Electrical Tech Note — 540

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555 Timer

The 555 timer is a versatile and rugged timing device. It uses an external series RC (resistor capacitor) circuit to establish the timing rate. Refer to Tech Note 512 for a discussion of series capacitor resistor timing circuits. The basic internal workings of the timer are a voltage divider, two op-amp comparators, an SR (set reset) flip-flop, a bipolar junction transistor, and an inverter. The 555 timer will operate from a dc power supply with as little as +5 Vdc or as high as +15 Vdc. A diagram of the main internal components is shown in Figure 540.1. One basic function of the 555 timer is to produce an output for a selected period of time than turn off. This action in electronic terminology is known as a monostable multivibrator or one-shot. Another basic function is to create a continuous series of on-off pulses at a desired rate. This type of device is known as an astable multivibrator.

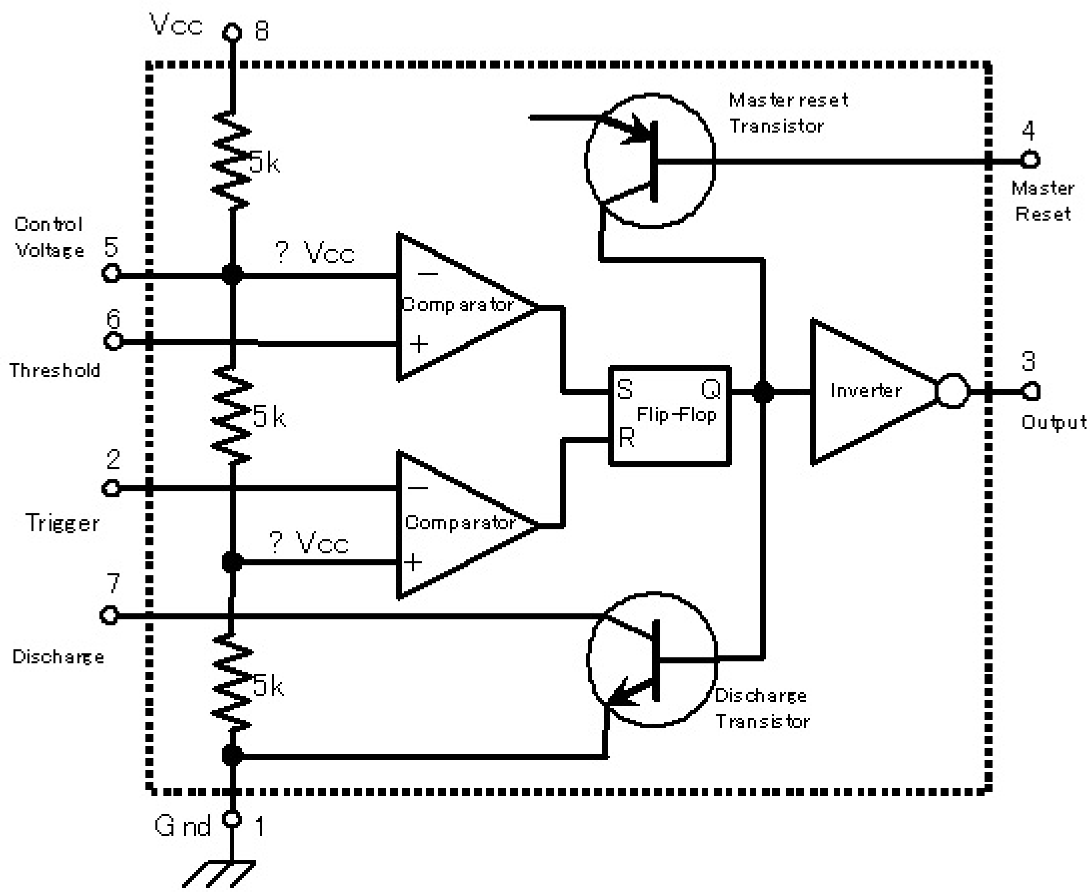

Figure 540.1 *The voltage divider of the 555 timer sets fixed voltages to inputs of the op-amp comparators which feed into an SR flip-flop. The output of the flip-flop is inverted for the output of the timer. The output of the flip-flop also operates a bipolar transistor that is used to discharge the external capacitor of the timing circuit.*

Basic Component Operation: The timer gets it's name from the value of three resistors used internally to divide the supply voltage (V_{CC}) into two-thirds (2/3 V_{CC}) and one-third (1/3 V_{CC}). Three 5k ohm resistors are connected in series between the supply voltage and ground. These values act as reference voltages to inputs of op-amp comparators.

The output of the comparators in the 555 timer is either +V_{CC}, or ground (logic 1 or 0). If the voltage on the inverting input (minus input) of the op-amp comparator is positive with respect to the voltage on the non-inverting input (plus input) then the op-amp output will be ground potential or the logic zero state (See Figure 540.2). Any time the comparator minus input has a greater voltage than the plus input the output will be ground or logic zero. When the plus input is at a higher voltage than the minus input the output of the comparator will be +V_{CC} or the logic one state. The voltages applied to the inputs of the comparators in Figure 540.2 are typical voltages when the 555 timer is powered from a + 5 Vdc supply.

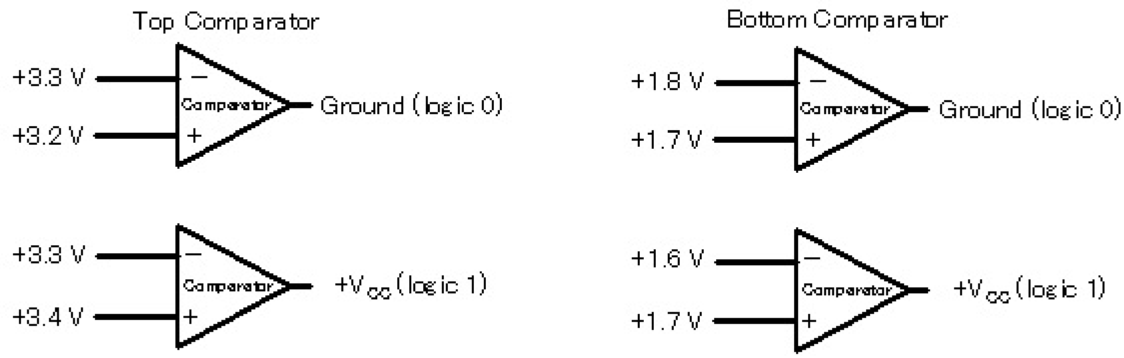

Figure 540.2 *Two examples are shown for the output states of op-amp comparators with a higher and lower voltage applied to the minus input compared to the plus input. When the voltage at the minus input is higher than at the plus input the comparator output will be at ground potential or logic zero. When the voltage at the minus input is lower than at the plus input the comparator output will be at +V_{CC} or logic one.*

The next component in the 555 timer is a set reset flip-flop. A flip-flop is a basic storage cell or memory cell in a digital electronic device. It can store indefinitely a logic one state (+V_{CC}) or a logic zero state (ground). The letter **Q** is used to label the output of the flip-flop. The inputs are the set and reset. The dormant state of the flip-flop is when logic zero is applied to both inputs. The output will remain in whatever state it was in up to that point. Refer to Figure 540.3 for the following sequence of operations applied to a set reset flip-flop. In Figure 540.1, a one state is applied to the reset to get the output at a zero state. With both inputs at the zero state, the output remains at the zero state. If a logic one is put at the set input the output will go to the logic one state. If the set input reverts back to the zero state, the output will remain at the logic one state indefinitely. To put the output back at logic zero, a logic one must be applied to the reset. When that logic one is no longer at the reset input the flip-flop output will remain at the zero state until a one state is applied to the set input. There is a condition that must be avoided in the design of a digital circuit and that is the chance a one state is applied to the set and reset at the same time. This will confuse the flip-flop and the output will be unpredictable. Figure 540.3 is a review of the output states of a set reset flip-flop starting with a logic one applied to the reset input.

An internal bipolar junction transistor is inside the 555 timer and is used as a switch to discharge the external capacitor by connecting it to ground at the desired time (See Figure 540.1). In the case of the one-shot a manual switch can be used to start the timing by grounding one of the inputs of one of the comparators. In the case of the astable multivibrator the base of this common emitter NPN transistor connection is activated once each charging cycle.

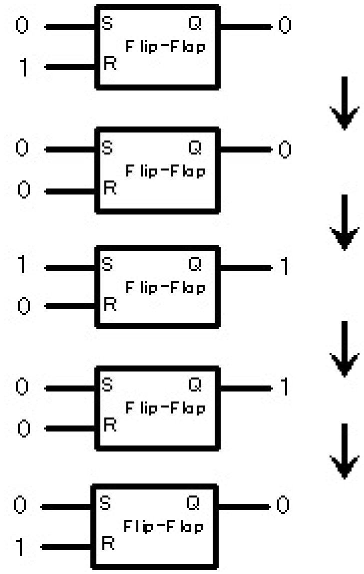

Figure 540.3 *The basic states of a set reset flip-flop are shown starting with a logic one applied to the reset. Note that when both input are at the logic zero state the previous output value is maintained indefinitely.*

The final basic digital component of the 555 timer is an inverter connected between the output of the SR flip-flop and the output terminal of the 555 timer. An inverter changes a logic one state into a logic zero state or it changes a logic zero state into a logic one state. The output of the 555 timer is either +V_{CC} or ground. When the output is at the +V_{CC} or one state it can be used to drive a load such as an LED. If an LED polarity is reversed and connected directly to the power supply (+V_{CC}) it can be operated by grounding the LED through the 555 timer output. Figure 540.4 shows two LEDs connected to the same output of the 555 timer, but reversed so that when one is lighted the other will be off.

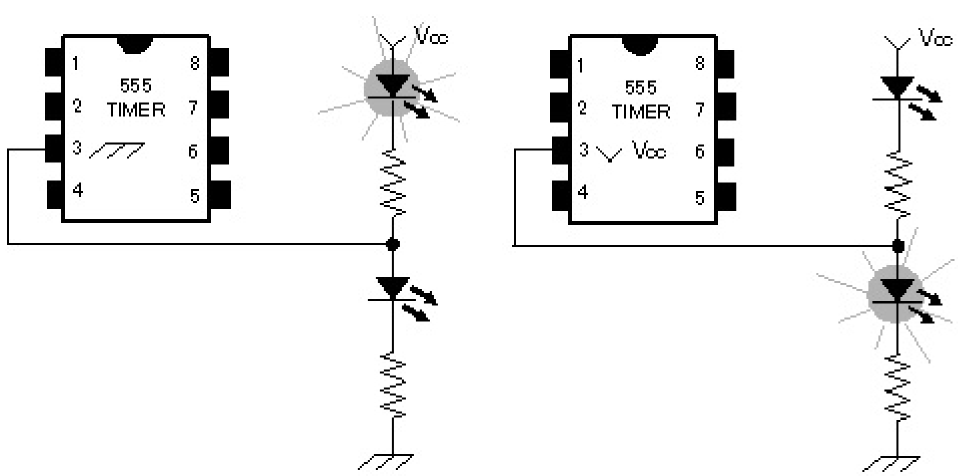

Figure 540.4 *The output terminal of the 555 timer can be used to either supply the supply voltage (+V_{CC}) to a load or to ground the load through the timer output. In this case the LEDs are connected in reverse so that when one is lighted the other will be off.*

Connecting the 555 Timer: The following discussion in this Tech Note will show how to connect the 555 timer as a one-shot to produce a time delay of a desired duration, and as an astable multivibrator to produce a series of pulses at a desired frequency. For these applications 555 timer terminal 5 is not needed and it will be tied to ground through a 0.01 μf capacitor. With all digital devices it is not a good idea to just let a terminal float. The master reset of the 555 timer will not be used and it will be tied to a one state (+V_{CC}). If connected to ground it will reset the timer. The 555 timer requires a connection to +V_{CC} which is terminal 8 and a connection to ground which is terminal 1. These connections are required for both circuits described in this Tech Note and are shown in Figure 540.5. An LED will be connected to the 555 timer output terminal 3 as an indication of the timer operation. For the following circuits the LED will be connected to ground so it will be receiving it's source of voltage from the 555 timer.

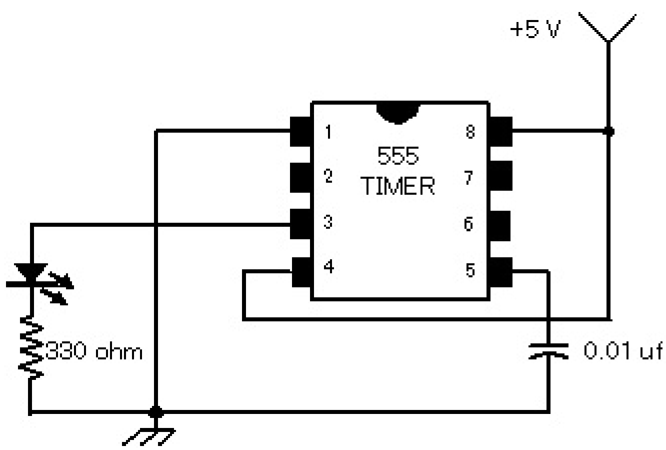

Figure 540.5 *For the following circuits described in this Tech Note terminal 1 will be connected to ground, terminal 8 will be connected to +V_{CC}, terminal 4 will be connected to +V_{CC}, and terminal 5 will be connected to ground through a 0.01 μf capacitor.*

One-Shot Connection of the 555 Timer: The object of a one-shot is to produce a time delay of a desired length and then turn off. For this circuit a normally open manual momentary push button will be used to start the timing. When the push button is pressed the LED will light immediately and will remain on until the desired time delay has expired. The time delay is determined by the values of a capacitor and resistor in an external series RC circuit connected to terminals 6 and 7 as shown in Figure 540.6.

Assume the push button circuit is open in Figure 540.6. There will be +5 volts at the minus input to the bottom comparator. The plus input of the bottom comparator is connected to the voltage divider and is at a fixed +1.7 volts assuming the power supply is +5 volts. Refer back to Figure 540.2. The output of the bottom comparator will be at the zero state. The capacitor in the series RC circuit will charge and the voltage at the plus input of the top comparator will rise until it exceeds the fixed +3.3 volts applied to the minus input of the top comparator by the voltage divider. At that moment the output of the top comparator will switch from the zero state to a one state which will set the SR flip-flop. The output of the SR flip-flop will go from the zero state to a one state thus turning on the bipolar junction transistor. When that transistor turns on it will connect the plus input of the top comparator to ground and discharge the capacitor. The voltage at the plus input of the top comparator will drop to 0 volts and the output to the comparator will switch from the one state to a zero state but the SR flip-flop will continue to provide a one output to the bipolar junction transistor keeping the plus input of the top comparator at 0 volts. Since an inverter is connected to the output of the 555 timer the output will be zero and the LED will be off.

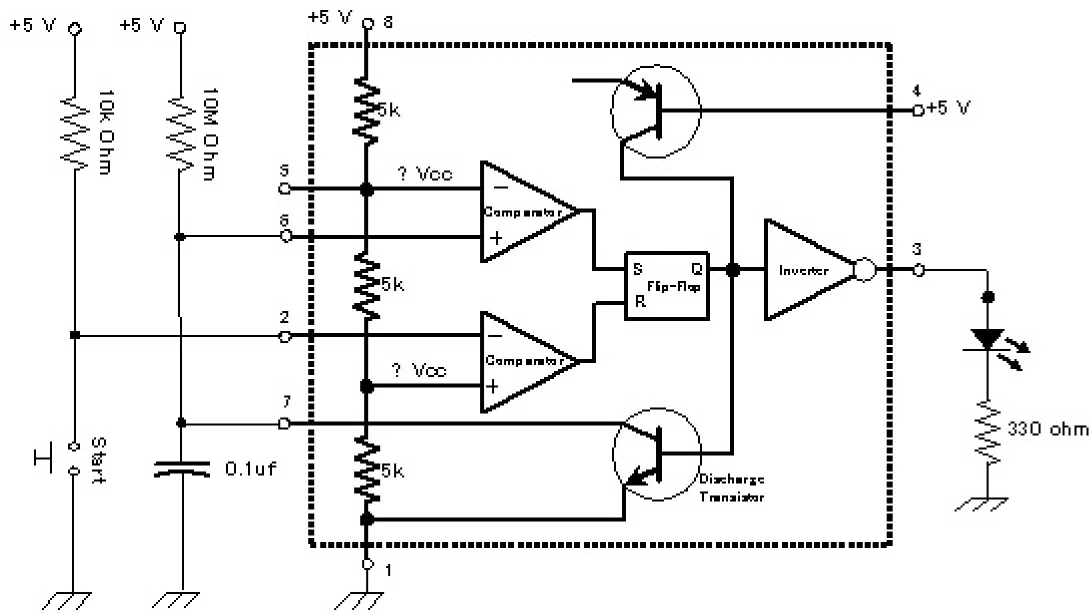

Figure 540.6 *A 555 timer can be used the create a one-shot time delay by connecting an external series RC circuit and a momentary normally open push button to temporarily ground the input to one of the comparators.*

By pressing the momentary push button the minus input to the bottom comparator will go from +5 volts to 0 volts. The output of the bottom comparator will go from a zero state to a one state thus applying a one state to the SR flip-flop reset. The output of the SR flip-flop will go from a one state to a zero state and the bipolar junction transistor will turn off allowing the capacitor to charge. The output of the 555 timer will go to the one state and the LED will light when the momentary push button is pressed. The capacitor will charge until the voltage across the capacitor reaches two-thirds of the supply voltage. The time required to charge the capacitor can be determined using the values of the capacitor and series resistor and the capacitor charging formula from Tech Note 512.

Since the capacitor voltage is known to be two-thirds of the supply voltage the voltage will cancel out of the equation and a formula for the time in seconds based upon the chosen values of R and C is given by Equation 540.1. A graph of the output of the 555 timer connected for the one-shot time delay mode is shown in Figure 540.7.

$$E_C = E_S\left(1 - \frac{1}{e^{\frac{t}{RC}}}\right)$$ **Equation 512.7**

$$t = 1.1 \times R \times C$$ **Equation 540.1**

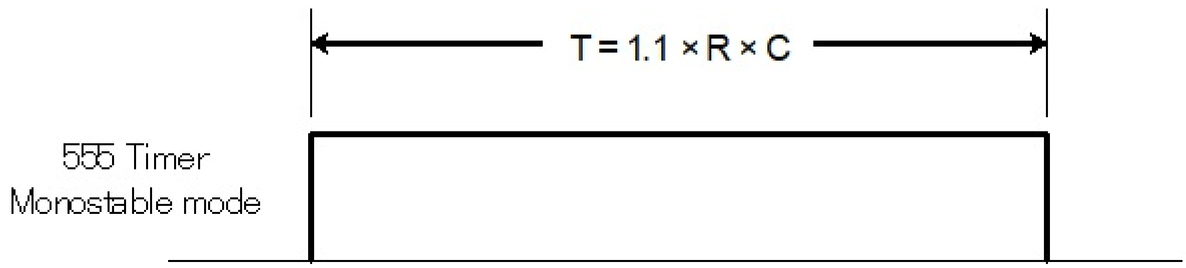

Figure 540.7 *When a 555 timer is connected in the one-shot time delay mode the output will go to a one state immediately when the momentary push button is pressed and will remain at the one state until the predetermined time delay has expired.*

Astable Multivibrator Connection of the 555 Timer: The object of an a stable multivibrator is to produce a continuous series of pulses at a predetermined frequency. The values of the resistors and capacitor in the external series RC circuit determine the frequency and the time duration of the on period and off period. Using a 555 timer to produce a series of pulses has the drawback of not being able to produce pulses where the on and off periods are equal. If that is important then some other method of creating a series of pulses will need to be employed. Figure 540.8 shows the connection of the external RC circuit to the 555 timer to create a series of pulses. For the example given in Figure 540.8 the period is about 1.7 seconds with an on period of about 1.1 seconds and an off period of about 0.6 seconds.

Operating in the astable mode a capacitor is connected in series with two resistors. The point where the resistor connects to the capacitor is connected to the plus input of the top comparator and also to the minus input of the bottom comparator. The point where the two resistors are joined is connected to the collector of the discharge transistor inside the 555 timer. The capacitor will charge through the two resistors until the voltage across the capacitor just barely exceeds the two-thirds V_{CC} applied to the minus input of the top comparator. This will produce a one state at the output of the top comparator which will set the SR flip-flop and produce a one state output from the flip-flop that will turn on the discharge transistor. The capacitor will discharge only through one of the resistors as shown in Figure 540.8. The capacitor will discharge faster than it will charge. The capacitor will discharge only until the voltage at the minus input of the bottom comparator becomes slightly less than the one-third V_{CC} applied to the plus input of the bottom comparator. This will produce a one state output from the bottom comparator which will reset to SR flip-flop to a zero output which turns off the discharge transistor. The capacitor voltage at this point has dropped to one-third V_{CC} and it will now begin to charge until it's voltage rises to two-thirds V_{CC}. This cycle is repeated indefinitely.

The time required to charge and discharge the capacitor from one-third VCC to two-thirds VCC depends upon the value of the capacitor and the values of the two resistors. Since the capacitor voltage is a known function of the supply voltage Equation 512.7 can be used to determine the period of the pulses, and the period of the on time and the off time. The output pulse pattern of the 555 timer operated in the astable mode is shown in Figure 540.9 along with the equations needed to determine the overall period and frequency as well as the period for the on time and off time.

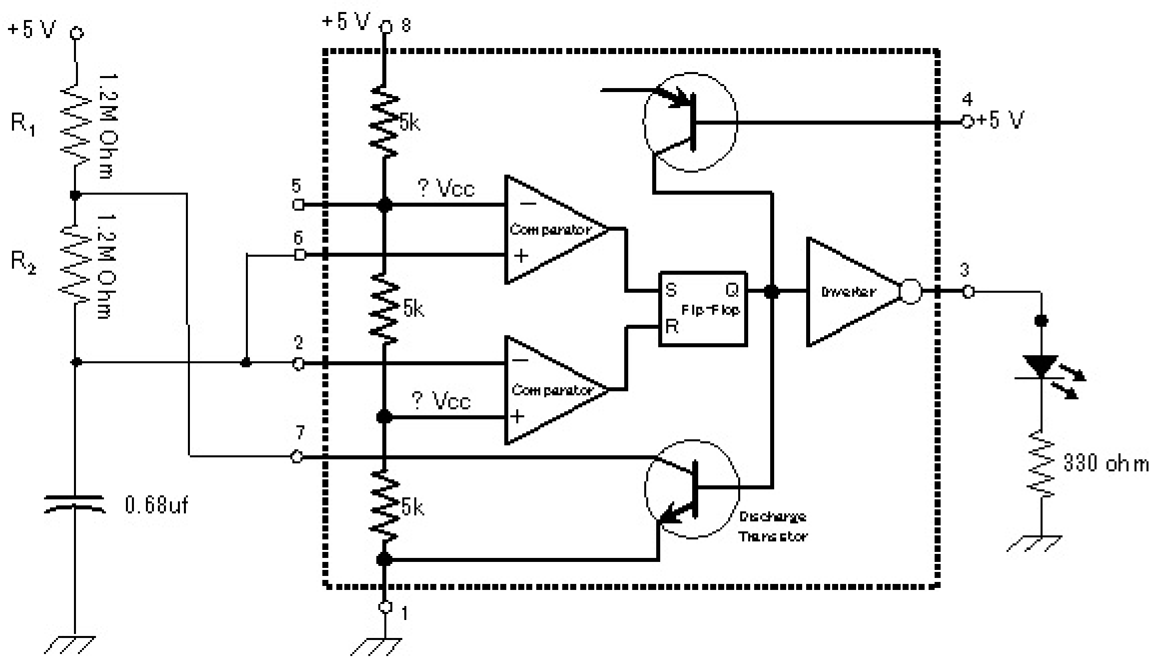

Figure 540.8 *To operate the 555 timer in the astable pulse mode two series resistors connected in series with a capacitor are connected to the comparators and discharge transistor to create an repetitive series of pulses.*

$$f = \frac{1.443}{C \times (R_1 + 2R_2)}$$ **Equation 540.2**

$$P = \frac{1}{f}$$ **Equation 540.3**

On period (t_1) $t_1 = 0.693 \times C \times (R_1 + R_2)$ **Equation 540.4**

Off period (t_2) $t_2 = 0.693 \times C \times R_2$ **Equation 540.5**

When the values of the two resistors in the RC circuit are the same (R1 = R2) the previous equations are simplified. When a particular frequency is desires and the value of the resistors or the capacitor is chosen, the following equations can be used to determine the value of the other component to achieve the desired frequency.

$$C = \frac{0.481}{f \times R}$$ **Equation 540.6**

$$R = \frac{0.481}{f \times C}$$ **Equation 540.7**

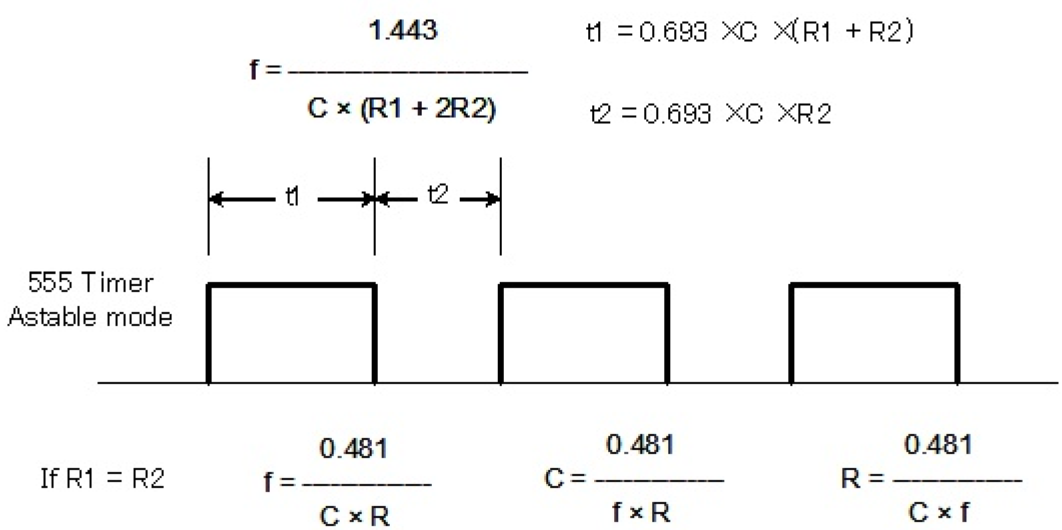

***Figure 540.9** The astable mode of operation of the 555 timer produces a continuous series of pulses with a period that can be calculated based upon the charging equation for a series RC circuit.*

Conclusion: The 555 timer though a digital device that was developed in the distant past is rugged and has many useful applications. Refer to Figures 540.1, 540.5, 540.6, and 540.8 for terminal numbers and connections for operating the 555 timer in the one-shot time delay mode and the astable pulse generating mode.