**Oscillators**

Oscillators are circuits that produce a continuous signal of some type without the need for an input. They make use of operational amplifiers. Operational amplifiers cannot work without the and inputs, but it is not always necessary that they have an input. This is exactly what happens in oscillators, where a steady output is generated.

A few different types of outputs are possible, depending on how we manipulate the resistor values inside the oscillator. We can have sine wave oscillators, square wave oscillators or triangular wave oscillators.

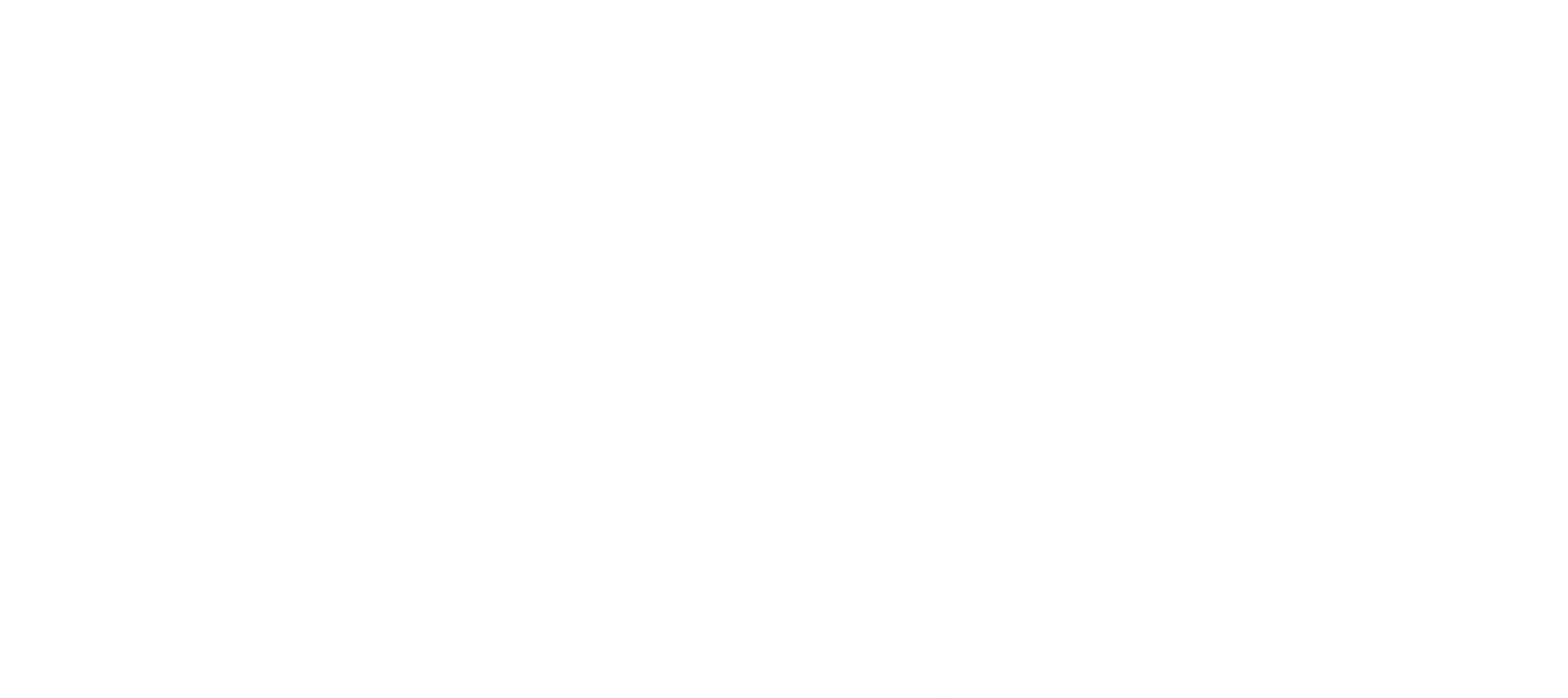
There are a lot of operations in digital circuitry that make use of a clock to maintain synchronization. This clock is an oscillator, specifically, a Crystal Oscillator.

There are three types of oscillators:

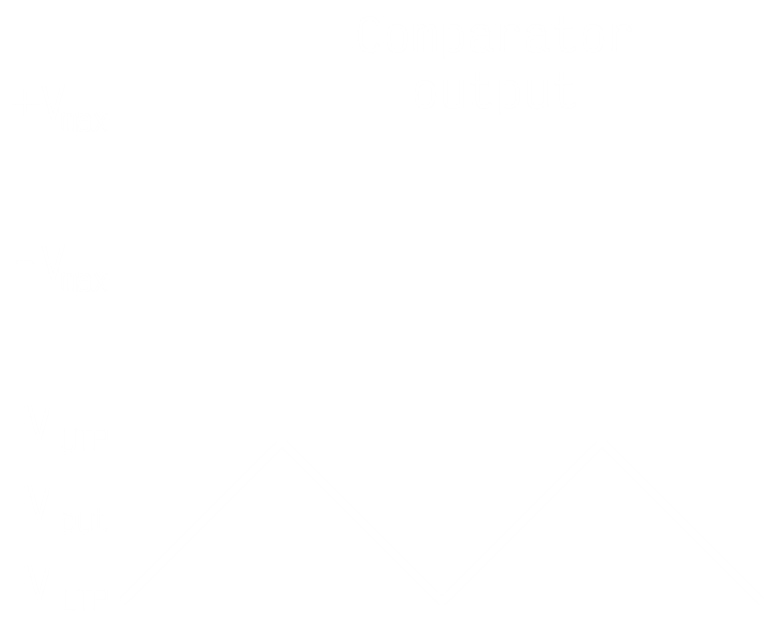
1. RC Oscillators – Wien Bridge Oscillators, Phase-Shift Oscillators
2. LC Oscillators – Crystal Oscillators
3. Relaxation Oscillators

### Triangular Wave Oscillator

A triangular wave oscillator consists of a comparator and an integrator.



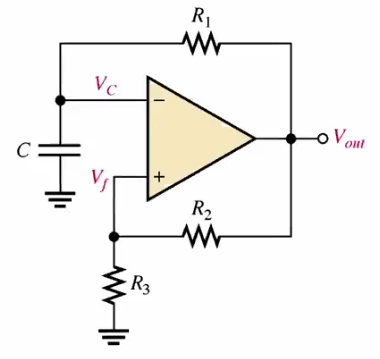
This results in a triangular wave in the output.



- upper limit

- lower limit

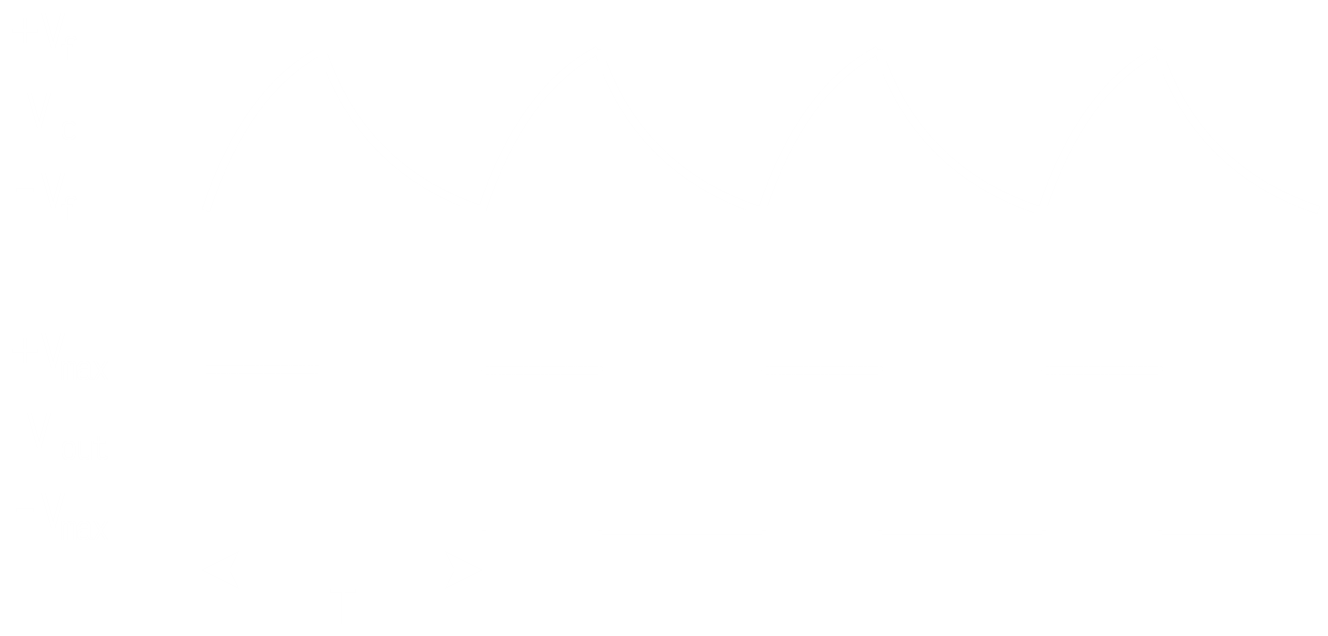
### Square-Wave Oscillators



* Note that this diagram is incorrect. should be .

Square-wave relaxation oscillators are somewhat like Schmitt triggers and comparator circuits.

The charging and discharging of the capacitor cause the op-amp to switch states rapidly, thus producing a square wave. Essentially, is being compared to in this case, and since comes from the capacitor, it changes almost instantaneously.



is the integration of .

The frequency of the output is determined by the RC time constant.

where

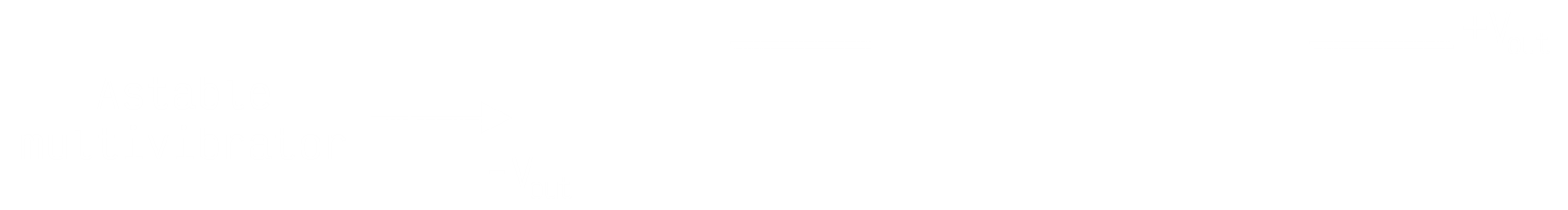
## Multivibrator Circuits

Multivibrators are a special type of circuits used for generator pulse signals. The pulse signals can be rectangular or square wave signals. They generally produce outputs in two states, high or low.

A specific characteristic of multivibrators is the use of passive elements like resistors and capacitors to determine the output state.

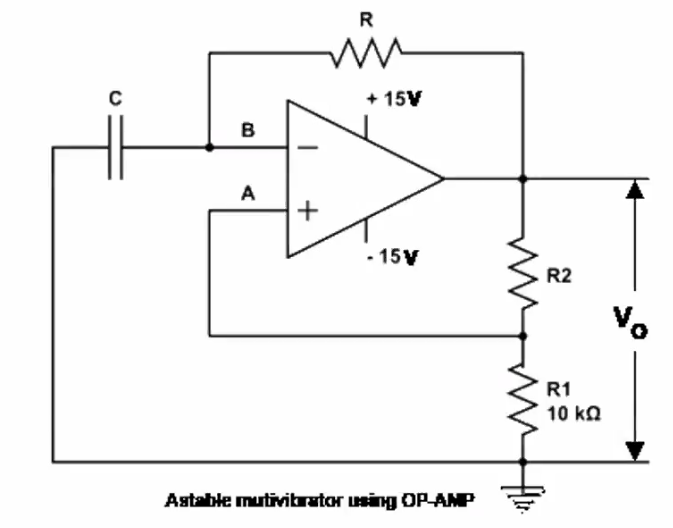
### Astable Multivibrators

Astable multivibrators have no stable state. They jump repeatedly from one state to the other.



The interesting thing about astable multivibrators is that they do not have any input signals.

Within the circuit, an RC element is commonly used to determine the frequency of the output. LC elements can also be used, but are less convenient and more costly, especially since astable oscillators are generally used for relatively low frequencies for which the coils are quite large.

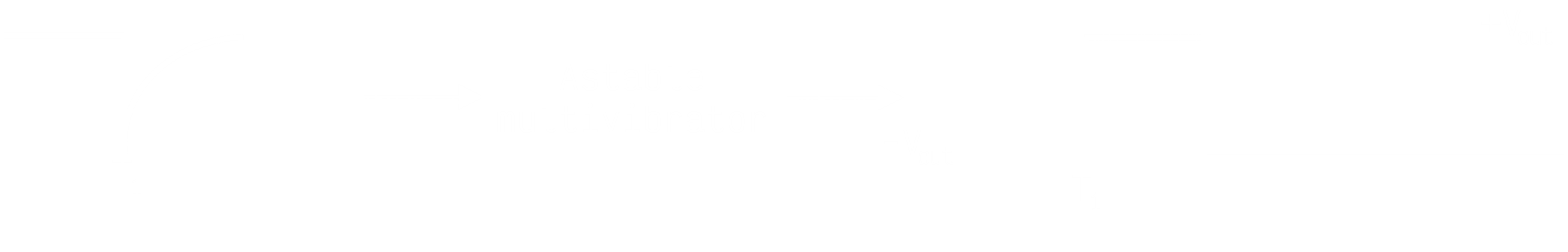


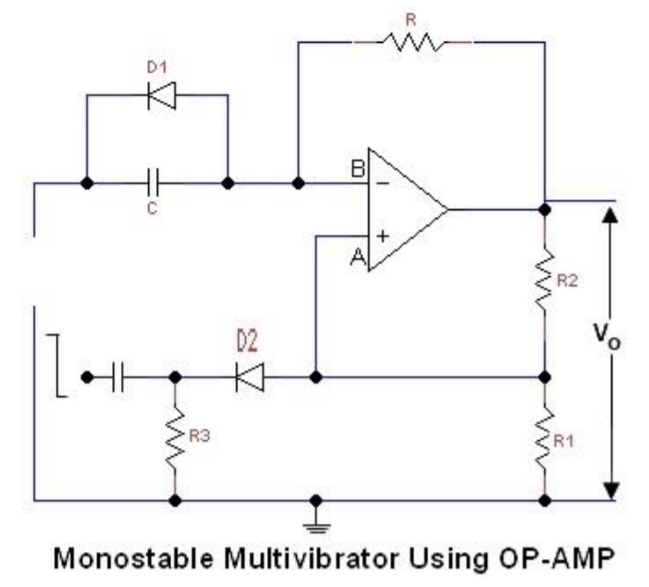
Notice that the astable multivibrator’s circuit is just a square-wave generator.

The details of the circuitry is beyond the scope of this course. Knowing what the circuit looks like should suffice.

### Monostable Multivibrators

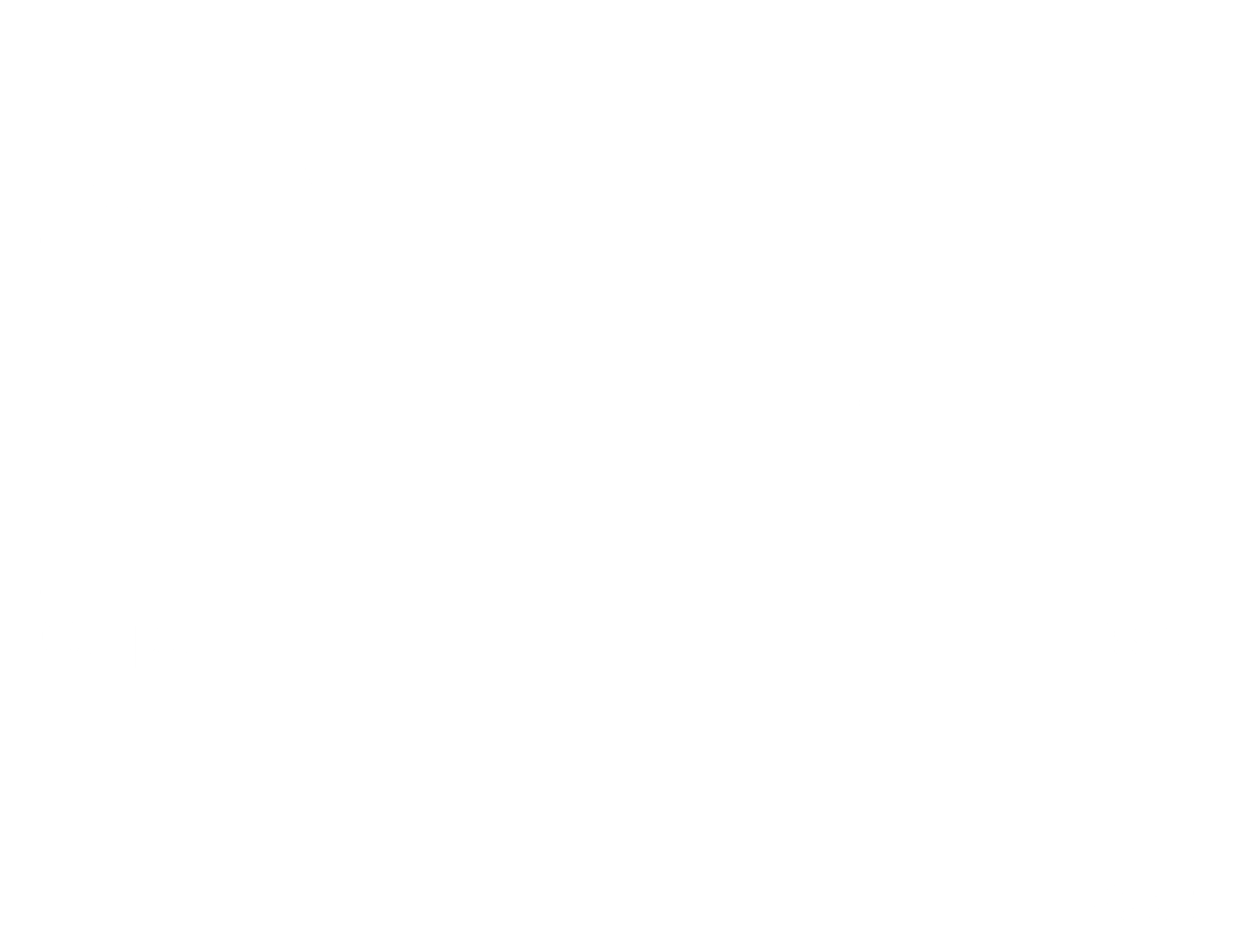
Monostable multivibrators, also called one-shot multivibrators, have a single stable state. This could be the high state or the low state. A trigger pulse input causes the multivibrator to switch to the opposite state, called a quasi-stable state, for a short period of time.

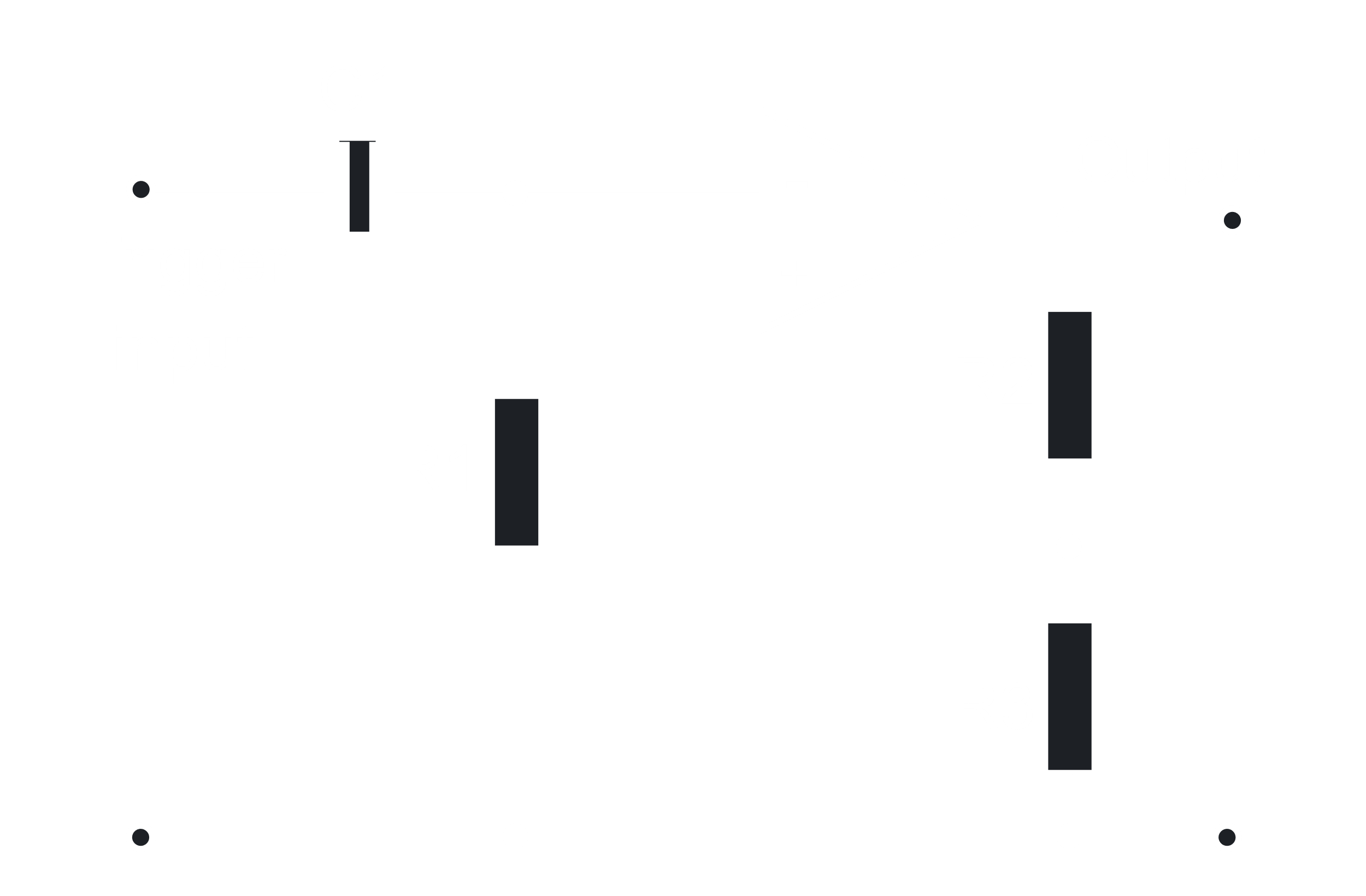




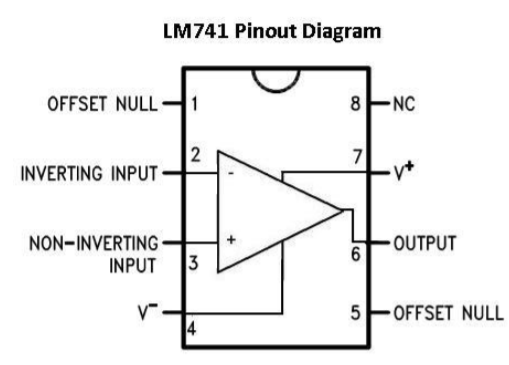
### Bistable Multivibrators

Bistable multivibrators have both of their states as stable states. The switching between states is caused by two trigger pulses. Bistable multivibrators are more commonly called latches, or flip flops.





### LM741 Op-Amp



The offset null inputs are the only new parts of this IC. They are used to apply voltages that nullify the difference between the input voltages.

The other noticeable feature is pin 8, NC. This is not supposed to be connected to anything.

## 555 Timer

The 555 timer is an 8-pin IC that is capable of producing accurate time delays and/or oscillations. It is used to produce analogue and digital signals perfectly.

In the time delay mode, the delay is controlled by an external resistor and capacitor. In the oscillator mode, the frequency of oscillations and duty cycles are both controlled with two external resistors and one capacitor.

### Capacitor Charging and Discharging

The equation for charging a capacity is:

where is the voltage across the capacitor,

is the voltage across the capacitor when fully charged and

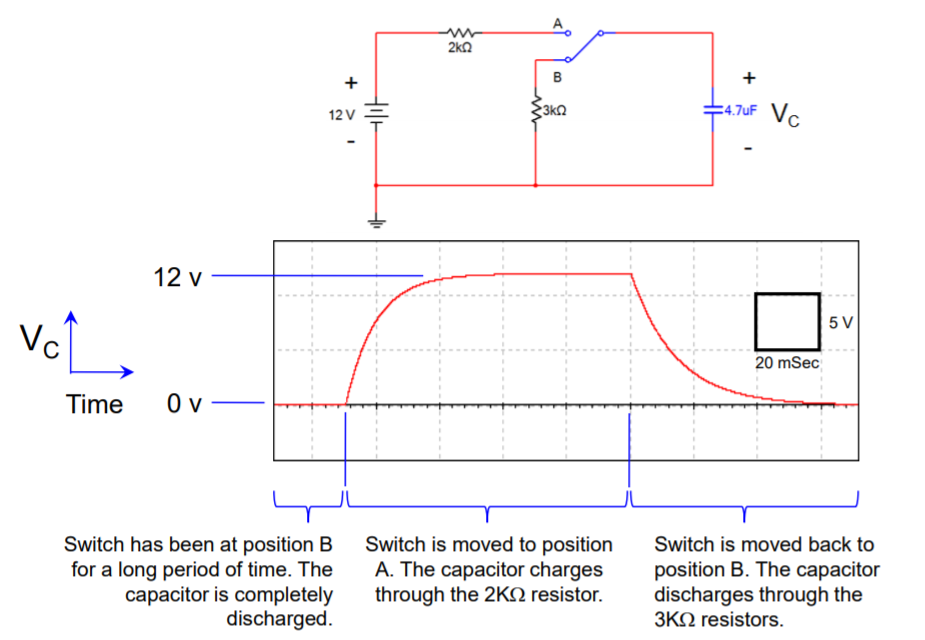
is the voltage across the capacitor when we start charging it

The equation for discharging a capacitor is given by:

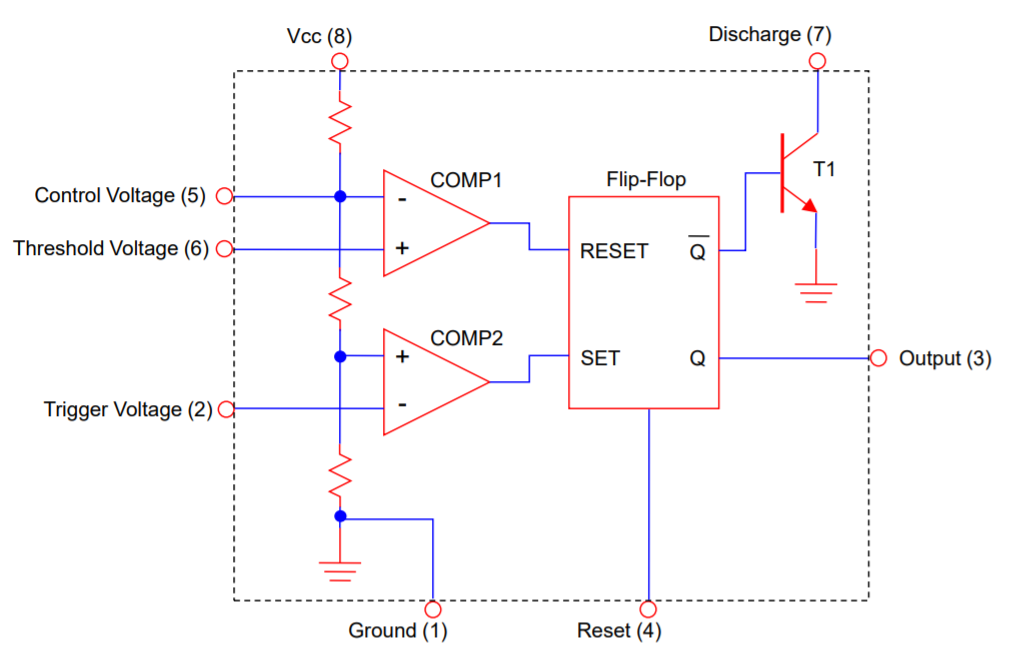
where is the voltage across the capacitor

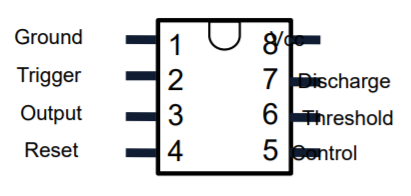
is the voltage across the capacitor as it begins to discharge

is the voltage across the capacitor when it is fully discharged



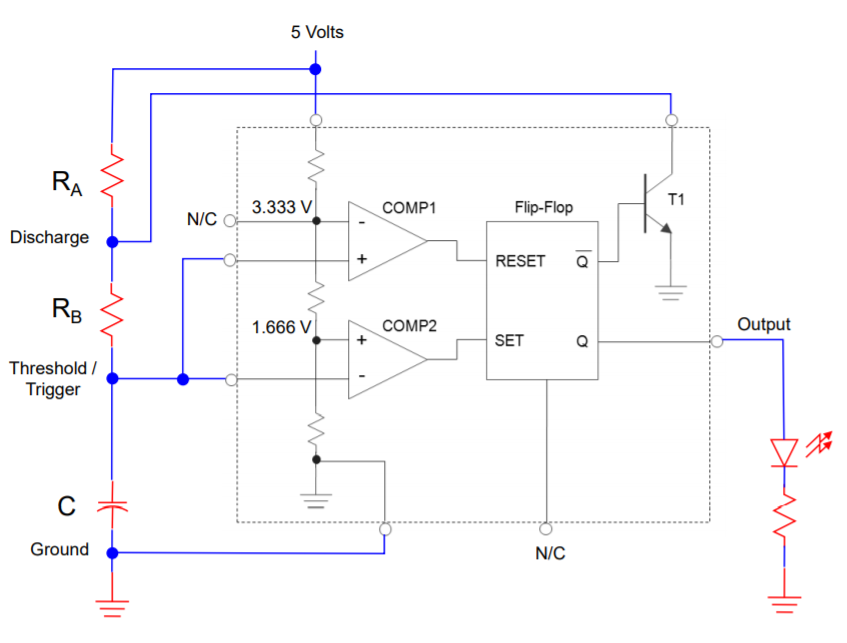
### Timer Circuit



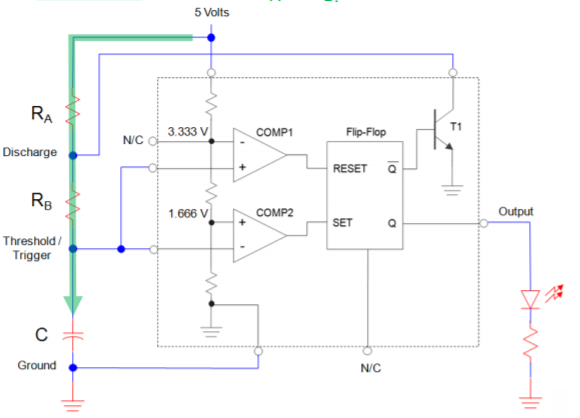


Note that all the resistors have the same resistance. This means 1/3rd of the voltage is dropped at each. This causes the inverting terminal of the first comparator to receive twice the voltage that the non-inverting terminal of the second comparator does. The external threshold and trigger voltages supplied determine how the comparisons are done and what output is received.

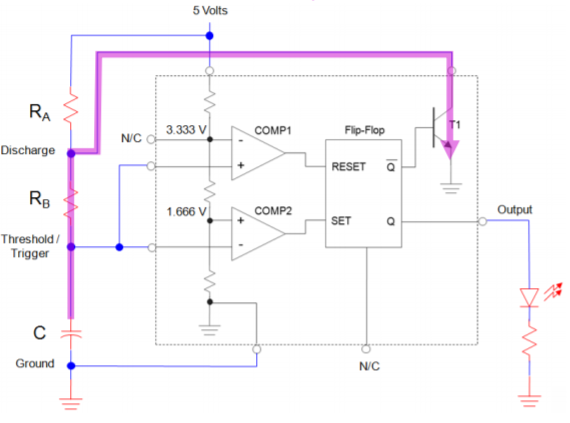
The external part of the circuit looks like this:



The capacitor is charged through and in a certain period of time, called the high time.



The capacitor is discharged through , with the charge flowing towards , in a certain time period called the low time.

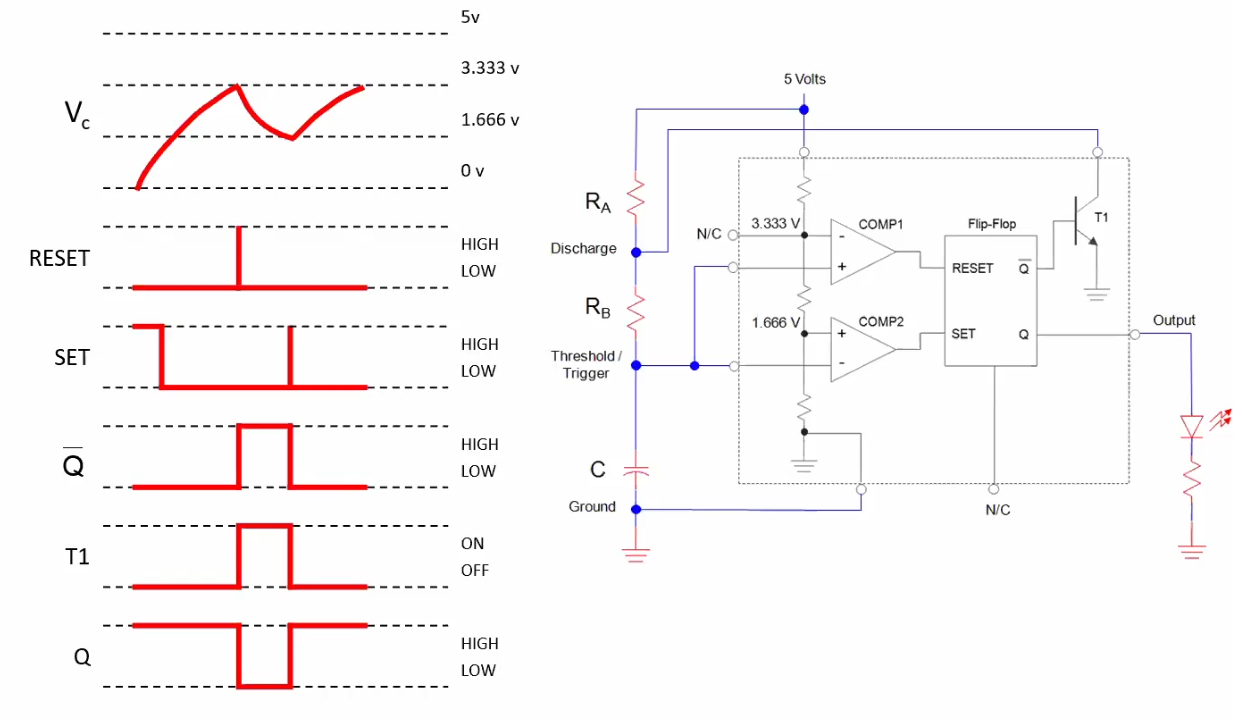


The discharge process occurs when is on.

The ratio of time for which a device is operational to the total time period is called the duty cycle (). In this case, the ratio of to total time is the duty cycle, or duty factor. The values of and can be calculated to find the total time.

Using just the two values of and , we can define several equations:

### Detailed Analysis



Initially, we have a drop at the inverting terminal of , with no voltage at the non-inverting terminal, since the capacitor is still being charged. As such, the reset is off. There is a drop at the non-inverting terminal of , which means that set is on. This causes to be high and to be low, which in turn means that is off.

As the capacitor is charging, some voltage is also going to the inverting terminal of and the non-inverting terminal of . When this value reaches , set switches off, and when it reaches , reset is triggered which flips and . This in turn turns on , causing the capacitor to begin discharging.

When the capacitor charge reaches , set switches on again causing and to flip again and to switch off which again results in the capacitor beginning to charge.

We can use everything going on here to see how the equations for and we saw earlier are derived.

When the capacitor is charging,

When the capacitor is discharging,

**Oscillators**

This topic can be found in the book ‘Electronic Devices and Circuit Theory - Robert L. Boylestad, Louis Nashelsky (11th Edition)’ in Chapter 14, Page 775 – 777, 788 – 791, 798 and 800 (page numbers may be inaccurate).

An oscillator provides a source of repetitive AC signals across its output terminals without needing an input, other than the DC supply of course. The signal generated is usually of constant amplitude. The wave shape and amplitude are determined by the design of the oscillator circuit and choice of component values. The frequency of the output wave may be fixed or variable, depending on the oscillator design.

A feedback oscillator depends on positive feedback (don’t we all) from the output to maintain oscillations. The feedback gain must be kept to unity to prevent the output from become distorted. Positive feedback is when a portion of the output voltage of an amplifier is fed back to the input with no net phase shift, resulting in a reinforcement of the output signal.

The output voltage can be either sinusoidal or non-sinusoidal, depending on the type of oscillator.

## Types of Oscillators

The two major classifications of oscillators are feedback oscillators and relaxation oscillators. When classified by the type of signal they produce, we have a few types:

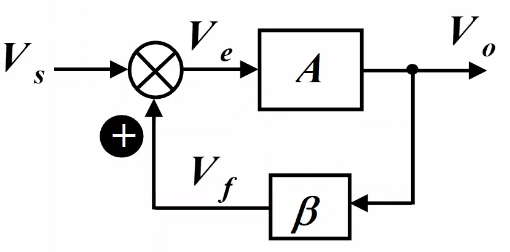
* Sine Wave Oscillators – These produce sine waves as output.
* Relaxation Oscillators and Astable Multivibrators – These produce square waves and rectangular pulses.
* Sweep Oscillators – These produce sawtooth waves.

## Applications

Oscillators are used to generate signals. As such, they can be used

* As local oscillator to transform the radio frequency signals to infra-red signals in a receiver.
* To generate radio frequency carriers in a transmitter
* To generate clocks in digital systems
* As sweep circuits in TV sets and CROs

## Basic Principles



- (i)

- (ii)

- (iii)

The closed loop gain (gain of an op-amp with feedback) is

The equations we saw above were in the time domain. If we want to shift to the frequency domain, we have to replace the with .

At some specific frequency, ,

Replacing the value , the closed loop gain becomes infinite, meaning we will have an infinite output without any input, a.k.a. oscillation.

Thus, to achieve oscillation, we must satisfy the condition . This is called the Barkhausen criterion.

The frequency of the oscillation is determined by the phase characteristics of the feedback loop. The loop oscillates at the frequency for which the phase is zero.

### Barkhausen Criterion

The Barkhausen criterion has two conditions that a linear electronic circuit must abide by to act as an electronic oscillator:

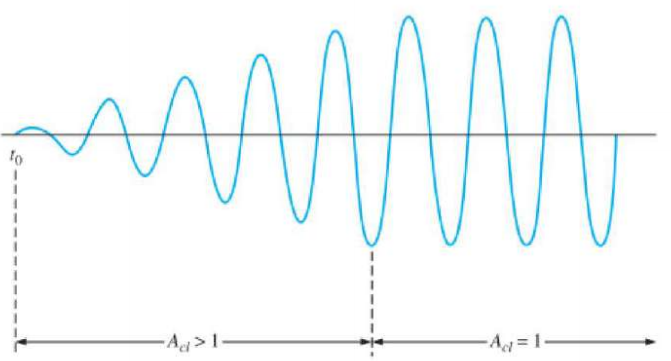
1. , where is the gain of the amplifying element in the circuit and is the transfer function of the feedback path.
2. The total phase shift around the loop is or integral multiples of . This just means that all the signals must be in-phase at those points.

Even though these conditions are necessary for oscillation, they are not sufficient conditions.

### Start Up Conditions

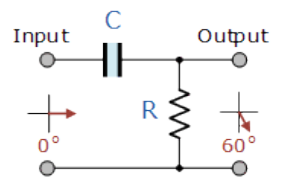
Initially, the voltage gain over the positive feedback loop must be greater than . This is so that the output can be increased to the desired level. The oscillation that occurs during this time is called growing oscillation.

After the output has reached the desired level, the voltage gain must be decreased to to sustain the output at the desired level. Thus, this oscillation is called the sustained oscillation.

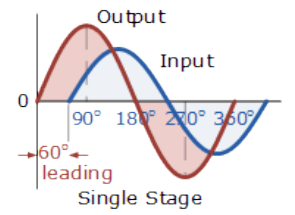


There is a third type of oscillation, called decaying oscillation, where the voltage gain drops below and the output begins to decrease.

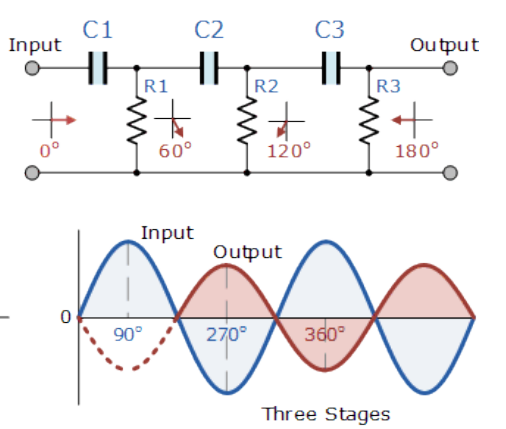
## RC Phase Shift Network



The circuit above shows a single resistor-capacitor network which produces an output that leads the input by . The exact angle can be adjusted by changing the values of and .



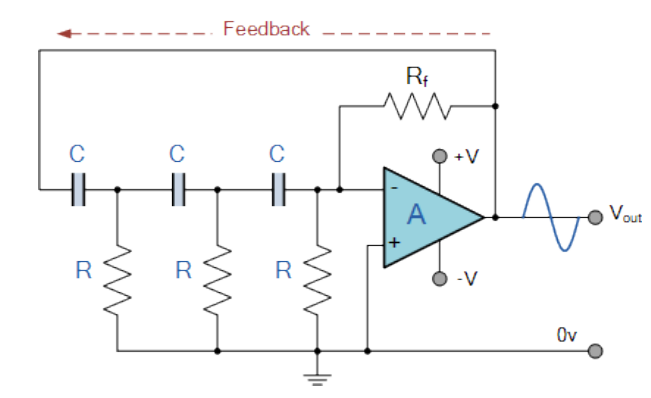
We can place multiple such circuits one after another to achieve a greater leading angle. For oscillation, phase shift is required, so we can place three such circuits.



We know

The phase shift can be calculated as

### Op-Amp RC Oscillator Circuit



For an op-amp, since the feedback is connected to the inverting input, phase shift is obtained from there, while the RC network produces the other phase shift.

Although it is possible to produce a phase shift using a two-stage RC network, the stability of the oscillator at low frequencies is generally poor. Using more stages results in better stability.

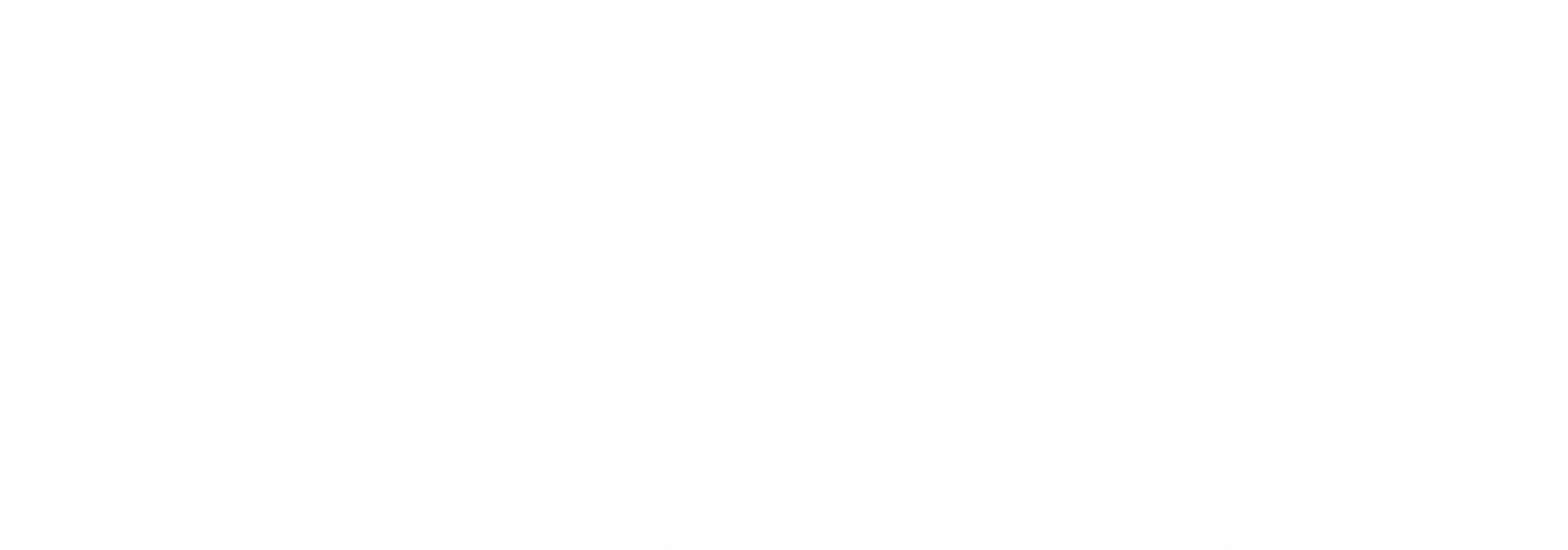
RC oscillators are stable and provide a well-shaped sine wave output with a frequency proportional to . A wider frequency range is possible when using a variable capacitor. However, their use is restricted to frequency applications due to their bandwidth limitations in producing the desired phase shift at high frequencies.

If all the resistors and capacitors in the RC network are equal, the frequency of oscillations is given by

where is the number of RC stages.

### Phase Shift Networks

A phase shift network uses three RC circuits to provide a phase shift. Coupled with an inverting amplifier which causes a phase shift, this provides the necessary feedback to sustain oscillations.



In the circuit above,

and

Since ,

Again,

The loop gain (the gain of an op-amp without feedback), , is given by

Substituting for ,

To satisfy the condition that , the real component must be , since the numerator here is imaginary. Thus,

From here, we can also see that

Finally,

Here, is and is .

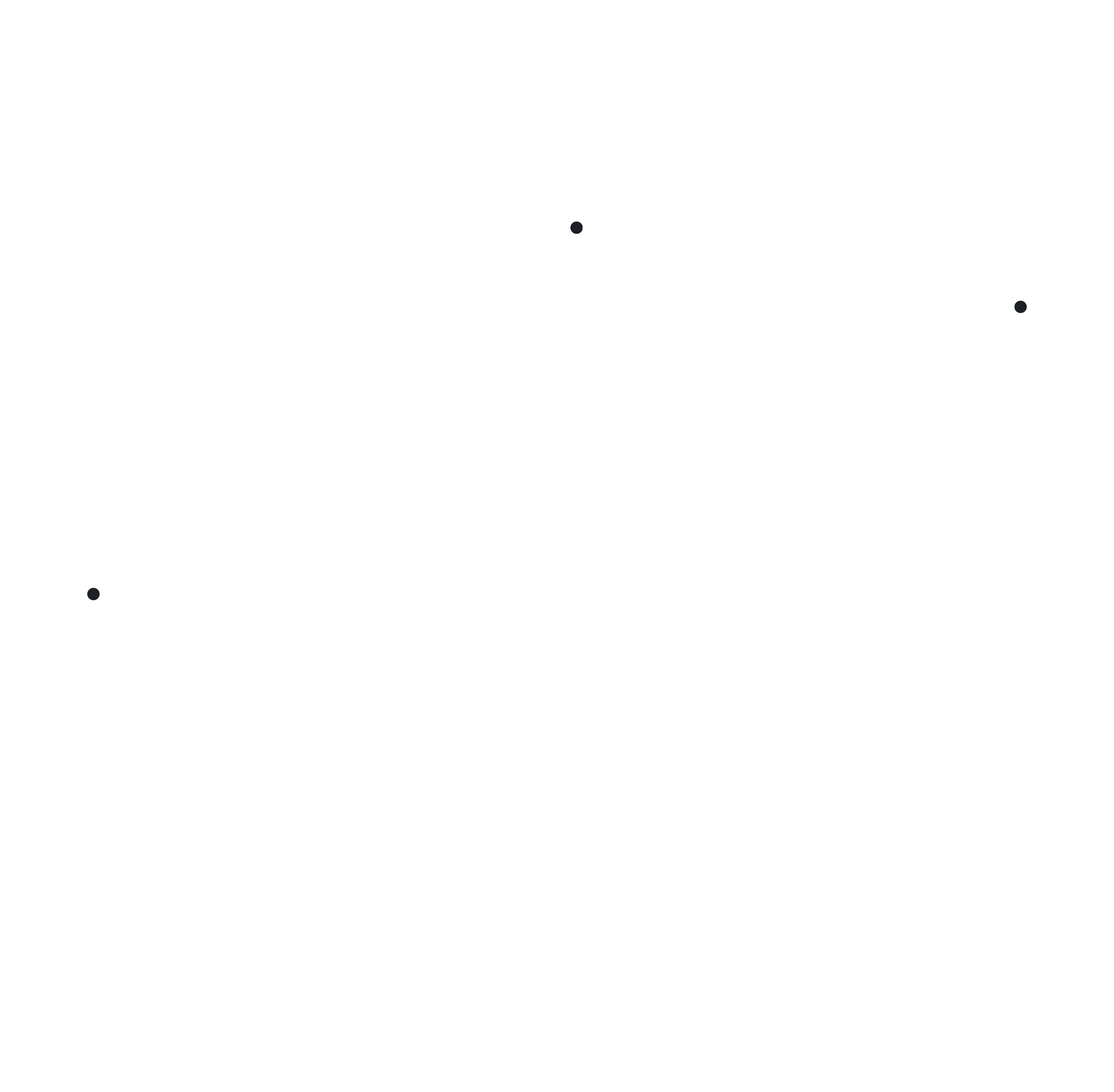
So, to start oscillation, the ratio of must be slightly greater than .

To maintain oscillations, the gain must be (no clue where this came from).

The frequency of oscillations is given by

### Wein Bridge Oscillator

The Wein bridge oscillator is a two stage RC amplifier circuit. It has good stability at its resonant frequency, low distortion and is very easy to tune, making it popular as an audio frequency oscillator. However, the phase shift of the output signal is considerably different from the previous phase shift RC oscillator.



The Wein bridge oscillator uses a feedback circuit consisting of a series RC circuit and a parallel RC circuit with the same component values. This results in either a phase delay or a phase advance, depending on the frequency. At the resonant frequency, , the phase shift is . Due to this dual natural, this circuit is called a lead-lag circuit. A lead-lag circuit is basically a band-pass with narrow bandwidth. The voltage divided in the circuit limits the gain.

The loop gain for the oscillator is given by

where , the impedance of the parallel RC circuit is

and , the impedance of the series RC circuit is

Thus,

Substituting for ,

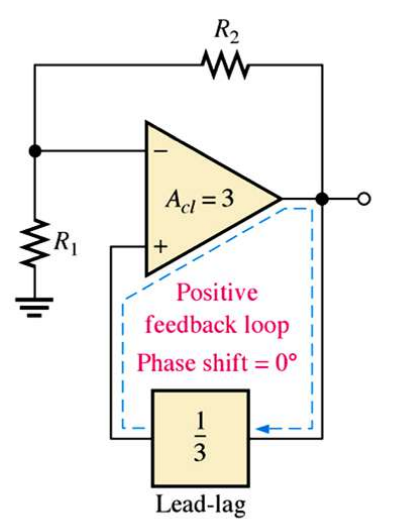
For oscillator frequency ,

At the frequency of oscillation, must be . However, in this case, the real component is a fixed value. Thus, we need to make the imaginary component .

Here, is and is .

To start oscillators, must be slightly larger than .

The drawback of Wein bridge oscillators is that the output voltage is the input voltage. This means that such oscillators are only useful if we know the input voltage will be very high.



Since only of the signal can be brought back using the positive feedback loop, the voltage divider ratio must be adjusted so that a feedback loop gain of is produced. Thus, that ratio needs to be .

Say . This value ensures the loop gain of unity oscillators. For , there will be growing oscillations and for , there will be decreasing oscillations.

## Crystal Controlled Oscillators

The most stable and accurate type of feedback oscillator uses a piezoelectric crystal in the feedback loop to control the frequency. Some substances, such as Quartz, exhibit a property called the piezoelectric effect. When a changing mechanical stress is applied across the crystal to cause it to vibrate, a voltage develops at the frequency of mechanical vibration. Conversely, when an ac voltage is applied across the crystal, it vibrates at the frequency of the applied voltage. The greatest vibration occurs at the crystal’s natural resonant frequency, which is determined by the physical dimensions and by the way the crystal is cut.

A great advantage of the crystal is that it exhibits a very high . The impedance of the crystal is minimum at the series resonant frequency, thus providing maximum feedback. The frequency can be fine-tuned using a capacitor which ‘pulls’ the resonant frequency of the crystal slightly up or down.

### Modes

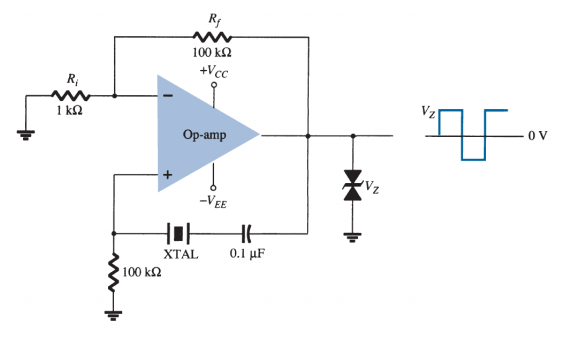
Piezoelectric crystals can oscillate in one of two modes, fundamental or overtone.

The fundamental frequency of a crystal is the lowest frequency at which it is naturally resonant. It depends on the crystal’s dimensions, the way it is cut, etc. Usually, this is less than .

Overtones are approximate integer multiples of the fundamental frequency.

### Crystal Oscillators

Op-amps can be used with crystal oscillators. Many crystal oscillators are available in IC packages.



The crystal is connected in series and operates at the series-resonant frequency.