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 $C$.

![ Circuit diagram ](a) Circuit diagram

![ Output waveform ](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:

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

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

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

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

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.

$$\frac{2R_2}{R_1} + 1 = 2.718 \quad (16-67)$$

$$2R_2 = 1.718R_1 \quad (16-68)$$

$$R_2 = 0.859R_1 \quad (16-69)$$

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

$$f_o = \frac{1}{2RC} \quad (16-70)$$

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

![Circuit diagram](image)

(a) Circuit diagram

![Output waveform](image)

(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:

$$ t_H = 0.69(R_1 + R_2)C $$  \hspace{1cm} (16-71)

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

$$ t_L = 0.69R_2C $$  \hspace{1cm} (16-72)

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

$$ T = t_H + t_L = 0.69(R_1 + 2R_2)C $$  \hspace{1cm} (16-73)

$$ f_o = \frac{1}{T} = \frac{1}{0.69(R_1 + 2R_2)C} $$  \hspace{1cm} (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).

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

$$t_H = 0.69(R_1)C = 0.69RC$$  \hspace{1cm} (16-75)

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

$$t_L = 0.69(R_2)C = 0.69RC$$  \hspace{1cm} (16-76)

$$T = t_H + t_L = 0.69RC + 0.69RC = 1.38RC$$  \hspace{1cm} (16-77)

$$f_o = \frac{1}{T} = \frac{1}{1.38RC}$$  \hspace{1cm} (16-78)

$$d = \frac{t_H}{T} = \frac{0.69RC}{1.38RC} = 0.5$$  \hspace{1cm} (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

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