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Waveform Generators (9)

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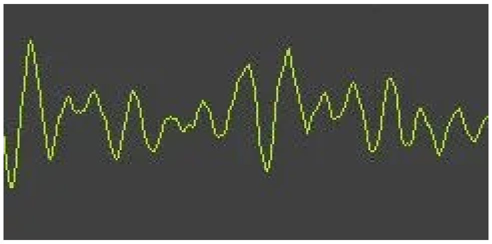
Electrical Waveforms

In the *Oscillators* tutorials we saw that an oscillator is an electronic circuit used to generate an ouput of continuous electrical waveforms. Generally this output signal is in the form of a sinusoid at some predetermined frequency or wavelength set by the resonant components of the circuit.

We also saw that there are many different types of oscillator circuits available but generally they all consist of an amplifier and either an Inductor-Capacitor, (LC) or Resistor-Capacitor, (RC) tank circuit used to produce a sine wave type output signal.

But sometimes in electronic circuits we need to produce many different types, frequencies and shapes of **Signal Waveforms** such as Square Waves, Rectangular Waves, Triangular Waves, Sawtooth Waveforms and a variety of pulses and spikes.



Typical Electrical Waveform

These types of signal waveform can then be used for either timing signals, clock signals or as trigger pulses. However, before we can begin to look at how the different types of waveforms are produced, we firstly need to understand the basic characteristics that make up **Electrical Waveforms**.

Technically speaking, **Electrical Waveforms** are basically visual representations of the variation of a voltage or current over time. In plain English this means that if we plotted these voltage or current variations on a piece of graph paper against a base (x-axis) of time, (t) the resulting plot or drawing would represent the shape of a **Waveform** as shown. There are many different types of electrical waveforms available but generally they can all be broken down into two distinctive groups.

1. Uni-directional Waveforms – these electrical waveforms are always positive or negative in nature flowing in one forward direction only as they do not cross the zero axis point. Common uni-directional waveforms include Square-wave timing signals, Clock pulses and Trigger pulses.
2. Bi-directional Waveforms – these electrical waveforms are also called alternating waveforms as they alternate from a positive direction to a negative direction constantly crossing the zero axis point. Bi-directional waveforms go through periodic changes in amplitude, with the most common by far being the Sine-wave.

Whether the waveform is uni-directional, bi-directional, periodic, non-periodic, symmetrical, non-symmetrical, simple or complex, all electrical waveforms include the following three common characteristics:

- ✔ Period: – This is the length of time in seconds that the waveform takes to repeat itself from start to finish. This value can also be called the *Periodic Time*, (T) of the waveform for sine waves, or the *Pulse Width* for square waves.
- ✔ Frequency: – This is the number of times the waveform repeats itself within a one second time period. Frequency is the reciprocal of the time period, ($f = 1/T$) with the standard unit of frequency being the *Hertz*, (Hz).
- ✔ Amplitude: – This is the magnitude or intensity of the signal waveform measured in volts or amps.

Periodic Waveforms

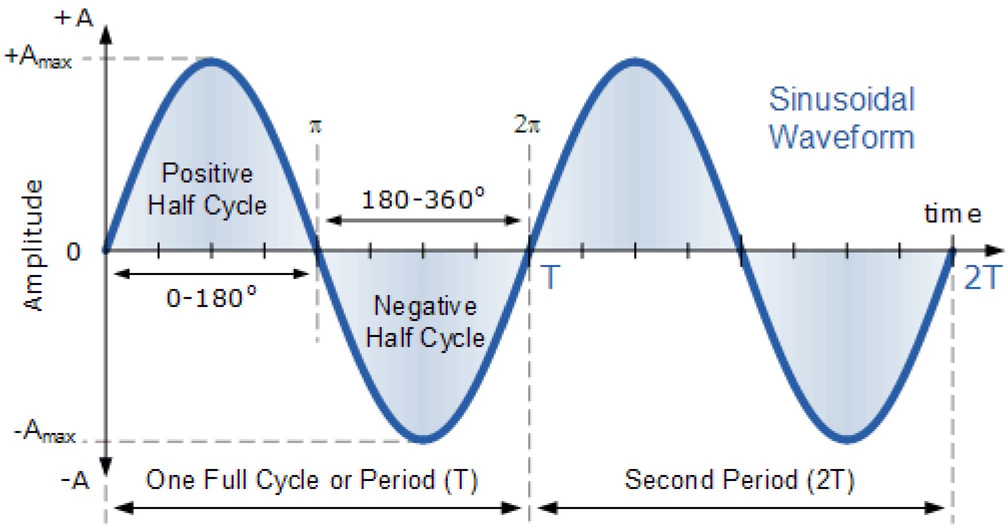
Periodic waveforms are the most common of all the electrical waveforms as it includes **Sine Waves**. The AC (Alternating Current) mains waveform in your home is a sine wave and one which constantly alternates between a maximum value and a minimum value over time.

The amount of time it takes between each individual repetition or cycle of a sinusoidal waveform is known as its "periodic time" or simply the *Period* of the waveform. In other words, the time it takes for the waveform to repeat itself.

Then this period can vary with each waveform from fractions of a second to thousands of seconds as it depends upon the frequency of the waveform. For example, a sinusoidal waveform which takes one second to complete its cycle will have a periodic time of one second. Likewise a sine wave which takes five seconds to complete will have a periodic time of five seconds and so on.

So, if the length of time it takes for the waveform to complete one full pattern or cycle before it repeats itself is known as the "period of the wave" and is measured in seconds, we can then express the waveform as a period number per second denoted by the letter T as shown below.

A Sine Wave Waveform



Units of periodic time, (T) include: Seconds (s), milliseconds (ms) and microseconds (μs).

For sine wave waveforms only, we can also express the periodic time of the waveform in either degrees or radians, as one full cycle is equal to 360° (T = 360°) or in Radians as 2pi, 2π (T = 2π), then we can say that 2π radians = 360° – (Remember this!).

We now know that the time it takes for electrical waveforms to repeat themselves is known as the periodic time or period which represents a fixed amount of time. If we take the reciprocal of the period, (1/T) we end up with a value that denotes the number of times a period or cycle repeats itself in one second or cycles per second, and this is commonly known as **Frequency** with units of **Hertz**, (**Hz**). Then Hertz can also be defined as "cycles per second" (cps) and 1Hz is exactly equal to 1 cycle per second.

Relationship between Frequency and Periodic Time

$$\text{Frequency} = \frac{1}{\text{Periodic time}} \quad \text{or} \quad f = \frac{1}{T}\ \text{Hz}$$

$$\text{Periodic time} = \frac{1}{\text{Frequency}} \quad \text{or} \quad T = \frac{1}{f}\ \text{sec}$$

Where: f is in Hertz and T is in Seconds.

One **Hertz** is exactly equal to one cycle per second, but one hertz is a very small unit so prefixes are used that denote the order of magnitude of the waveform such as **kHz**, **MHz** and even **GHz**.

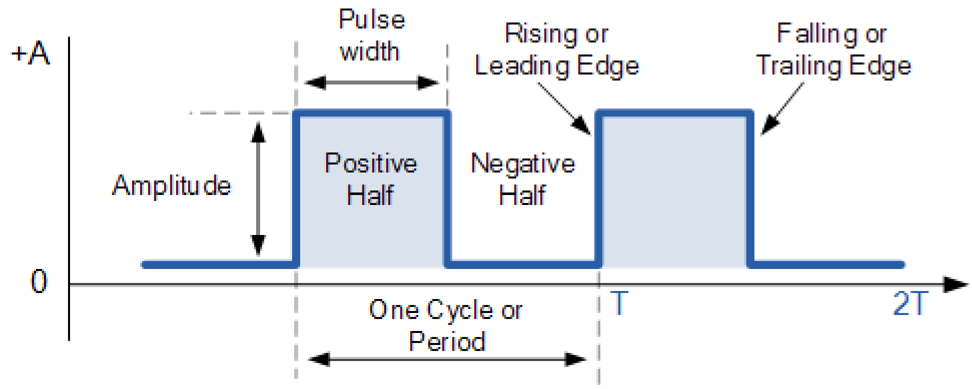
Prefix	Definition	Written as	Time Period
Kilo	Thousand	kHz	1ms
Mega	Million	MHz	1us
Giga	Billion	GHz	1ns
Tera	Trillion	THz	1ps

Square Wave Electrical Waveforms

Square-wave Waveforms are used extensively in electronic and micro electronic circuits for clock and timing control signals as they are symmetrical waveforms of equal and square duration representing each half of a cycle and nearly all digital logic circuits use square wave waveforms on their input and output gates.

Unlike sine waves which have a smooth rise and fall waveform with rounded corners at their positive and negative peaks, square waves on the other hand have very steep almost vertical up and down sides with a flat top and bottom producing a waveform which matches its description, – "Square" as shown below.

A Square Wave Waveform



We know that square shaped electrical waveforms are symmetrical in shape as each half of the cycle is identical, so the time that the pulse width is positive must be equal to the time that the pulse width is negative or zero. When square wave waveforms are used as "clock" signals in digital circuits the time of the positive pulse width is known as the "Duty Cycle" of the period.

Then we can say that for a square wave waveform the positive or "ON" time is equal to the negative or "OFF" time so the duty cycle must be 50%, (half of its period). As frequency is equal to the reciprocal of the period, (1/T) we can define the frequency of a square wave waveform as:

$$\text{Frequency} = \frac{1}{\text{"ON" time} + \text{"OFF" time}}$$

Electrical Waveforms Example No1

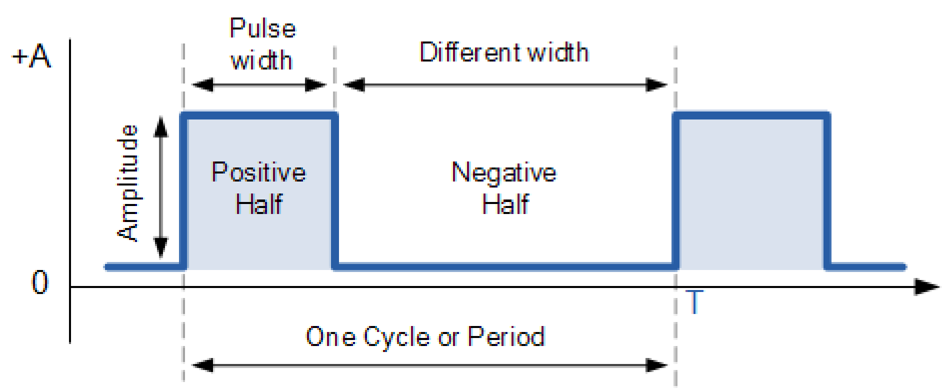
A Square Wave electrical waveform has a pulse width of 10ms, calculate its frequency, (f).

For a square wave shaped waveform, the duty cycle is given as 50%, therefore the period of the waveform must be equal to: 10ms + 10ms or 20ms

$$\text{Frequency} = \frac{1}{\text{Period}} = \frac{1}{10\text{mS} + 10\text{mS}} = 50\text{Hz}$$

So to summarise a little about Square Waves. A **Square Wave Waveform** is symmetrical in shape and has a positive pulse width equal to its negative pulse width resulting in a 50% duty cycle. Square wave waveforms are used in digital systems to represent a logic level "1", high amplitude and logic level "0", low amplitude. If the duty cycle of the waveform is any other value than 50%, (half-ON half-OFF) the resulting waveform would then be called a **Rectangular Waveform** or if the "ON" time is really small a **Pulse**.

A Rectangular Waveform



The example above shows that the positive pulse width is shorter in time than the negative pulse width. Equally, the negative pulse width could be shorter than the positive pulse width, either way the resulting waveform shape would still be that of a rectangular waveform.

These positive and negative pulse widths are sometimes called "Mark" and "Space" respectively, with the ratio of the Mark time to the Space time being known as the "Mark-to-Space" ratio of the period and for a Square wave waveform this would be equal to one.

Electrical Waveforms Example No2

A Rectangular waveform has a positive pulse width (Mark time) of 10ms and a duty cycle of 25%, calculate its frequency.

The duty cycle is given as 25% or 1/4 of the total waveform which is equal to a positive pulse width of 10ms. If 25% is equal to 10mS, then 100% must be equal to 40mS, so then the period of the waveform must be equal to: 10ms (25%) + 30ms (75%) which equals 40ms (100%) in total.

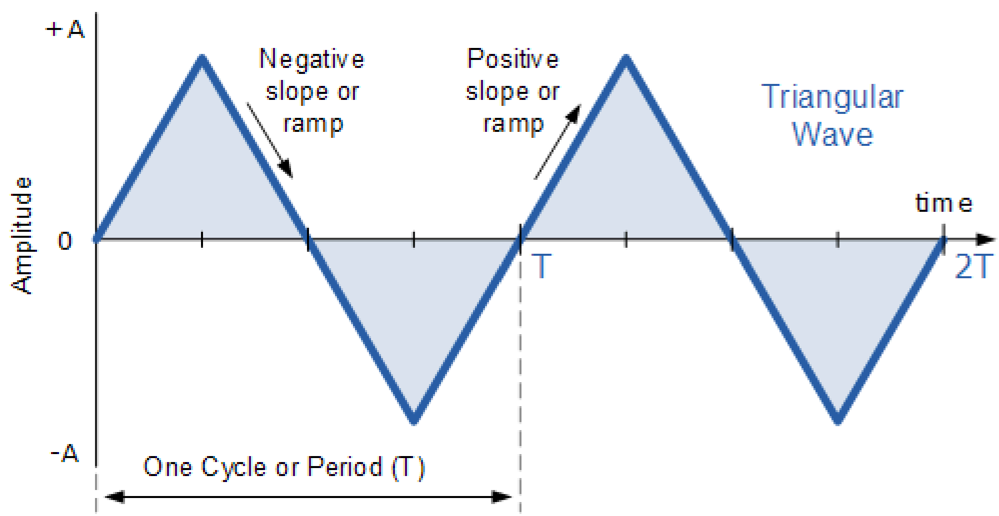
$$\text{Frequency} = \frac{1}{\text{Period}} = \frac{1}{10\text{mS} + 30\text{mS}} = 25\text{Hz}$$

Rectangular Waveforms can be used to regulate the amount of power being applied to a load such as a lamp or motor by varying the duty cycle of the waveform. The higher the duty cycle, the greater the average amount of power being applied to the load and the lower the duty cycle, the less the average amount of power being applied to the load and an excellent example of this is in the use of “Pulse Width Modulation” speed controllers.

Triangular Waveforms

Triangular Waveforms are generally bi-directional non-sinusoidal waveforms that oscillate between a positive and a negative peak value. Although called a triangular waveform, the triangular wave is actually more of a symmetrical linear ramp waveform because it is simply a slow rising and falling voltage signal at a constant frequency or rate. The rate at which the voltage changes between each ramp direction is equal during both halves of the cycle as shown below.

A Triangular Waveform

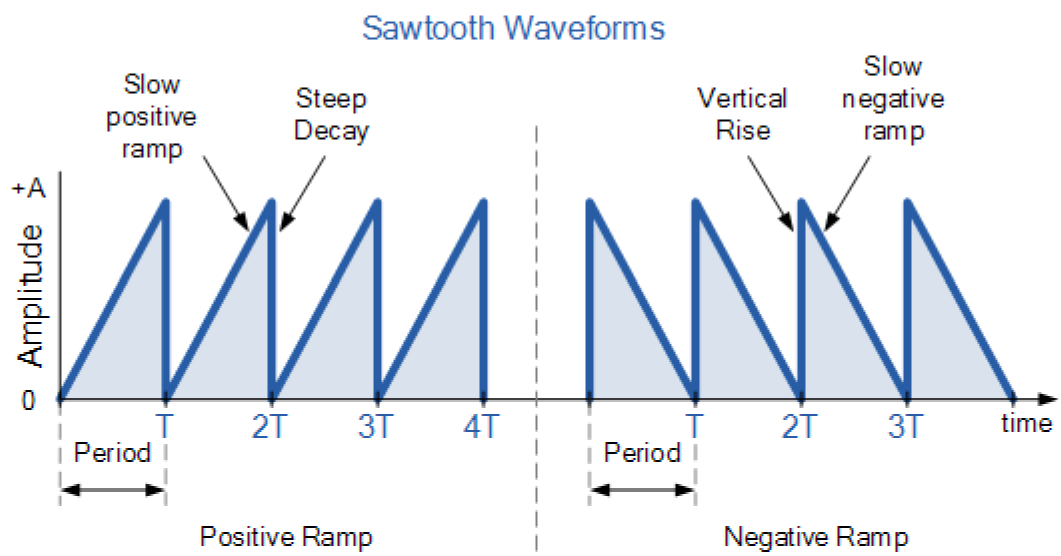


Generally, for **Triangular Waveforms** the positive-going ramp or slope (rise), is of the same time duration as the negative-going ramp (decay) giving the triangular waveform a 50% duty cycle. Then any given voltage amplitude, the frequency of the waveform will determine the average voltage level of the wave over time.

So for a slow rise and slow delay time of the ramp will give a lower average voltage level than a faster rise and decay time. However, we can produce non-symmetrical triangular waveforms by varying either the rising or decaying ramp values to give us another type of waveform known commonly as a **Sawtooth Waveform**.

Sawtooth Waveforms

Sawtooth Waveforms are another type of periodic waveform. As its name suggests, the shape of the waveform resembles the teeth of a saw blade. Sawtoothed waveforms can have a mirror image of themselves, by having either a slow-rising but extremely steep decay, or an extremely steep almost vertical rise and a slow-decay as shown below.



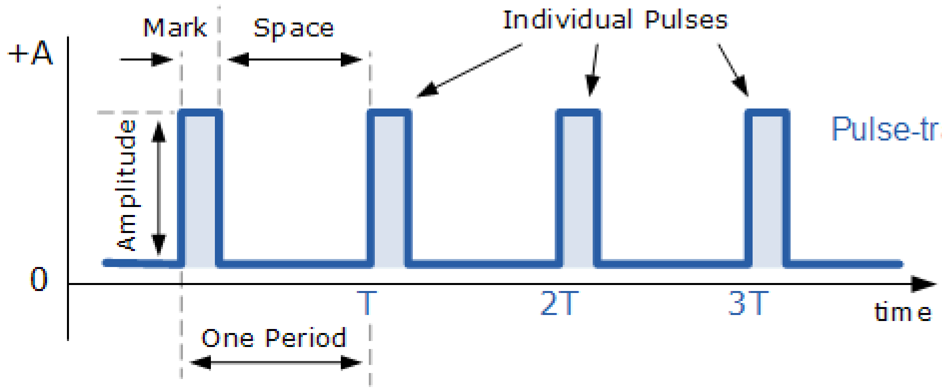
The positive ramp **Sawtooth Waveform** is the more common of the two waveform types with the ramp portion of the wave being almost perfectly linear. The Sawtooth waveform is commonly available from most function generators and consists of a fundamental frequency (*ƒ*) and all its integer ratios of harmonics, such as: 1/2, 1/4, 1/6 1/8 … 1/n etc. What this means in practical terms is that the **Sawtooth Waveform** is rich in harmonics and for music synthesizers and musicians gives the quality of the sound or tonal colour to their music without any distortion.

Trigger and Pulse Electrical Waveforms

Although technically **Triggers** and **Pulses** are two separate waveforms, we can combine them together here, as a “Trigger” is basically just a very narrow “Pulse”. The difference being is that a trigger can be either positive or negative in direction whereas a pulse is only positive in direction.

A **Pulse Waveform** or "Pulse-train" as they are more commonly called, is a type of non-sinusoidal waveform that is similar to the Rectangular waveform we looked at earlier. The difference being that the exact shape of the pulse is determined by the "Mark-to-Space" ratio of the period and for a pulse or trigger waveform the Mark portion of the wave is very short with a rapid rise and decay shape as shown below.

Pulse Electrical Waveforms



A **Pulse** is a waveform or signal in its own right. It has very different Mark-to-Space ratio compared to a high frequency square wave clock signal or even a rectangular waveform.

The purpose of a "Pulse" and that of a trigger is to produce a very short signal to control the time at which something happens for example, to start a Timer, Counter, Monostable or Flip-flop etc, or as a trigger to switch "ON" *Thyristors*, *Triacs* and other power semiconductor devices.

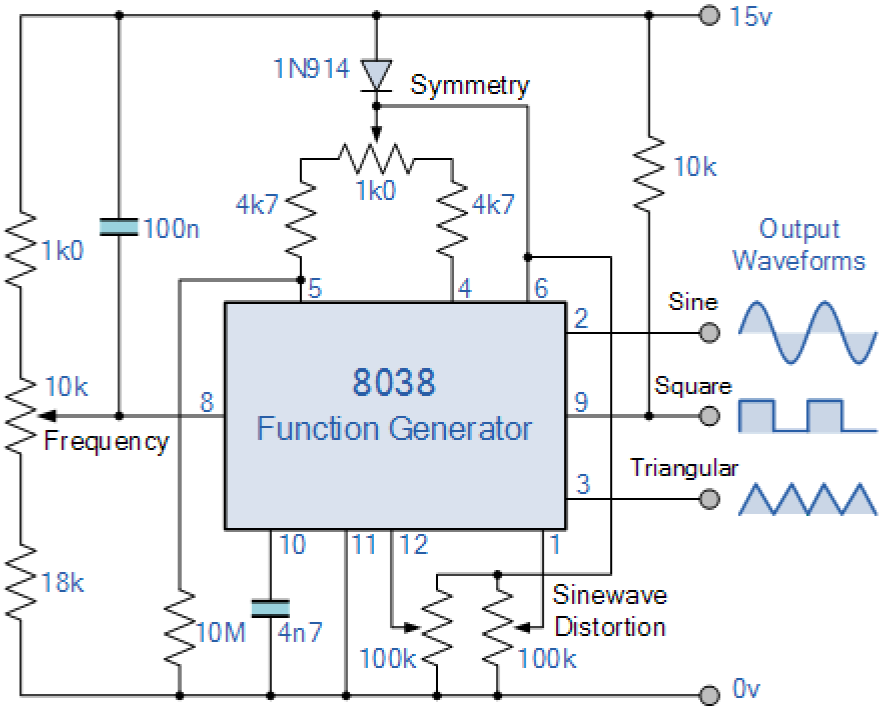
Function Generator

A **Function Generator** or sometimes called a **Waveform Generator** is a device or circuit that produces a variety of different waveforms at a desired frequency. It can generate Sine waves, Square waves, Triangular and Sawtooth waveforms as well as other types of output waveforms.

There are many "off-the-shelf" waveform generator IC's available and all can be incorporated into a circuit to produce the different periodic waveforms required.

One such device is the 8038 a precision waveform generator IC capable of producing sine, square and triangular output waveforms, with a minimum number of external components or adjustments. Its operating frequency range can be selected over eight decades of frequency, from 0.001Hz to 300kHz, by the correct choice of the external R-C components.

Electrical Waveforms Generator IC



The frequency of oscillation is highly stable over a wide range of temperature and supply voltage changes and frequencies as high as 1MHz is possible. Each of the three basic waveform outputs, sinusoidal, triangular and square are simultaneously available from independent output terminals. The frequency range of the 8038 is voltage controllable but not a linear function. The triangle symmetry and hence the sine wave distortion are adjustable.

In the next tutorial about Waveforms, we will look at **Multivibrators** that are used to produce continuous output waveforms or single individual pulses. One such multivibrator circuit that is used as a pulse generator is called a Monostable Multivibrator.

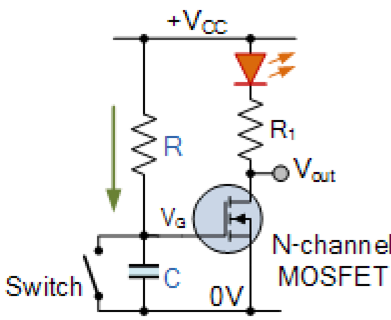
https://www.electronics-tutorials.ws/waveforms/monostable.html

Monostable Multivibrator

Multivibrators produce an output wave shape resembling that of a symmetrical or asymmetrical square wave and as such are the most commonly used of all the square wave generators. The monostable multivibrator belongs to a family of oscillators commonly called "**Relaxation Oscillators**".

Generally speaking, discrete multivibrators consist of a two transistor cross coupled switching circuit designed so that one or more of its outputs are fed back as an input to the other transistor with a resistor and capacitor (RC) network connected across them to produce the feedback tank circuit.

Multivibrators have two different electrical states, an output "HIGH" state and an output "LOW" state giving them either a stable or quasi-stable state depending upon the type of multivibrator. One such type of a two state pulse generator configuration are called **Monostable Multivibrators**.



MOSFET Monostable Multivibrator

Monostable Multivibrators have only ONE stable state (hence their name: "Mono"), and produce a single output pulse when it is triggered externally. Monostable Multivibrators only return back to their first original and stable state after a period of time determined by the time constant of the RC coupled circuit.

Consider the MOSFET circuit on the left. The resistor R and capacitor C form an RC timing circuit. The N-channel enhancement mode MOSFET is switched "ON" due to the voltage across the capacitor with the drain connected LED also "ON".

When the switch is closed the capacitor is short circuited and therefore discharges while at the same time the gate of the MOSFET is shorted to ground. The MOSFET and therefore the LED are both switched "OFF". While the switch is closed the circuit will always be "OFF" and in its "unstable state".

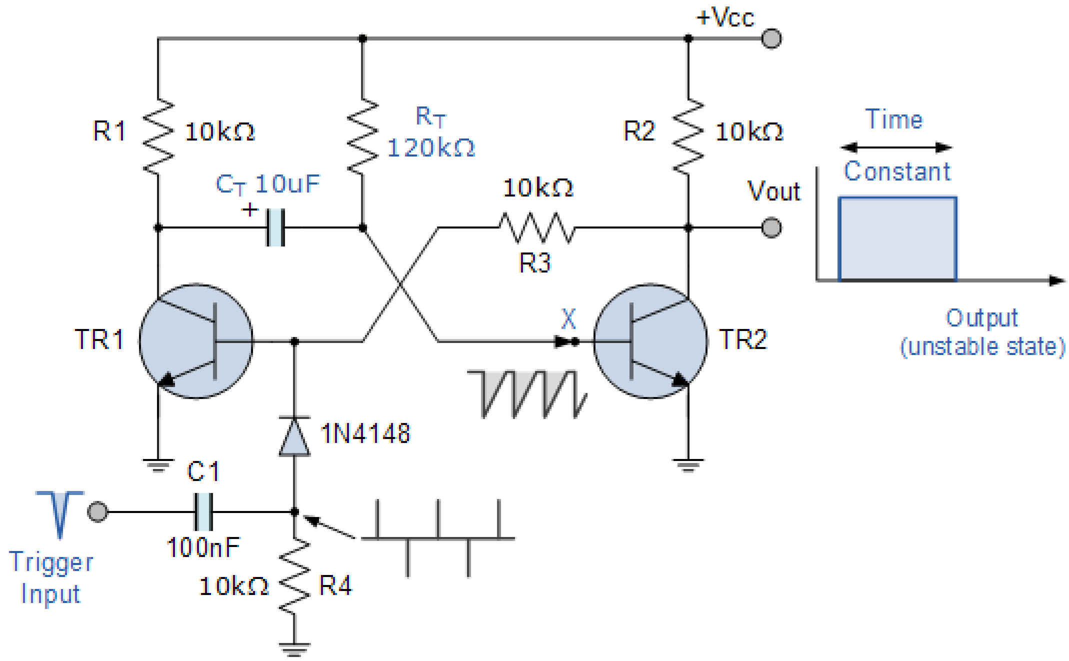
When the switch is opened, the fully discharged capacitor starts to charge up through the resistor, R at a rate determined by the RC time constant of the resistor-capacitor network. Once the capacitors charging voltage reaches the lower threshold voltage level of the MOSFETs gate, the MOSFET switches "ON" and illuminates the LED returning the circuit back to its stable state.

Then the application of the switch causes the circuit to enter its unstable state, while the time constant of the RC network returns it back to its stable state after a preset timing period thereby producing a very simple "one-shot" or **Monostable Multivibrator** MOSFET circuit.

Monostable Multivibrators or "One-Shot Multivibrators" as they are also called, are used to generate a single output pulse of a specified width, either "HIGH" or "LOW" when a suitable external trigger signal or pulse T is applied. This trigger signal initiates a timing cycle which causes the output of the monostable to change its state at the start of the timing cycle and will remain in this second state.

The timing cycle of the monostable is determined by the time constant of the timing capacitor, C_T and the resistor, R_T until it resets or returns itself back to its original (stable) state. The monostable multivibrator will then remain in this original stable state indefinitely until another input pulse or trigger signal is received. Then, **Monostable Multivibrators** have only **ONE** stable state and go through a full cycle in response to a single triggering input pulse.

Monostable Multivibrator Circuit



The basic collector-coupled transistor Monostable Multivibrator circuit and its associated waveforms are shown above. When power is firstly applied, the base of transistor TR2 is connected to Vcc via the biasing resistor, R_T thereby turning the transistor "fully-ON" and into saturation and at the same time turning TR1 "OFF" in the process. This then represents the circuits "Stable State" with zero output. The current flowing into the saturated base terminal of TR2 will therefore be equal to $Ib = (Vcc - 0.7)/R_T$.

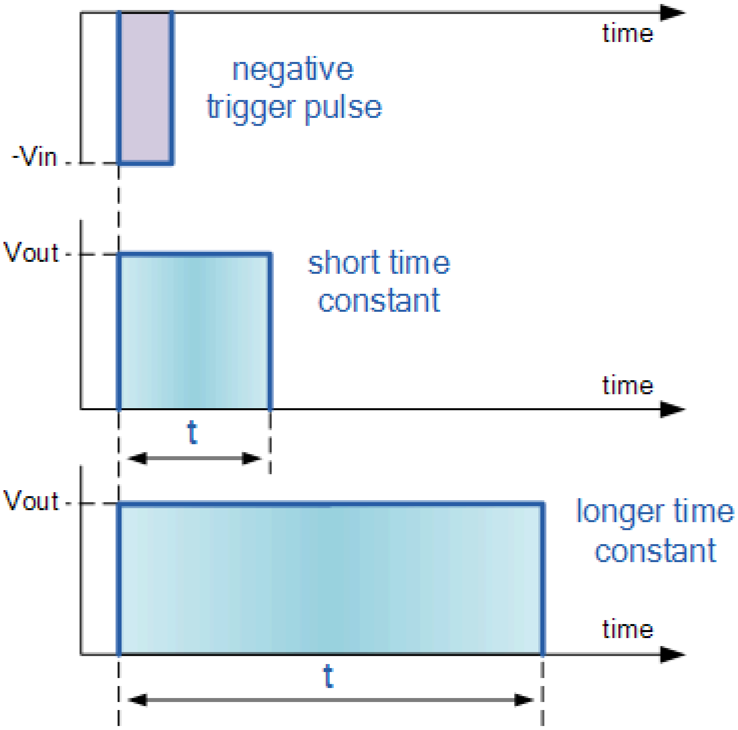
If a negative trigger pulse is now applied at the input, the fast decaying edge of the pulse will pass straight through capacitor, C1 to the base of transistor, TR1 via the blocking diode turning it "ON". The collector of TR1 which was previously at Vcc drops quickly to below zero volts effectively giving capacitor C_T a reverse charge of -0.7v across its plates. This action results in transistor TR2 now having a minus base voltage at point X holding the transistor fully "OFF". This then represents the circuits second state, the "Unstable State" with an output voltage equal to Vcc.

Timing capacitor, C_T begins to discharge this -0.7v through the timing resistor R_T, attempting to charge up to the supply voltage Vcc. This negative voltage at the base of transistor TR2 begins to decrease gradually at a rate determined by the time constant of the R_T C_T combination.

As the base voltage of TR2 increases back up to Vcc, the transistor begins to conduct and doing so turns "OFF" again transistor TR1 which results in the monostable multivibrator automatically returning back to its original stable state awaiting a second negative trigger pulse to restart the process once again.

Monostable Multivibrators can produce a very short pulse or a much longer rectangular shaped waveform whose leading edge rises in time with the externally applied trigger pulse and whose trailing edge is dependent upon the RC time constant of the feedback components used. This RC time constant may be varied with time to produce a series of pulses which have a controlled fixed time delay in relation to the original trigger pulse as shown below.

Monostable Multivibrator Waveforms

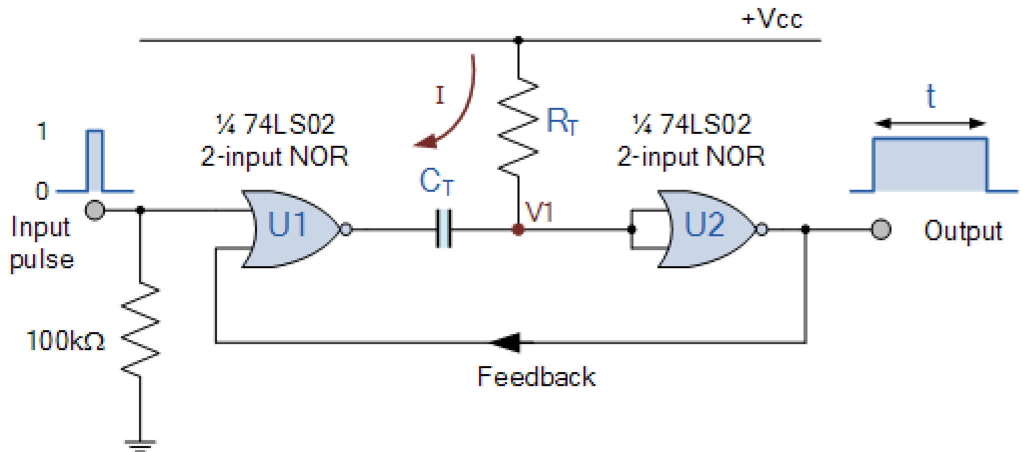


The time constant of **Monostable Multivibrators** can be changed by varying the values of the capacitor, C_T the resistor, R_T or both. Monostable multivibrators are generally used to increase the width of a pulse or to produce a time delay within a circuit as the frequency of the output signal is always the same as that for the trigger pulse input, the only difference is the pulse width.

TTL/CMOS Monostable Multivibrator

As well as producing Monostable Multivibrators from individual discrete components such as transistors, we can also construct monostable circuits using commonly available integrated circuits. The following circuit shows how a basic monostable multivibrator circuit can be constructed using just two 2-input Logic “NOR” Gates.

NOR Gate Circuit



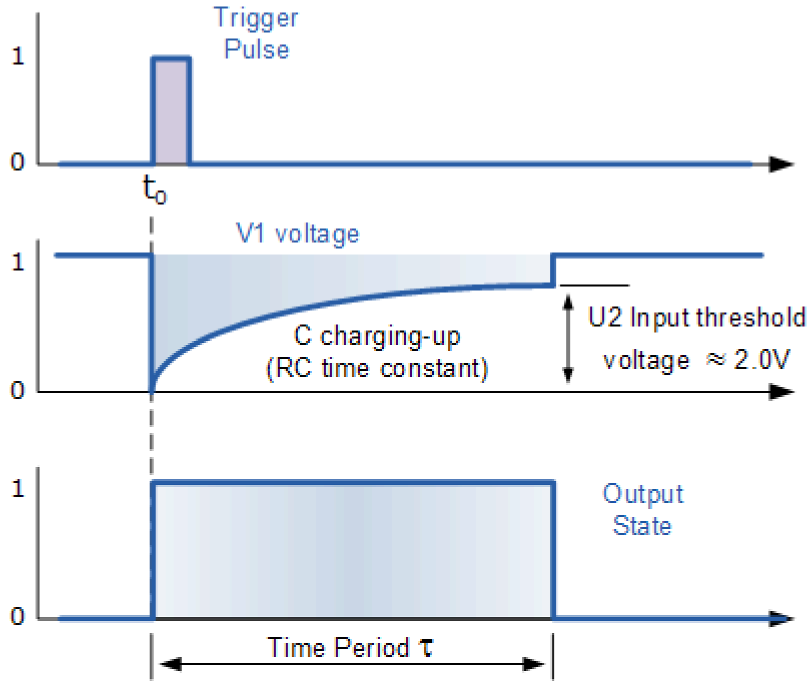
Suppose initially that the trigger input is LOW at a logic level “0” so that the output from the first NOR gate U1 is HIGH at logic level “1”, (NOR gate principals). The resistor, RT is connected to the supply voltage so is also equal to logic level “1”, which means that the capacitor, C_T has the same charge on both of its plates. Junction V1 is therefore equal to this voltage so the output from the second NOR gate U2 will be LOW at logic level “0”. This then represents the circuits “Stable State” with zero output.

When a positive trigger pulse is applied to the input at time t0, the output of the first NOR gate U1 goes LOW taking with it the left hand plate of capacitor CT thereby discharging the capacitor. As both plates of the capacitor are now at logic level “0”, so too is the input to the second NOR gate, U2 resulting in an output equal to logic level “1”. This then represents the circuits second state, the “Unstable State” with an output voltage equal to +Vcc.

The second NOR gate, U2 will maintain this second unstable state until the timing capacitor now charging up through resistor, R_T reaches the minimum input threshold voltage of U2 (approx. 2.0V). This causes U2 to change state as a logic level “1” value has now appeared on its inputs.

The NOR gates output resets to logic “0” which in turn is fed back (feedback loop) to one input of U1. This action automatically returns the monostable back to its original stable state and awaiting a second trigger pulse to restart the timing process once again.

NOR Gate Monostable Waveforms



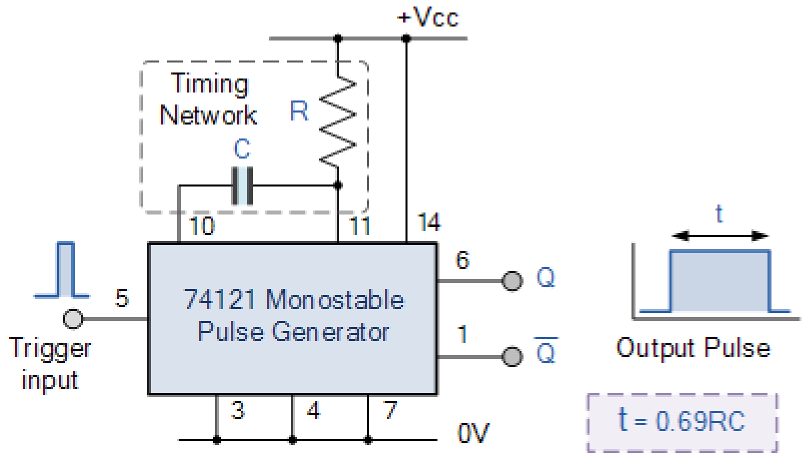
This then gives us an equation for the time period of the circuit as:

$$\tau = 0.7RC$$

Where, R is in Ω and C in Farads.

We can also make monostable pulse generators using special IC's and there are already integrated circuits dedicated to this such as the 74LS121 standard one shot monostable multivibrator or the 74LS123 or the 4538B re-triggerable monostable multivibrator which can produce output pulse widths from as low as 40 nanoseconds up to 28 seconds by using only two external RC timing components with the pulse width given as: T = 0.69RC in seconds.

74LS121 Monostable Multivibrator



This monostable pulse generator IC can be configured to produce an output pulse on either a rising-edge trigger pulse or a falling-edge trigger pulse. The 74LS121 can produce pulse widths from about 10ns to about 10ms with a maximum timing resistor of 40kΩ and a maximum timing capacitor of 1000uF.

Tutorial Summary

Then to summarize, the Monostable Multivibrator circuit has only ONE stable state making it a "one-shot" pulse generator. When triggered by a short external trigger pulse either positive or negative.

Once triggered the monostable changes state and remains in this second state for an amount of time determined by the preset time period of the RC feedback timing components used. One this time period has passed the monostable automatically returns itself back to its original low state awaiting a second trigger pulse.

Monostable multivibrators can therefore be considered as triggered pulse generators and are generally used to produce a time delay within a circuit as the frequency of the output signal is the same as that for the trigger pulse input the only difference being the pulse width.

One main disadvantage of "monostable multivibrators" is that the time between the application of the next trigger pulse has to be greater than the preset RC time constant of the circuit to allow the capacitor time to charge and discharge.

In the next tutorial about Multivibrators, we will look at one that has TWO stable states that requires two trigger pulses to switched over from one stable state to the other. This type of multivibrator circuit is called a Bistable Multivibrator also known by their more common name of "Flip-flops".

https://www.electronics-tutorials.ws/waveforms/bistable.html

Bistable Multivibrator

The **Bistable Multivibrator** is another type of two state device similar to the Monostable Multivibrator we looked at in the previous tutorial but the difference this time is that BOTH states are stable.

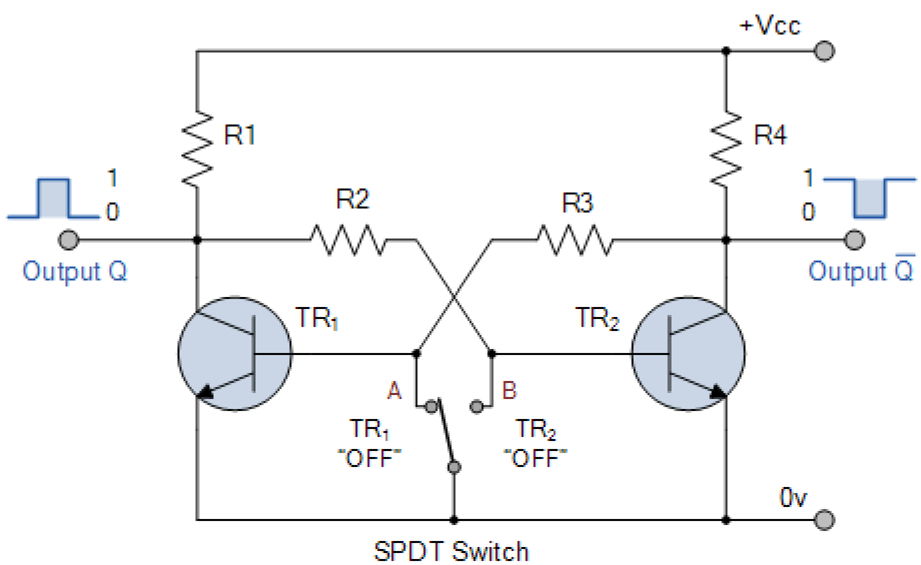
Bistable Multivibrators have **TWO** stable states (hence the name: "Bi" meaning two) and maintain a given output state indefinitely unless an external trigger is applied forcing it to change state.

The bistable multivibrator can be switched over from one stable state to the other by the application of an external trigger pulse thus, it requires two external trigger pulses before it returns back to its original state. As bistable multivibrators have two stable states they are more commonly known as Latches and Flip-flops for use in sequential type circuits.

The discrete **Bistable Multivibrator** is a two state non-regenerative device constructed from two cross-coupled transistors operating as "ON-OFF" transistor switches. In each of the two states, one of the transistors is cut-off while the other transistor is in saturation, this means that the bistable circuit is capable of remaining indefinitely in either stable state.

To change the bistable over from one state to the other, the bistable circuit requires a suitable trigger pulse and to go through a full cycle, two triggering pulses, one for each stage are required. Its more common name or term of "flip-flop" relates to the actual operation of the device, as it "flips" into one logic state, remains there and then changes or "flops" back into its first original state. Consider the circuit below.

Bistable Multivibrator Circuit



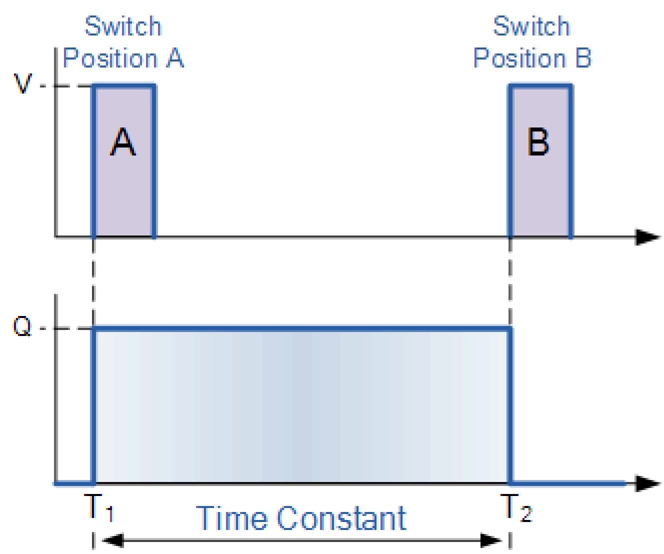
The **Bistable Multivibrator** circuit above is stable in both states, either with one transistor "OFF" and the other "ON" or with the first transistor "ON" and the second "OFF". Lets suppose that the switch is in the left position, position “A”. The base of transistor TR_1 will be grounded and in its cut-off region producing an output at Q. That would mean that transistor TR_2 is “ON” as its base is connected to Vcc through the series combination of resistors R1 and R2. As transistor TR_2 is “ON” there will be zero output at $\overline{Q}$, the opposite or inverse of Q.

If the switch is now move to the right, position “B”, transistor TR_2 will switch “OFF” and transistor TR_1 will switch “ON” through the combination of resistors R3 and R4 resulting in an output at Q and zero output at $\overline{Q}$ the reverse of above. Then we can say that one stable state exists when transistor TR1 is “ON” and TR_2 is “OFF”, switch position “A”, and another stable state exists when transistor TR_1 is “OFF” and TR_2 is “ON”, switch position “B”.

Then unlike the monostable multivibrator whose output is dependent upon the RC time constant of the feedback components used, the bistable multivibrators output is dependent upon the application of two individual trigger pulses, switch position “A” or position “B”.

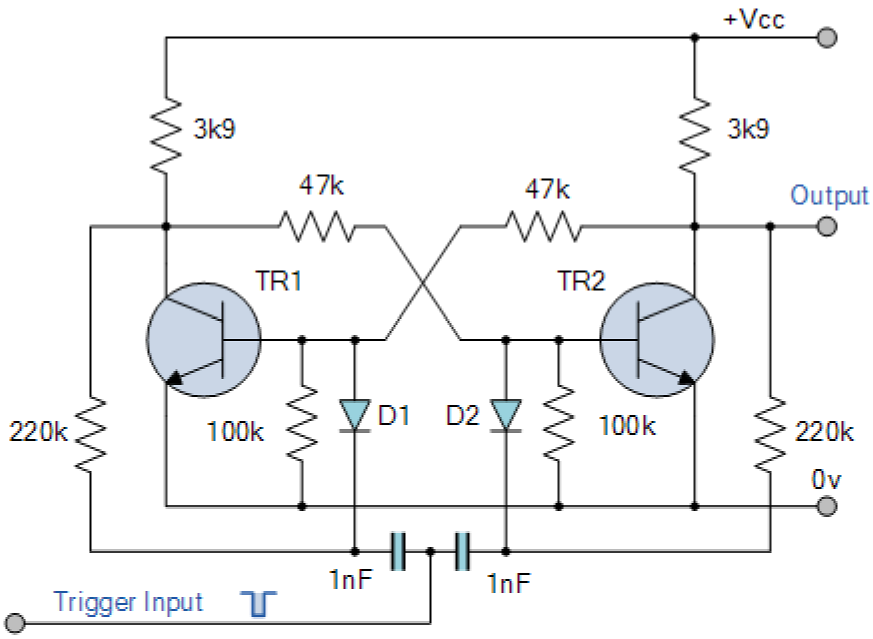
So **Bistable Multivibrators** can produce a very short output pulse or a much longer rectangular shaped output whose leading edge rises in time with the externally applied trigger pulse and whose trailing edge is dependent upon a second trigger pulse as shown below.

Bistable Multivibrator Waveform



Manually switching between the two stable states may produce a bistable multivibrator circuit but is not very practical. One way of toggling between the two states using just one single trigger pulse is shown below.

Sequential Switching



Switching between the two states is achieved by applying a single trigger pulse which in turn will cause the “ON” transistor to turn “OFF” and the “OFF” transistor to turn “ON” on the negative half of the trigger pulse. The circuit will switch sequentially by applying a pulse to each base in turn and this is achieved from a single input trigger pulse using a biased diodes as a steering circuit.

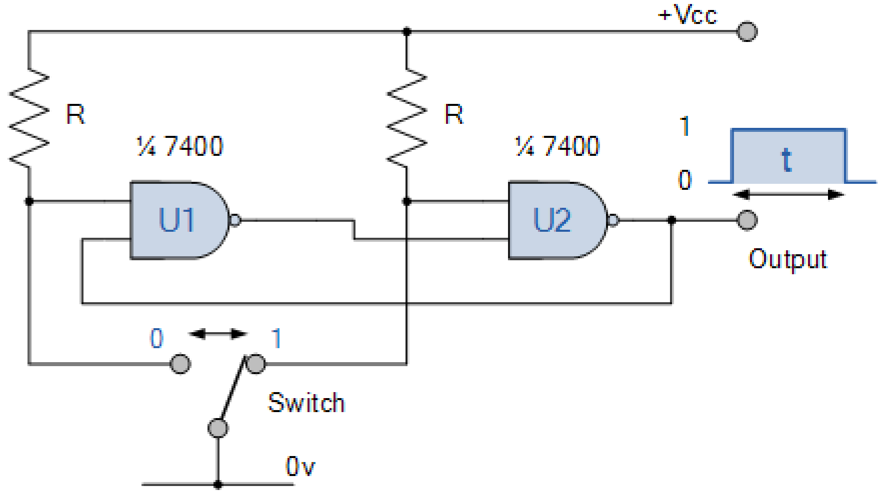
Then on the application of a first negative pulse switches the state of each transistor and the application of a second pulse negative pulse resets the transistors back to their original state acting as a divide-by-two counter. Equally, we could remove the diodes, capacitors and feedback resistors and apply individual negative trigger pulses directly to the transistor bases.

Bistable Multivibrators have many applications producing a set-reset, SR flip-flop circuit for use in counting circuits, or as a one-bit memory storage device in a computer. Other applications of bistable flip-flops include frequency dividers because the output pulses have a frequency that are exactly one half ($f/2$) that of the trigger input pulse frequency due to them changing state from a single input pulse. In other words the circuit produces **Frequency Division** as it now divides the input frequency by a factor of two (an octave).

TTL/CMOS Bistable Multivibrators

As well as producing a bistable multivibrator from individual discrete components such as transistors, we can also construct bistable circuits using commonly available integrated circuits. The following circuit shows how a basic bistable multivibrator circuit can be constructed using just two 2-input Logic "NAND" Gates.

NAND Gate Bistable Multivibrator



The circuit above shows us how we can use two NAND gates connected together to form a basic bistable multivibrator. This type of bistable circuit is also known as a "Bistable Flip-flop". The manually controlled bistable multivibrator is activated by the single-pole double-throw switch (SPDT) to produce a logic "1" or a logic "0" signal at the output.

You may have noticed that this circuit looks a little familiar, and you would be right!. This type of bistable switching circuit is more commonly called a SR NAND Gate Flip-flop being almost identical to the one we looked at back in the sequential logic tutorials. In that particular tutorial we saw that this type of NAND gate bistable makes an excellent "switch debounce" circuit allowing only one switching action to control its output.

In the next tutorial about Multivibrators, we will look at one that has **NO** stable states because it is continually switching over from one stable state to the other. This type of multivibrator circuit is called an Astable Multivibrator also known by their more common name of "free-running oscillator".

https://www.electronics-tutorials.ws/waveforms/astable.html

Astable Multivibrator

Regenerative switching circuits such as the **Astable Multivibrator** are the most commonly used type of relaxation oscillator because not only are they simple, reliable and ease of construction they also produce a constant square wave output waveform.

Unlike the Monostable Multivibrator or the Bistable Multivibrator we looked at in the previous tutorials that require an "external" trigger pulse for their operation, the **Astable Multivibrator** has automatic built in triggering which switches it continuously between its two unstable states both set and reset.

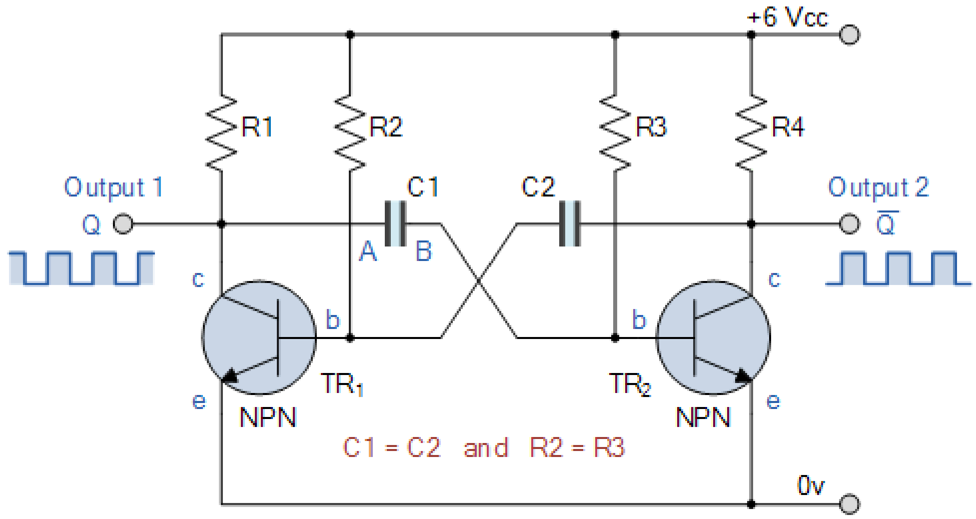
The **Astable Multivibrator** is another type of cross-coupled transistor switching circuit that has **NO** stable output states as it changes from one state to the other all the time. The astable circuit consists of two switching transistors, a cross-coupled feedback network, and two time delay capacitors which allows oscillation between the two states with no external triggering to produce the change in state.

In electronic circuits, astable multivibrators are also known as **Free-running Multivibrator** as they do not require any additional inputs or external assistance to oscillate. Astable oscillators produce a continuous square wave from its output or outputs, (two outputs no inputs) which can then be used to flash lights or produce a sound in a loudspeaker.

The basic transistor circuit for an **Astable Multivibrator** produces a square wave output from a pair of grounded emitter cross-coupled transistors. Both transistors either NPN or PNP, in the multivibrator are biased for linear operation and are operated as Common Emitter Amplifiers with 100% positive feedback.

This configuration satisfies the condition for oscillation when: ($\beta A = 1 \angle 0^\circ$). This results in one stage conducting "fully-ON" (Saturation) while the other is switched "fully-OFF" (cut-off) giving a very high level of mutual amplification between the two transistors. Conduction is transferred from one stage to the other by the discharging action of a capacitor through a resistor as shown below.

Basic Astable Multivibrator Circuit



Assume a 6 volt supply and that transistor, TR_1 has just switched "OFF" (cut-off) and its collector voltage is rising towards Vcc, meanwhile transistor TR_2 has just turned "ON". Plate "A" of capacitor C1 is also rising towards the +6 volts supply rail of Vcc as it is connected to the collector of TR_1 which is now cut-off. Since TR_1 is in cut-off, it conducts no current so there is no volt drop across load resistor R1.

The other side of capacitor, C1, plate "B", is connected to the base terminal of transistor TR_2 and at 0.6v because transistor TR_2 is conducting (saturation). Therefore, capacitor C1 has a potential difference of +5.4 volts across its plates, (6.0 – 0.6v) from point A to point B.

Since TR_2 is fully-on, capacitor C2 starts to charge up through resistor R2 towards Vcc. When the voltage across capacitor C2 rises to more than 0.6v, it biases transistor TR_1 into conduction and into saturation.

The instant that transistor, TR_1 switches "ON", plate "A" of the capacitor which was originally at Vcc potential, immediately falls to 0.6 volts. This rapid fall of voltage on plate "A" causes an equal and instantaneous fall in voltage on plate "B" therefore plate "B" of C1 is pulled down to **-5.4v** (a reverse charge) and this negative voltage swing is applied the base of TR_2 turning it hard "OFF". One unstable state.

Transistor TR_2 is driven into cut-off so capacitor C1 now begins to charge in the opposite direction via resistor R3 which is also connected to the +6 volts supply rail, Vcc. Thus the base of transistor TR_2 is now moving upwards in a positive direction towards Vcc with a time constant equal to the C1 x R3 combination.

However, it never reaches the value of Vcc because as soon as it gets to 0.6 volts positive, transistor TR2 turns fully "ON" into saturation. This action starts the whole process over again but now with capacitor C2 taking the base of transistor TR1 to **-5.4v** while charging up via resistor R2 and entering the second unstable state.

Then we can see that the circuit alternates between one unstable state in which transistor TR_1 is "OFF" and transistor TR_2 is "ON", and a second unstable in which TR_1 is "ON" and TR_2 is "OFF" at a rate determined by the RC values. This process will repeat itself over and over again as long as the supply voltage is present.

The amplitude of the output waveform is approximately the same as the supply voltage, Vcc with the time period of each switching state determined by the time constant of the RC networks connected across the base terminals of the transistors. As the transistors are switching both "ON" and "OFF", the output at either collector will be a square wave with slightly rounded corners because of the current which charges the capacitors. This could be corrected by using more components as we will discuss later.

If the two time constants produced by C2 x R2 and C1 x R3 in the base circuits are the same, the mark-to-space ratio (t1/t2) will be equal to one-to-one making the output waveform symmetrical in shape. By varying the capacitors, C1, C2 or the resistors, R2, R3 the mark-to-space ratio and therefore the frequency can be altered.

We saw in the RC Discharging tutorial that the time taken for the voltage across a capacitor to fall to half the supply voltage, 0.5Vcc is equal to 0.69 time constants of the capacitor and resistor combination. Then taking one side of the astable multivibrator, the length of time that transistor TR_2 is "OFF" will be equal to 0.69T or 0.69 times the time constant of C1 x R3. Likewise, the length of time that transistor TR_1 is "OFF" will be equal to 0.69T or 0.69 times the time constant of C2 x R2 and this is defined as.

Astable Multivibrators Periodic Time

$$\text{Periodic Time, } T = t_1 + t_2$$
$$t_1 = 0.69C_1R_3$$
$$t_2 = 0.69C_2R_2$$

Where, R is in Ω's and C in Farads.

By altering the time constant of just one RC network the mark-to-space ratio and frequency of the output waveform can be changed but normally by changing both RC time constants together at the same time, the output frequency will be altered keeping the mark-to-space ratios the same at one-to-one.

If the value of the capacitor C1 equals the value of the capacitor, C2, C1 = C2 and also the value of the base resistor R2 equals the value of the base resistor, R3, R2 = R3 then the total length of time of the **Multivibrators** cycle is given below for a symmetrical output waveform.

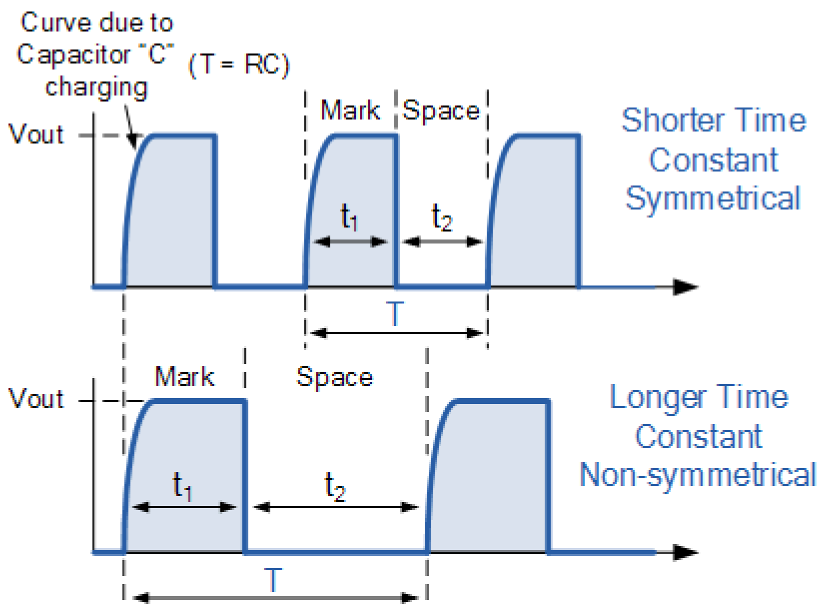
Frequency of Oscillation

$$f = \frac{1}{T} = \frac{1}{1.38RC}$$

Where, R is in Ω's, C is in Farads, T is in seconds and f is in Hertz.

and this is known as the "Pulse Repetition Frequency". So **Astable Multivibrators** can produce TWO very short square wave output waveforms from each transistor or a much longer rectangular shaped output either symmetrical or non-symmetrical depending upon the time constant of the RC network as shown below.

Astable Multivibrator Waveforms



Astable Multivibrator Example No1

An Astable Multivibrators circuit is required to produce a series of pulses at a frequency of 500Hz with a mark-to-space ratio of 1:5. If R2 = R3 = 100kΩ, calculate the values of the capacitors, C1 and C2 required.

$$T = \frac{1}{f} = \frac{1}{500\text{Hz}} = 2\times10^{-3}$$

$$T = t_1 + t_2 \quad \text{at a ratio of } 1:5$$

$$t_1 = 3.33\times10^{-4} \quad (1/6T)$$

$$t_2 = 1.66\times10^{-3} \quad (5/6T)$$

and by rearranging the formula above for the periodic time, the values of the capacitors required to give a mark-to-space ratio of 1:5 are given as:

$$C_1 = \frac{3.33\times10^{-4}}{0.69\times100\text{k}\Omega} = 4.83\times10^{-9}\text{F} \;\text{ or }\; 4.83\text{nF}$$

$$C_2 = \frac{1.66\times10^{-3}}{0.69\times100\text{k}\Omega} = 2.41\times10^{-8}\text{F} \;\text{ or }\; 24.1\text{nF}$$

The values of 4.83nF and 24.1nF respectively, are calculated values, so we would need to choose the nearest preferred values for C1 and C2 allowing for the capacitors tolerance. In fact due to the wide range of tolerances associated with the humble capacitor the actual output frequency may differ by as much as ±20%, (400 to 600Hz in our simple example) from the actual frequency needed.

If we require the output astable waveform to be non-symmetrical for use in timing or gating type circuits, etc, we could manually calculate the values of R and C for the individual components required as we did in the example above.

However, when the two timing resistors and capacitors are both of equal value, we can make our life a little bit easier for ourselves by using timing tables. Timing tables show the astable multivibrators calculated frequencies for different combinations or values of both R and C relevant to our circuit. For example:

Astable Multivibrator Frequency Table

Res.	Capacitor Values								
	1nF	2.2nF	4.7nF	10nF	22nF	47nF	100nF	220nF	470nF
1.0kΩ	714.3kHz	324.6kHz	151.9kHz	71.4kHz	32.5kHz	15.2kHz	7.1kHz	3.2kHz	1.5kHz
2.2kΩ	324.7kHz	147.6kHz	69.1kHz	32.5kHz	14.7kHz	6.9kHz	3.2kHz	1.5kHz	691Hz
4.7kΩ	151.9kHz	69.1kHz	32.3kHz	15.2kHz	6.9kHz	3.2kHz	1.5kHz	691Hz	323Hz
10kΩ	71.4kHz	32.5kHz	15.2kHz	7.1kHz	3.2kHz	1.5kHz	714Hz	325Hz	152Hz
22kΩ	32.5kHz	14.7kHz	6.9kHz	3.2kHz	1.5kHz	691Hz	325Hz	147Hz	69.1Hz
47kΩ	15.2kHz	6.9kHz	3.2kHz	1.5kHz	691Hz	323Hz	152Hz	69.1Hz	32.5Hz
100kΩ	7.1kHz	3.2kHz	1.5kHz	714Hz	325Hz	152Hz	71.4Hz	32.5Hz	15.2Hz
220kΩ	3.2kHz	1.5kHz	691Hz	325Hz	147Hz	69.1Hz	32.5Hz	15.2Hz	6.9Hz
470kΩ	1.5kHz	691Hz	323Hz	152Hz	69.1Hz	32.5Hz	15.2Hz	6.6Hz	3.2Hz
1MΩ	714Hz	325Hz	152Hz	71.4Hz	32.5Hz	15.2Hz	6.9Hz	3.2Hz	1.5Hz

Pre-calculated frequency tables can be very useful in determining the required values of both R and C for a particular symmetrical output frequency without the need to keep recalculating them every time a different frequency is required.

By changing the two fixed resistors, R2 and R3 for a dual-ganged potentiometer and keeping the values of the capacitors the same, the frequency from the **Astable Multivibrators** output can be more easily “tuned” to give a particular frequency value or to compensate for the tolerances of the components used.

For example, selecting a capacitor value of 10nF from the table above. By using a 100kΩ's potentiometer for our resistance, we would get an output frequency that can be fully adjusted from slightly above 71.4kHz down to 714Hz, some 3 decades of frequency range. Likewise a capacitor value of 47nF would give a frequency range from 152Hz to well over 15kHz.

Astable Multivibrator Example No2

An **Astable Multivibrator** circuit is constructed using two timing capacitors of equal value of 3.3uF and two base resistors of value 10kΩ. Calculate the minimum and maximum frequencies of oscillation if a 100kΩ dual-gang potentiometer is connected in series with the two resistors.

With the potentiometer at 0%, the value of the base resistance is equal to 10kΩ.

$$f = \frac{1}{1.38 \times 3.3\text{uF} \times 10\text{k}\Omega} = 22\,\text{Hz}$$

with the potentiometer at 100%, the value of the base resistance is equal to 10kΩ + 100kΩ = 110kΩ.

$$f = \frac{1}{1.38 \times 3.3\text{uF} \times 110\text{k}\Omega} = 2.0\,\text{Hz}$$

Then the output frequency of oscillation for the astable multivibrator can be varied from between 2.0 and 22 Hertz.

When selecting both the resistance and capacitance values for reliable operation, the base resistors should have a value that allows the transistor to turn fully "ON" when the other transistor turns "OFF". For example, consider the circuit above. When transistor TR_2 is fully "ON", (saturation) nearly the same voltage is dropped across resistor R3 and resistor R4.

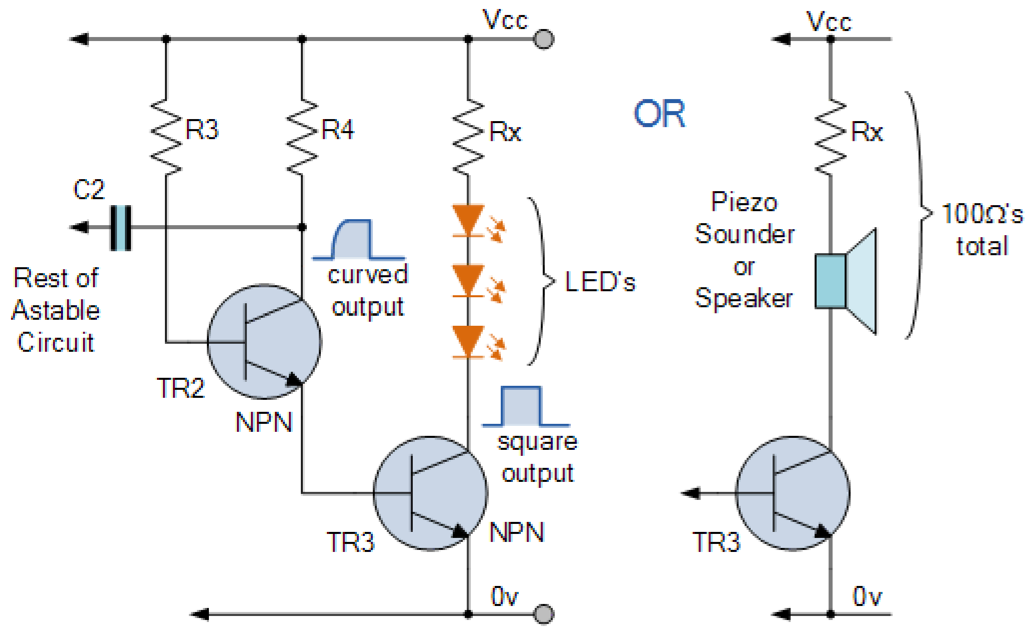
If the transistor being used has a current gain, β of 100 and the collector load resistor, R4 is equal to say 1kΩ the maximum base resistor value would therefore be 100kΩ. Any higher and the transistor may not turn fully "ON" resulting in the multivibrator giving erratic results or not oscillate at all. Likewise, if the value of the base resistor is too low the transistor may not switch "OFF" and the multivibrator would again not oscillate.

An output signal can be obtained from the collector terminal of either transistor in the Astable Multivibrators circuit with each output waveform being a mirror image of itself. We saw above that the leading edge of the output waveform is slightly rounded and not square due to the charging characteristics of the capacitor in the cross-coupled circuit.

But we can introduce another transistor into the circuit that will produce an almost perfectly square output pulse and which can also be used to switch higher current loads or low impedance loads such as LED's or loudspeakers, etc without affecting the operation of the actual astable multivibrator.

However, the down side to this is that the output waveform is not perfectly symmetrical as the additional transistor produces a very small delay. Consider the two circuits below.

Astable Multivibrators Driving Circuit



An output with a square leading edge is now produced from the third transistor, TR_3 connected to the emitter of transistor, TR2. This third transistor switches “ON” and “OFF” in unison with transistor TR_2. We can use this additional transistor to switch Light Emitting Diodes, Relays or to produce a sound from a Sound Transducer such as a speaker or piezo sounder as shown above.

The load resistor, Rx needs to be suitably chosen to take into account the forward volt drops and to limit the maximum current to about 20mA for the LED circuit or to give a total load impedance of about 100Ω for the speaker circuit. The speaker can have any impedance less than 100Ω.

By connecting an additional transistor, TR_4 to the emitter circuit of the other transistor, TR_1 in a similar fashion we can produce an astable multivibrator circuit that will flash two sets of lights or LED’s from one to the other at a rate determined by the time constant of the RC timing network.

In the next tutorial about Waveforms and Signals, we will look at the different types of **Astable Multivibrators** that are used to produce a continuous output waveform. These circuits known as relaxation oscillators produce either a square or rectangular wave at their outputs for use in sequential circuits as either a clock pulse or timing signal. These types of circuits are called Waveform Generators.

https://www.electronics-tutorials.ws/waveforms/generators.html

Waveform Generators

In the previous tutorials we have looked in detail at different types of waveform generators including the transistor multivibrator circuits which can be used as relaxation oscillators to produce either a square or rectangular wave at their outputs for use as clock and timing signals.

But it is also possible to construct basic **Waveform Generator** circuits from simple integrated circuits or operational amplifiers connected to a resistor-capacitor (RC) tank circuit or to a quartz crystal to produce the required binary or square wave output waveform at the desired frequency.

This waveform generation tutorial would be incomplete without some examples of digital regenerative switching circuits, since it illustrates both the switching action and operation of waveform generators used for generating square waves for use as timing or sequential waveforms.

We know that regenerative switching circuits such as *Astable Multivibrators* are the most commonly used type of relaxation oscillator as they produce a constant square wave output, making them ideal as a digital **Waveform Generator**.

Astable multivibrators make excellent oscillators because they switch continuously between their two unstable states at a constant repetition rate thereby producing a continuous square wave output with a 1:1 mark-space ratio ("ON" and "OFF" times the same) from its output.

In this tutorial we will look at some of the different ways we can construct waveform generators using just standard TTL and CMOS logic circuits along with some additional discrete timing components.

Schmitt Waveform Generators

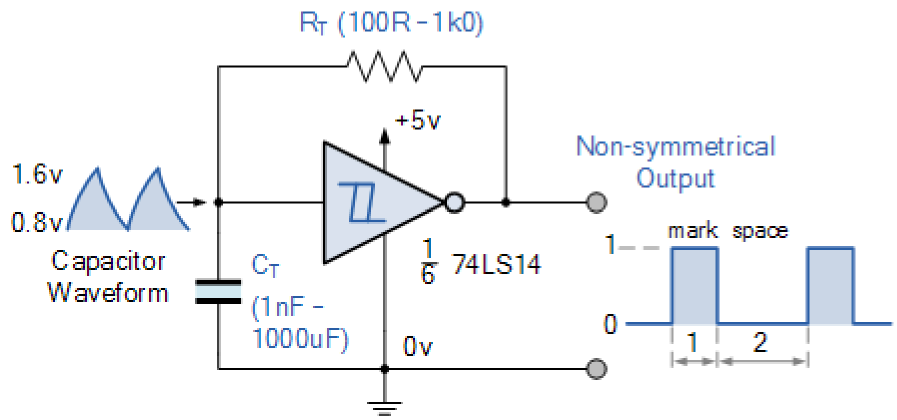
Simple **Waveform Generators** can be constructed using basic Schmitt trigger action inverters such as the TTL 74LS14. This method is by far the easiest way to make a basic astable waveform generator.

When used to produce clock or timing signals, the astable multivibrator must produce a stable waveform that switches quickly between its "HIGH" and "LOW" states without any distortion or noise, and Schmitt inverters do just that.

We know that the output state of a Schmitt inverter is the opposite or inverse to that of its input state, (NOT gate principles) and that it can change state at different voltage levels giving it "hysteresis".

Schmitt inverters use a Schmitt trigger action that changes state between an upper and a lower threshold level as the input voltage signal increases and decreases about the input terminal. This upper threshold level "sets" the output and the lower threshold level "resets" the output which equates to a logic "0" and a logic "1" respectively for an inverter. Consider the circuit below.

Schmitt Inverter Waveform Generator



This simple waveform generator circuit consists of a single TTL 74LS14 Schmitt inverter logic gate with a capacitor, C connected between its input terminal and ground, (0v) and the positive feedback required for the circuit to oscillate being provided by the feedback resistor, R.

So how does it work?. Assume that the charge across the capacitors plates is below the Schmitt's lower threshold level of 0.8 volt (Datasheet value). This therefore makes the input to the inverter at a logic "0" level resulting in a logic "1" output level (inverter principals).

One side of the resistor R is now connected to the logic "1" level (+5V) output while the other side of the resistor is connected to the capacitor, C which is at a logic "0" level (0.8v or below). The capacitor now starts to charge up in a positive direction through the resistor at a rate determined by the RC time constant of the combination.

When the charge across the capacitor reaches the 1.6 volt upper threshold level of the Schmitt trigger (datasheet value) the output from the Schmitt inverter rapidly changes from a logic level "1" to a logic level "0" state and the current flowing through the resistor changes direction.

This change now causes the capacitor that was originally charging up through the resistor, R to begin to discharge itself back through the same resistor until the charge across the capacitors plates reaches the lower threshold level of 0.8 volts and the inverters output switches state again with the cycle repeating itself over and over again as long as the supply voltage is present.

So the capacitor, C is constantly charging and discharging itself during each cycle between the inputs upper and lower threshold levels of the Schmitt inverter producing a logic level "1" or a logic level "0" at the inverters output. However, the output waveform is not symmetrical producing a duty cycle of about 33% or 1/3 as the mark-to-space ratio between "HIGH" and "LOW" is 1:2 respectively due to the input gate characteristics of the TTL inverter.

The value of the feedback resistor, (R) MUST also be kept low to below 1kΩ for the circuit to oscillate correctly, 220R to 470R is good, and by varying the value of the capacitor, C to vary the frequency.

Also at high frequency levels the output waveform changes shape from a square shaped waveform to a trapezoidal shaped waveform as the input characteristics of the TTL gate are affected by the rapid charging and discharging of the capacitor. The frequency of oscillation for **Schmitt Waveform Generators** is therefore given as:

Schmitt Waveform Frequency

$$f = \frac{1}{1.2RC}$$

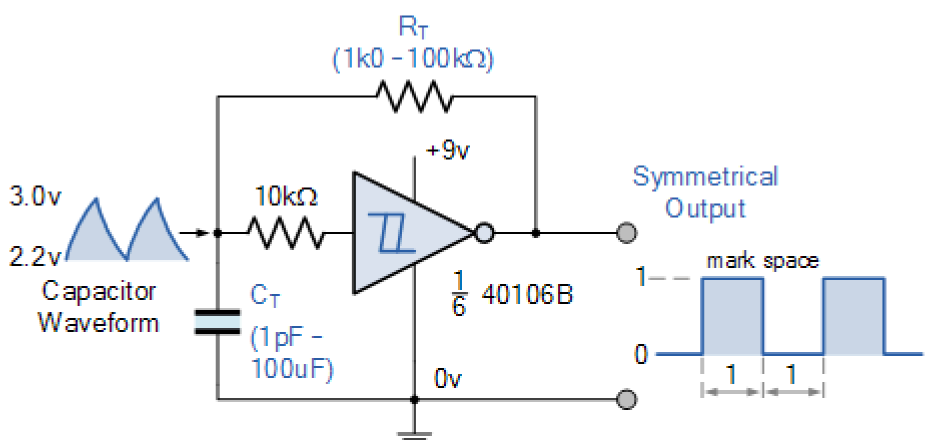
With a resistor value between: 100R to 1kΩ, and a capacitor value of between: 1nF to 1000uF. This would give a frequency range of between 1Hz to 1MHz, (high frequencies produce waveform distortion).

Generally, standard TTL logic gates do not work too well as waveform generators due to their average input and output characteristics, distortion of the output waveform and low value of feedback resistor required, resulting in a large high value capacitor for low frequency operation.

Also TTL oscillators may not oscillate if the value of the feedback capacitor is too small. However, we can also make Astable Multivibrators using better CMOS logic technology that operate from a 3V to 15V supply such as the CMOS 40106B Schmitt Inverter.

The CMOS 40106 is a single input inverter with the same Schmitt-trigger action as the TTL 74LS14 but with very good noise immunity, high bandwidth, high gain and excellent input/output characteristics to produce a more "squarer" output waveform as shown below.

CMOS Schmitt Waveform Generator



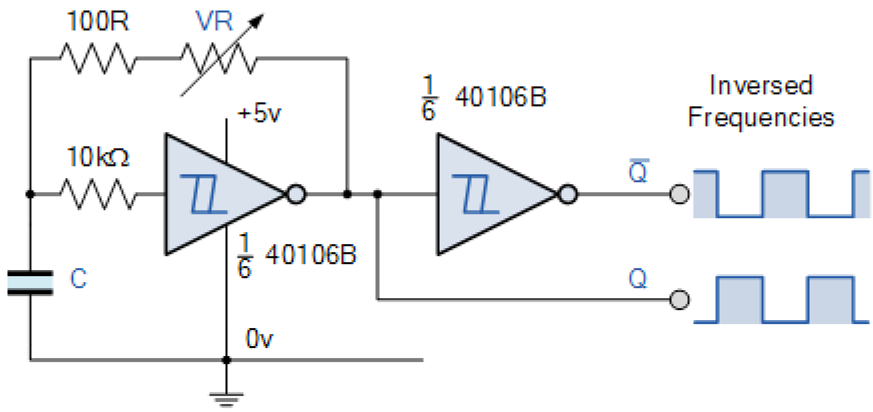
The Schmitt waveform generators circuit for the CMOS 40106 is basically the same as that for the previous TTL 74LS14 inverter, except for the addition of the 10kΩ resistor which is used to prevent the capacitor from damaging the sensitive MOSFET input transistors as it discharges rapidly at higher frequencies.

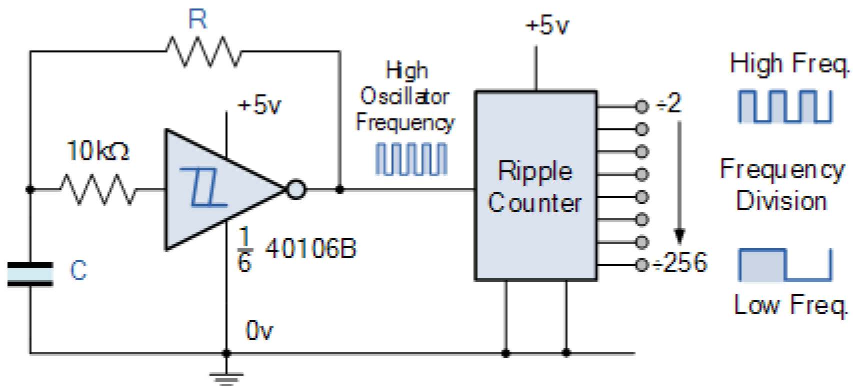
The mark-space ratio is more evenly matched at about 1:1 with the feedback resistor value increased to below 100kΩ resulting in a smaller and cheaper timing capacitor, C.

The frequency of oscillation may not be the same as: (1/1.2RC) as CMOS input characteristics are different to TTL. With a resistor value between: 1kΩ and 100kΩ, and a capacitor value of between: 1pF to 100uF. This would give a frequency range of between 0.1Hz to 100kHz.

Schmitt Inverter Waveform Generators can also be made from a variety of different logic gates connected to form an inverter circuit. The basic Schmitt astable multivibrator circuit can be easily modified with some additional components to produce different outputs or frequencies. For example, two inverse waveforms or multiple frequencies and by changing the fixed feedback resistor to a potentiometer the output frequency can be varied as shown below.

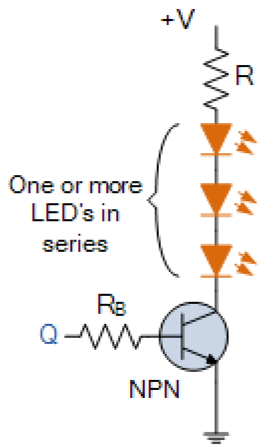
Clock Waveform Generators





In the first circuit above, an additional Schmitt Inverter has been added to the output of the Schmitt waveform generator to produce a second waveform that is the inverse or mirror image of the first producing two complementary output waveforms, so when one output is “HIGH” the other is “LOW”. This second Schmitt inverter also improves the shape of the inverse output waveform but adds a small “gate delay” to it so it is not exactly in synch with the first.

Also, the output frequency of the oscillator circuit can be varied by changing the fixed resistor, R into a potentiometer but a smaller feedback resistor is still required to prevent the potentiometer from shorting out the inverter when its at its minimum value, 0Ω.



We can also use the two complementary outputs, Q and Q of the first circuit to alternatively flash two sets of lights or LED's by connecting their outputs directly to the bases of two switching transistors as shown.

In this way one or several LED's connected together in series with the collector of the switching transistors resulting in alternating flashes of each set of LED's as each transistor is switched "ON" in turn.

Also when using this type of circuit, remember to calculate a suitable series resistor, R to limit the LED current to below 20mA (red LED's) for the voltage you are using.

In order to generate a very low frequency output of a few Hertz to flash the LED's, Schmitt waveform generators use high value timing capacitors which themselves can be physically large and expensive.

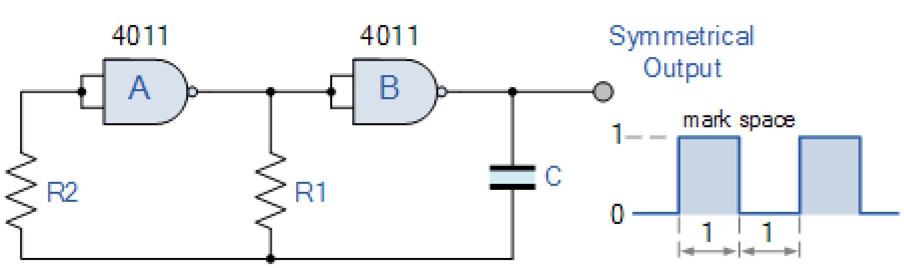
One alternative solution is too use a smaller value capacitor to generate a much higher frequency, say 1kHz or 10kHz, and then divide this main clock frequency down into individual smaller ones until the required low frequency value is achieved, and the second circuit above does just that.

The lower circuit above shows the oscillator being used to drive the clock input of a ripple counter. Ripple counters are basically a number of divide-by-2, D-type flip-flops cascaded together to form a single divide-by-N counter, where N is equal to the counters bit-count such as the CMOS 4024 7-bit Ripple Counter or the CMOS 4040 12-bit Ripple Counter.

The fixed clock frequency produce by the Schmitt astable clock pulse circuit is divided into a number of different sub-frequencies such as, $f\div2$, $f\div4$, $f\div8$, $f\div256$, etc, up to the maximum "Divide-by-n" value of the ripple counter being used.

The process of using either "Flip-flops", "Binary Counters" or "Ripple Counters" to divide a main fixed clock frequency into different sub-frequencies is known as Frequency Division and we can use it to obtain a number of frequency values from a single waveform generator.

NAND Gate Waveform Generators



In this type of waveform generator circuit, the RC network is formed from resistor, R1 and the capacitor, C with this RC network being controlled by the output of the first NAND gate.

The output from this R1C network is fed back to the input of the first NAND gate via resistor, R2 and when the charging voltage across the capacitor reaches the upper threshold level of the first NAND gate, the NAND gate changes state causing the second NAND gate to follow it, thereby change state and producing a change in the output level.

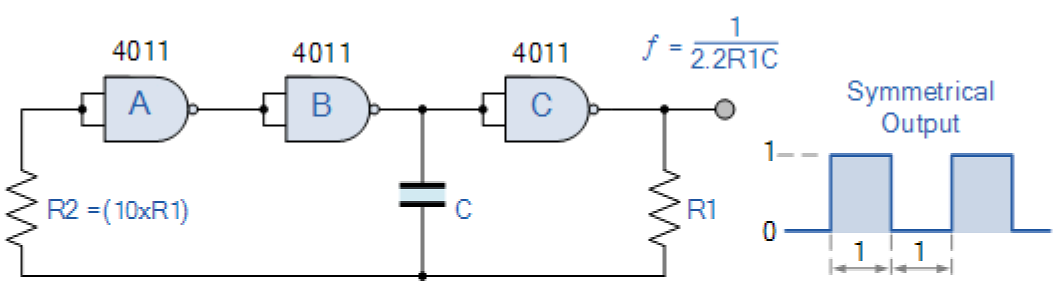
The voltage across the R1C network is now reversed and the capacitor begins to discharge through the resistor until it reaches the lower threshold level of the first NAND gate causing the two gates to change state once again.

Like the previous Schmitt waveform generators circuit above, the frequency of oscillation is determined by the R1C time constant which is given as: 1/2.2R1C. Generally R2 is given a value that is 10 times the value of resistor R1.

When high stability or guaranteed self-starting is required, **CMOS Waveform Generators** can be made using three inverting NAND gates or any three logic inverters for that matter, connected together as shown below producing a circuit that is sometimes called “the ring of three” waveform generator.

The frequency of oscillation is determined again by the R1C time constant, the same as for the two gate oscillator above, and which is given as: 1/2.2R1C when R2 has a value that is 10 times the value of resistor, R1.

Stable NAND Gate Waveform Generator



The addition of the extra NAND gate guarantees that the oscillator will start even with very low capacitor values. Also the stability of the waveform generator is greatly improved as it is less susceptible to power supply variations due to its threshold triggering level being nearly half of the supply voltage.

The amount of stability is mainly determined by the frequency of oscillation and generally speaking, the lower the frequency the more stable the oscillator becomes.

As this type of waveform generator operates at nearly half or 50% of the supply voltage the resultant output waveform has very nearly a 50% duty cycle, 1:1 mark-space ratio. The three gate waveform generator has many advantages over the previous two gate oscillator above but its one big disadvantage is that it uses an additional logic gate.

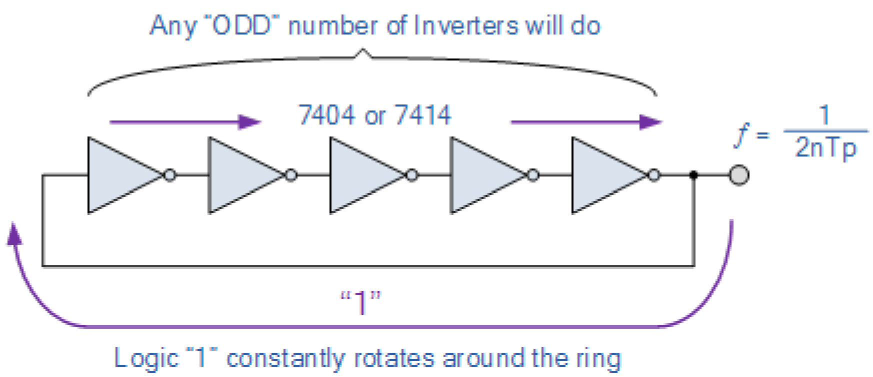
Ring Type Waveform Generator

We have seen above that **Waveform Generators** can be made using both TTL and the better CMOS logic technology with an RC network producing a time delay within the circuit when connected across either one, two or even three logic gates to form a simple RC Relaxation Oscillator.

But we can also make waveform generators using just Logic NOT Gates or in other words Inverters without any additional passive components connected to them.

By connecting together any **ODD** number (3, 5, 7, 9 etc) of NOT gates to form a “ring” circuit, so that the output of the ring is connected straight back to the input of the ring the circuit will continue to oscillate as a logic level “1” constantly rotates around the network producing an output frequency that is determined by the propagation delays of the inverters used.

Ring Waveform Generator



The frequency of oscillation is determined by the total propagation delay of the Inverters used within the ring and which itself is determined by the type of gate technology, TTL, CMOS, BiCMOS that the inverter is made from.

Propagation delay or propagation time, is the total time required (usually in Nanoseconds) for a signal to pass straight through the Inverter from a logic “0” arriving at the input to it producing a logic “1” at its output.

Also for this type of ring waveform generator circuit variations in the supply voltage, temperature and load capacitance all affect the propagation delay of logic gates. Generally an average propagation delay time will be given in the manufacturers data sheets for the type of digital logic gates being used with the frequency of oscillation given as:

$$f = \frac{1}{2nTp} \text{ in Hz}$$

Where: f is the frequency of Oscillation, n is the number of gates used and Tp is the propagation delay time for each gate.

For example. Assume that a simple waveform generator circuit has five individual Inverters connected together in series chain to form a **Ring Oscillator**. If the propagation delay time for each Inverter is given as being 8 nano-seconds (8ns). Then the frequency of oscillation of the circuit would be given as:

$$f = \frac{1}{2nTp} = \frac{1}{2 \times 5 \times 8 \times 10^{-9}} = 12.5\text{MHz}$$

Of course, this is not really a practical oscillator due mainly to its instability and very high oscillation frequency, 10's of Megahertz depending upon the type of logic gate technology used, and in our simple example it was calculated as 12.5MHz !!

The ring oscillator output frequency can be "tuned" a little by varying the number of Inverters used within the ring but it is much better to use a more stable RC waveform generator like the ones we have discussed above.

Nevertheless, it does show that logic gates can be connected together to produce logic based waveform generators and badly designed digital circuits with lots of gates, signal paths and feedback loops have been known to oscillate unintentionally.

By using a RC network across the Inverter circuit, the frequency of oscillation can be accurately controlled producing a more practical astable relaxation oscillator circuit for use in many general electronic applications.

In the next tutorial about Waveforms and Waveform Generation, we will examine the 555 Timer which is one of the most popular and versatile integrated circuits ever produced that can generate a wide range of different waveforms and timing signals from monostable to astable multivibrators.

https://www.electronics-tutorials.ws/waveforms/555_timer.html

555 Timer Tutorial

We have seen that Multivibrators and CMOS Oscillators can be easily constructed from discrete components to produce relaxation oscillators for generating basic square wave output waveforms. But there are also dedicated IC's such as the 555 timer especially designed to accurately produce the required output waveform with the addition of just a few extra timing components.

One such device that has been around since the early days of IC's and has itself become something of an industry "standard" is the **555 Timer Oscillator** which is more commonly called the "**555 Timer**".

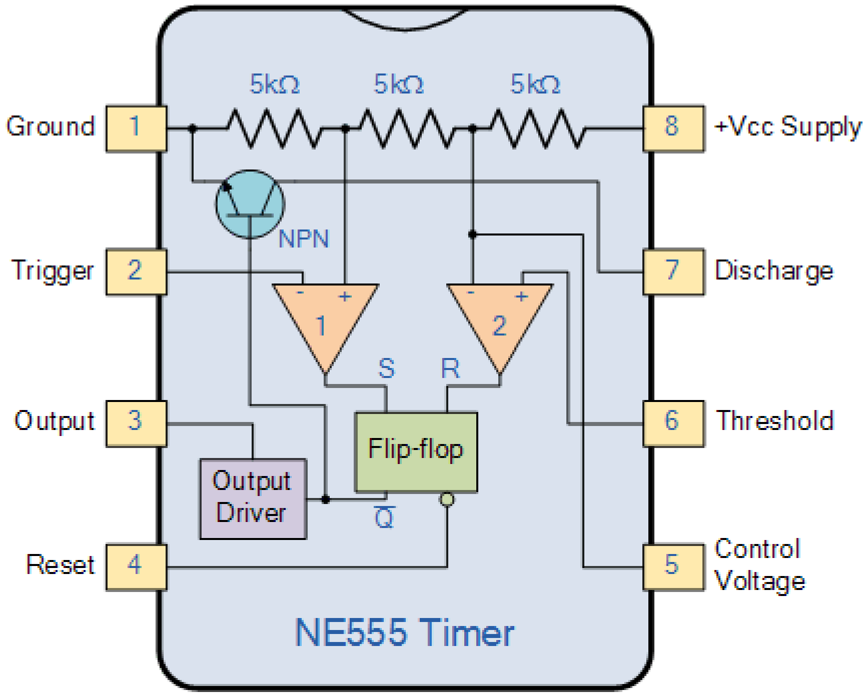
The basic **555 timer** gets its name from the fact that there are three internally connected 5kΩ resistors which it uses to generate the two comparators reference voltages. The 555 timer IC is a very cheap, popular and useful precision timing device which can act as either a simple timer to generate single pulses or long time delays, or as a relaxation oscillator producing a string of stabilised waveforms of varying duty cycles from 50 to 100%.

The 555 timer chip is extremely robust and stable 8-pin device that can be operated either as a very accurate Monostable, Bistable or Astable Multivibrator to produce a variety of applications such as one-shot or delay timers, pulse generation, LED and lamp flashers, alarms and tone generation, logic clocks, frequency division, power supplies and converters etc, in fact any circuit that requires some form of time control as the list is endless.

The single 555 Timer chip in its basic form is a Bipolar 8-pin mini Dual-in-line Package (DIP) device consisting of some 25 transistors, 2 diodes and about 16 resistors arranged to form two comparators, a flip-flop and a high current output stage as shown below. As well as the 555 Timer there is also available the NE556 Timer Oscillator which combines TWO individual 555's within a single 14-pin DIP package and low power CMOS versions of the single 555 timer such as the 7555 and LMC555 which use MOSFET transistors instead.

A simplified “block diagram” representing the internal circuitry of the 555 timer is given below with a brief explanation of each of its connecting pins to help provide a clearer understanding of how it works.

555 Timer Block Diagram



- Pin 1. – **Ground**, The ground pin connects the 555 timer to the negative (0v) supply rail.
- Pin 2. – **Trigger**, The negative input to comparator No 1. A negative pulse on this pin “sets” the internal Flip-flop when the voltage drops below 1/3Vcc causing the output to switch from a “LOW” to a “HIGH” state.
- Pin 3. – **Output**, The output pin can drive any TTL circuit and is capable of sourcing or sinking up to 200mA of current at an output voltage equal to approximately Vcc – 1.5V so small speakers, LEDs or motors can be connected directly to the output.
- Pin 4. – **Reset**, This pin is used to “reset” the internal Flip-flop controlling the state of the output, pin 3. This is an active-low input and is generally connected to a logic “1” level when not used to prevent any unwanted resetting of the output.
- Pin 5. – **Control Voltage**, This pin controls the timing of the 555 by overriding the 2/3Vcc level of the voltage divider network. By applying a voltage to this pin the width of the output signal can be varied independently of the RC timing network. When not used it is connected to ground via a 10nF capacitor to eliminate any noise.
- Pin 6. – **Threshold**, The positive input to comparator No 2. This pin is used to reset the Flip-flop when the voltage applied to it exceeds 2/3Vcc causing the output to switch from “HIGH” to “LOW” state. This pin connects directly to the RC timing circuit.

- Pin 7. **– Discharge**, The discharge pin is connected directly to the Collector of an internal NPN transistor which is used to “discharge” the timing capacitor to ground when the output at pin 3 switches “LOW”.
- Pin 8. **– Supply +Vcc**, This is the power supply pin and for general purpose TTL 555 timers is between 4.5V and 15V.

The **555 Timers** name comes from the fact that there are three 5kΩ resistors connected together internally producing a voltage divider network between the supply voltage at pin 8 and ground at pin 1. The voltage across this series resistive network holds the negative inverting input of comparator two at 2/3Vcc and the positive non-inverting input to comparator one at 1/3Vcc.

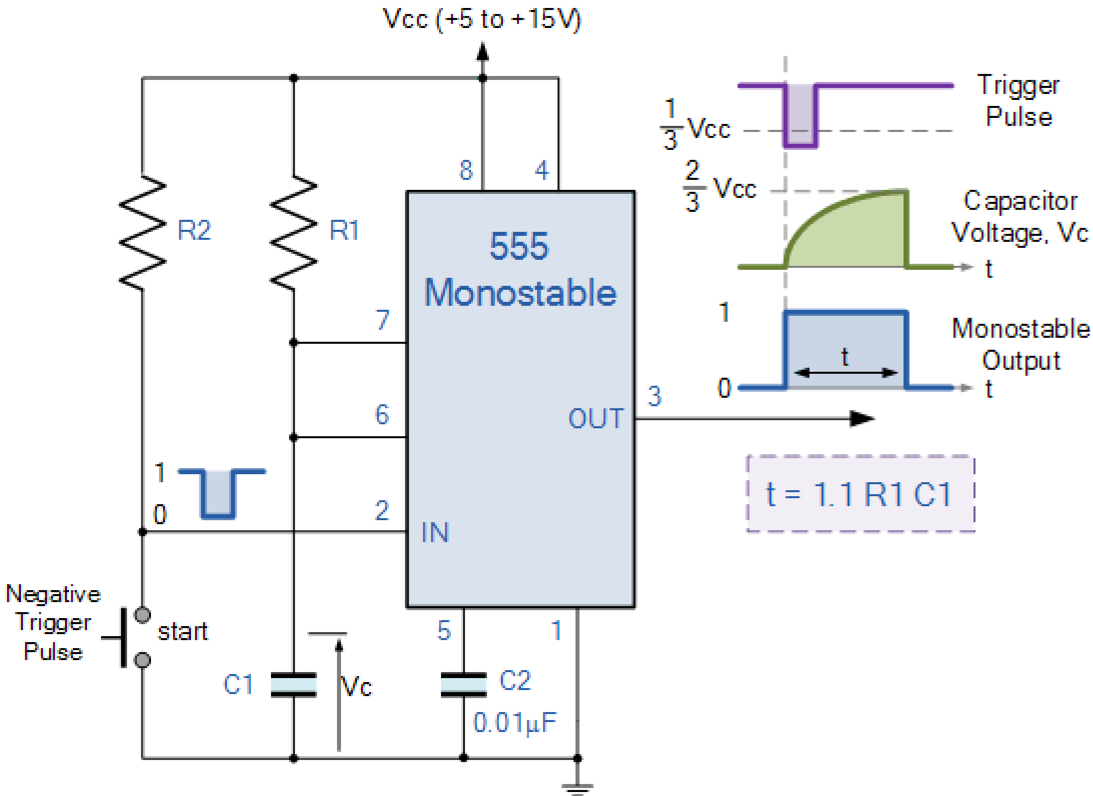
The two comparators produce an output voltage dependent upon the voltage difference at their inputs which is determined by the charging and discharging action of the externally connected RC network. The outputs from both comparators are connected to the two inputs of the flip-flop which in turn produces either a “HIGH” or “LOW” level output at Q based on the states of its inputs. The output from the flip-flop is used to control a high current output switching stage to drive the connected load producing either a “HIGH” or “LOW” voltage level at the output pin.

The most common use of the 555 timer oscillator is as a simple astable oscillator by connecting two resistors and a capacitor across its terminals to generate a fixed pulse train with a time period determined by the time constant of the RC network. But the 555 timer oscillator chip can also be connected in a variety of different ways to produce Monostable or Bistable multivibrators as well as the more common Astable Multivibrator.

The Monostable 555 Timer

The operation and output of the **555 timer monostable** is exactly the same as that for the transistorised one we look at previously in the Monostable Multivibrators tutorial. The difference this time is that the two transistors have been replaced by the 555 timer device. Consider the 555 timer monostable circuit below.

Monostable 555 Timer



When a negative (0V) pulse is applied to the trigger input (pin 2) of the Monostable configured 555 Timer oscillator, the internal comparator, (comparator No1) detects this input and “sets” the state of the flip-flop, changing the output from a “LOW” state to a “HIGH” state. This action in turn turns “OFF” the discharge transistor connected to pin 7, thereby removing the short circuit across the external timing capacitor, C1.

This action allows the timing capacitor to start to charge up through resistor, R1 until the voltage across the capacitor reaches the threshold (pin 6) voltage of 2/3Vcc set up by the internal voltage divider network. At this point the comparators output goes “HIGH” and “resets” the flip-flop back to its original state which in turn turns “ON” the transistor and discharges the capacitor to ground through pin 7. This causes the output to change its state back to the original stable “LOW” value awaiting another trigger pulse to start the timing process over again. Then as before, the Monostable Multivibrator has only “ONE” stable state.

The **Monostable 555 Timer circuit** triggers on a negative-going pulse applied to pin 2 and this trigger pulse must be much shorter than the output pulse width allowing time for the timing capacitor to charge and then discharge fully. Once triggered, the 555 Monostable will remain in this “HIGH” unstable output state until the time period set up by the R1 x C1 network has elapsed. The amount of time that the output voltage remains “HIGH” or at a logic “1” level, is given by the following time constant equation.

$$\tau = 1.1\, R_1 C_1$$

Where, t is in seconds, R is in Ω and C in Farads.

555 Timer Example No1

A Monostable 555 Timer is required to produce a time delay within a circuit. If a 10uF timing capacitor is used, calculate the value of the resistor required to produce a minimum output time delay of 500ms.

500ms is the same as saying 0.5s so by rearranging the formula above, we get the calculated value for the resistor, R as:

$$R = \frac{t}{1.1C} = \frac{0.5}{1.1 \times 10uF} = \frac{0.5}{1.1 \times 10 \times 10^{-6}} = 45.5k\Omega$$

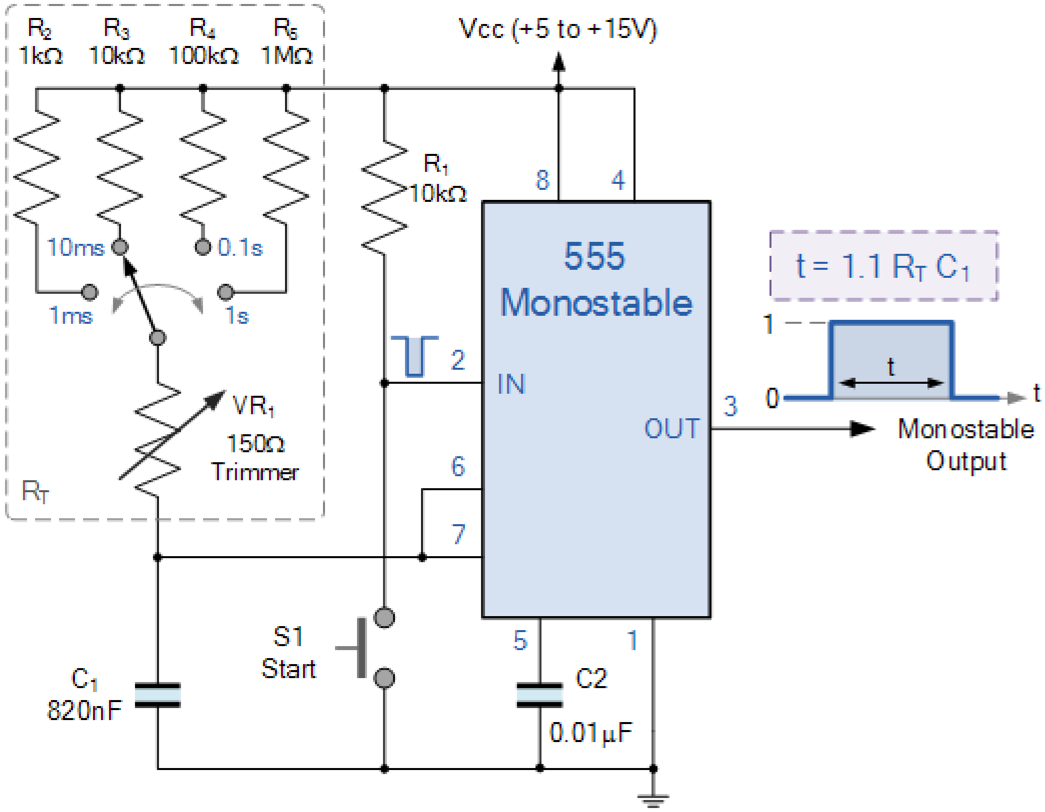
The calculated value for the timing resistor required to produce the required time constant of 500ms is therefore, 45.5KΩ. However, the resistor value of 45.5KΩ does not exist as a standard value resistor, so we would need to select the nearest preferred value resistor of 47kΩ which is available in all the standard ranges of tolerance from the E12 (10%) to the E96 (1%), giving us a new recalculated time delay of 517ms.

If this time difference of 17ms (500 – 517ms) is unacceptable instead of one single timing resistor, two different value resistor could be connected together in series to adjust the pulse width to the exact desired value, or a different timing capacitor value chosen.

We now know that the time delay or output pulse width of a monostable 555 timer is determined by the time constant of the connected RC network. If long time delays are required in the 10’s of seconds, it is not always advisable to use high value timing capacitors as they can be physically large, expensive and have large value tolerances, e.g, ±20%.

One alternative solution is to use a small value timing capacitor and a much larger value resistor up to about 20MΩ’s to produce the require time delay. Also by using one smaller value timing capacitor and different resistor values connected to it through a multi-position rotary switch, we can produce a Monostable 555 timer oscillator circuit that can produce different pulse widths at each switch rotation such as the switchable Monostable 555 timer circuit shown below.

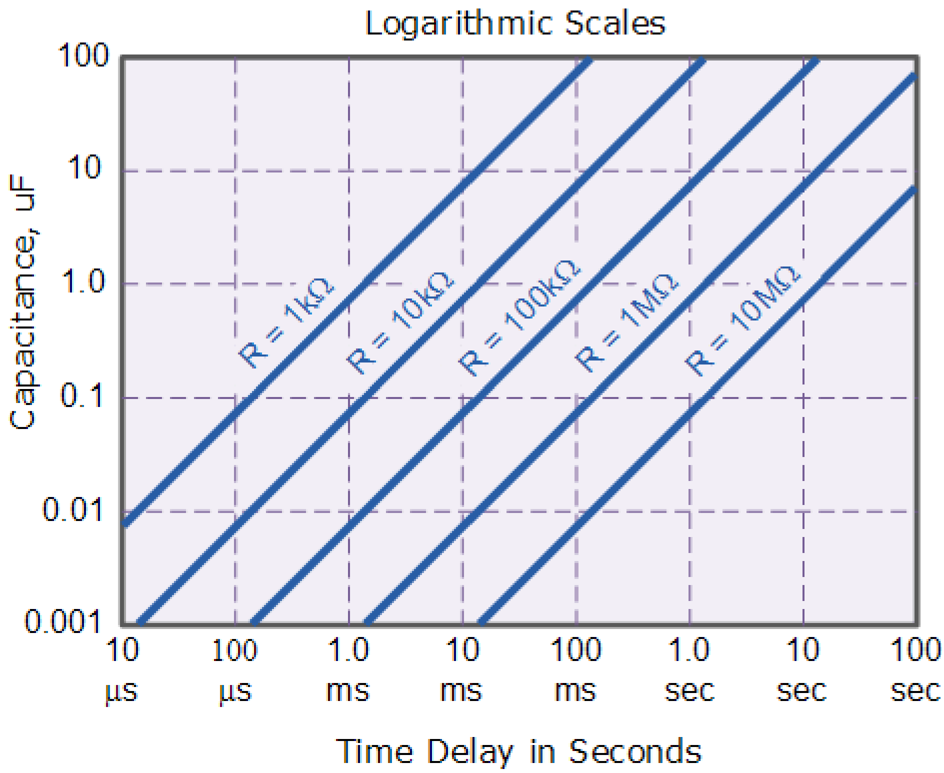
A Switchable Monostable Circuit



We can manually calculate the values of R and C for the individual components required as we did in the example above. However, the choice of components needed to obtain the desired time delay requires us to calculate with either kilohm's (KΩ), Megaohm's (MΩ), microfarad's (µF) or picafarad's (pF) and it is very easy to end up with a time delay that is out by a factor of ten or even a hundred.

We can make our life a little easier by using a type of chart called a "Nomograph" that will help us to find the monostable multivibrators expected frequency output for different combinations or values of both the R and C. For example,

Monostable Nomograph



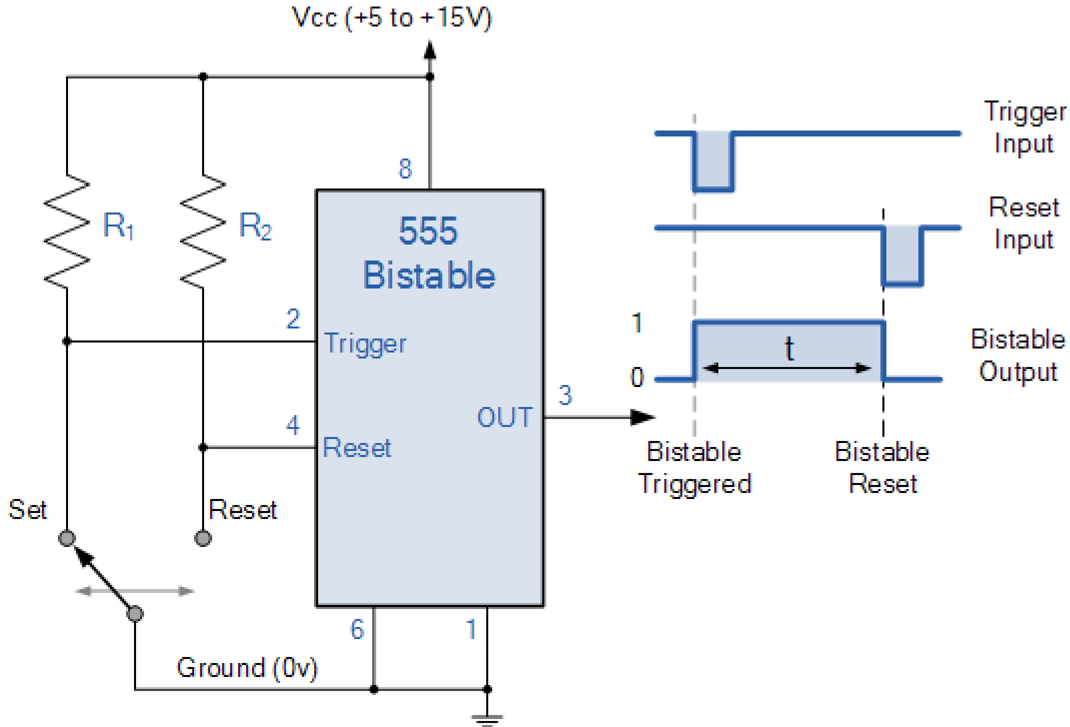
So by selecting suitable values of C and R in the ranges of 0.001uF to 100uF and 1kΩ to 10MΩ respectively, we can read the expected output frequency directly from the nomograph graph thereby eliminating any error in the calculations. In practice the value of the timing resistor for a monostable 555 timer should not be less than 1kΩ or greater than 20MΩ.

Bistable 555 Timer

As well as the one shot **555 Monostable** configuration above, we can also produce a Bistable (two stable states) device with the operation and output of the **555 Bistable** being similar to the transistorised one we look at previously in the Bistable Multivibrators tutorial.

The **555 Bistable** is one of the simplest circuits we can build using the 555 timer oscillator chip. This bistable configuration does not use any RC timing network to produce an output waveform so no equations are required to calculate the time period of the circuit. Consider the Bistable 555 Timer circuit below.

Bistable Flip-flop Circuit



The switching of the output waveform is achieved by controlling the trigger and reset inputs of the 555 timer which are held "HIGH" by the two pull-up resistors, R1 and R2. By taking the trigger input (pin 2) "LOW", switch in set position, changes the output state into the "HIGH" state and by taking the reset input (pin 4) "LOW", switch in reset position, changes the output into the "LOW" state.

This 555 timer circuit will remain in either state indefinitely and is therefore bistable. Then the **Bistable 555 timer** is stable in both states, "HIGH" and "LOW". The threshold input (pin 6) is connected to ground to ensure that it cannot reset the bistable circuit as it would in a normal timing application.

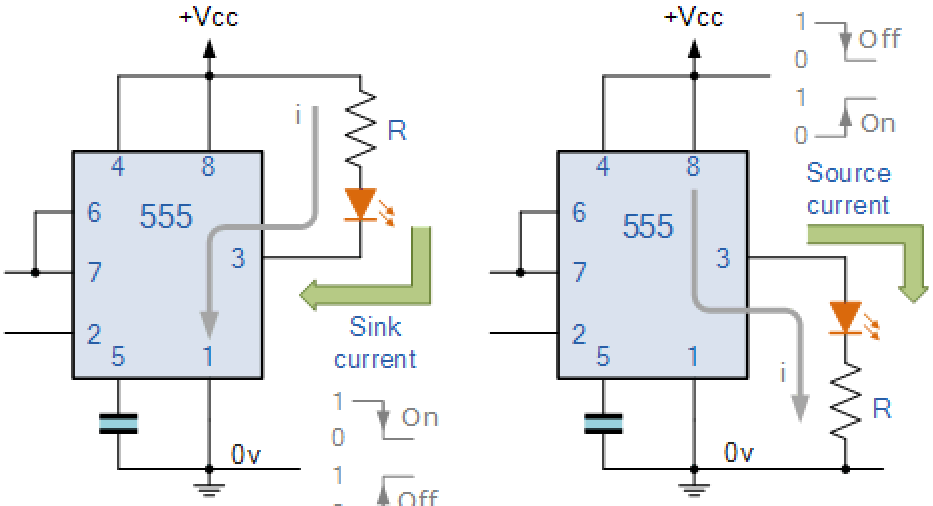
555 Timer Output

We could not finish this **555 Timer** tutorial without discussing something about the switching and drive capabilities of the 555 timer or indeed the dual **556 Timer IC**.

The output (pin 3) of the standard 555 timer or the 556 timer, has the ability to either "Sink" or "Source" a load current of up to a maximum of 200mA, which is sufficient to directly drive output transducers such as relays, filament lamps, LED's motors, or speakers etc, with the aid of series resistors or diode protection.

This ability of the 555 timer to both "Sink" (absorb) and "Source" (supply) current means that the output device can be connected between the output terminal of the 555 timer and the supply to sink the load current or between the output terminal and ground to source the load current. For example.

Sinking and Sourcing the 555 Timer Output

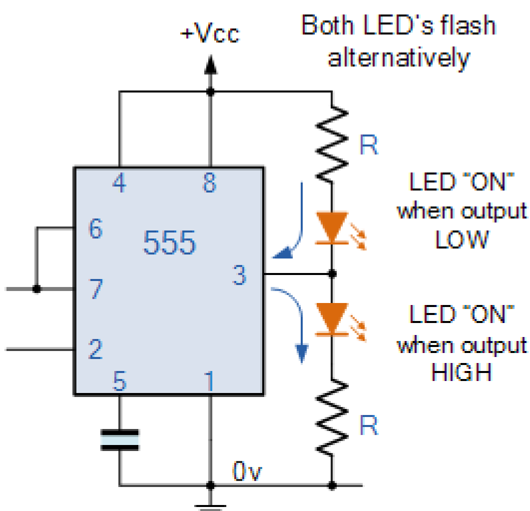


LED "ON" when pin 3 is LOW (Sinking)

LED "ON" when pin 3 is HIGH (Sourcing)

In the first circuit above, the LED is connected between the positive supply rail (+Vcc) and the output pin 3. This means that the current will "Sink" (absorb) or flow into the 555 timer output terminal and the LED will be "ON" when the output is "LOW".

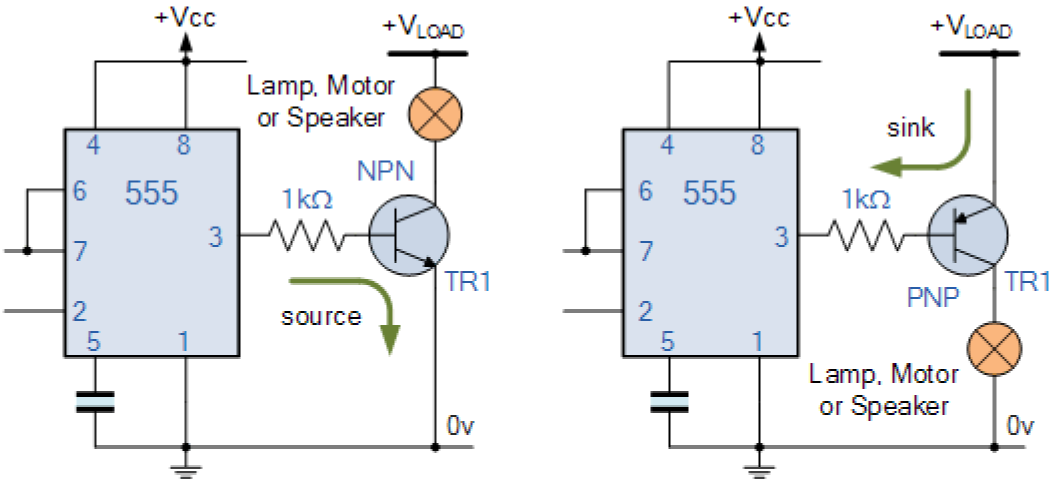
The second circuit above shows that the LED is connected between the output pin 3 and ground (0v). This means that the current will "Source" (supply) or flow out of the 555 timers output terminal and the LED will be "ON" when the output is "HIGH".



The ability of the 555 timer to both sink and source its output load current means that both LED's can be connected to the output terminal at the same time but only one will be switched "ON" depending whether the output state is "HIGH" or "LOW". The circuit to the left shows an example of this. the two LED's will be alternatively switched "ON" and "OFF" depending upon the output. Resistor, R is used to limit the LED current to below 20mA.

We said earlier that the maximum output current to either sink or source the load current via pin 3 is about 200mA at the maximum supply voltage, and this value is more than enough to drive or switch other logic IC's, LED's or small lamps, etc. But what if we wanted to switch or control higher power devices such as motors, electromagnets, relays or loudspeakers. Then we would need to use a Transistor to amplify the 555 timers output in order to provide a sufficiently high enough power to drive the load.

555 Timer Transistor Driver



The transistor in the two examples above, can be replaced with a Power MOSFET device or Darlington transistor if the load current is high. When using an inductive load such as a motor, relay or electromagnet, it is advisable to connect a freewheeling (or flywheel) diode directly across the load terminals to absorb any back emf voltages generated by the inductive device when it changes state.

Thus far we have look at using the 555 Timer to generate monostable and bistable output pulses. In the next tutorial about Waveform Generation we will look at connecting the 555 in an astable multivibrator configuration. When used in the astable mode both the frequency and duty cycle of the output waveform can be accurately controlled to produce a very versatile waveform generator.

https://www.electronics-tutorials.ws/waveforms/555_oscillator.html

555 Oscillator Tutorial

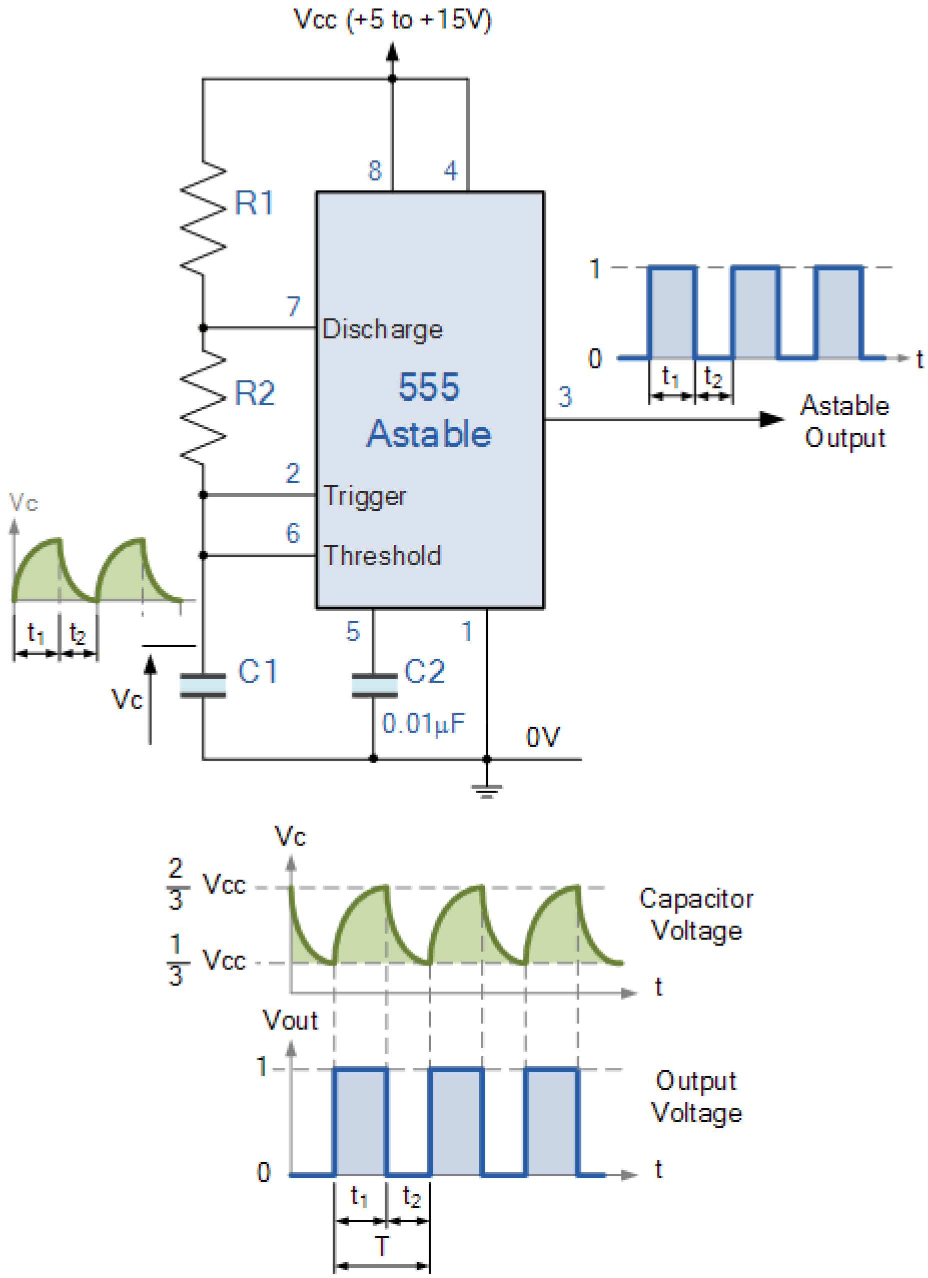
The **555 Timer IC** can be connected either in its Monostable mode thereby producing a precision timer of a fixed time duration, or in its Bistable mode to produce a flip-flop type switching action. But we can also connect the 555 timer IC in an Astable mode to produce a very stable **555 Oscillator** circuit for generating highly accurate free running waveforms whose output frequency can be adjusted by means of an externally connected RC tank circuit consisting of just two resistors and a capacitor.

The **555 Oscillator** is another type of relaxation oscillator for generating stabilized square wave output waveforms of either a fixed frequency of up to 500kHz or of varying duty cycles from 50 to 100%. In the previous 555 Timer tutorial we saw that the Monostable circuit produces a single output one-shot pulse when triggered on its pin 2 trigger input.

Whereas the 555 monostable circuit stopped after a preset time waiting for the next trigger pulse to start over again, in order to get the 555 Oscillator to operate as an astable multivibrator it is necessary to continuously re-trigger the 555 IC after each and every timing cycle.

This re-triggering is basically achieved by connecting the *trigger* input (pin 2) and the *threshold* input (pin 6) together, thereby allowing the device to act as an astable oscillator. Then the 555 Oscillator has no stable states as it continuously switches from one state to the other. Also the single timing resistor of the previous monostable multivibrator circuit has been split into two separate resistors, R1 and R2 with their junction connected to the discharge input (pin 7) as shown below.

Basic Astable 555 Oscillator Circuit



In the **555 Oscillator** circuit above, pin 2 and pin 6 are connected together allowing the circuit to re-trigger itself on each and every cycle allowing it to operate as a free running oscillator. During each cycle capacitor, C charges up through both timing resistors, R1 and R2 but discharges itself only through resistor, R2 as the other side of R2 is connected to the *discharge* terminal, pin 7.

Then the capacitor charges up to 2/3Vcc (the upper comparator limit) which is determined by the 0.693(R1+R2)C combination and discharges itself down to 1/3Vcc (the lower comparator limit) determined by the 0.693(R2*C) combination. This results in an output waveform whose voltage level is approximately equal to Vcc – 1.5V and whose output “ON” and “OFF” time periods are determined by the capacitor and resistors combinations. The individual times required to complete one charge and discharge cycle of the output is therefore given as:

Astable 555 Oscillator Charge and Discharge Times

$$t_1 = 0.693(R_1 + R_2).C$$
$$\text{and}$$
$$t_2 = 0.693 \times R_2 \times C$$

Where, R is in Ω and C in Farads.

When connected as an astable multivibrator, the output from the **555 Oscillator** will continue indefinitely charging and discharging between 2/3Vcc and 1/3Vcc until the power supply is removed. As with the monostable multivibrator these charge and discharge times and therefore the frequency are independent on the supply voltage.

The duration of one full timing cycle is therefore equal to the sum of the two individual times that the capacitor charges and discharges added together and is given as:

555 Oscillator Cycle Time

$$T = t_1 + t_2 = 0.693(R_1 + 2R_2).C$$

The output frequency of oscillations can be found by inverting the equation above for the total cycle time giving a final equation for the output frequency of an Astable 555 Oscillator as:

555 Oscillator Frequency Equation

$$f = \frac{1}{T} = \frac{1.44}{(R_1 + 2R_2).C}$$

By altering the time constant of just one of the RC combinations, the **Duty Cycle** better known as the “Mark-to-Space” ratio of the output waveform can be accurately set and is given as the ratio of resistor R2 to resistor R1. The Duty Cycle for the 555 Oscillator, which is the ratio of the “ON” time divided by the “OFF” time is given by:

555 Oscillator Duty Cycle

$$\text{Duty Cycle} = \frac{T_{ON}}{T_{OFF} + T_{ON}} = \frac{R_1 + R_2}{(R_1 + 2R_2)} \ \%$$

The duty cycle has no units as it is a ratio but can be expressed as a percentage (%). If both timing resistors, R1 and R2 are equal in value, then the output duty cycle will be 2:1 that is, 66% ON time and 33% OFF time with respect to the period.

555 Oscillator Example No1

An **Astable 555 Oscillator** is constructed using the following components, R1 = 1kΩ, R2 = 2kΩ and capacitor C = 10uF. Calculate the output frequency from the 555 oscillator and the duty cycle of the output waveform.

t_1 – capacitor charge “ON” time is calculated as:

$$\begin{aligned} t_1 &= 0.693(R_1 + R_2).C \\ &= 0.693(1000 + 2000) \times 10 \times 10^{-6} \\ &= 0.021s = 21ms \end{aligned}$$

t_2 – capacitor discharge “OFF” time is calculated as:

$$\begin{aligned} t_2 &= 0.693\, R_2.C \\ &= 0.693 \times 2000 \times 10 \times 10^{-6} \\ &= 0.014s = 14ms \end{aligned}$$

Total periodic time (T) is therefore calculated as:

$$T = t_1 + t_2 = 21ms + 14ms = 35ms$$

The output frequency, f is therefore given as:

$$f = \frac{1}{T} = \frac{1}{35ms} = 28.6Hz$$

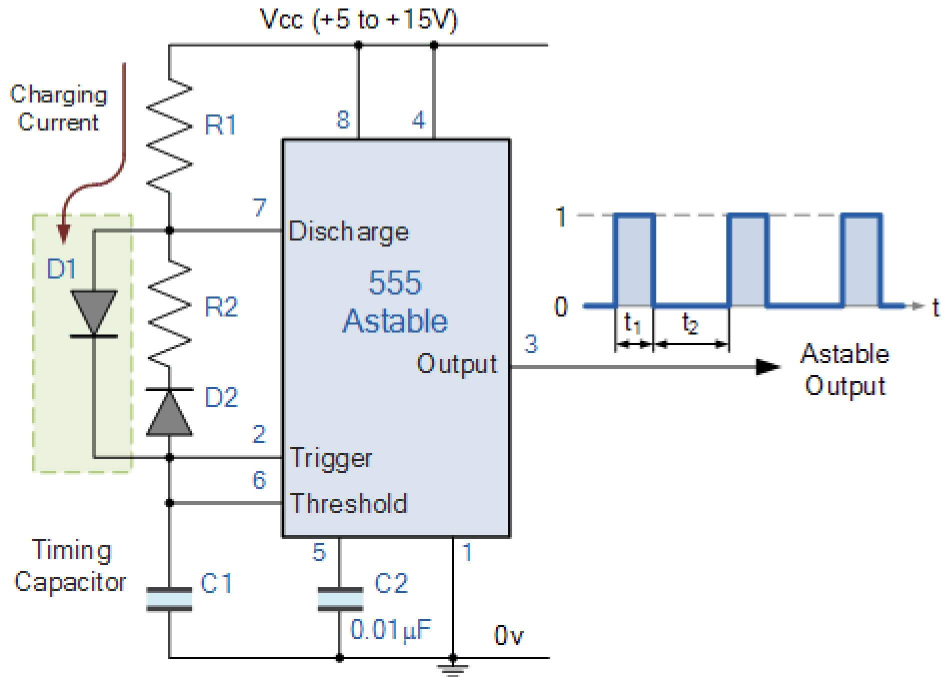
Giving a duty cycle value of:

$$\text{Duty Cycle} = \frac{R_1 + R_2}{(R_1 + 2R_2)} = \frac{1000 + 2000}{(1000 + 2 \times 2000)} = 0.6 \text{ or } 60\%$$

As the timing capacitor, C charges through resistors R1 and R2 but only discharges through resistor R2 the output duty cycle can be varied between 50 and 100% by changing the value of resistor R2. By decreasing the value of R2 the duty cycle increases towards 100% and by increasing R2 the duty cycle reduces towards 50%. If resistor, R2 is very large relative to resistor R1 the output frequency of the 555 astable circuit will determined by R2 x C only.

The problem with this basic astable 555 oscillator configuration is that the duty cycle, the “mark to-space” ratio will never go below 50% as the presence of resistor R2 prevents this. In other words we cannot make the outputs “ON” time shorter than the “OFF” time, as (R1 + R2)C will always be greater than the value of R1 x C. One way to overcome this problem is to connect a signal bypassing diode in parallel with resistor R2 as shown below.

Improved 555 Oscillator Duty Cycle



By connecting this diode, D1 between the *trigger* input and the *discharge* input, the timing capacitor will now charge up directly through resistor R1 only, as resistor R2 is effectively shorted out by the diode. The capacitor discharges as normal through resistor, R2.

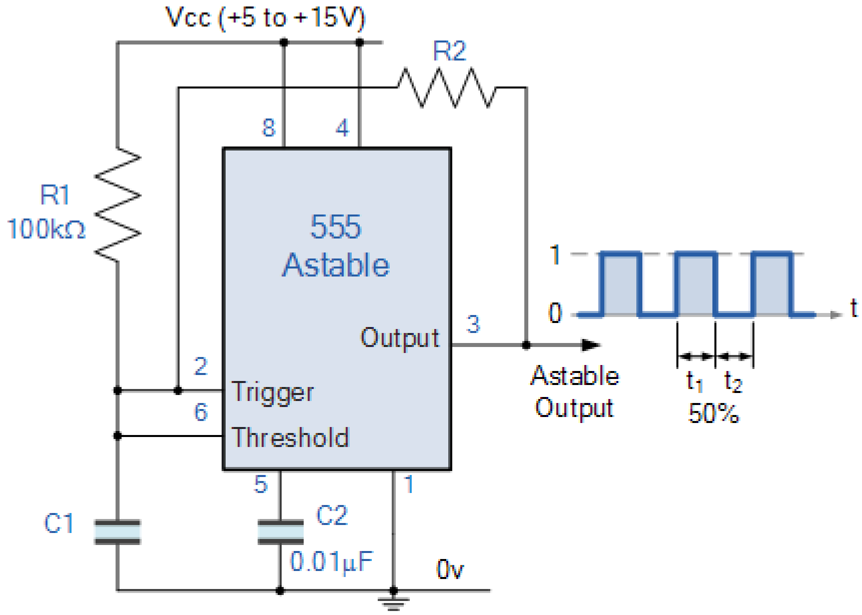
An additional diode, D2 can be connected in series with the discharge resistor, R2 if required to ensure that the timing capacitor will only charge up through D1 and not through the parallel path of R2. This is because during the charging process diode D2 is connected in reverse bias blocking the flow of current through itself.

Now the previous charging time of t1 = 0.693(R1 + R2)C is modified to take account of this new charging circuit and is given as: 0.693(R1 x C). The duty cycle is therefore given as D = R1/(R1 + R2). Then to generate a duty cycle of less than 50%, resistor R1 needs to be less than resistor R2.

Although the previous circuit improves the duty cycle of the output waveform by charging the timing capacitor, C1 through the R1 + D1 combination and then discharging it through the D2 + R2 combination, the problem with this circuit arrangement is that the 555 oscillator circuit uses additional components, i.e. two diodes.

We can improve on this idea and produce a fixed square wave output waveform with an exact 50% duty cycle very easily and without the need for any extra diodes by simply moving the position of the charging resistor, R2 to the output (pin 3) as shown.

50% Duty Cycle Astable Oscillator



The 555 oscillator now produces a 50% duty cycle as the timing capacitor, C1 is now charging and discharging through the same resistor, R2 rather than discharging through the timers discharge pin 7 as before. When the output from the 555 oscillator is HIGH, the capacitor charges up through R2 and when the output is LOW, it discharges through R2. Resistor R1 is used to ensure that the capacitor charges up fully to the same value as the supply voltage.

However, as the capacitor charges and discharges through the same resistor, the above equation for the output frequency of oscillations has to be modified a little to reflect this circuit change. Then the new equation for the 50% Astable 555 Oscillator is given as:

50% Duty Cycle Frequency Equation

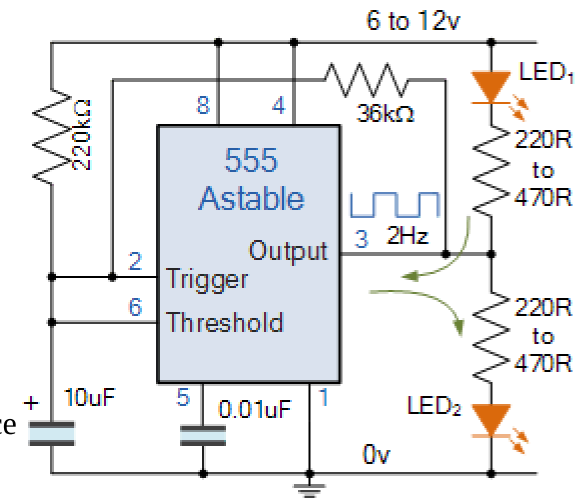
$$f = \frac{1}{0.693(2R_2).C}\ \text{Hz}$$

Note that resistor R1 needs to be sufficiently high enough to ensure it does not interfere with the charging of the capacitor to produce the required 50% duty cycle. Also changing the value of the timing capacitor, C1 changes the oscillation frequency of the astable circuit.

555 Oscillator Applications

We said previously that the maximum output to either sink or source the load current via pin 3 is about 200mA and this value is more than enough to drive or switch other logic IC’s, a few LED’s or a small lamp etc and that we would need to use a bipolar transistor or MOSFET to amplify the 555’s output to drive larger current loads such as motor or relays.

But the **555 Oscillator** can also be used in a wide range of waveform generator circuits and applications that require very little output current such as in electronic test equipment for producing a whole range of different output test frequencies.



The 555 can also be used to produce very accurate sine, square and pulse waveforms or as LED or lamp flashers and dimmers to simple noise making circuits such as metronomes, tone and sound effects generators and even musical toys for Christmas.

We could very easily build a simple 555 oscillator circuit to flash a few LED's "ON" and "OFF" similar to the one shown, or to produce a high frequency noise from a loudspeaker. But one very nice and simple to build science project using an astable based 555 oscillator is that of an Electronic Metronome.

Metronomes are devices used to mark time in pieces of music by producing a regular and recurring musical beat or click. A simple electronic metronome can be made using a 555 oscillator as the main timing device and by adjusting the output frequency of the oscillator the tempo or "Beats per Minute" can be set.

So for example, a tempo of 60 beats per minute means that one beat will occur every second and in electronics terms that equates to 1Hz. So by using some very common musical definitions we can easily build a table of the different frequencies required for our metronome circuit as shown below.

Metronome Frequency Table

Musical Definition	Rate	Beats per Minute	Cycle Time (T)	Frequency
Larghetto	Very Slow	60	1sec	1.0Hz
Andante	Slow	90	666ms	1.5Hz
Moderato	Medium	120	500ms	2.0Hz
Allegro	Fast	150	400ms	2.5Hz
Presto	Very Fast	180	333ms	3.0Hz

The output frequency range of the metronome was simply calculated as the reciprocal of 1 minute or 60 seconds divided by the number of beats per minute required, for example (1/(60 secs / 90 bpm) = 1.5Hz) and 120bpm is equivalent to 2Hz, and so on. So by using our now familiar equation above for calculating the output frequency of an astable 555 oscillator circuit the individual values of R1, R2 and C can be found.

The time period of the output waveform for an astable 555 Oscillator is given as:

$$T = t_1 + t_2 = 0.693(R_1 + 2R_2).C$$

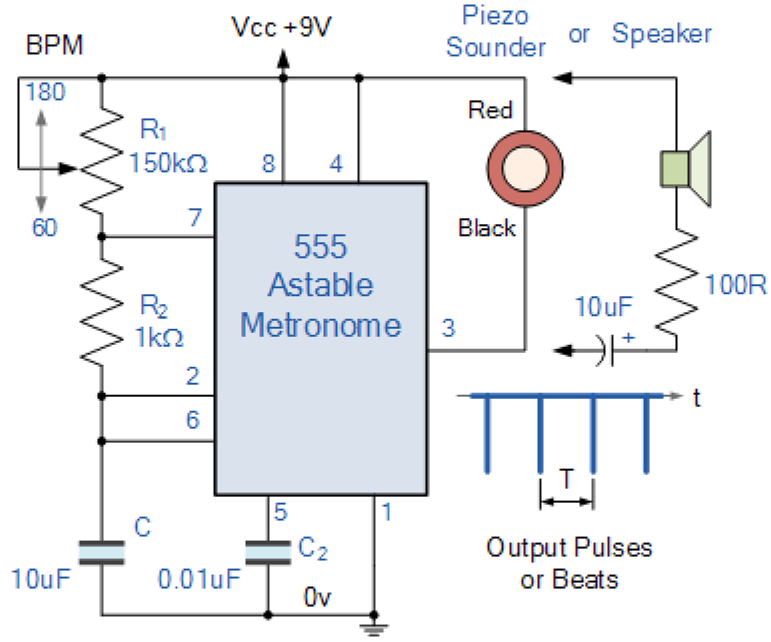
For our electronic metronome circuit, the value of the timing resistor R1 can be found by rearranging the equation above to give:

$$R_1 = \frac{T}{0.693 \times C} - 2R_2$$

Assuming a value for resistor R2 = 1kΩ and capacitor C = 10uF the value of the timing resistor R1 for our frequency range is given as 142k3Ω at 60 beats per minute to 46k1Ω at 180 beats per minute, so a variable resistor (potentiometer) of 150kΩ would be more than enough for the metronome circuit to produce the full range of beats required and some more. Then the final circuit for our electronic metronome example would be given as:

555 Electronic Metronome

R1 position	Beats per minute
142.3kΩ	60bpm
94.2kΩ	90bpm
70.1kΩ	120bpm
55.7kΩ	150bpm
46.1kΩ	180bpm



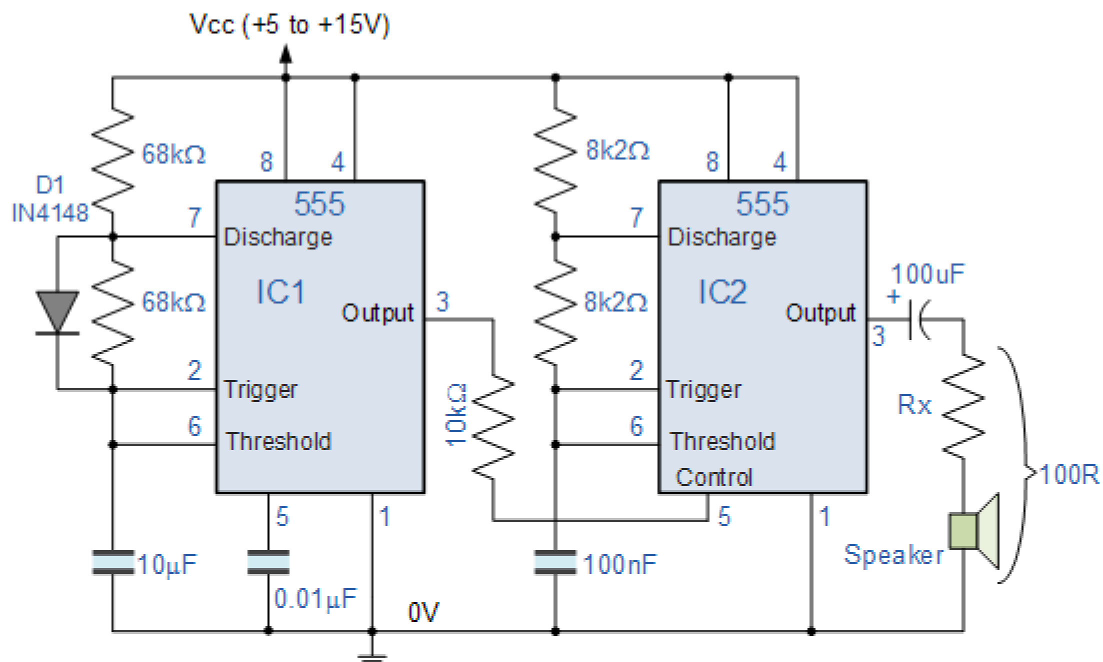
This simple metronome circuit demonstrates just one simple way of using a 555 oscillator to produce an audible sound or note. It uses a 150kΩ potentiometer to control the full range of output pulses or beats, and as it has a 150kΩ value it can be easily calibrated to give an equivalent percentage value corresponding to the position of the potentiometer. For example, 60 beats per minute equals 142.3kΩ or 95% rotation.

Likewise, 120 beats per minute equals 70.1kΩ or 47% rotation, etc. Additional resistors or trimmer's can be connected in series with the potentiometer to pre-set the outputs upper and lower limits to predefined values, but these additional components will need to be taken into account when calculating the output frequency or time period.

While the above circuit is a very simple and amusing example of sound generation, it is possible to use the **555 Oscillator** as a noise generator/synthesizer or to make musical sounds, tones and alarms by constructing a variable-frequency, variable-mark/space ratio waveform generator.

In this tutorial we have used just a single 555 oscillator circuit to produce a sound but by cascading together two or more 555 oscillator chips, various circuits can be constructed to produce a whole range of musical and sound effects. One such novelty circuit is the police car "Dee-Dah" siren given in the example below.

555 Oscillator Police "Dee-Dah" Siren



The circuit simulates a warble-tone alarm signal that simulates the sound of a police siren. IC1 is connected as a 2Hz non-symmetrical astable multivibrator which is used to frequency modulate IC2 via the 10kΩ resistor. The output of IC2 alternates symmetrically between 300Hz and 660Hz taking 0.5 seconds to complete each alternating cycle.

https://www.electronics-tutorials.ws/waveforms/555-circuits-part-1.html

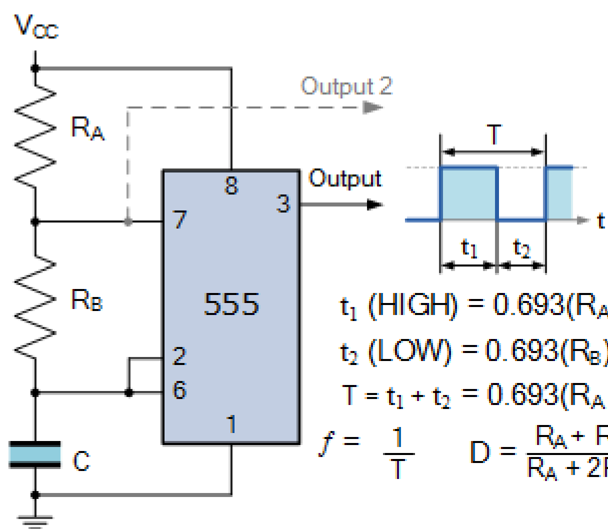
555 Circuits Part 1

We have seen in the last few tutorials that the **555 Timer** can be configured with externally connected components as multivibrators, oscillators and timers, with timing intervals ranging from a few microseconds to many hours. As the 555 timer is one of our favourite, cheapest and easily configurable chips, let's look at using it to create some different 555 circuits part 1.

As we have seen previously, the 555 timer comes as a single device within an 8-pin dual-in-line package (DIP) or as the 556 device which has two 555 chips in a single 14-pin dual-in-line package. The two 555 timers within the 556 operate independently of each other but share a common VCC supply and ground (0V) connection.

The standard TTL 555 can operate from a supply voltage between 4.5 volts and 18 volts, with its output voltage approximately 2 volts lower than its supply voltage VCC. The 555 can source or sink a maximum output current of 200mA, (but it may get hot at this level), so the circuit variations are unlimited. Note that the CMOS versions of the 555, the 7555 and the 7556 may have different voltage and current ratings.

But first let us remind ourselves of some of the basic formulas we can use to calculate the oscillation frequency.



t_1 (HIGH) $= 0.693(R_A + R_B)C$

t_2 (LOW) $= 0.693(R_B)C$

$T = t_1 + t_2 = 0.693(R_A + 2R_B)C$

$f = \dfrac{1}{T} \qquad D = \dfrac{R_A + R_B}{R_A + 2R_B}$

Where: t_1 is the output high duration, t_2 is the output low duration, T is the periodic time of the output waveform, f is the frequency of the output waveform, and $0.693 = \ln(2)$

When connected as an astable oscillator, capacitor C charges through RA and RB but discharges only through RB.

Thus the duty cycle D is determined by the ratio of these two resistors. With the proper selection of resistors RA and RB, duty cycles of between 50 and 100% can be easily set.

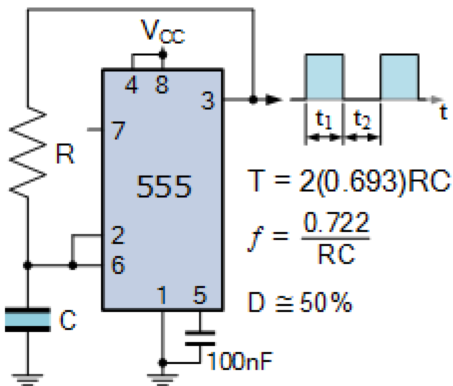
The total time period T is given as the capacitor charging time, t1 (Output High) plus the discharging time, t2 (Output Low) as the capacitor charges and discharges between 1/3Vcc and 2/3Vcc respectively.

In this mode of operation the charging and discharging times and therefore the frequency, f which is given as: 1/T, is independent of the supply voltage.

Simple 555 Oscillator

The basic 555 oscillator circuit is very versatile, and in this 555 circuits part 1 tutorial we can create a number of interesting variations from it. The simplest 555 free-running astable oscillator circuit connects pin 3 (output) directly to the timing capacitor via a single resistor as shown.

Simple 555 Oscillator



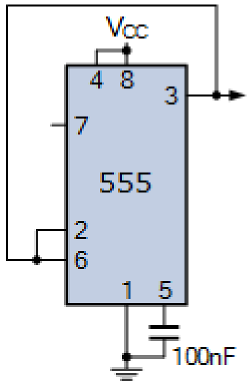
When the output at pin 3 is HIGH, the capacitor charges up through the resistor. When the voltage across the capacitor reaches 2/3Vcc, pin 6 (Threshold) causes the output at pin 3 to change state and goes LOW.

The capacitor now discharges back through the same resistor until pin 2 (Trigger) reaches 1/3Vcc causing the output to change state once again. The capacitor continually charges and discharges between 2/3Vcc and 1/3Vcc back and forth through the same resistor creating a HIGH and LOW state at the output, pin 3.

As the capacitor charges and discharges through the same resistor, the duty cycle of this basic arrangement is very close to 50% or 1:1. The series of square wave output pulses produced have a cycle time (T) equal to approximately 2(0.693)*RC or 2lin(2)*RC. The output waveform frequency (f) is therefore equal to: 0.722/RC.

So for example, if we want to generate a 1kHz output square-wave waveform, then R = 3.3kΩ and C = 220nF using preferred component values.

555 Circuits Part 1 – The Fastest 555 Oscillator



By varying the value of either R or C the 555 astable multivibrator circuit can be made to oscillate at any desired output frequency. But what is the maximum frequency of oscillations we can produce from a single 555 timer chip.

To get the 555 to operate at its highest frequency in this 555 circuits Part 1 tutorial, it is necessary to continuously retrigger it the instant the output changes state, from high to low, or low to high. The fastest switching speed can be obtained by removing both the R and C timing components and feeding the output signal directly back the trigger inputs.

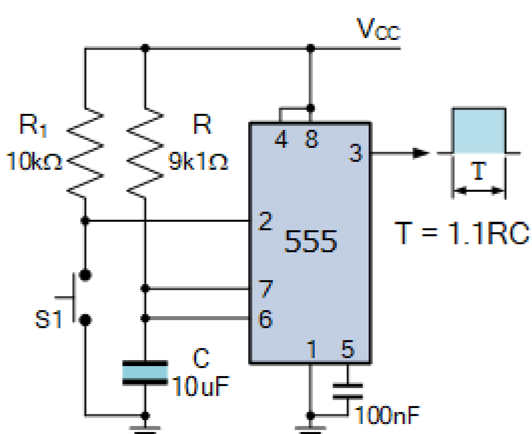
By connecting the output, (pin 3) to both the trigger input, (pin 2) and the threshold input, (pin 6), every time the output changes state it re-triggers the 555 to change state again. However, the output waveform will not be symmetrical or a square wave but a series of negative pulses.

The highest oscillation frequency obtained using this arrangement will depend on the supply voltage, the type of 555 chip used, TTL or CMOS and the manufacturer as the internal circuitry differs from manufacturer to manufacturer. But it is possible to produce an output frequency as high as 350kHz at 5 volts.

555 Circuits Part 1 – The Slowest 555 Oscillator

If we go back to the previous 555 oscillator circuit in this 555 circuits part 1 tutorial and replace the timing capacitor with a large value electrolytic, such as a 220uF or a 470uF capacitor, by selecting the appropriate timing resistor the frequency of oscillation can be reduced to much less than 1Hz. If this is the case, then the 555 circuit stops becoming an oscillator and becomes a timer or delay circuit whose pulse width could be 10’s of seconds.

555 Timer Circuit



In this time delay circuit, the threshold, (pin 6) and the discharge, (pin 7) are tied together at the junction of the RC timing components and the output remains LOW and stable until the 555 is triggered into action by the application of a negative pulse on the trigger input, (pin 2).

The 555’s trigger terminal is held HIGH via resistor R1 until the pushbutton switch, S1 is closed. Operation of S1 momentarily shorts pin 2 to ground and therefore below 1/3Vcc initiating the delay cycle.

Once tiggered the output on pin 3 switches HIGH for some pre-calculated duration determined by the circuits RC time constant and will not respond to any additional triggering of switch S1 until after the timed delay period has been reached, at which point the output at pin 3 returns LOW again.

This makes this manually triggered monostable circuit useful in switch debounce applications as a single pulse is created no matter how many times the switch is depressed. The width of the monostable output pulse period in which the output is HIGH is given as: 1.1RC in seconds, where R is in Ohms and C is in Farads.

So for our simple 555 time delay circuit, the output delay in which the output is in a HIGH state is calculated as: 1.1*9100*10*10-6 = 100ms. By selecting appropriate values of R and C output delays of a few micro-seconds to many hours can be obtained. However, for long timing delays requiring large value electrolytic capacitors, the timing period is generally not that accurate as an electrolytic capacitors tolerance can be extremely large, upto +/-50%.

This can be overcome by changing the timing resistor to a potentiometer to compensate for the capacitor's tolerances, or by selecting low leakage electrolytic capacitors. In practice, the timing resistor should not exceed about 10MΩ or a timing capacitor greater than 470uF as both of these combined would give a delay pulse of about 5170 seconds or about 1.5 hours.

555 Circuits Part 1 – A Modified Duty Cycle

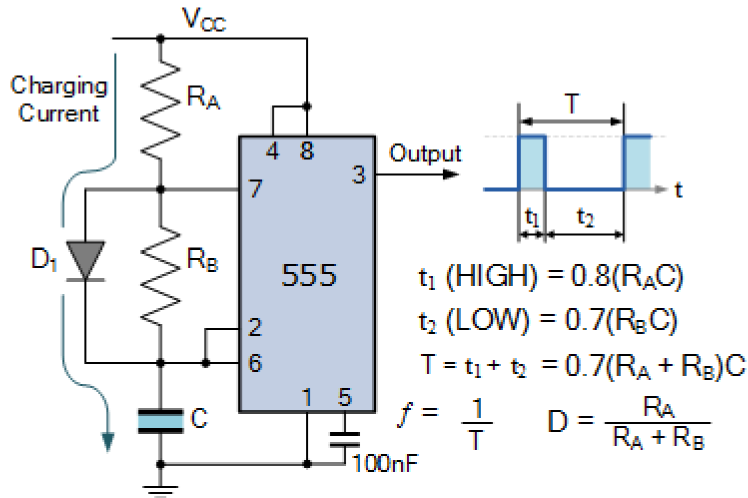
We said previously that the duty cycle, that is the ratio of ON time to total cycle time, is limited to between 50% and 100% for the standard 555 oscillator circuit. But some applications may require a specific duty cycle to be set below 50%, that is the t1 (HIGH) time is less or shorter than the t2 (LOW) time which are set by the ratios of RA and RB.

As the resistance of RA becomes much larger than RB, the duty cycle increases towards unity (100%) as RB approaches zero.

Likewise, as the resistance of RB increases with respect to RA, the duty cycle approaches 50% (or 1:1) giving the output waveform a more square-wave appearance. However to get a full 50% duty cycle, RA would need to be zero Ohms which is not allowed as this would short out VCC to ground through the discharge pin 7.

One way of achieving a lower than 50% duty cycle is to include a diode within the RC timing circuit as shown.

50% Duty Cycle



The addition of diode, D1 across pins 6 and 7 of the basic 555 oscillator circuit, shorts out resistor RB during the charging cycle.

The diode, which can be any general purpose silicon diode, allows the capacitor to charge directly from RA, as RA and D1 are effectively in series removing resistor RB from the charging cycle, although a very small leakage current will still flow through RB.

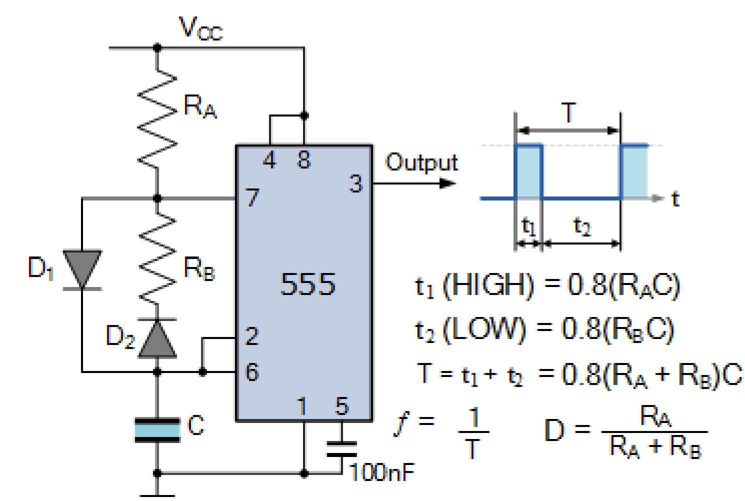
During the discharge cycle when the output at pin 3 is LOW, diode D1 is reverse biased so the circuit functions the same as before discharging through resistor RB and into pin 7 of the 555.

Thus during the charging cycle when the output is HIGH, RA and C control the t1 timing period, while during the discharging cycle when the output is LOW, RB and C control the t2 timing period.

Note that because of the presence of diode, D1 across RB, the diodes 0.7 volt forward voltage drop makes the circuit more sensitive to variations in supply voltage, Vcc. Thus the t1 timing expression is modified to approximately 0.8RC to account for this diode drop.

555 Circuits Part 1 – An Improved Duty Cycle

We can improve on the previous circuit by adding a second diode, D2 in series with the discharging resistor, RB as shown.



With the inclusion of D2, any parallel leakage current flowing through RB during the charging cycle is completely blocked as diode, D2 is reverse biased during this timing period.

During the discharging period, the capacitor discharges back through the series connection of D2 and RB as diode D1 is reverse biased during this cycle.

Thus both the charging and discharging paths for the timing capacitor become identical as the timing capacitor charges through RA and D1 and discharges through RB and D2 allowing for either timing period to be adjusted without affecting the other.

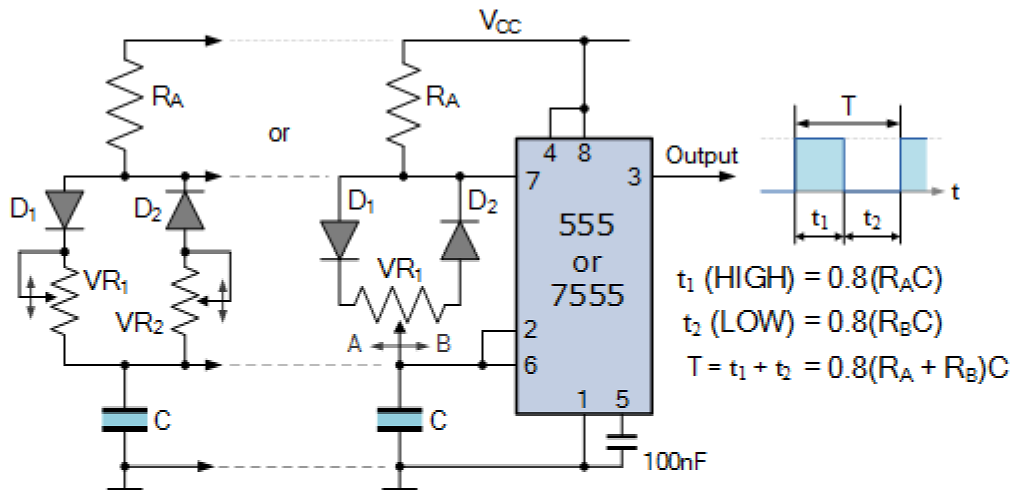
As part of this 555 circuits part 1 tutorial we can make an interesting version of the improved duty cycle circuit using diodes, is that if you make the two timing resistors, RA and RB identical, that is RA = RB, the duty cycle will be exactly 50% producing a square wave output waveform.

Again the standard 555 astable oscillator equations are modified slightly to account for the inclusion of the diodes, and as before, due to the forward diode voltage drops, the timing periods are sensitive to supply voltage variations.

Fully Independent Timing Periods

We can improve once again on the above circuit by replacing the fixed value resistor, RB with one or two potentiometers is series with the two diodes. The inclusion of variable resistors would allow for fully independent variations in the RC charging and discharging timing periods as shown.

Fully Independent 555 Oscillator



The timing circuit on the left shows the use of two potentiometers within the oscillator design. Using two potentiometers, VR1 and VR2, one each in series with the diodes.

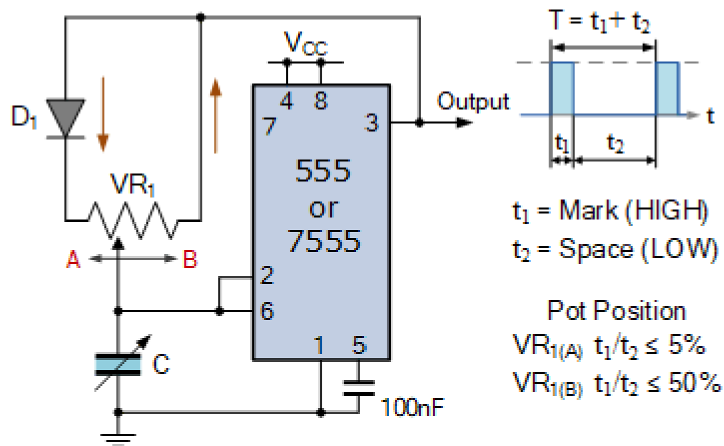
The timing period for both the charging cycle (output high) and the discharging cycle (output low) can now be independently adjusted allowing full control over the duty cycle without affecting the output frequency. A simpler alternative variation on the previous circuit is by using a single potentiometer to control the two output timing periods at the same time as shown on the right hand circuit.

With the potentiometers wiper arm at its center position, the resistive value between point A and the wiper is equal to the resistive value between point B and the wiper. Thus the value of RB now becomes the value of VR1 and the duty cycle of the output waveform will be equal to 50%. Thereby producing a pulse modulated square wave shaped output waveform.

As the potentiometers wiper arm is varied from the center to point A, the duty cycle decreases. Likewise, as the potentiometers wiper arm is varied in the reverse direction from the center to point B, the duty cycle is increased. Thus the duty cycle of the output waveform can be varied from low to high, without any major changes to the output frequency.

We can take this idea one step further by converting a 50% duty cycle 555 astable circuit into one which allows us to vary tON to the tOFF times similar to the previous circuit. This ON/OFF (Mark/Space) ratio can be altered by adding a single diode and potentiometer (or one diode and two fixed resistors) as shown.

Varying the 555's Duty Cycle



When power is first applied, the timing capacitor C1 is uncharged and output (pin 3) goes HIGH, so C1 quickly charges up via the forward-biased diode, D1 and one half of the potentiometer, VR1.

When pin 6 (Threshold) of the 555 detects 2/3 Vcc, output pin 3 switches LOW and capacitor C1 slowly discharges back through the other half of the potentiometer, as now the diode is reverse-biased, until pin 2 (Trigger) detects 1/3 Vcc causing the output, pin 3 to switch back HIGH again repeating the cycle once again.

The amount of time that the 555's output is HIGH is called the "MARK", and the amount of time when the 555's output is LOW is called the "SPACE". So by varying the potentiometer between point "A" (lowest) and point "B" (highest) we can alter the mark-to-space ratio (its Duty Cycle) of the output waveform between about 5% (position A) and a maximum of 50% (position B). Remember that if the Mark and Space lengths are the same then the output will be 1:1.

The advantage of this circuit is that we can produce short Mark (HIGH) lengths or pulses of time with very long lengths of Space (LOW) periods for all sorts of pulse and timing applications. If we reverse the direction of the diode, D1 we can create a timing circuit with a short Space but long Mark period, that is short OFF pulse but long ON duration.

The disadvantage of this basic variable duty cycle circuit is that the duration of the timing period changes as the potentiometer is adjusted due to the interaction of the two halves of the potentiometer. To compensate for this, if a fixed timing period T is required then the value of the timing capacitor, C1 must be adjusted or changed.

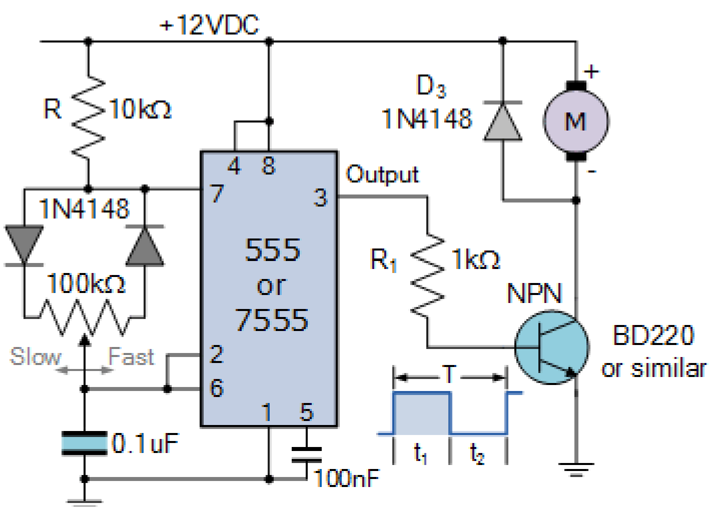
One very good use of either variable timing circuit is in controlling the speed of DC motors using pulse width modulation.

Pulse Width Modulation Motor Control

Pulse width modulation or PWM, is a way of controlling the average voltage value applied to a load by constantly switching it ON and OFF at different duty cycles. Rather than control the rotational speed of a motor by carefully applying less and less voltage to it, we can control its speed by alternatively switching the voltage fully ON and OFF in such a way that the average ON time produces the same effect as a varying the supply voltage.

In effect the control voltage applied across the terminals of the motor is controlled by the duty cycle of the 555's output waveform which in turn controls the speed of rotation. We could also use this pulse width modulation method to control the brightness of a lamp or LED.

Pulse Width Modulation Control



The speed of rotation of the DC motor is controlled using the potentiometer which inturn varies the duty cycle of the output waveform from about 5% to 95%. Resistor R1 limits current flow into the base of the switching transistor, and diode D3 is used in parallel with the motor to suppression and voltage transients as the motor is switched ON and OFF.

The switching transistor given in the example is a BD220 NPN Power transistor, rated at 70 volts, 4 amps, but any equivalent transistor would do provided it can safely handle the motor load current. The switching transistor may require a heatsink to dissipate the heat.

https://www.electronics-tutorials.ws/waveforms/555-circuits-part-2.html

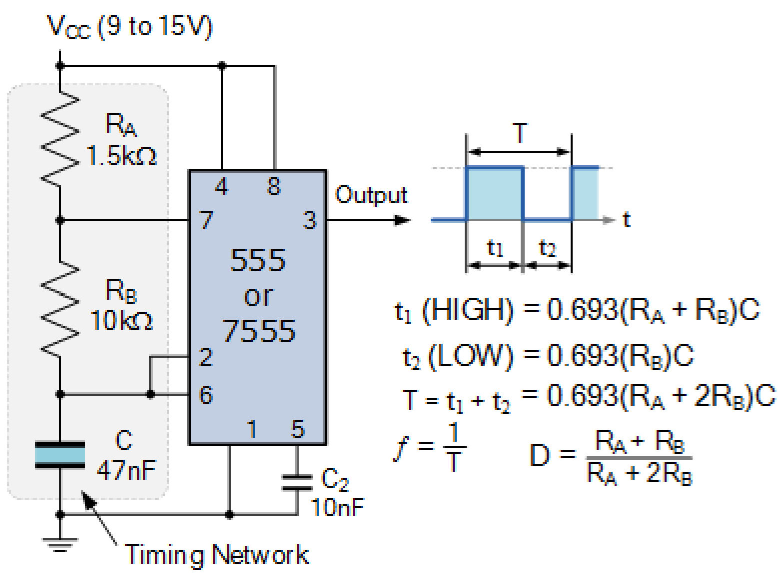
555 Circuits Part 2

This 555 Circuits Part 2 tutorial continues on from our first look at the operation of the 555 timer. This second tutorial looks at some practical uses and circuits we can build when using the 555 as an astable multivibrator.

We recall from the our previous tutorial about the 555 timer that to get it to oscillate as a square-wave oscillator we need to continuously retrigger it with the timing period, T and therefore output frequency, f being set by the timing capacitor C and feedback resistors RA and RB. The duty cycle, D as well as the frequency is controlled by the ratio of these timing resistors.

With that in mind, we can design our basic 555 multivibrator to give us an output frequency of about 1500 hertz using preferred component values as shown.

Basic 555 Multivibrator Circuit



Using the component values given will produce values of: t1 = 375uS, t2 = 325uS, T = 700uS, f = 1430Hz or 1.43kHz and a duty cycle, D of about 0.535, or 53.5%.

Note also that as the duty cycle is 53.5%, when the 555 astable oscillator is connected to a supply voltage of 9 volts, the average output DC equivalent voltage present on the output, pin 3 will be: 9*0.535 approximately equal to 4.8 volts, and when connected to a supply voltage of 15 volts, the equivalent DC output voltage will be 15*0.535 which equals about 8 volts. This voltage level represents the DC input voltage (VIN to the connected voltage multiplier circuit.

[2023-04-28]

555 Voltage Multipliers

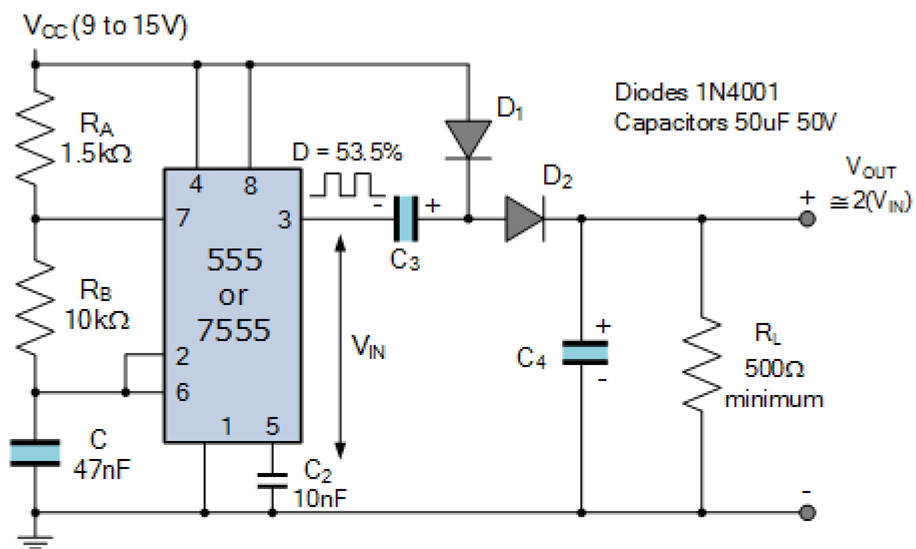
Transformers are very efficient devices for converting an AC primary input voltage to a secondary output voltage, either stepping the secondary voltage up or down with respect to the primary. But what if we wanted to convert a steady state DC voltage from one value to another, then we can not uses transformers for this.

The 555 timer can be used to convert a DC voltage to a much higher DC voltage, and even reversing the polarity of a DC voltage with just a few additional components added to its output pin. Many electronic applications require different low-current voltage supplies to power different parts of a circuit with the simple 555 oscillator above configured as a transformerless DC-to-DC voltage multiplier used to satisfy many of these low-power applications.

555 Voltage Doubler Circuit

The most basic and easily constructed DC-to-DC voltage multiplier is that of the voltage doubler. The 555 is configured as an astable multivibrator to supply the input conditions for the "charge pump" circuit created using the diode and capacitor network as shown.

555 Circuits Part 2 – The Voltage Doubler



This simple 555 voltage doubler circuit consists of a 555 oscillator and a single capacitor-diode voltage doubler network formed by C3, D1, D2 and C4. This voltage doubler circuit multiplies the supply voltage and produces an output that is approximately twice the voltage value of the input voltage minus the diode voltage drops.

When the output at pin 3 is LOW, the 50uF capacitor (C3) charges up to the supply voltage through diode, D1 with diode D2 off. When the output from the 555 goes HIGH, the voltage across C3 discharges through diode D2, as D1 is reverse biased, adding its voltage to the source voltage as VCC and C3 are now like two voltage sources in series.

The timing cycle from the 555 changes state again from HIGH to LOW and the cycle repeats once again, thus producing a DC load voltage which is twice the original input voltage, that is a multiplication factor of two (voltage doubler). Then a 555 voltage doubler circuit can produce an output voltage from about 10 to 30 volts at very low current.

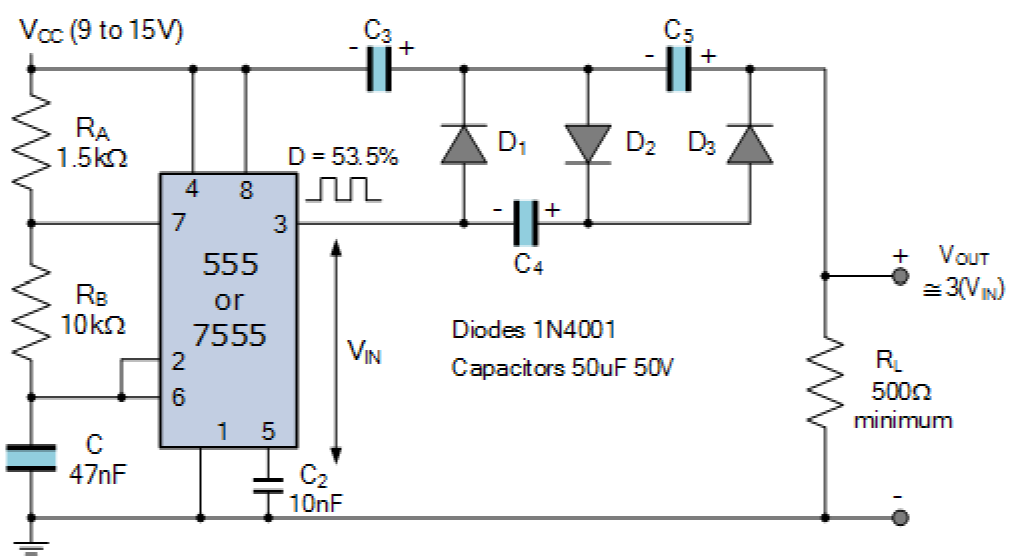
Another point to note is that the frequency of oscillation of the 555 astable multivibrator used to generate the square-wave input signal will determine the value of the capacitors used, as they along with the connected load value create a RC charging/discharging circuit to filter the output voltage. Too low a capacitance value, or too low the frequency of oscillation will produce ripples in the output voltage waveform and therefore a lower average DC output voltage.

With no-load connected, the output voltage will be twice the 555's original supply voltage. The actual output voltage will depend on the value of the connected load, RL and the load current, IL. As given, the 555 voltage doubler circuit above can supply about 30mA at the rated voltage.

There are many variations of the voltage doubler circuit above, but each one uses two diode/capacitor pairs to provide the x2 multiplication factor. By adding or cascading more diode/capacitor networks to the voltage doubler, we can create circuits which can create voltage multiplication ratios as high as we want.

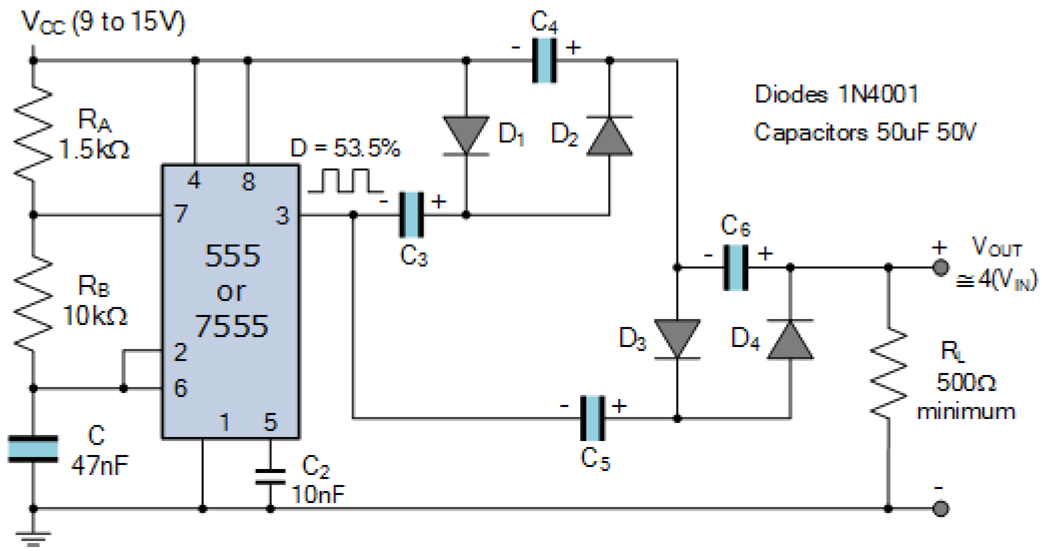
So for example, by adding half a diode/capacitor combination to the 555 voltage doubler circuit creates a voltage tripler circuit with a multiplication factor of x3, and adding a second full diode/capacitor section to the 555 voltage doubler circuit will create a voltage quadrupler circuit with a multiplication factor of x4, and so on as shown.

555 Circuits Part 2 – The Voltage Tripler



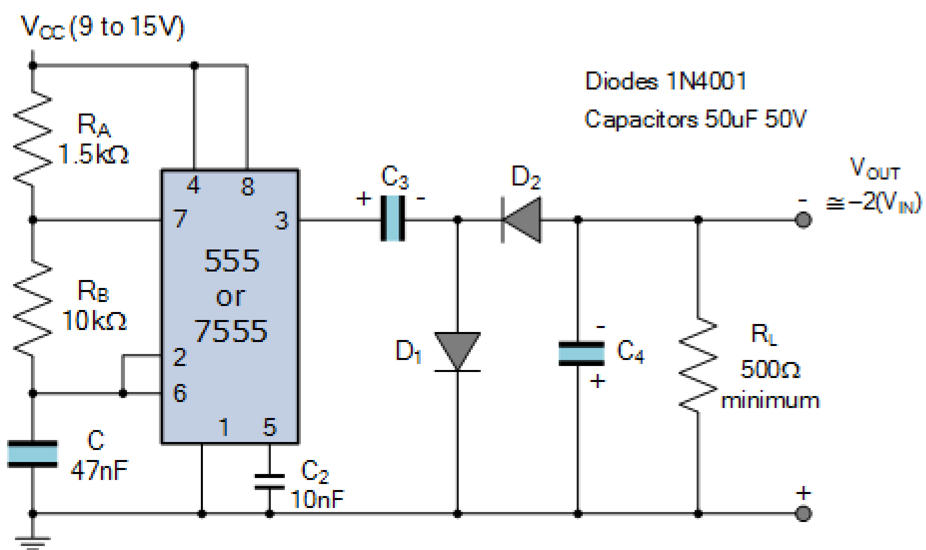
Voltage quadrupler using the 555 timer by cascading together two voltage doubler networks giving an output voltage of approximately 4VIN if losses and diode voltage drops are ignored.

555 Voltage Quadrupler Circuit



As well as producing voltage multipliers with different positive output voltages, we can also configure them to produce negative output voltages by simply reversing the directions and the polarities of the diodes and capacitors used as shown.

555 Circuits Part 2 – The Negative Voltage Doubler

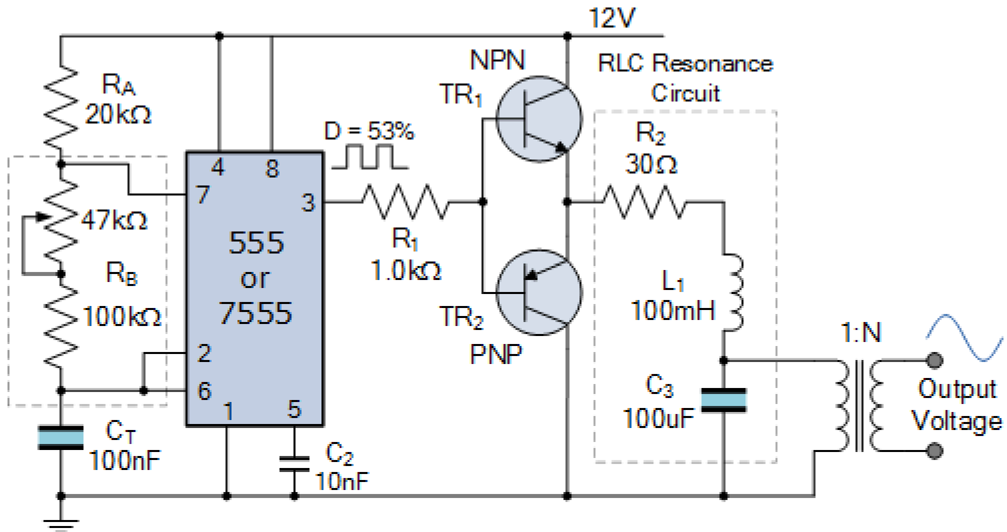


Then we have seen that 555 timer based voltage multipliers can be used to double, triple or even quadruple a single supply voltage to provide various positive and negative output voltages. While in theory there is no limit to the amount of voltage multiplication that can be produced by cascading together multiple diode/capacitor sections to produce progressively higher voltages such as those used in air ionizers or bug zappers. However, care must be taken to ensure against electric shock when dealing with such high output voltages.

555 Circuits Part 2 – The DC-to-AC Inverter

We can take this idea of a 555 voltage multiplier one step further by using the basic 555 timer circuit to produce a DC-to-AC inverter. With the 555 configured to operate as a square-wave oscillator and a few additional components, we can produce a sine-wave output at the desired voltage level, either 120 volts or 240 volts as shown.

555 DC-to-AC Inverter



So how does the 555 DC-to-AC Inverter circuit work. The 555 timer is configured to oscillate as an astable multivibrator producing a square-wave output the same as before. This time however we want the output frequency to be the same as the AC mains frequency, that is either 50Hz or 60Hz and this is achieved using a 47kΩ potentiometer.

Timing resistance RB consists of a fixed value resistor of 100kΩ in series with a potentiometer of 47kΩ. When the potentiometer is adjusted so that its wiper is in its zero position, RB = 100kΩ (0 + 100kΩ), and when it is adjusted in the opposite direction to its maximum position, RB = 147kΩ (47kΩ + 100kΩ).

So by using the previous formulas, the output frequency from the 555 can be adjusted using the potentiometer from about 46Hz to 65Hz, providing the required 50Hz or 60Hz output frequencies as we would expect to see from the AC mains supply.

The square-wave output frequency from pin 3 of the 555 is fed via a current limiting resistor, R1 to the bases of two complementary transistors. When the output is HIGH (current source) the NPN transistor conducts and the PNP transistor is OFF, and when the output is LOW (current sink) the PNP transistor conducts and the NPN transistor is OFF. Thus as the square-wave output signal alternates between HIGH and LOW, it switches one or the other transistor as they are complementary pairs.

Transistors TR1 and TR2 can be any reasonable complementary NPN and PNP transistor such as the TIP41, 2N2222 and TIP42, 2N2907 respectively, or a matched Darlington pair such as the NPN

TIP140, TIP3055 and PNP TIP145, TIP2955 respectively. The choice of output transistors will depend on voltage and current ratings of the transformers primary winding but ideally it should have a low VA rating.

The complementary output stage of TR1 and TR2 is used to drive the primary winding of a small transformer whose ratio of primary to secondary turns will produce the desired output voltage. However if we were to feed the transformers primary directly from the transistor stage, the output waveform from the transformers secondary winding would be that of a square-wave. Thus as we are building a DC-to-AC inverter, we need some way of converting the 555 timers square-wave output on pin 3 into a sinusoidal shaped waveform from the transformers secondary winding.

The RLC filter circuit connected between the transistor stage and the primary winding acts as an RLC resonance circuit tuned to the required output frequency. However, as we can adjust the output frequency from between 46Hz to 65Hz using the potentiometer, the RLC resonance circuits resonant frequency will not be exact for the 50Hz or 60Hz frequencies, but we can calculate the values for somewhere inbetween.

Using standard preferred component values, the filter network of resistor R2, inductor L1 and capacitor C3 produce an RLC resonance circuit tuned to about 52Hz. The transformers primary winding is connected across the capacitor producing a reasonably sinusoidal waveform on the secondary at the required voltage determined by the transformers turns ratio.

Then we can use the 555 timer to produce a very basic DC-to-AC inverter at the required AC output voltage and frequency, for example 120V at 60Hz, or 240V at 50Hz, from a single 12 volt DC supply with an output wattage rating depending on the output transistor stage and transformer used.