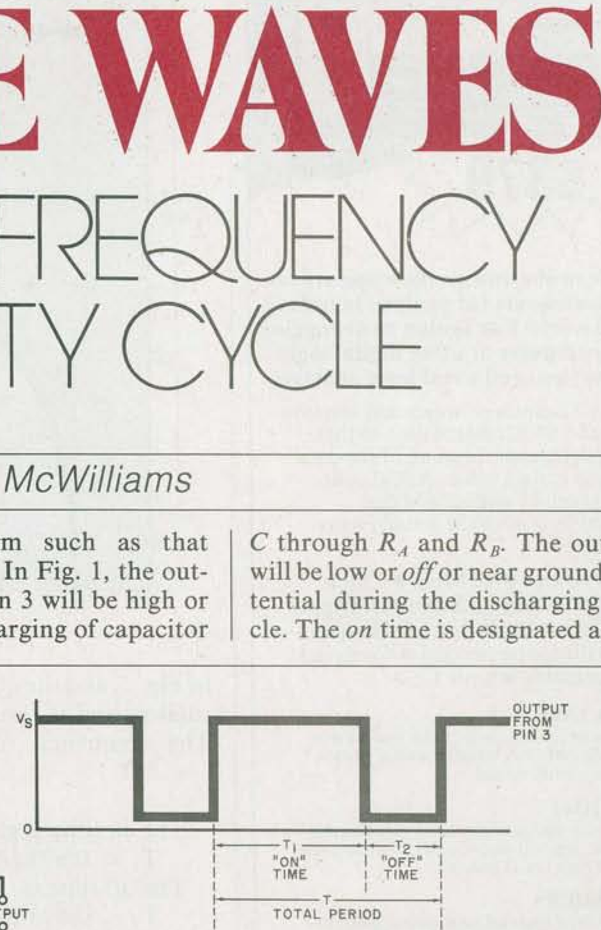

Fig. 2. Output of the circuit in Fig. 1, with characteristics defined.

Examples:

(1) *Given:* f = 1000 Hz, C = 0.1 µF, D = 0.7
Solution: C × f = 10^2 µF-Hz;
from equation (B) or Fig. 3,
R_B = 4.3 kΩ;
from equation (A) or Fig. 4,
R_A/R_B = 1.333;
therefore: R_A = (1.333)(4.3 kΩ) = 5.73 kΩ

(2) *Given:* f = 50,000 Hz, C = 100 pF, D = 0.51
Solution: C × f = 5 µF-Hz;
from equation (B) or Fig. 3,
R_B = 141 kΩ;
from equation (A) or Fig. 4,
R_A/R_B = 0.041;
therefore; R_A = (0.041)(141 kΩ) = 5.78 kΩ

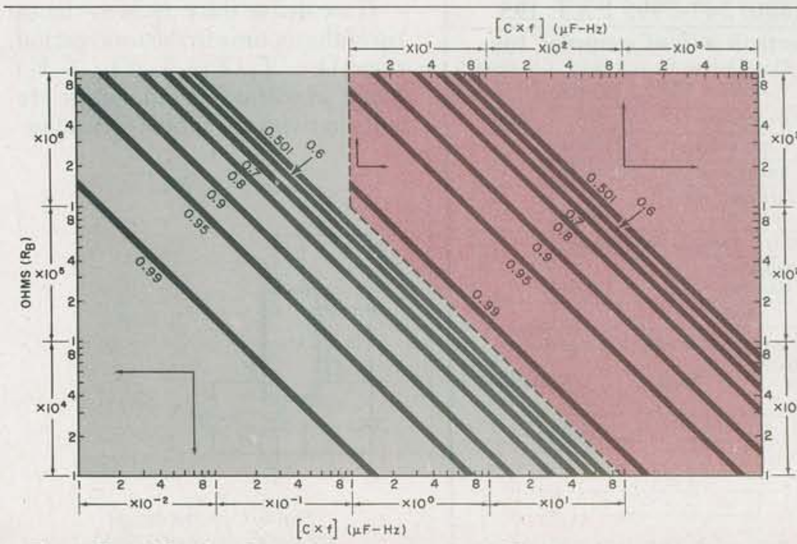

Fig. 3. Plot of C×f vs. R_B, which can be used with Fig. 4 to determine circuit values.

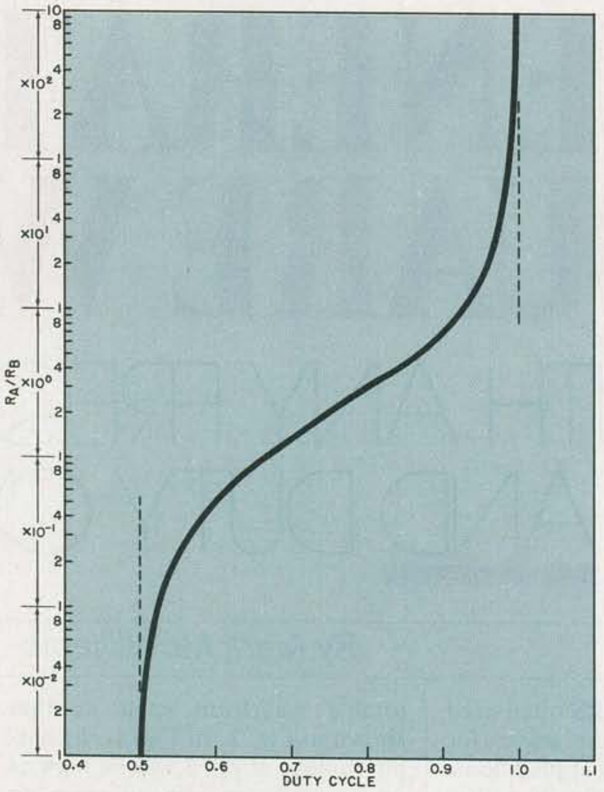

Fig. 4. Duty cycle vs. resistance ratio R_A/R_B based on Eq. (A).

in Fig. 2, and the *off* time as T_2. The total period is thus $T = T_1 + T_2$. The frequency of oscillation is $f = 1/T$.

The *on* time is given by

$$T_1 = 0.693\,(R_A + R_B)C$$

The *off* time is

$$T_2 = 0.693\,R_BC$$

Thus

$$f = 1/(T_1 + T_2) = 1.443/(R_A + 2R_B)C$$

If we define duty cycle as the ratio of the *on* time to the total period, then $D = T_1/T = T_1/(T_1 + T_2)$. Some algebraic manipulation results in two very simple formulas:

$$R_A/R_B = (2D - 1)/(1 - D) \quad \text{(A)}$$
$$R_B = 1.443\,(1 - D)/Cf \quad \text{(B)}$$

where f is in Hz, R_B and R_A are in ohms, C is in farads, and $0.5 < D < 1$.

Note that, given a particular capacitor, one can quickly calculate the R_A and R_B values necessary to achieve a desired frequency *and* a desired duty cycle.

These two equations are presented graphically in Fig. 3 and Fig. 4. For convenience in plotting, C and f were combined to form one variable, $C \times f$. In the plots, the units of $C \times f$ are (μF - Hz) and R_B is in ohms.

Of course, equations A and B give more accurate answers than the plots but the extra decimal places are meaningless if wide-tolerance capacitors are used.

If a duty cycle of *exactly* 0.5000 must be produced, it can be done by connecting the timer output at pin 3 to the clock input of a J-K flip-flop. The output of the flip-flop will be a perfectly symmetrical square wave at half the frequency of the timer output. This configuration is shown in Fig. 5 and is independent of the value of R_A and R_B. ◇

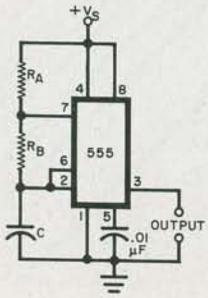

Fig. 5. Use this circuit for a duty cycle of 0.5000.