Rectangular Wave & Square Wave Generators (Op-Amp Schmitt Triggers & 555 Timers)

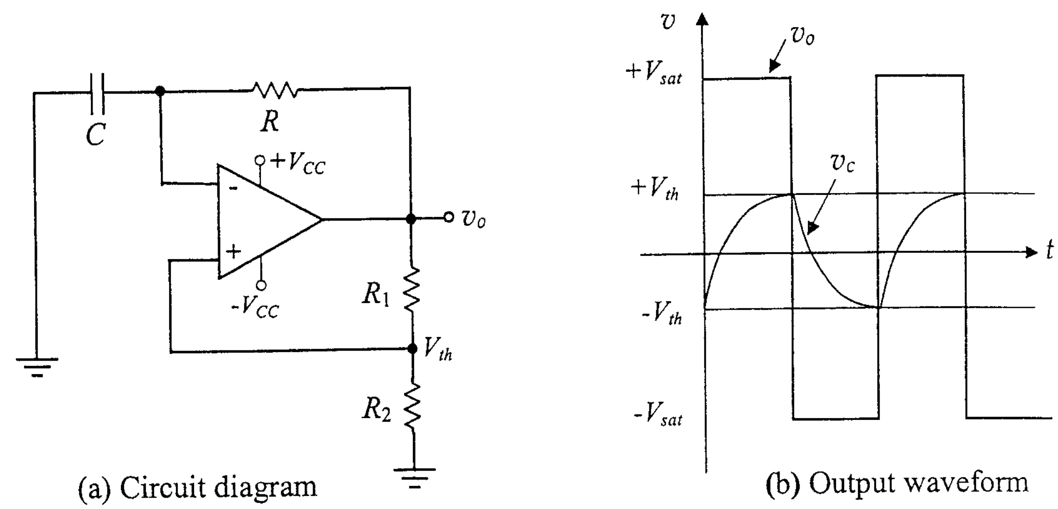


Figure 16-15: Square-wave generator

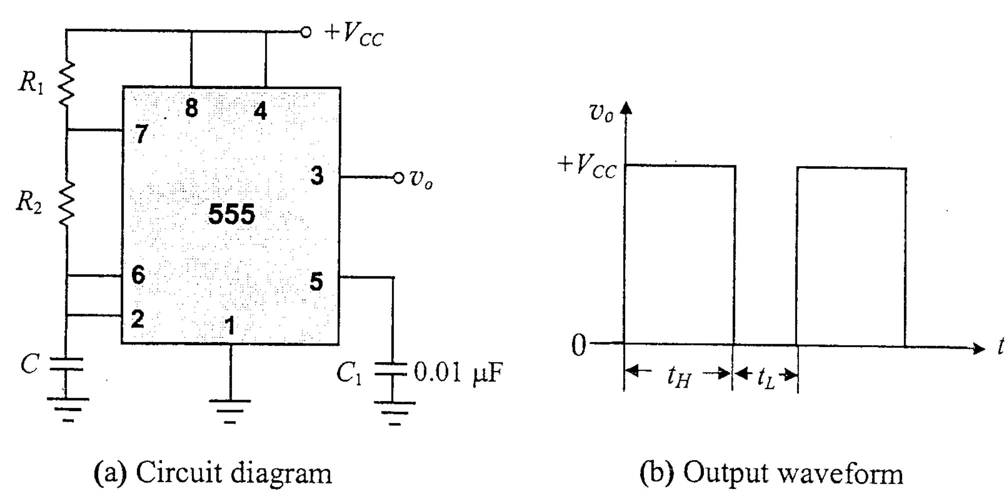
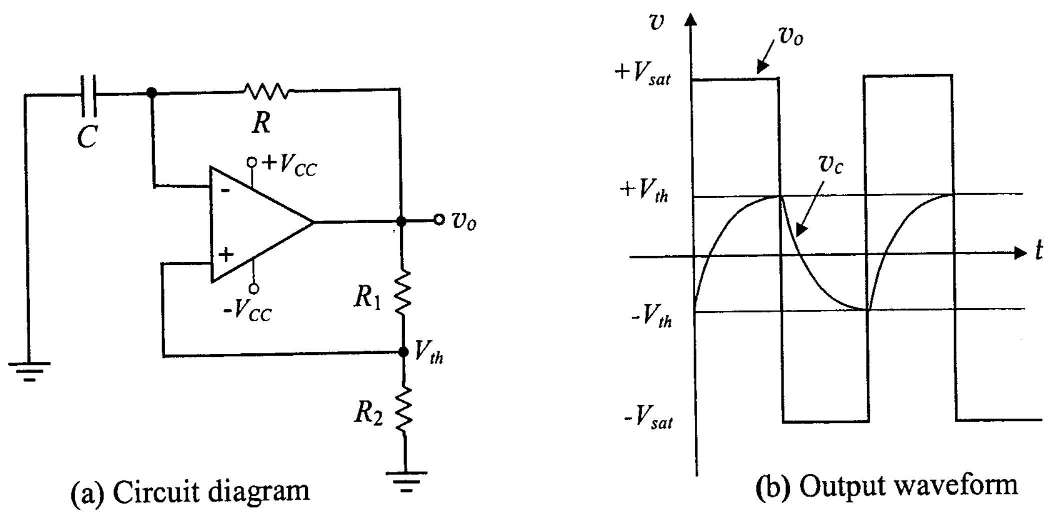


Figure 16-17: The 555 timer connected as a rectangular waveform generator

Electronic Devices: a design approach, Ali Aminian & Marian Kazimierczuk, 2004

SQUARE-WAVE GENERATOR

Recall that the output of the Schmitt trigger, which was introduced in Chapter 11 as a bi-reference level comparator, is a square wave with $\pm v_{o(p)} = \pm V_{sat}$ of the op-amp. With the addition of a capacitor C and a feedback resistor R, as shown in Figure 16-15(a), the need for an input signal is eliminated and the output frequency can also be controlled by proper selection of the R and C.



(a) Circuit diagram (b) Output waveform

Figure 16-15: Square-wave generator

Referring to Equations 11-7 and 11-8, the upper and lower threshold voltages (V_{UT} & V_{LT}) or ($\pm V_{th}$) can be written in one equation as follows:

$$\pm V_{th} = \pm V_{sat} \frac{R_2}{R_1 + R_2} \tag{16-64}$$

It can be shown, with some considerable algebraic effort, that the period of the output waveform is as follows:

$$T = 2RC \ln\left(\frac{2R_2}{R_1} + 1\right) \tag{16-65}$$

$$f_0 = \frac{1}{T} = \frac{1}{2RC \ln(2R_2 / R_1 + 1)} \tag{16-66}$$

However, if we select R_1 and R_2 such that $(1 + 2R_2/R_1) = 2.178$ (the natural log base), then $\ln(1 + 2R_2/R_1)$ will equal unity.

$$\frac{2R_2}{R_1} + 1 = 2.718 \tag{16-67}$$

$$2R_2 = 1.718R_1 \tag{16-68}$$

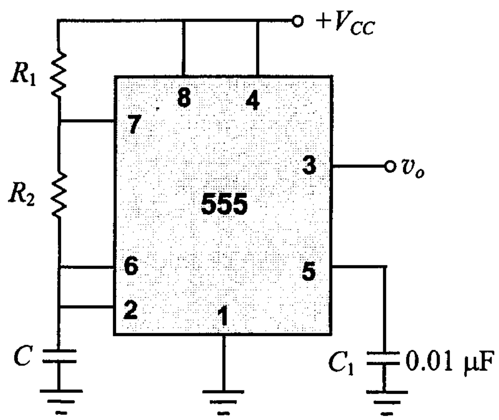
$$R_2 = 0.859R_1 \tag{16-69}$$

Hence, the output frequency is a function of R and C only, and its equation simplifies as follows:

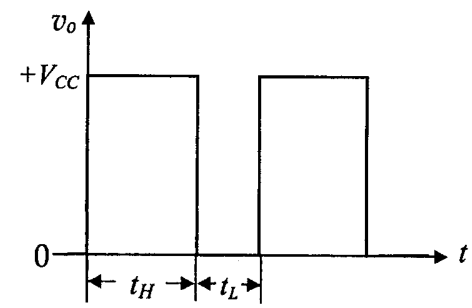
$$f_o = \frac{1}{2RC} \tag{16-70}$$

16.8 THE 555 TIMER

The 555 timer is a popular 8-pin integrated circuit (*IC*), which may be used in many applications including rectangular waveform generation. Figure 16-17 shows the common configuration of the 555 timer as it is connected to produce a rectangular waveform.



(a) Circuit diagram



(b) Output waveform

Figure 16-17: The 555 timer connected as a rectangular waveform generator

The time duration for which the output is high (t_H) is given by the following equation:

$$t_H = 0.69(R_1 + R_2)C \tag{16-71}$$

The time duration for which the output is low (t_L) is given by the following equation:

$$t_L = 0.69(R_2)C \tag{16-72}$$

Therefore, the period and frequency of the waveform are as follows:

$$T = t_H + t_L = 0.69(R_1 + 2R_2)C \tag{16-73}$$

$$f_o = \frac{1}{T} = \frac{1}{0.69(R_1 + 2R_2)C} \tag{16-74}$$

For a rectangular waveform, the ratio of the pulse duration (t_H) to the period T is referred to as the *duty cycle* (d) of the waveform. A square wave is a rectangular waveform with $d = 0.5$ or 50% duty cycle. Examining the equations for t_H and t_L, we notice that it would not be possible to produce a square wave with the circuit of Figure 16-16. However, there is a simple solution for this problem, and that is to connect a diode across the R_2 and let $R_1 = R_2 = R$, as illustrated in Figure 16-18(a).

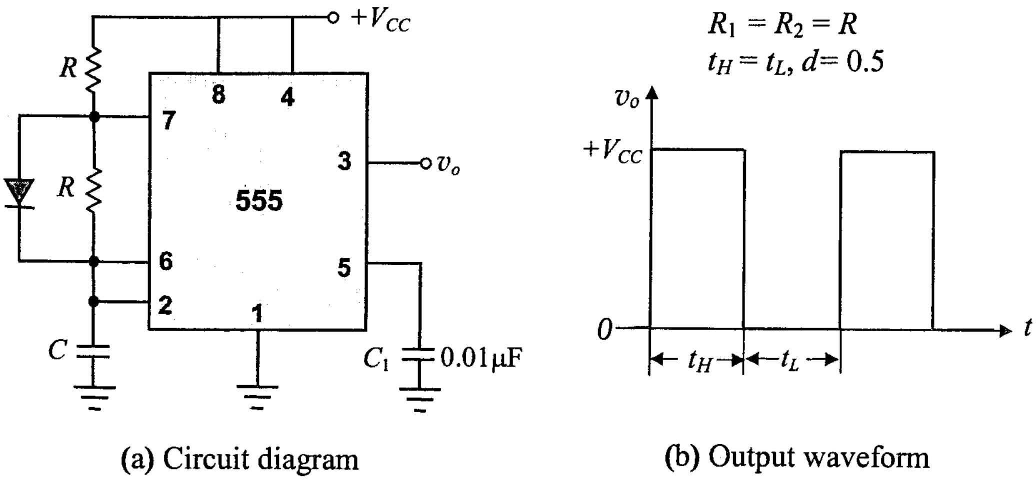


Figure 16-18: The 555 timer connected as a square-wave generator

When the output is high, the diode is forward-biased, shorting out R_2; hence,

$$t_H = 0.69(R_1)C = 0.69RC \tag{16-75}$$

When the output is low, the diode is unbiased, behaving like an open-circuit; hence,

$$t_L = 0.69(R_2)C = 0.69RC \tag{16-76}$$

$$T = t_H + t_L = 0.69RC + 0.69RC = 1.38RC \tag{16-77}$$

$$f_o = \frac{1}{T} = \frac{1}{1.38RC} \tag{16-78}$$

$$d = \frac{t_H}{T} = \frac{0.69RC}{1.38RC} = 0.5 \tag{16-79}$$

In order to produce a rectangular waveform with a duty cycle less than 50% ($t_H < t_L$), we can pick R_2 larger than R_1, as required. However, the practical solution is to split R_2 into a series combination of a fixed resistor and a potentiometer, so that R_2 can be adjusted for a desired duty cycle.

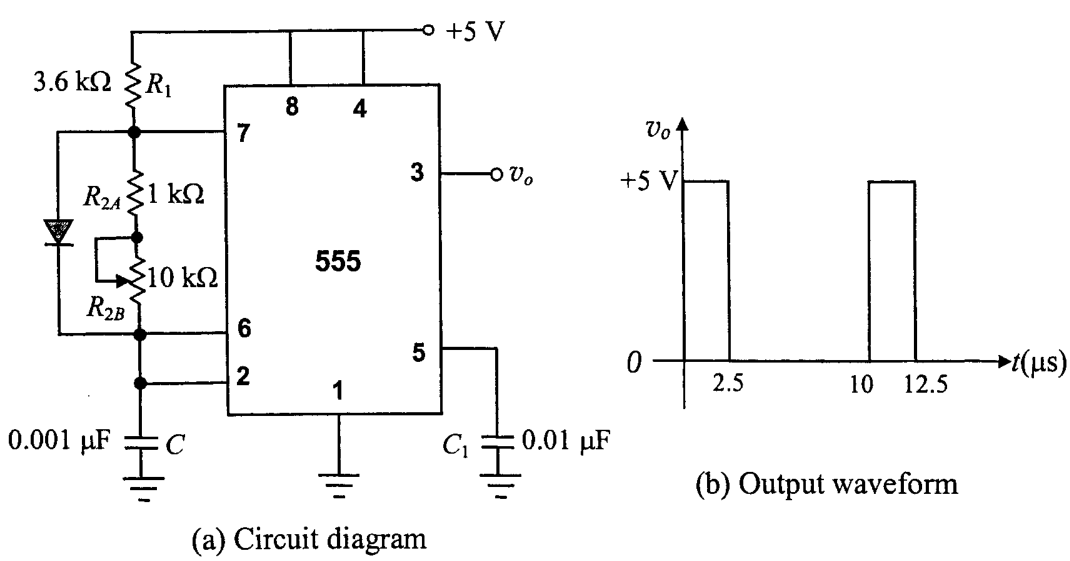


Figure 16-19: Rectangular waveform generator of Design Example 16-6