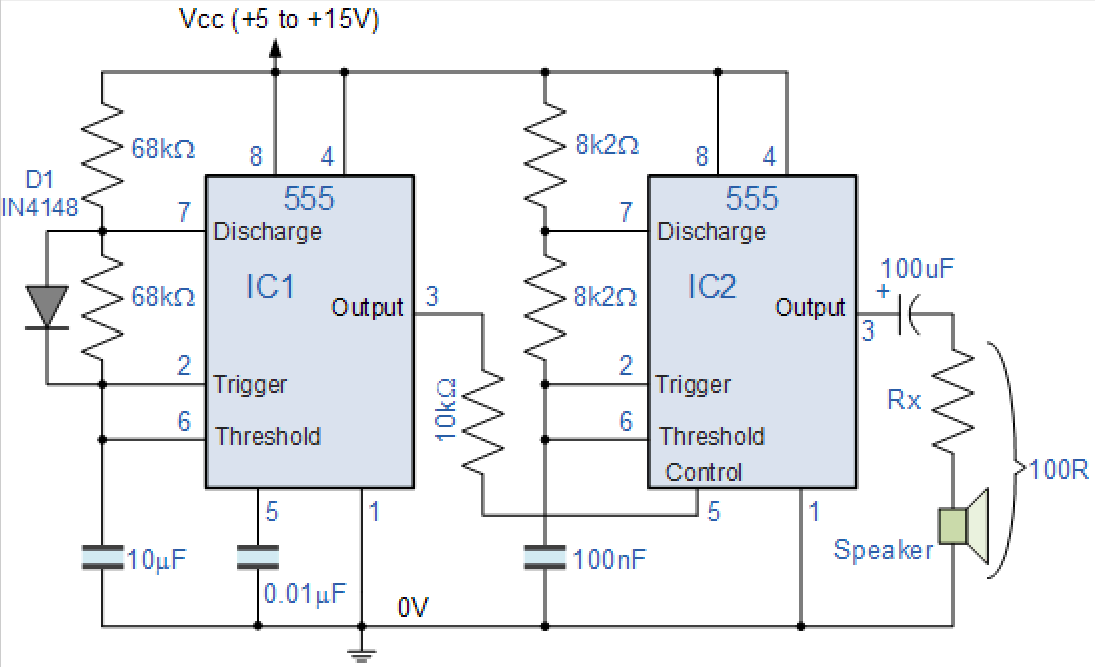


555 Oscillator Tutorial

The 555 IC can be used to create a free running astable oscillator to continuously produce square wave pulses

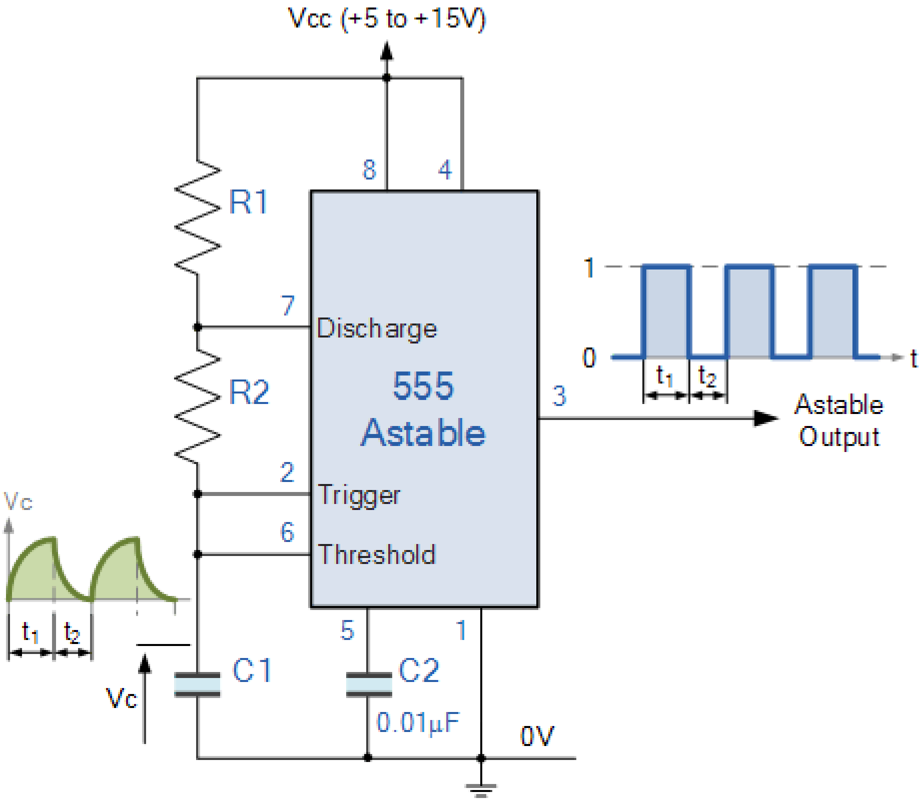
The **555 Timer IC** can be connected either in its Monostable mode thereby producing a precision timer of a fixed time duration, or in its Bistable mode to produce a flip-flop type switching action. But we can also connect the 555 timer IC in an Astable mode to produce a very stable **555 Oscillator** 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.

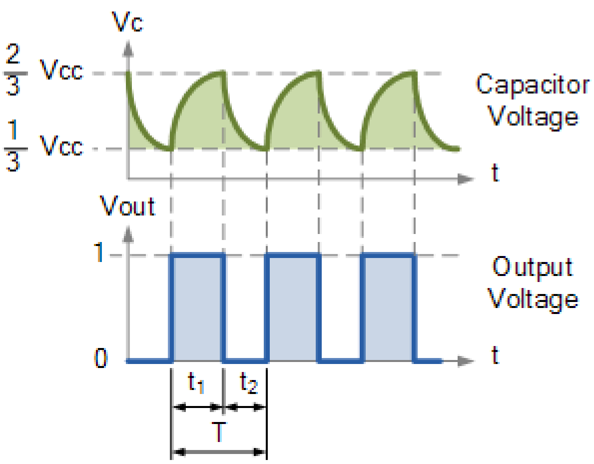
The **555 Oscillator** is another type of relaxation oscillator for generating stabilized square wave output waveforms of either a fixed frequency of up to 500kHz or of varying duty cycles from 50 to 100%. In the previous 555 Timer tutorial we saw that the Monostable circuit produces a single output 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

$$t_1 = 0.693(R_1 + R_2).C$$

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:

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

t_2 – capacitor discharge "OFF" time is calculated as:

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

Total periodic time (T) is therefore calculated as:

$$T = t_1 + t_2 = 21\text{ms} + 14\text{ms} = 35\text{ms}$$

The output frequency, *f* is therefore given as:

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

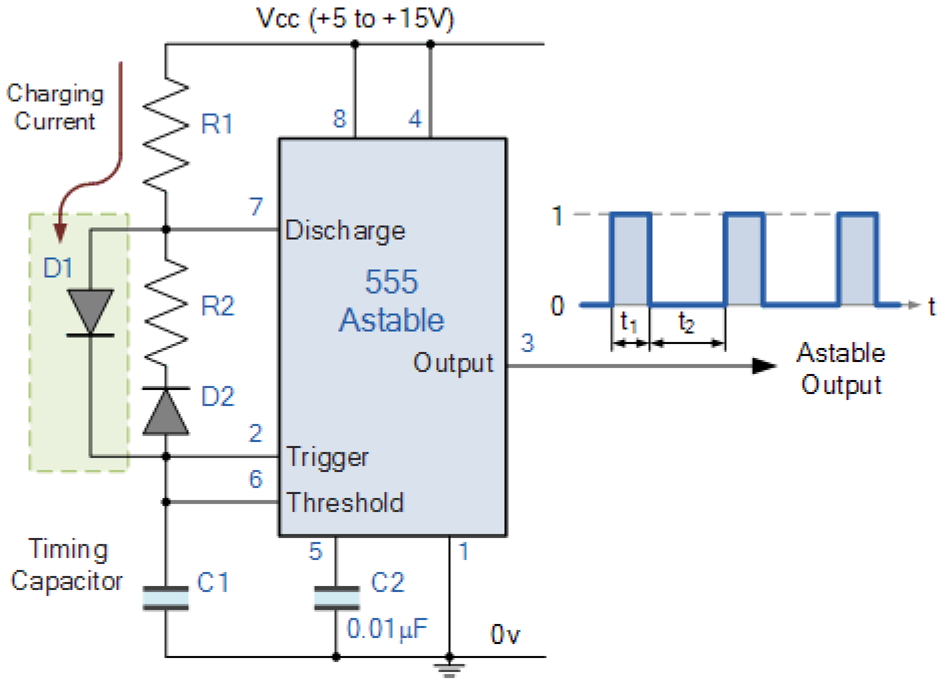
Giving a duty cycle value of:

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

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.

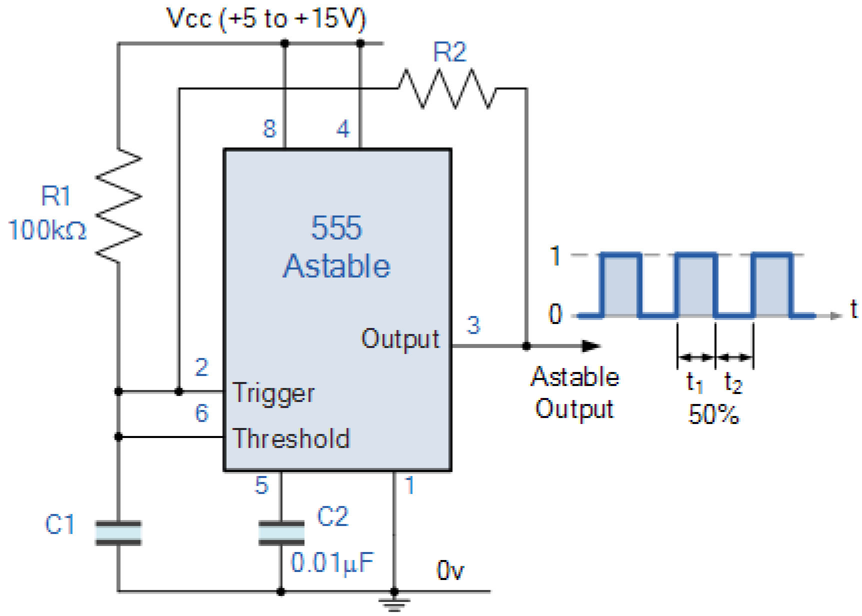
An additional diode, D2 can be connected in series with the discharge resistor, R2 if required to ensure that the timing capacitor will only charge up through D1 and not through the parallel path of R2. This is because during the charging process diode D2 is connected in reverse bias blocking the flow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

Now the previous charging time of $t_1 = 0.693(R1 + R2)C$ is modified to take account of this new charging circuit and is given as: $0.693(R1 \text{ x } C)$. 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.

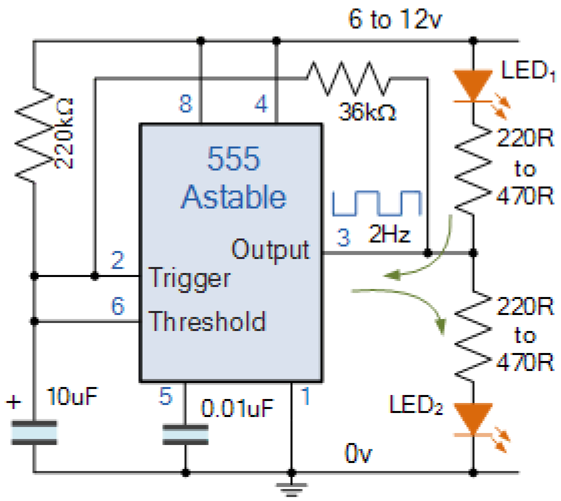
555 Oscillator Applications

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:

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

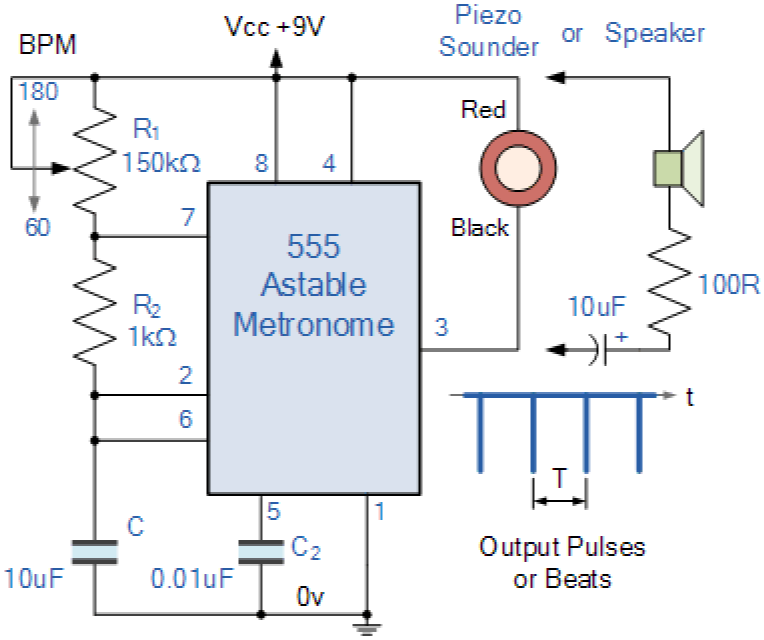
For our electronic metronome circuit, the value of the timing resistor R1 can be found by rearranging the equation above to give:

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

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



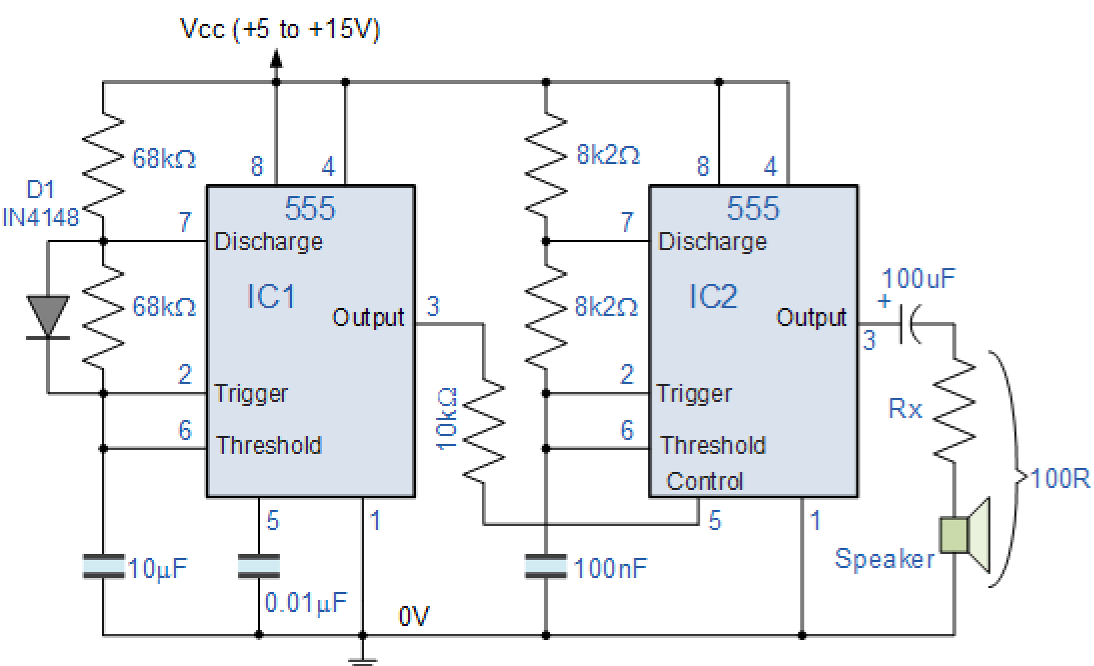
This simple metronome circuit demonstrates just one simple way of using a 555 oscillator to produce an audible sound or note. It uses a 150kΩ potentiometer to control the full range of output pulses or beats, and as it has a 150kΩ value it can be easily calibrated to give an equivalent percentage value 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 $10k\Omega$ resistor. The output of IC2 alternates symmetrically between 300Hz and 660Hz taking 0.5 seconds to complete each alternating cycle.

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- *Rick Saffery*

  This is the best reference I've yet to come across for the venerable 555 timer. Hat-tip to everyone who contributed to the content and the site itself. It's absolutely terrific!

  Posted on October 06th 2022 | 2:50 am
  Reply
  - *CircutScoper*

    Unfortunately the QC of some of the circuit descriptions might not be all it should be.

    For example, "50% Duty Cycle Frequency Equation" fails to mention that, if R2 > 50k, the circuit won't oscillate at all, because pin 2 will never reach Vcc/3 necessary to trigger the positive half-cycle.

    Posted on October 06th 2022 | 5:06 pm
    Reply
    - *Wayne Storr*