How to Build a Square Wave Generator

Posted by Graham Lambert | DIY Electronics | 2

This article is the first in a four-part series on oscillators. We will look at square wave generators in this article, but check out the other articles about sawtooth and triangle wave generators, sine wave generators, and crystal oscillators.

Oscillators

It is an electronic circuit that changes state from positive to negative in a repeating cycle without any stimulus other than DC power. This produces an AC waveform at the output.

Square wave generators

Square wave generators are generally used in electronics and in signal processing. It is just like a Schmitt trigger circuit in which the reference voltage for the comparator depends on the output voltage. It is also said to be an astable multivibrator.

A square-wave generator obviously produces a square wave. However, this may also be adjustable in mark-to-space ratio and is often used for timing, pulsing and clocking circuits. One of the easiest ways to generate a square-wave is by using a relaxation oscillator.

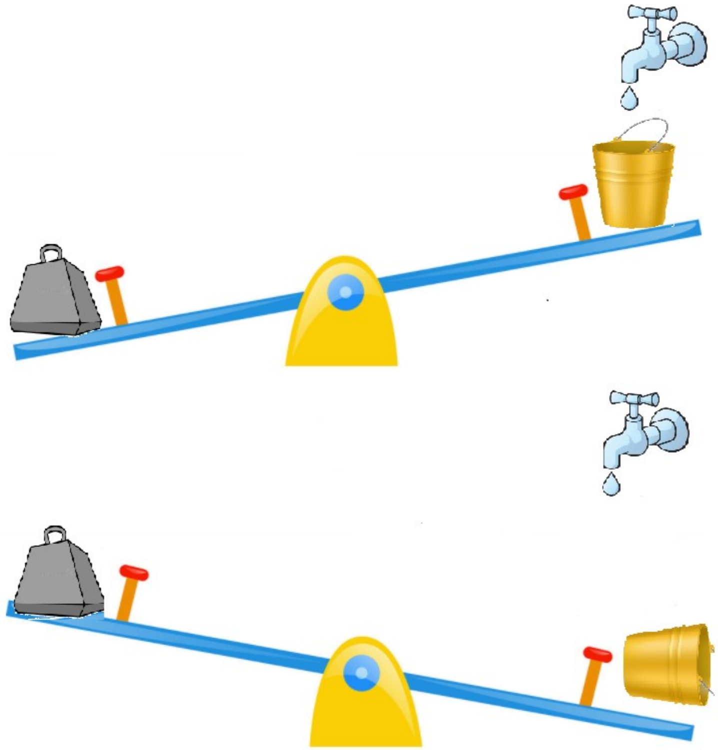
Relaxation oscillators

Relaxation oscillators have two alternating states: a long relaxation period in which the system comes to rest and then a short change-over period in which the stable point flips over to a second stable state for a period then flips back again. The period is set by the time constant which is usually an RC or LC pair.

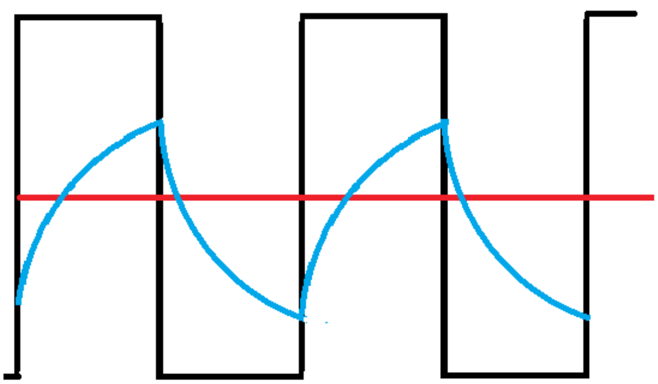
Some sort of active switching device is needed, such as a transistor pair or a uni-junction transistor or an op-amp comparator, or a custom chip such as a 555 timer. The active device switches between charging and discharging modes, producing a repeating waveform.

For any oscillator to qualify as a relaxation oscillator, it must:

- Produce a non-sinusoidal periodic waveform like triangular, square, or rectangular wave.
- The circuit of a relaxation oscillator must be nonlinear. This means the design of the circuit must use a semiconductor device like a transistor, MOSFET, or op-amp.
- The circuit design must use an energy-storing component like an inductor or capacitor that continuously charges and discharges to produce a cyclic waveform.



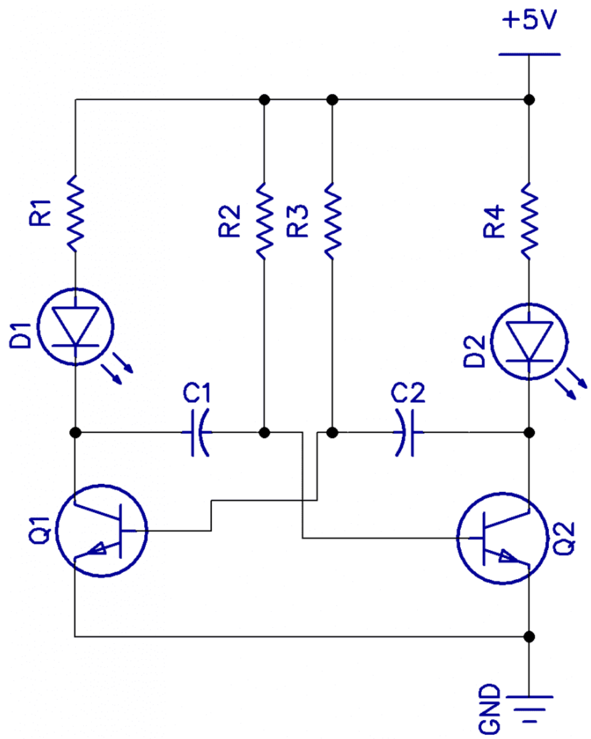
Seesaw A shows the seesaw in a state of equilibrium and at “relaxation,” but as the bucket slowly fills up, a critical tipping point is reached. The state rapidly changes as the bucket end drops and the bucket tips out. As the bucket drains, the left-hand side is now suddenly much heavier and falls to the ground again, and then the bucket lifts and begins to fill again. (Let’s assume it corrects itself again). In an electronic circuit, this is what is happening: a capacitor gets slowly charged through a resistor until a non-linear part of the circuit is reached, causing a sudden discharge, and the cycle begins again.

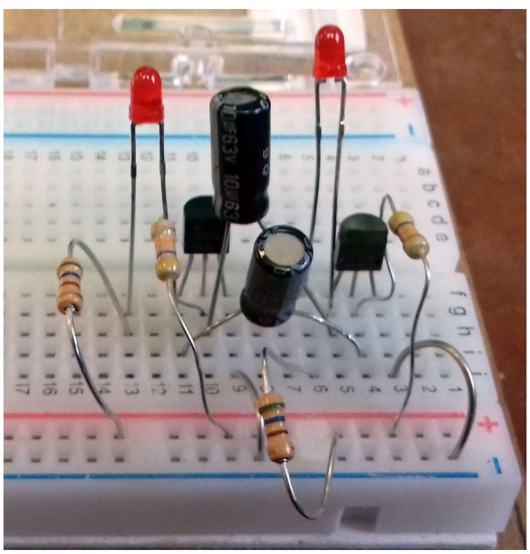


In the waveform above and the multi-vibrator circuit below, the blue curve shows the voltage across one of the capacitors C1. It charges until the bias trigger point is reached, then suddenly turning the other transistor on, then discharges again. The black curve is the voltage at the collector, which is the output. In the multi-vibrator below, either collector can be used as the output. However, in this circuit, we are just flashing two LEDs alternately.

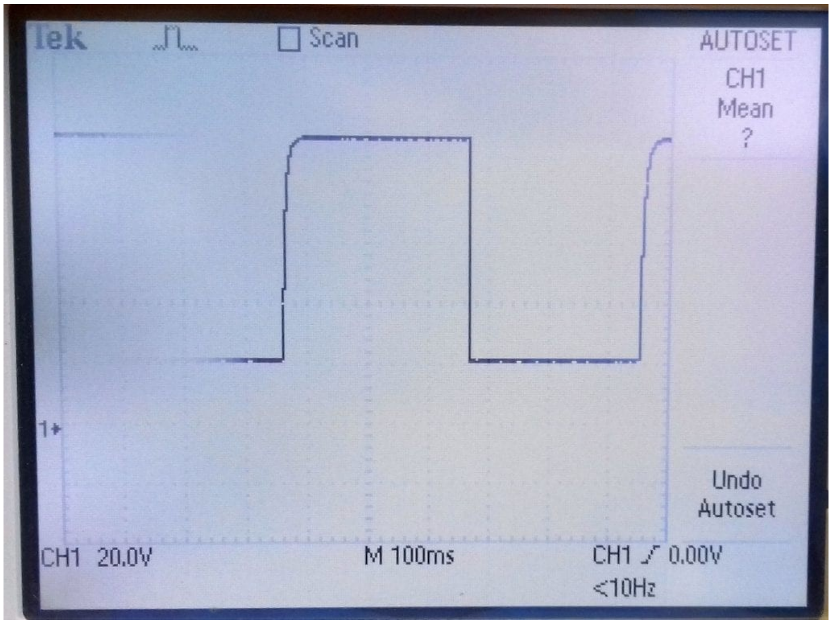
Shown below are the multivibrator circuit and a breadboard lash-up. The two LEDs flash alternately at about 1.5Hz. The transistors are any NPN GP transistors. The mark-space ratio can be varied by changing the C and/or R on one half.

R1 and R4 are 560Ω, R2 and R3 are 47k, and C1 and C2 are 10uF.



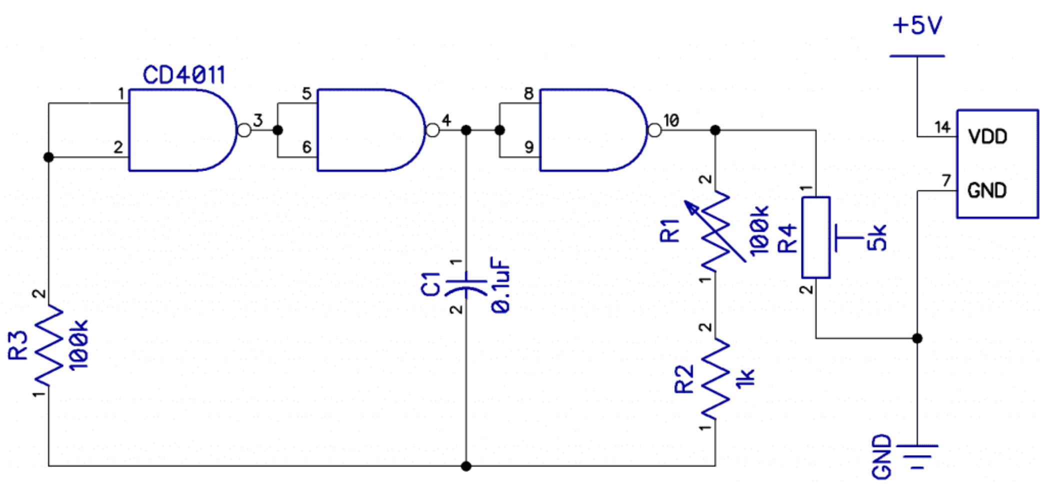


Below is the collector voltage waveform.



Shown here is the square wave output of the above multivibrator circuit. You can see that the square wave is fairly good, but there is a slight charging delay.

The period of each half is 0.69CR. So if R2 is 47k and C1 is 10uF, that would be 0.32S per half or 0.64 together. Then f = 1/0.64 = 1.5Hz.



A nice relaxation oscillator can be made from any inverting gates. Although two gates will work (NOR, NAND, OR, Schmitt), three gives a better startup. The frequency is set by R1 and C1:

$$f = \frac{1}{2.2R1C1}$$

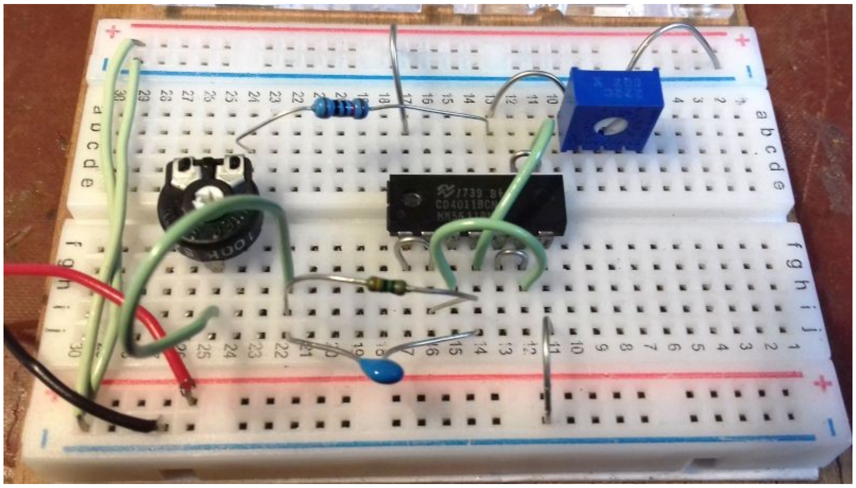
So, here we have

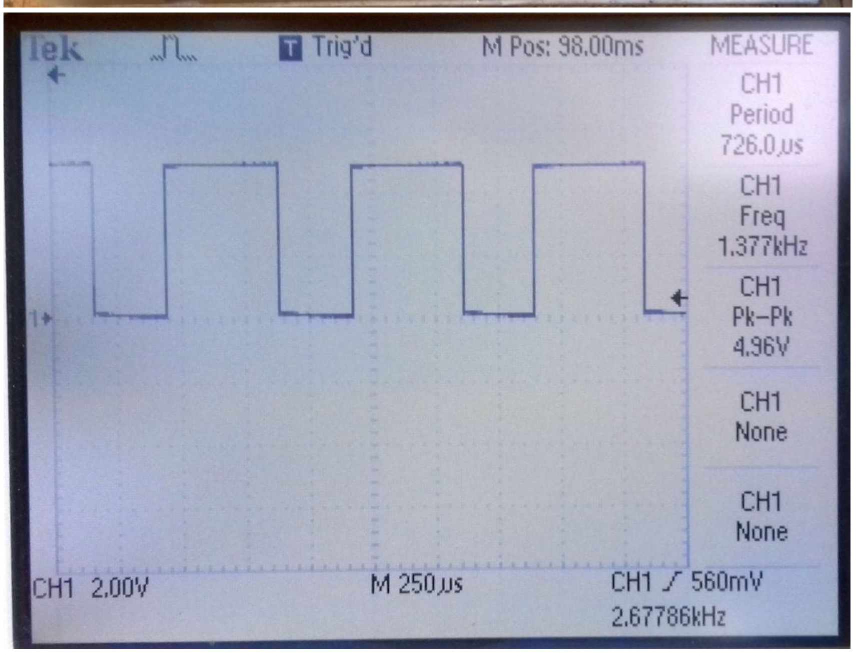
$$f = \frac{1}{2.2 * 100k * 0.1u}$$

which gives 45Hz.

The frequency is adjustable over a 10:1 range and the output is set by R4. R3 is for feedback and is not involved in the timing. The waveform is nice and square.

With R1=100k, C=.004 f=1kHz, C=.04 f=100Hz, C=0.4 f=10Hz.





That's all for square wave oscillators! A good oscillator can be made from the famous 555 timer and we will look at that in the next article on sawtooth and triangular wave generators. Leave a comment below if you have questions about anything!

How to Build a Sawtooth and Triangle Wave Generator

Posted by Graham Lambert | DIY Electronics | 2

This is part two of the four-part tutorial series on wave generators and oscillators. Check out the other articles in this series: square wave generators, sine wave generators, and crystal oscillators.

What is an oscillator? It is an electronic circuit that changes the state from positive to negative in a repeating cycle without any stimulus other than DC power. This produces an AC waveform at the output. That being said, oscillators generate a repetitive waveform of the desired shape, frequency, and amplitude, usually used to drive other circuits.

Sawtooth and Triangular Oscillators

Now, let's look at triangle and sawtooth oscillators. What is the difference between them?

A triangle wave has a symmetrical rise and fall of the waveform, but a sawtooth (also called a ramp oscillator) rises very sharply (ideally instantaneously) and then falls gradually.

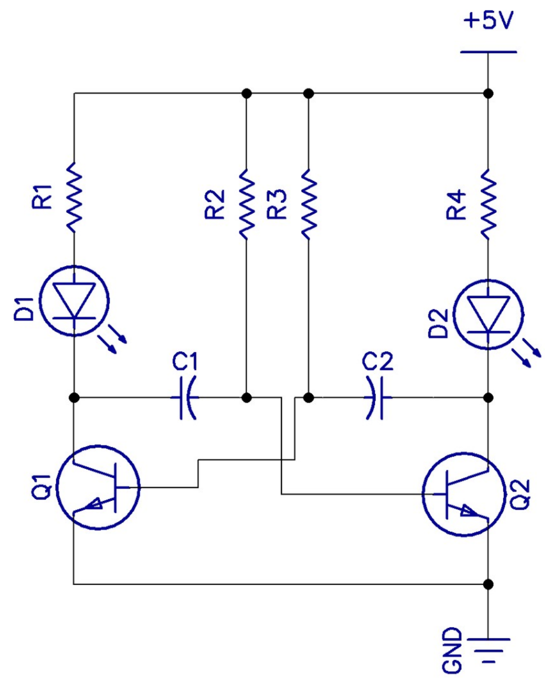
Triangle waves contain an infinite number of odd harmonics, which are often used in synthesizing musical sounds. They sound like horns and trombones. They are sometimes used in switch-mode power supplies and motor control circuits. They are often used as time-base or sweep generators and in subtractive audio synthesis as the harmonics are integers and easy to work with digitally.

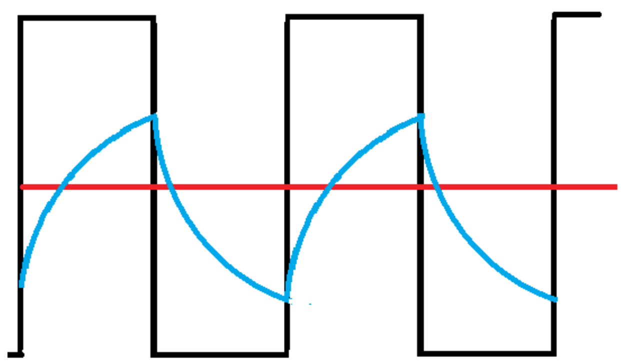
Sawtooth waves contain an equal amount of even and odd harmonics (unlike square waves which contain only even harmonics that's why the sound is more musical such as guitar and fuzz box).

One of the easiest ways to generate a triangle wave is from a relaxation oscillator generating a square wave and then integrating it.

Relaxation Oscillators

In the previous article on How to Build a Square Wave Generator, we learned about relaxation oscillators. The sawtooth and triangle wave generators are relaxation oscillators.

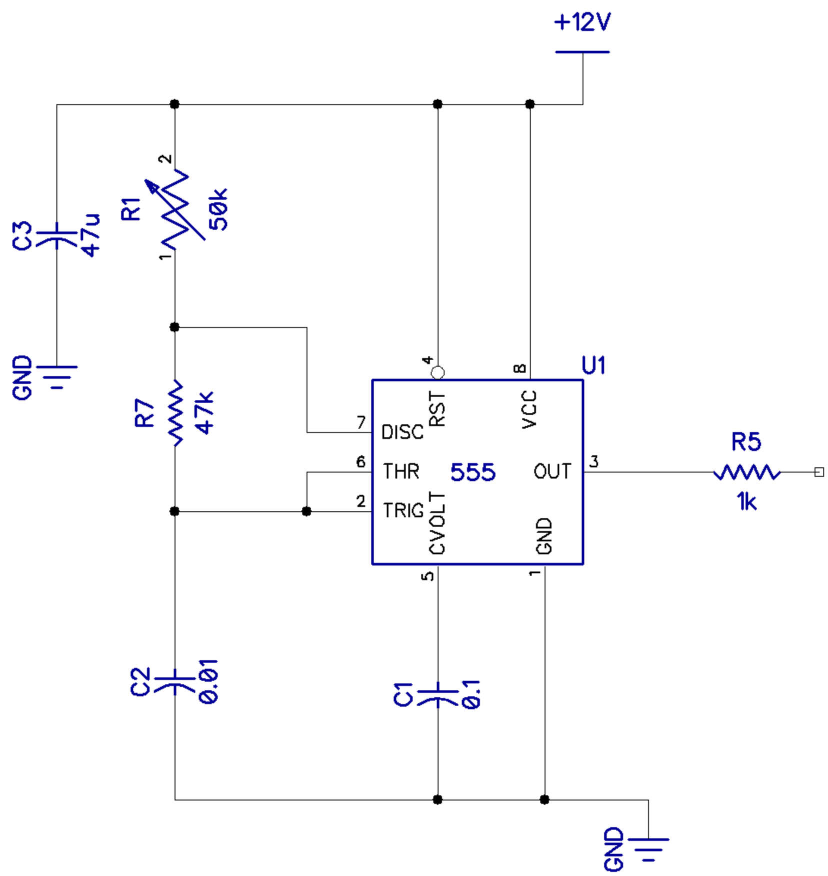




In the waveform above, the blue curve shows the voltage across one of the capacitors. It charges until the trigger point is reached, then discharges again. The black curve is the voltage at the collector, which is the square wave output. In the multivibrator, either collector can be used as the output, although in this circuit, we are just flashing two LEDs alternately.

The waveform across the capacitor looks almost like the triangle wave we are looking for, except that there is a curve to the slope as the capacitor charges and discharges. Adding a constant current source to the charge current could fix this, but there are better ways.

The easiest way to generate a triangle wave is to generate a square wave and then feed it to an integrator.

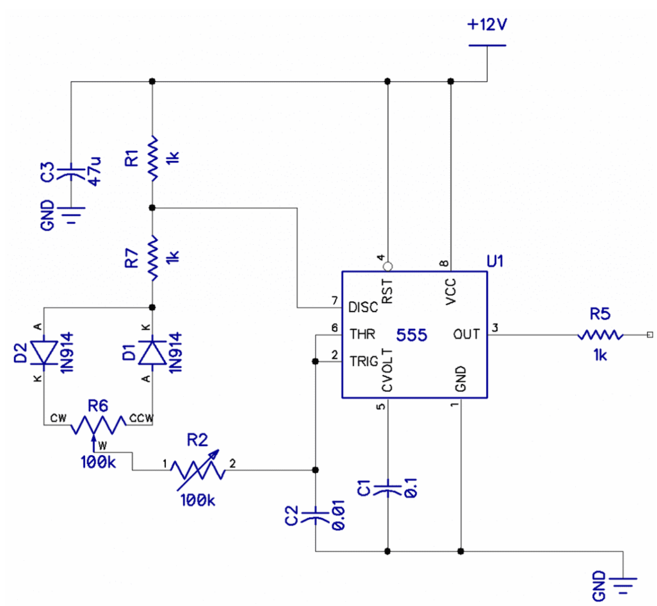


Shown above is a basic square wave oscillator using the famous 555 timer in its astable configuration. This, too, is a relaxation oscillator. R1, R7, and C2 set the frequency, and when R1 and R7 are equal, the mark-space ratio becomes almost equal.

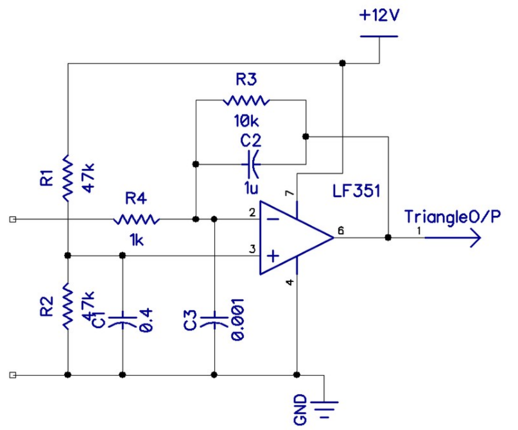
f = 1.44/(R1+2R7)*C = 1000Hz

Below this, on the left side, is a modified circuit to give plenty of variation in the mark-space ratio, which we will use to perfect our triangle wave. R6 sets the mark-space ratio and R2 sets the frequency. By careful adjustment of the mark-space ratio, the time constants on the rising and falling slopes of the triangle waveform of the integrator can be made perfectly symmetrical.

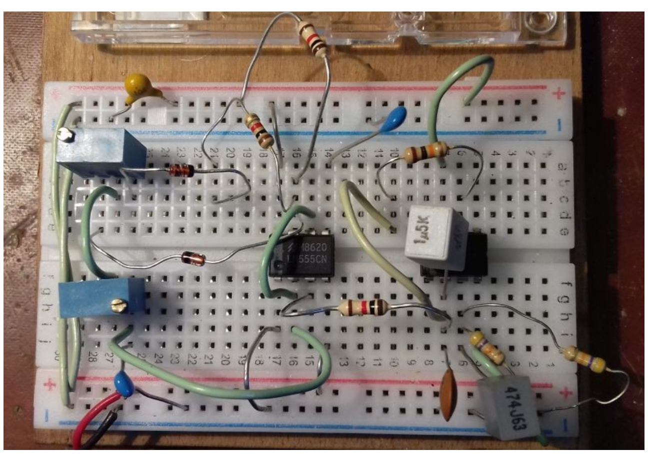
On the right is the integrator. The output of the square wave oscillator is fed into pin 2 of the integrator which converts the square wave into a triangle wave. C3 removes any sharp edge transitions while R3 provides some DC feedback for stability.



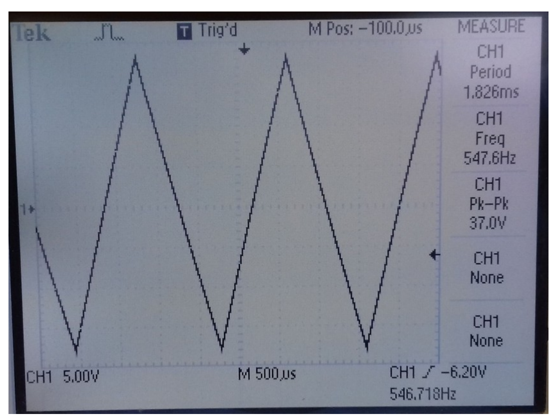
555 with an adjustable mark-space ratio



Op-amp integrator



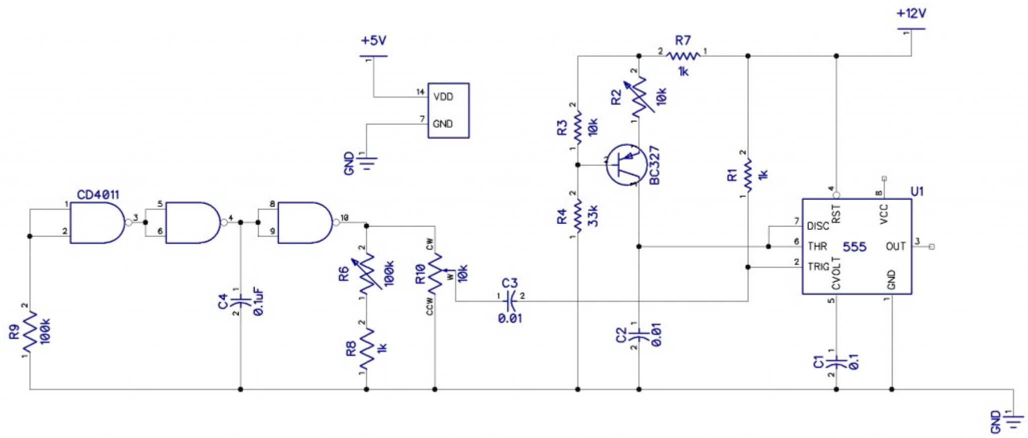
Breadboard of variable mark-space and integrator



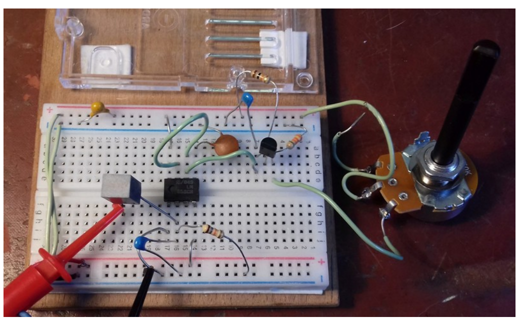
Output waveform

Generating a sawtooth or ramp is a little trickier if you want the rise time to be practically zero and a clean linear slope to the fall. The circuit below features the identical [CMOS 4011](#) square wave oscillator we used in part 1 ([square wave oscillators](#)). The square wave output is fed into the trigger input of a 555 configured as a monostable, which fires every time a low going pulse is received at pin 2 (trigger). The charge rate is now controlled by a constant current source ([BC327](#)) to linearize the slope of the ramp (we mentioned this earlier).

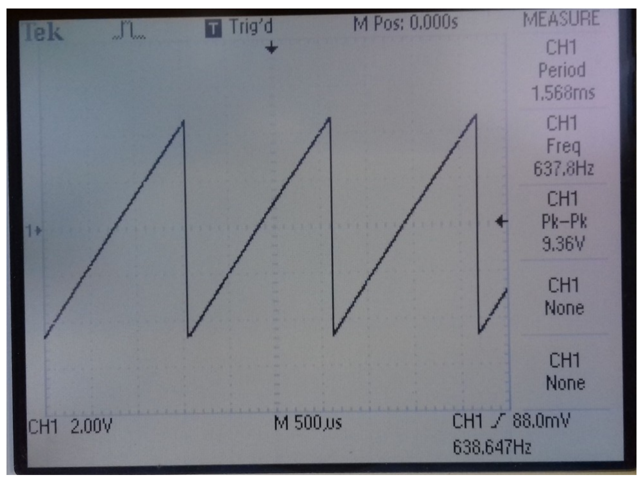
Shown below is a breadboard of the monostable and the very fine resulting waveform. The frequency is, of course, a function of the square wave generator and is 1/(2.2R6*C4).



CMOS square wave feeding a 555 monostable



Breadboard of sawtooth oscillator



Output waveform

Thanks for reading! In part 3, we will look at [sine wave oscillators](#). Be sure to leave a comment below if you have any questions!

How to Build a Sine Wave Generator

Posted by Graham Lambert | DIY Electronics | 1

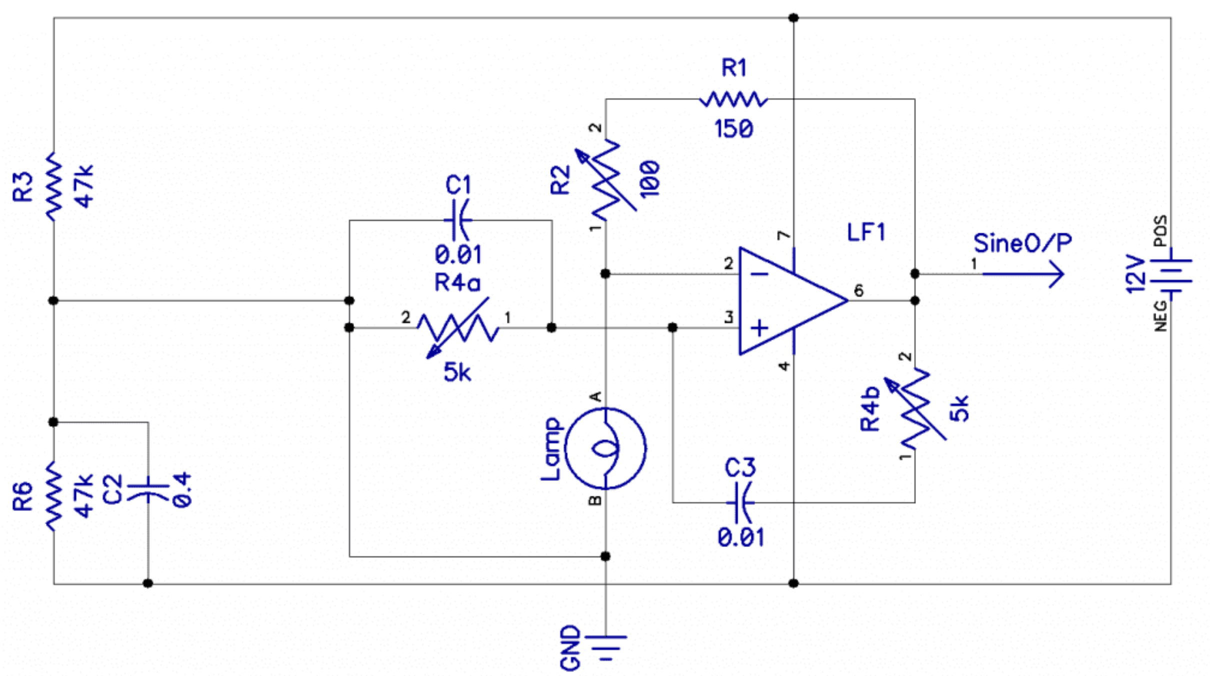
This is part three of a four-part tutorial series on wave generators and oscillators. Check out the other articles in this series: square wave generators, sawtooth and triangle wave generators, and crystal oscillators. In this article we will talk about sine waves and sine wave generators.

Sine waves, ideally, should contain no harmonics at all and are often used in signal generators used to test amplifiers and filters and radio frequency (RF) circuits to provide the carrier signals for receivers and transmitters. Spectral purity and stability are paramount. Although there are several ways to generate sine waves such as a digital source e.g. an Arduino, for this tutorial, we will look at three more common ways to do it.

Method 1: Wien Bridge Oscillators

Max Wien invented the Wien bridge oscillator in 1891. In 1939 under Frederick Terman's guidance, two students at Stanford University, Hewlett and Packard, developed a working audio signal generator in their garage using a Wien bridge and a lamp stabilizer. This was their first product and the beginning of the Hewlett Packard company!

The circuit below is very much the same design except that it uses an op-amp instead of tubes (valves). It still uses the very suitable lamp amplitude regulator method.



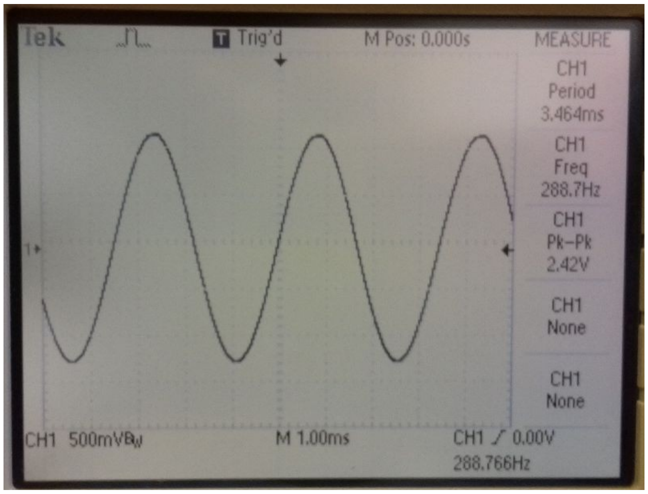
The bridge circuit is C1 R4a and C3 R4b. R4 is a dual-ganged potentiometer and controls the frequency, which is 1/2πRC. Assuming R4 is central, say 2k, this would be 1/(2*π* 5k * 0.01u) =

3kHz. The lamp is a small 12V incandescent light bulb. As the filament heats up, its resistance goes up, reducing the current through it, reducing the gain and amplitude at the output, so you have a very effective negative feedback amplitude control. The idea is to adjust R2 so that the circuit only goes into oscillation. This gives a smaller output but the best low distortion performance.

C1 R4a is a series or high-pass filter, and C3 R4b is a parallel low-pass filter. When they are the same at any given point, the positive feedback from the output to the non-inverting input causes the amp to oscillate at a gain set by 1+ R2/Rlamp.

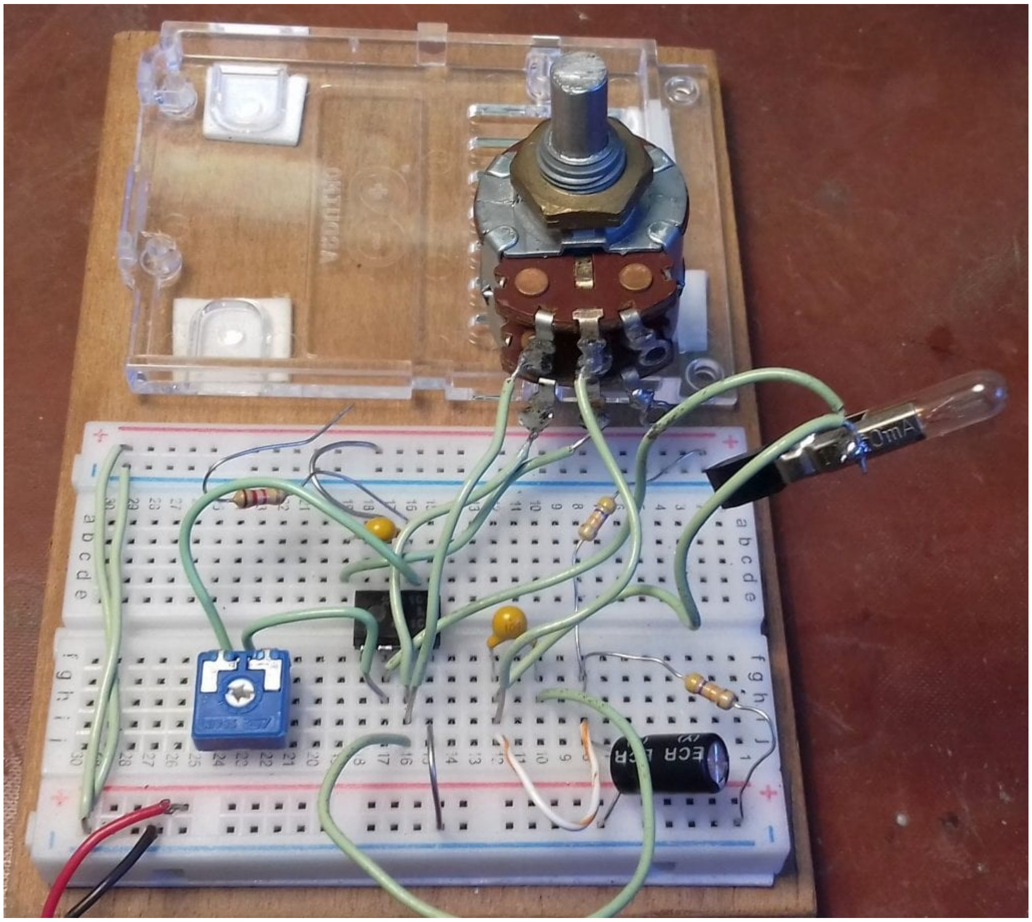
As you can see from the Fourier display in the oscilloscope images below, the worst harmonic is 58dB down; this is about 0.13% THD. If you were to follow this circuit with a low pass filter set to cut just after the set frequency, you could knock another 30dB off, making it well below 0.01% assuming the filter doesn't add too much distortion of its own.

If an oscillator is very clean, amplitude stable, and able to tune over a 10:1 frequency range, and with a selectable cap range, it makes a nice test oscillator. But a bigger value potentiometer would be better—I only had a 50k lying around. Note that the potentiometer should be linear and not logarithmic.



A good clean sine wave

All harmonics > 58dB down

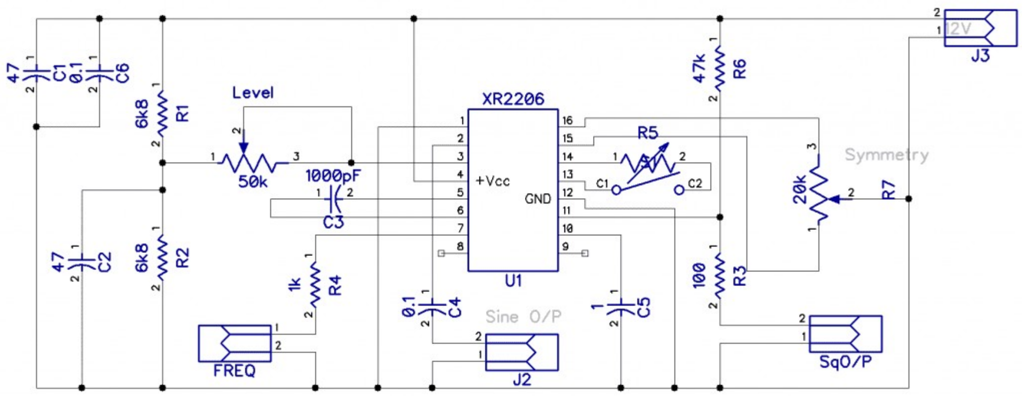


Wien bridge breadboard showing the pilot lamp type and the dual ganged pot

Method 2: XR2206

Another very convenient way to generate a good sine wave with a 10:1 tuning ratio is the [XR2206 monolithic generator](). This chip gives you a bonus of a square wave output that you can use to drive a frequency display. Adjusting R5 and R7 will set the THD to below 1%. Also, opening the switch on pin 13 will change the sine wave to a pretty good triangle wave shape.

This oscillator will easily work from 10Hz to 100kHz, making a very nice bench audio signal generator or a full-fledged function generator. Combining two of these function generators and modulating the one with the other, just about any alarm sound or police/ambulance siren can be synthesized.



A XR2206 sine, square and triangle wave generator

A XR2206 audio oscillator

XR2206 PCB

Method 3: Clapp Oscillator

If you need to have a sine wave at much higher frequencies than we can get with the Wien bridge and the XR2206, you need to go for an RF (radio frequency) type oscillator. Two prevalent types are Colpitts and Clapp, both of which use a tapped capacitor. Both are excellent choices. A slight variation of the Colpitts turns it into a Clapp oscillator.

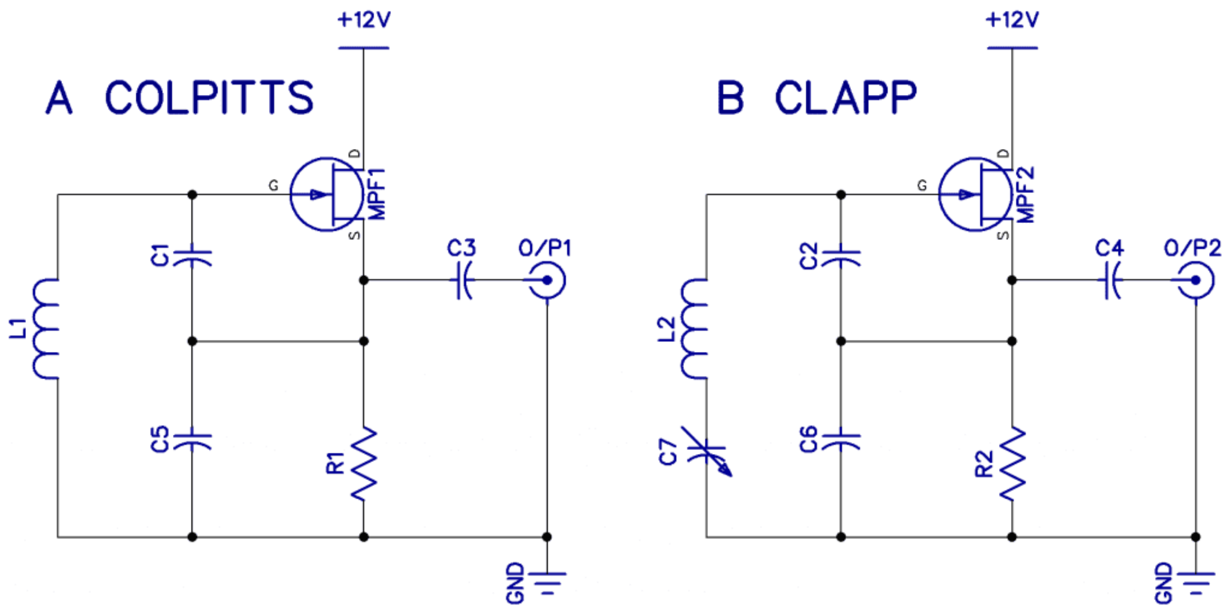
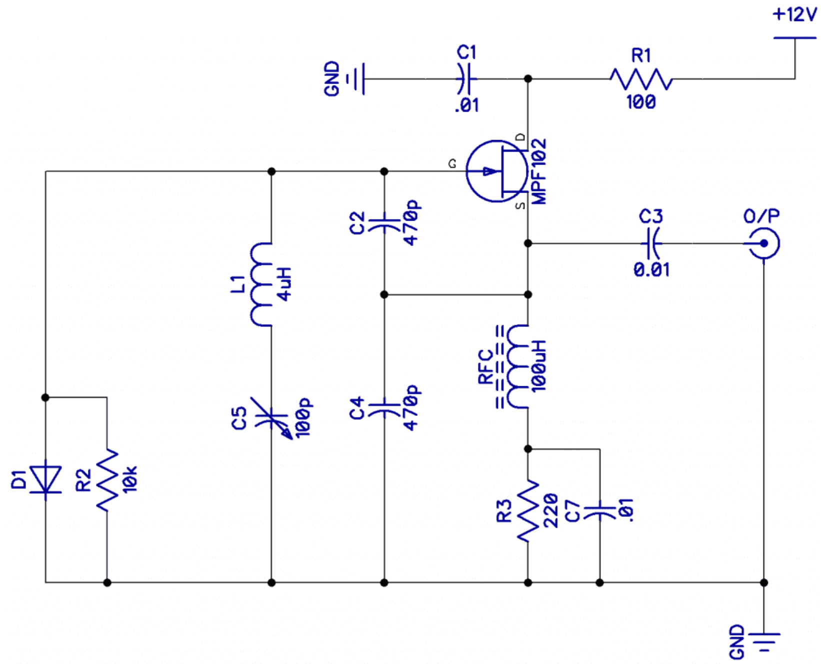


Diagram A shows a basic Colpitts. Note that C1 and C5 are in series/parallel with L1 and form the resonant circuit. In the Clapp shown in diagram B, the value of C7 is made much smaller than C2 and C6 and has a much larger effect on the tuning. If C7 is much smaller, frequency f is mostly dependent on C7 alone and more stable and tuned over a better range. This is why Clapp circuits are often the more popular choice for radio VFO's (variable frequency oscillators).

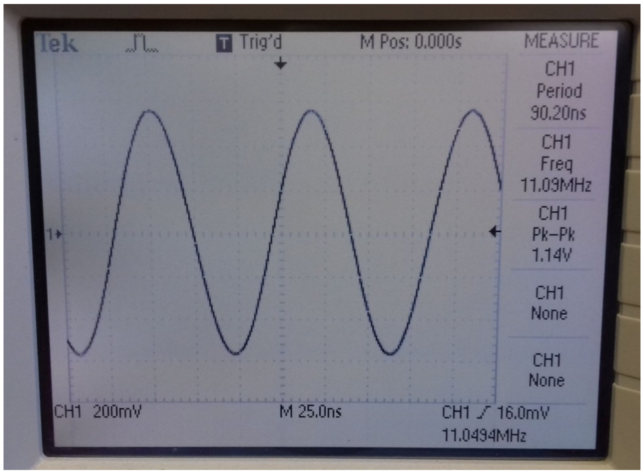
$$f = \frac{1}{2\Pi\sqrt{LC}}$$

$$C = \frac{1}{\frac{1}{C5} + \frac{1}{C2} + \frac{1}{C4}}$$

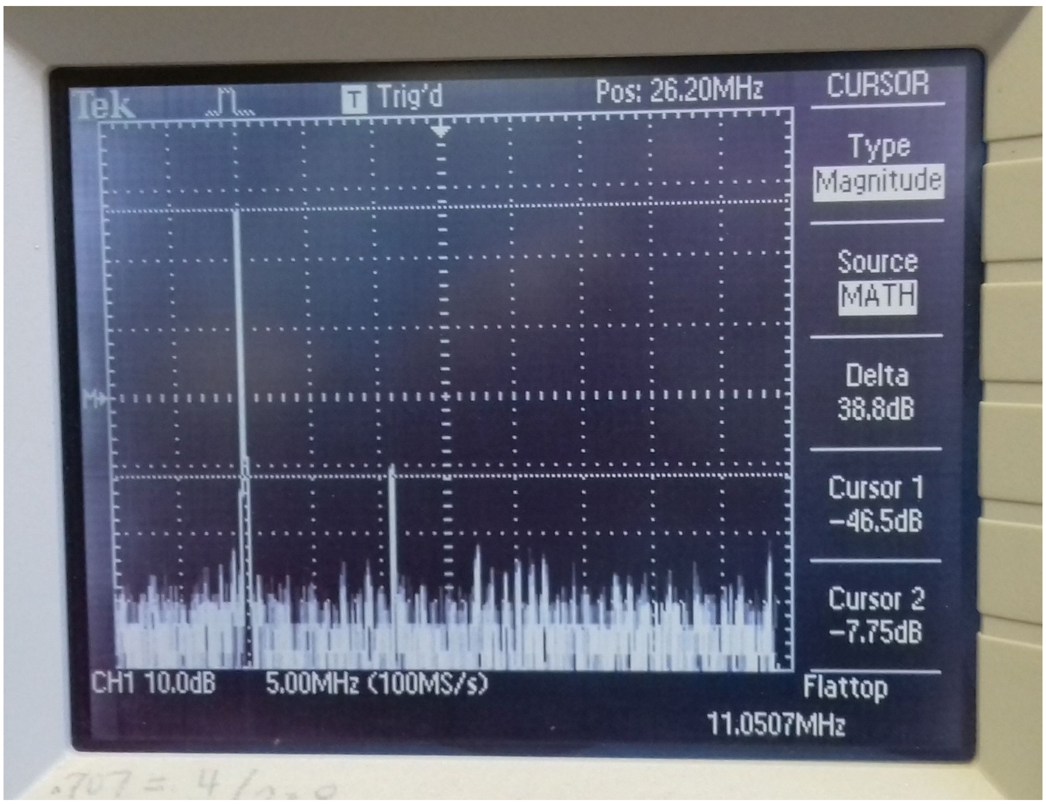
Shown below is a working Clapp VFO, and there are some interesting additions to the basic circuit. C1 R1 provides decoupling from the supply. RFC is about 10 turns of magnet wire on a ferrite ring, giving the source a higher impedance, and R3 provides bias to the FET. C2 and C4 are the main feedback caps, and C5 is the variable tuning capacitor. D1 R2 helps keep the amplitude down, making a better sine wave.



Below is the Clapp waveform of the circuit above, which is a good sine wave. Next to that is the Fourier display showing the second harmonic which is almost 40dB down (about 1% THD).



Wave form of Clapp oscillator



Fourier display of Clapp oscillator 2nd harmonic is 1%

Now, we have looked at four different sine wave oscillators, all giving nice clean waveforms. For the last article in this series, we will look at crystal oscillators. Be sure to leave a comment below if you have any questions!

How to Build Crystal Oscillator Circuits

Posted by Graham Lambert | DIY Electronics | 1

So we're down to part four of our tutorial series on wave generators and oscillators! Check out some of the previous articles in this series:

- How to Build a Square Wave Generator
- How to Build a Sawtooth and Triangle Wave Generator
- How to Build a Sine Wave Generator

And for this last one, we will look at crystal oscillators.

Crystal oscillators must surely be the most common of all electronic components. They are everywhere—on your phone, radio, TV, PC, laptop, microcontroller, and Arduino, to name a few. This is because they are unique in working at a single frequency—they are highly stable and drift-free. In this tutorial, we will look inside the can and see how crystal oscillators actually work.

How Crystal Oscillators Work

Crystal oscillators are loosely divided by the frequency they work at and whether they are fundamental oscillators—work at the frequency marked on the can or at even multiples of that (overtone oscillators).

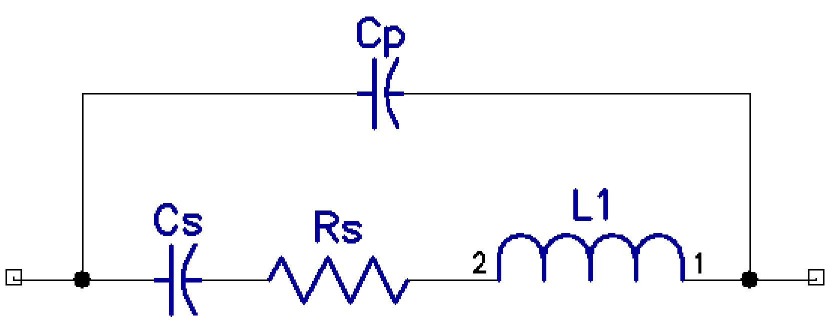
Any oscillator needs only two things to work—positive feedback and some amplifier. The amplifier can be a transistor, FET, op-amp, or digital gate. The kind of amplifier you will need will depend on the frequency. Op-amps may work at low-frequency gates low to medium and transistors and FETs at any frequency, especially at the higher end.

Not only do crystals come in many shapes and sizes, but they also come in different quartz cuts.

Let’s take a look inside a crystal oscillator:

As you can see from the picture above, there are three main parts. The wire leads connect to two silvered plates on either side of the quartz slice which form a capacitor. Finally, the quartz itself will behave like an inductor (a large one) and a tiny capacitor in series:

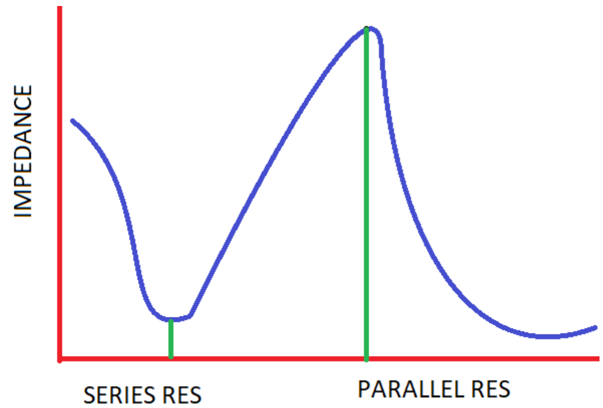
For example, look at the equivalent circuit below:



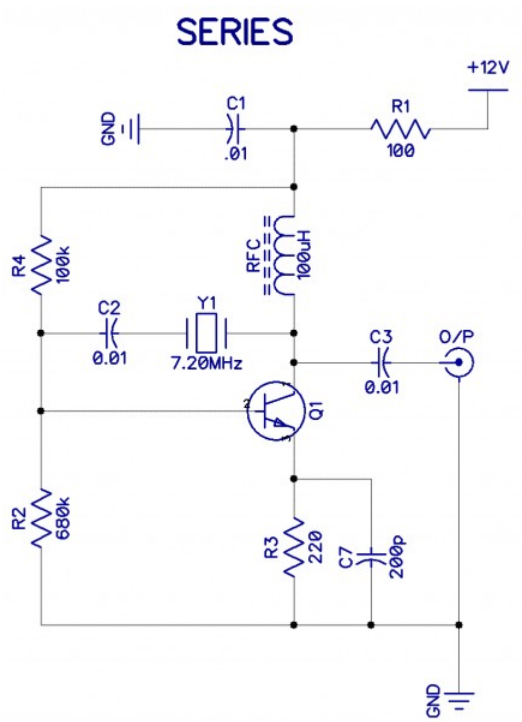
Rs is the resistance of the leads, Cp is the capacitance of the silvered plates, and L and Cs are hidden inside the quartz.

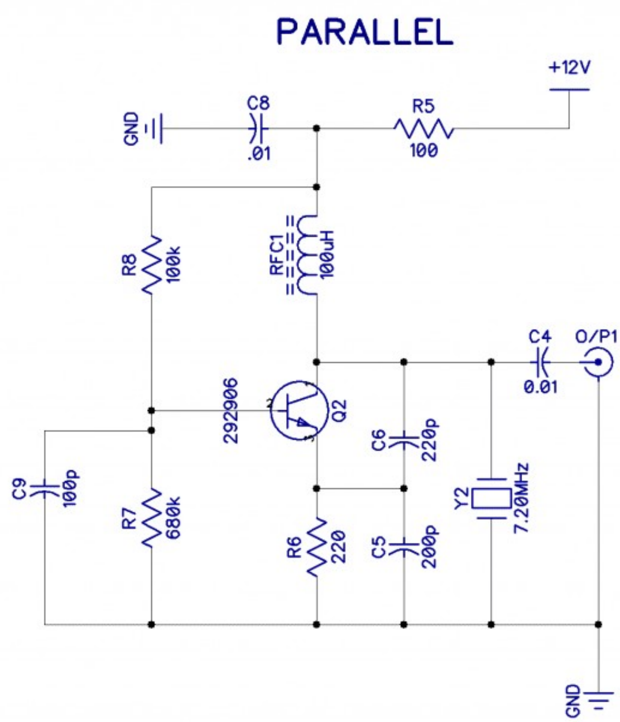
The property that makes the crystal so very stable at one frequency is its Q, and this is huge, typically 20 to 30 thousand. As Cp and Cs are very small, for L to resonate, it has to be huge, typically several Henries! Q is the ratio of reactance to resistance.

As you can see from the graph below, crystals have two resonant points. A lower impedance series resonance that is largely governed by Cs and L1, and a larger impedance parallel resonance that is largely governed by Cs in series with L1 and both in parallel with Cp.



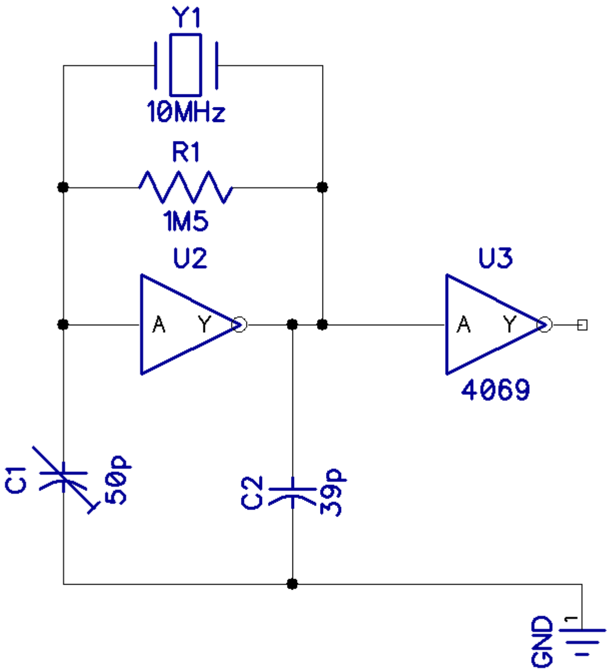
The two oscillator circuits below are suitable for using crystal oscillators in series or parallel mode:





Inverting Gate Oscillators

The simplest oscillator you can make is with one inverting gate like this:

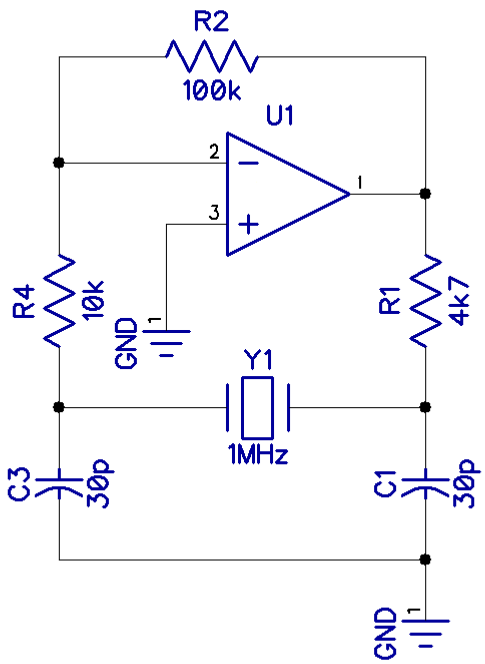


Almost any inverting gate CMOS will work here, including the 4069, 74HC04, 74HC14, etc.

Unintuitively, all digital gates have a gain, and if you bias them (like with the 1M5 resistor above), they work as amplifiers. The output only provides 180° of phase shift, so the capacitors are there to provide the rest of the phase shift to make the feedback positive (360°) and cause oscillation. None of these components are very critical. R1 can be anywhere from 10k to 10M, and C1 and C2 from 10p to 100p. It all depends on the frequency and the type of cut of the crystal. The values above are typical and work on my breadboard. I used a variable capacitor for C1 so that I could set the frequency to exactly 10.0000MHz on my counter. If you don't need to be that precise, you could just use a second 39p capacitor.

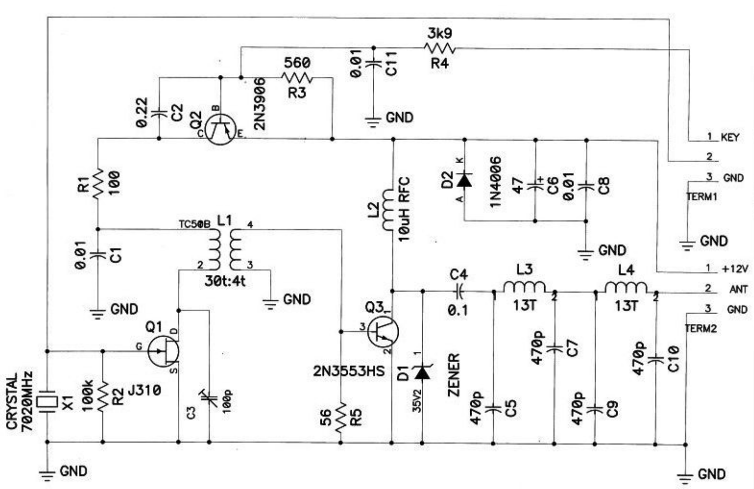
Crystal Oscillators and Op-Amps

Crystal oscillators can also be made with fast op-amps. Here, an LM318 op-amp is used. The output was not very clean, and there are better ways to make oscillators:



Radio Frequency Oscillators

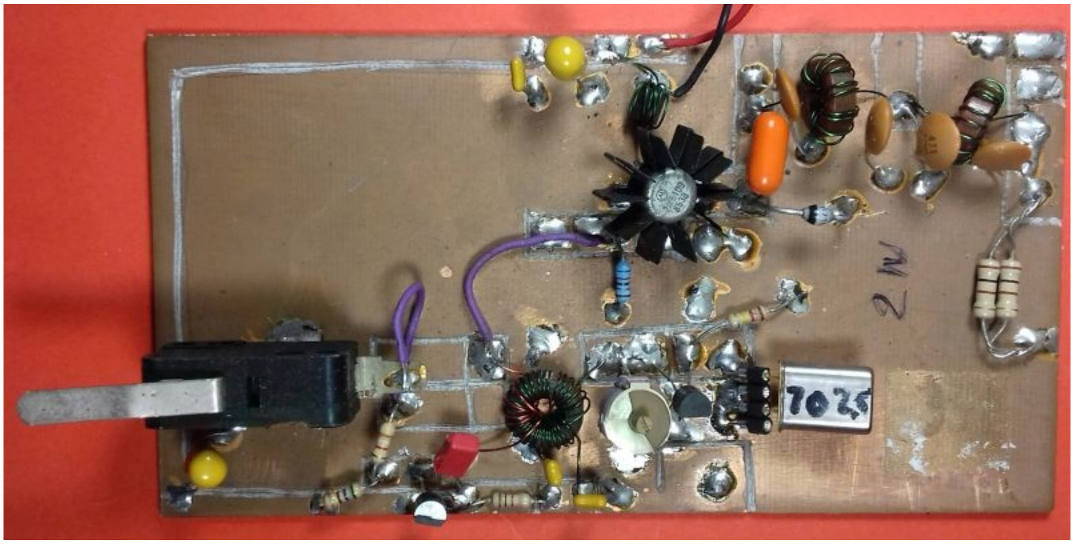
Radio hams have relied on crystal oscillators such as the circuit below for decades. Many spy transmitters were made during WW2 with circuits such as the one below (using valves, of course):



The main crystal oscillator is in the lower-left corner Q1, X1, etc., followed by a small 1W power amplifier (PA) Q3 driving a low pass filter and matching circuit. The oscillator is switched on and off through a key shaping circuit (Q2) to make it start and stop gently. This prevents clicks from being transmitted.

The FET oscillator’s drain circuit is a tuned circuit (L1 C3) to provide more power and a cleaner waveform. These all form an amateur band (40m) QRP CW (continuous wave or Morse code) transmitter.

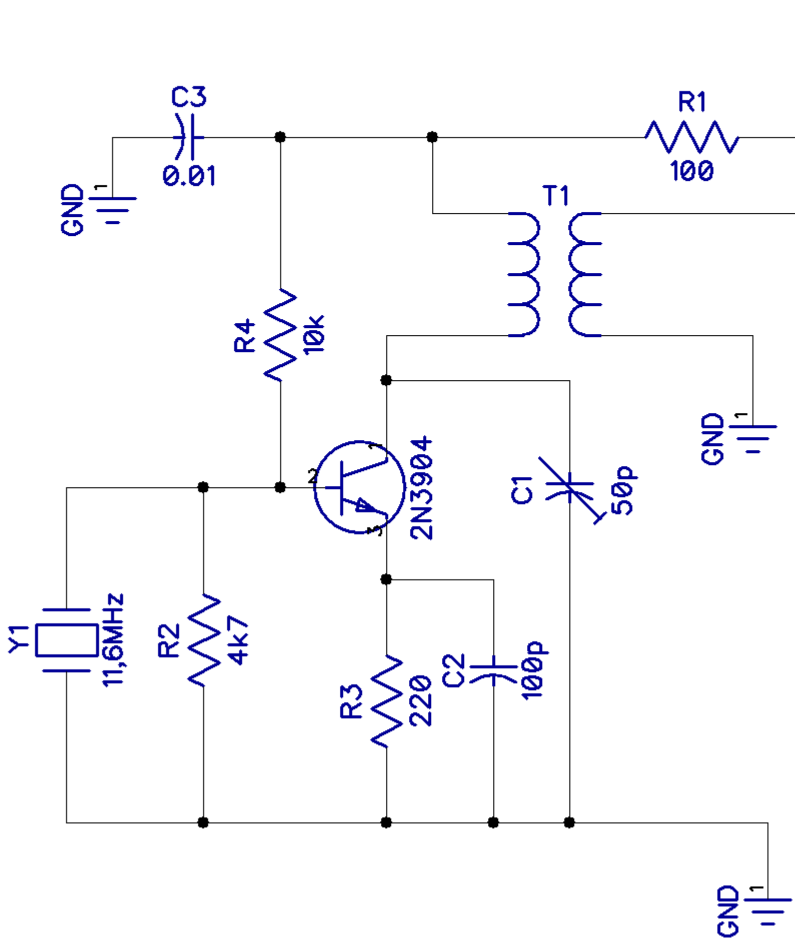
The completed prototype board is shown below with a detailed view of the crystal. Note that the Morse key is a micro switch.



Overtone Oscillator

Another useful crystal oscillator is the overtone oscillator shown in the schematic below. Standard-cut crystals are difficult to make; higher than 20MHz as the wafer of quartz becomes too thin. A solution to this is to use an overtone oscillator.

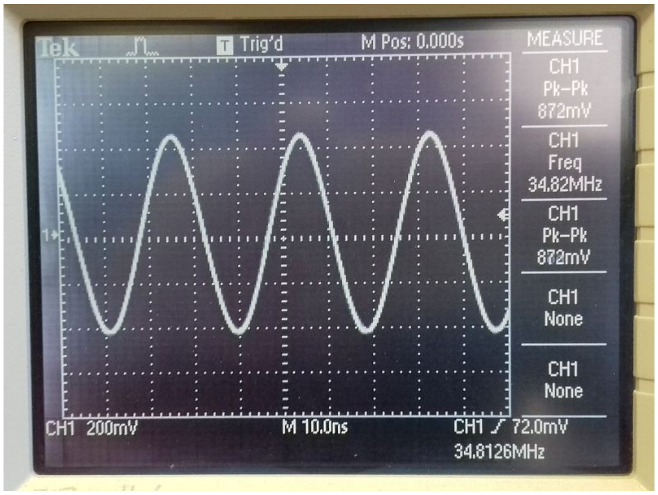
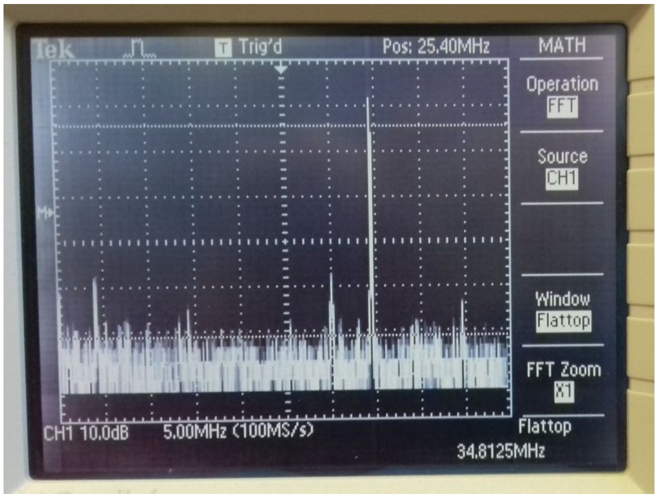
An example is the frequency source for a 144MH transmitter. The oscillator has a tuned load at an odd multiple of the fundamental frequency of the crystal. In fact, little or no part of the fundamental is present at the output. Although the circuit below will work with fundamental cut crystals, it is best to use overtone mode crystals for this application.



This oscillator has an 11.6MHz crystal and is tuned to the 3rd overtone or harmonic of 34.8MHz. The sine wave below is quite good, and there is almost nothing of the 11.6MHz fundamental in the 34MHz output in the Fourier display.

The output transformer is an Amidon T-50_6 type with 15 turns on the primary. The secondary turns will depend on what you connect it to.

If the output was followed by a tripler (3X) circuit, it would be the source for a 104MHz transceiver.

 *34MHz output of 11.6MHz overtone oscillator*	 *11.6MHz signal not visible*

This concludes the four-part series on oscillators! I hope you have learned as much from it as I have from researching and bread-boarding it! Be sure to leave a comment below if you have questions about anything!