Electrical Tech Note — 537

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Oscillators and Timers

Many electronic circuits require either a repetitive waveform with a specific frequency or they may require a means of counting or keeping time. Oscillators are used to convert a steady dc supply into a repetitive waveform at the desired frequency. This Tech Note will explore the basic operation of oscillators and the operation of a timing device knows as the 555 timer. There are many more advanced timers in use today, but they all function in a manner similar to the basic oscillator circuit and a timer known as the 555 timer. In this Tech Note references will be made to general operating principles of capacitors discussed in Tech Note 512, of inductors discussed in Tech Note 513, and of resonance discussed in Tech Note 514.

LC Oscillator: A *tank circuit* consisting of a capacitor in parallel with an inductor can be used to generate a repetitive sine wave with a frequency depending upon the value of capacitance and inductance. The frequency is that at which the circuit achieves *resonance*. All that is required is for a dc supply to place a charge on the capacitor. Figure 537.1 shows a capacitor connected in parallel with an inductor and a dc voltage source with a switch in the voltage source branch.

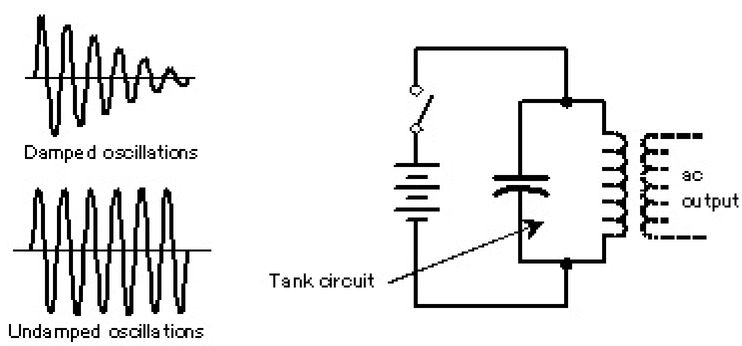

Figure 537.1 *Many oscillators use a tank circuit consisting of a capacitor in parallel with an inductor to produce a sinusoidal waveform at the resonant frequency of the circuit.*

When the voltage source is removed, the charge on the capacitor will be drained by passing current through the inductor. Current flow through the inductor results in a magnetic flux build-up around the inductor coil. The energy that was once stored in the charge on the capacitor plates is now stored as a magnetic flux around the inductor coil. When the capacitor becomes fully drained of charge, current stops and the magnetic flux around the inductor coil collapses, resulting is a continuation of current flow in the wires which again places a charge of the opposite polarity on the capacitor plates. The energy of the magnetic flux is then returned to the plates of the capacitor. The charge on the capacitor plates is now reversed and the process starts over again but with current flow in the opposite direction. The capacitor discharges through the inductor transferring the energy to a magnetic flux around the inductor coil. When the capacitor charge is fully drained, the magnetic flux build-up around the inductor coil collapses and continues the current flow thus transferring the energy back to the capacitor. One cycle has been completed and the process would continue endlessly at the resonant frequency of the circuit if it were not for the resistance of the wires. Current flow through a resistance produces heat which is energy lost from the circuit. This is called *damping*, and within a few cycles the waveform will have decayed to zero as shown in Figure 537.1. This lost energy can be restored if there is a way of making a brief connection to the dc source at just the right moment.

LC Oscillators: Even if the LC tank circuit has a high quality factor (high Q) there will still be some resistance in the circuit that will use energy and cause damping of the waveform. The oscillator will also feed into another circuit and that circuit will drain some of the energy. If the switch in the dc supply branch of Figure 537.1 can be closed briefly at just the right moment each cycle, the lost energy could be restored and the oscillator will operate continuously. Figure 537.2 shows circuits for two basic techniques utilizing an LC tank as the source of oscillations. The circuits shown utilize bipolar transistors as a switching device and amplifier to restore the lost energy (*regeneration*), but vacuum tubes, field effect transistors (FETs) and operational amplifiers can also be used. There are many types of oscillator circuits, but for the circuits shown in Figure 537.2, the sine wave output is through inductive coupling from the tank circuit inductor.

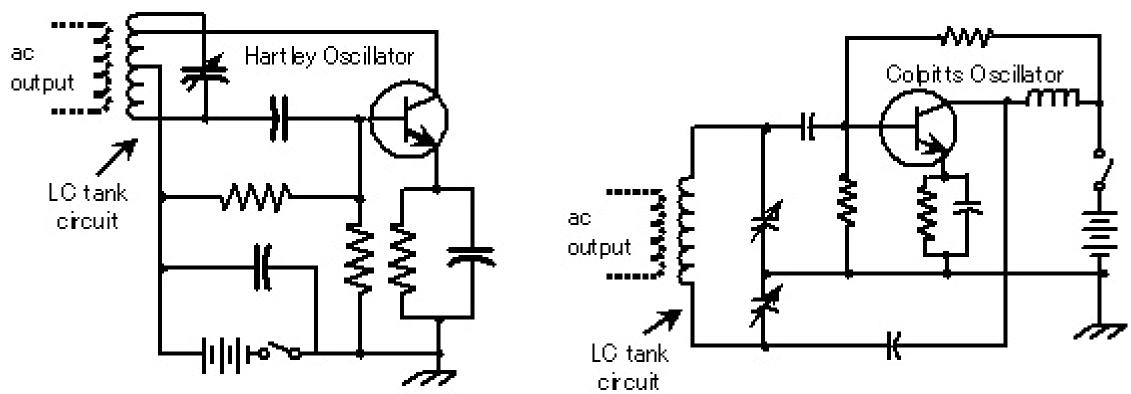

Figure 537.2 *Two basic oscillator circuits are the Hartley and Colpitts oscillators where the tank circuit is tapped to provide feedback to the switching device so that external current flow can be supplied to the coil at just the right moment.*

Crystal Oscillators: A crystal such as quartz exhibits what is known as the *piezoelectric effect*. If a very thin quartz crystal is sandwiched between two metal plates and pressure is applied to the metal plates they will squeeze the crystal. A small voltage can be measured between the two plates as pressure is applied. When the pressure is released, the crystal will return to it's original dimensions and while that is happening a voltage of opposite polarity can be measured between the metal plates. The quartz crystal will convert mechanical energy into electrical energy.

The piezoelectric process is actually reversible where electrical energy can be converted to mechanical energy by the crystal. If a voltage is applied to the metal plates, the crystal will distort. If the polarity of the voltage on the plates is reversed, the distortion will be in the opposite direction. If a sudden voltage is applied to the metal plates of the crystal and then immediately removed, a mechanical wave of distortion will occur in the crystal that will persist for a number of cycles before damping eventually brings it to a halt. As this cyclic mechanical distortion is occurring a voltage is produced between the metal plates that changes in polarity depending upon the direction of distortion of the crystal. The frequency of the mechanical vibration, and thus the frequency of the voltage oscillations of the metal plates, depends primarily upon the thickness of the crystal. An advantage of using crystal oscillators rather than electronic components is that they can produce oscillations at higher frequencies than LC oscillators and they tend to produce a much more stable oscillation.

Crystal oscillators can be purchased as complete timing packages for such tasks as pulse generators for microcomputers and other digital applications. Figure 537.3 shows the schematic symbol for a crystal in an oscillator circuit. If an electrical equivalent circuit was to be constructed for the crystal it would be a series connected inductor, capacitor, and resistor. Since both sides of the crystal are coated with a thin metal film (usually silver) there is a capacitance between these metal plates. This capacitance is in parallel with the equivalent circuit of the crystal. An oscillator crystal equivalent circuit is also shown in Figure 537.3 and it essentially is a parallel LC circuit. Mechanical distortion of the crystal produces electrical energy which is then stored on the plates of the capacitor which in turn produces mechanical distortion of the crystal. With such a crystal mechanical energy is converted to electrical energy and then back to mechanical energy in a repetitive manner. A switching and amplifying circuit is used to apply a voltage across the crystal at just the right moment to replace lost energy and keep the sustain crystal oscillations. A Colpitts crystal oscillator using a bipolar transistor is shown in Figure 537.3.

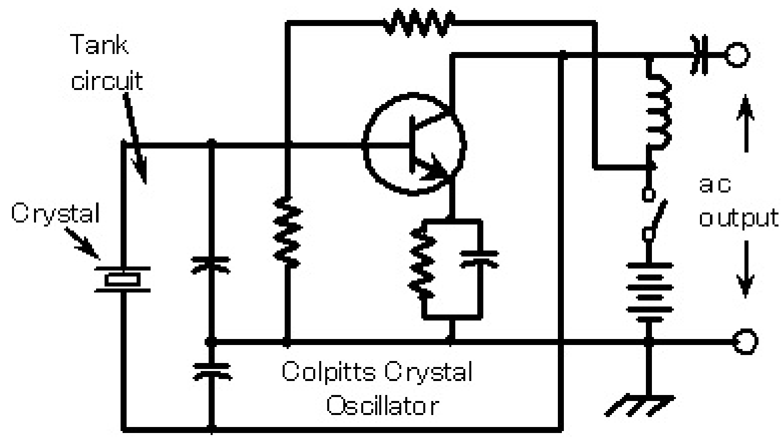

Figure 537.3 *In this Colpitts oscillator circuit a crystal replaces the inductor to form an equivalent tank circuit that produces oscillations at a fixed frequency depending upon the characteristics of the crystal.*

555 Timer: The operation of digital circuits requires a device that will produce a binary output of 0 or 1 at a specified rate. A binary *zero (0)* state is generally ground potential and a binary *one (1)* is some voltage high enough to trigger the electronic components used in the circuit. In the case of devices based upon bipolar transistors (TTL) the nominal one state is +5 Vdc. The 555 timer and similar timing devices can produce a continuous output of zero and one pulses where the frequency is determined by the selection of external components and the duration of the one and zero states can also be manipulated to fit the needs of the circuit. A schematic diagram of the internal circuitry of the 555 timer is shown in Figure 537.4. The timer gets it's name from the voltage divider which consists of three 5k ohm resistors in series at the input of the timer. This voltage divider creates two reference voltages ($\frac{2}{3}$ Vcc and $\frac{1}{3}$ Vcc) that feed into an op-amp comparator. The frequency of the output pulses is determined by an external RC charging circuit. When the voltage across the external capacitor reaches the threshold level of the upper comparator the bottom bipolar transistor shorts out the capacitor and the process repeats. The values of resistors R1 plus R2 determine the charging rate of the capacitor and the value of resistor R2 controls the discharging rate. Other components within the timer is a device called an RS flip-flop and an amplifier at the output.

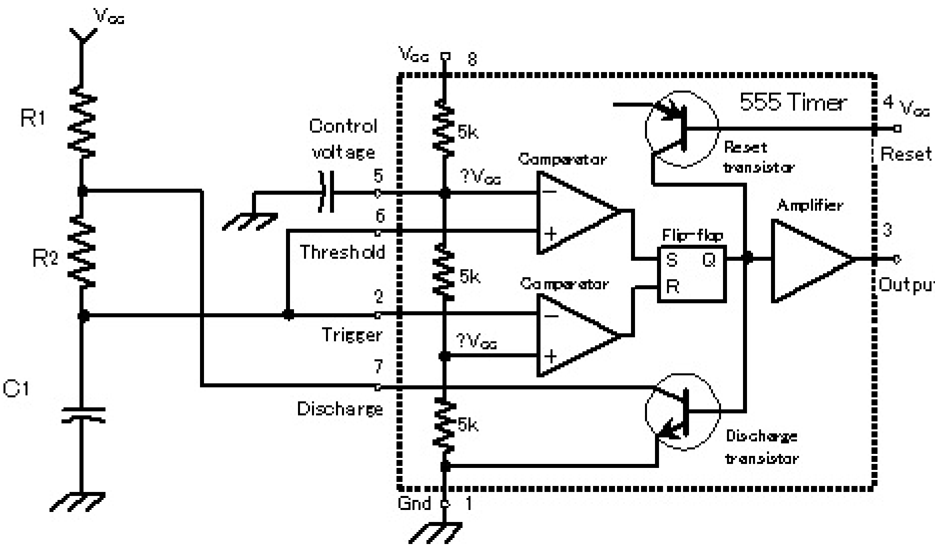

Figure 537.4. *This 555 timer circuit is for the astable mode where it produces a continuous series of pulses.*

This was the first commercially available IC timer introduced over 30 years ago. There have been many improvements over the years, but it remains to be used as a basic timing device in electronic circuits. It is available from a variety of manufacturers. A single timer is commonly mounted in an 8-pin package. The 556 timer has a 14-pin package and contains two 555 timers on a single chip. There is a quad version of the 555 timer in a 14-pin package known as the 558 timer. Between pin 8 (Vcc) and pin 1 (ground) are three 5k ohm resistors in series. These resistors form a voltage divider with 2/3 Vcc at one node and 1/3 Vcc at the other node. Each of these nodes are connected to the input of an op-amp comparator. The comparator outputs are connected to the inputs of an RS flip-flop. This RS flip-flop works like a “latch” that can have the output set at one or zero. The top comparator is connected to the set input (S) of the flip-flop and the bottom comparator is connected to the reset input (R). This type of flip-flop has two output terminals, but only the Q output is used. The flip-flop output is connected to a power output amplifier and two transistor switches. One transistor acts as a master reset if needed (pin 4). The other transistor is needed as a part of the timing cycle to creates a short-circuit to ground which is needed to discharge the timing capacitor. Timing is accomplished by choosing the values of the external capacitance and resistance. Operational variations are small for change in temperature and changes in supply voltage. Timing accuracy depends upon the tolerance of the external components. Typical supply voltages can range from 4.5 to 15 volts.

Refer to the previous diagram for the pin location on the package and the general description of the pin function on the schematic diagram. Pin 1 (ground) is to be connected to the power supply negative terminal and is the timer circuit ground. Pin 8 (+Vcc) is to be connected to the power supply positive terminal. It’s practical limits are 4.5 volts minimum to 16 volt maximum. This terminal is sometimes designated as (V+). The device will operate essentially the same over this operating range with only the output drive capability affected. The output drive capability is higher at the higher operating voltage.

Pin 5 is called the control voltage pin and is connected to the voltage divider at the 2/3 Vcc point. There are times in some circuits when access to this point is needed, but in most cases this pin is not used. It is not a good idea to just let this pin float, so it is recommended it be tied to ground with a 0.01 µf ceramic capacitor.

Pin 6 (threshold) is connected to the upper comparator and is used to reset the latch (flip-flop), which causes the output at pin 3 to go low (become 0). The voltage at this terminal will change as the external capacitor charges and discharges. The timer will be reset when the voltage at pin 6 changes from below 2/3 Vcc to above 2/3 Vcc. The voltage at this pin can range from ground to Vcc without any damage to the timer.

Pin 7 (discharge) is a transistor switch connected to ground used to discharge the timing capacitor. Pin 7 is connected to ground when the output at pin 3 is low (0). Resistance between pin 7 and ground is high when the output at pin 3 is high (+5 V). There is a small leakage current through the transistor of about 20 nA when the transistor is off.

Pin 4 (reset) is used to force the timer output to a low state (0) no matter what is going on with the rest of the circuit by taking this pin to 0.4 volts or less. When not in use it is recommended this pin be connected to Vcc to prevent any false operations of the timer.

Pin 2 (trigger) causes the output at pin 3 to go to the high state (+5 V). Triggering is accomplished with a fall in voltage by taking pin 2 from above 1/3 Vcc to below 1/3 Vcc. The trigger pulse must be shorter than the time interval determined by the external resistor and capacitor time constant. This trigger pulse needs to be at least 1μs or longer in duration. The current draw at pin 2 is about 500 nA which must flow through the external resistor. That resistor must be of low enough a value to allow this current flow at the supply voltage (Vcc) used. This point can be externally triggered causing the output to go high (+5 V) for a predetermined period of time from a fraction of a second to several days. This is known as monostable operation and the output will go low (0) after the timing is completed. Pin 2 can be connected to be automatically re-triggered so an endless series of pulses are generated. This is known as astable operation.

Pin 3 (output) is amplified and when the timer is connected to a +15 volt supply is about 200 mA. Theoutput high voltage will be about 1.7 volts less than Vcc. This means if Vcc is +5 volts, the output will be +3.3 volts. With a Vcc of +15 volts, the otput high vill be about +13.3 volts. To trigger the output to a high condition, the trigger input (pin 2) is momentarily taken from a high (+5 V) to a lower level. This causes the latch to be set and the output to go high (+5 V). Pin 2 is connected to the lower comparator and actuation of the lower comparator is the only way to go from a low (0) to a high level (+5 V) at the output. The lower comparator resets the “latch”. Switching time at the output is about 200 ns.

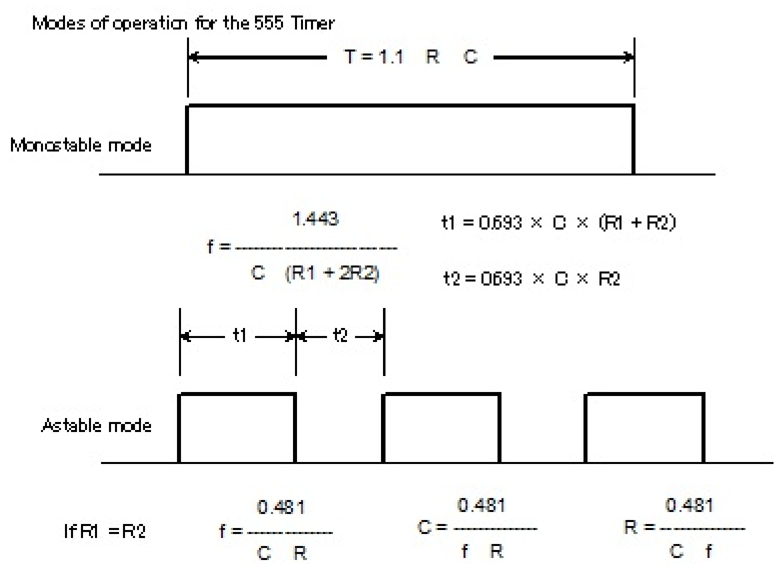

Figure 537.5. *The pulse pattern for both the monostable circuit of the 555 timer and the astable circuit. It is not possible for the pulse pattern t_1 and t_2 to be of equal duration.*

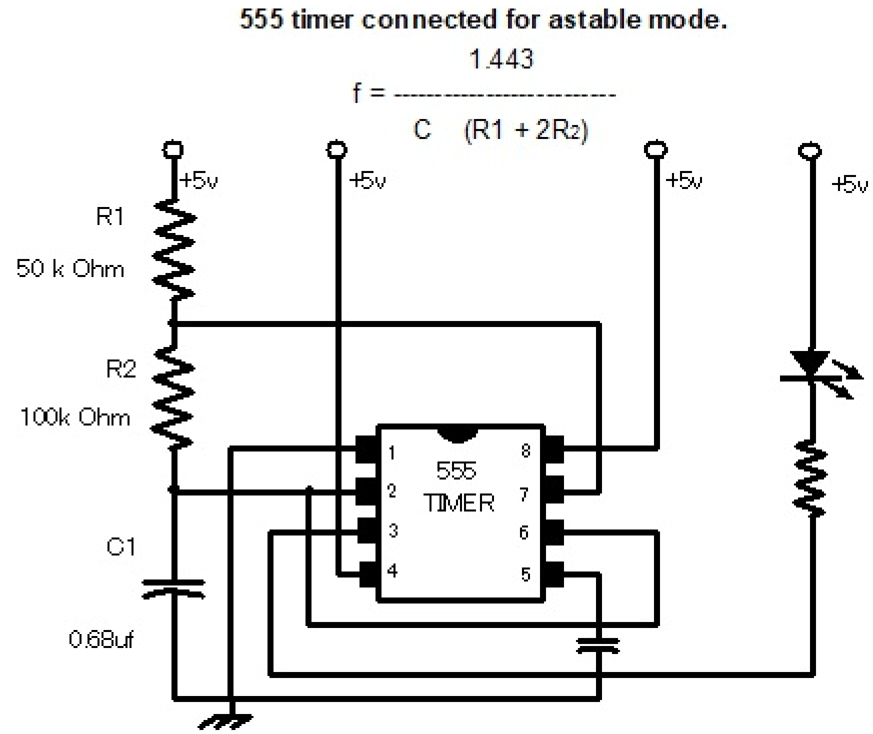

Figure 537.6. *The 555 timer connected in the astable mode.*

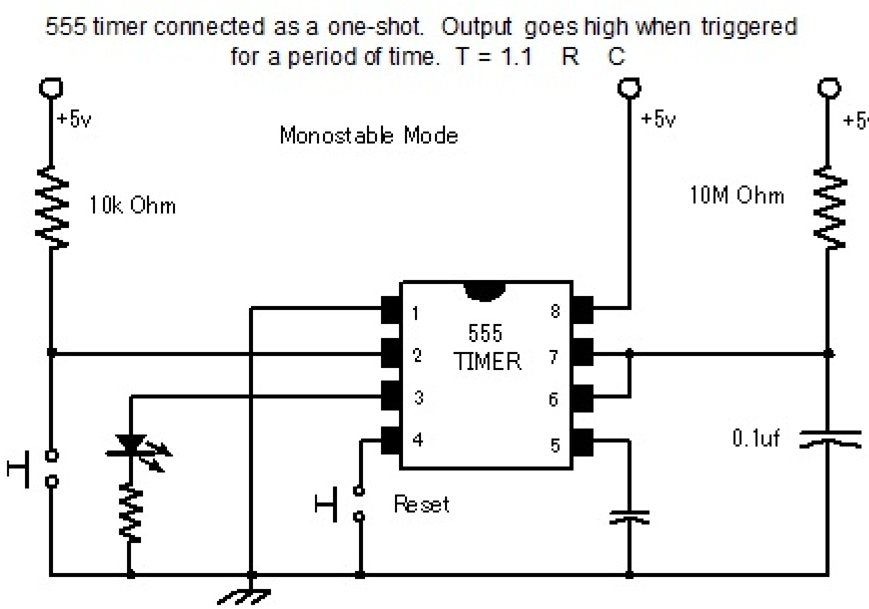

Figure 537.7. *The 555 timer connected in the monostable mode.*