Brass Tacks

An in-depth look at a radio-related topic

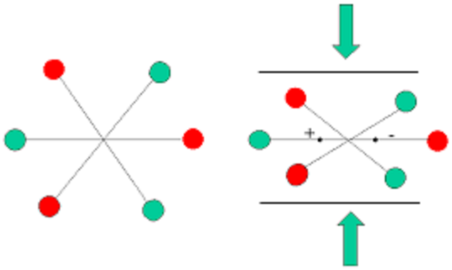
The crystal oscillator

Pretty much every electronic device in existence requires a reference signal whose voltage rises and falls, either sinusoidally or digitally, constantly and consistently; that is, at the same, unchanging frequency. Devices such as computers, cell phones, TVs, Wi-Fi routers, vehicles, and yes, ham radios, all require alternating signals they can count on. Most sub-components of these devices perform some critical function based on the steady cadence synchronized by that signal, often called a clock, which in turn is driven by an oscillator.

An electronic oscillator is a circuit or device that turns a DC voltage into a steady, periodic waveform, such as a sine wave or a square wave. There are many types and varieties of oscillators, of which the ***crystal oscillator*** is one, but how it works is a mystery to most. And to understand how the crystal oscillator works first requires an understanding of the workings at the very heart, an actual piece of (quartz or ceramic, for example) crystal. Note: this is very different from that of a crystal radio, which was covered in another article.

How it works

In 1880, two brothers of the French-most names you can think of, Pierre and Jacques Curie, were investigating the effects of temperature on crystalline structures. Their experiments led them to demonstrate that applying physical pressure on crystals can result in the crystals generating an electric voltage (potential difference between the two pressured sides of the crystal.) A year later, they confirmed the reverse effect, that applying a voltage to a crystal can slightly deform its physical structure.



In a crystalline lattice, the physical structure is held in place by each atom's electron forces balanced against the forces, locations, and distances of surrounding atoms. Because the lattice is electrically symmetrical, the net charge in any lattice cell is zero. When pressure is exerted on the lattice, the structure deforms a little, resulting in a small change in charge separation, positive one way and negative the other way, creating an electric dipole. This electric dipole then produces a net non-zero electric field, which presents a potential difference (voltage) between the sides of the crystal lattice. This process is known as the piezoelectric effect.

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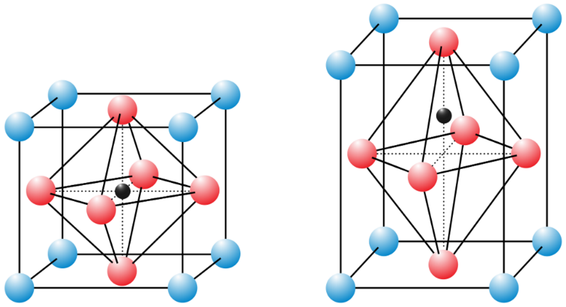
When the pressure is released, elasticity causes the lattice structure to spring back in the opposite direction, which in turn produces a voltage in the opposite polarity. The lattice then springs back yet again the other way, and the whole cycle repeats, over and over, until the lattice returns to its original, stable shape. The number of complete cycles per second that the crystal makes is known as its resonant frequency, which is largely determined by the crystal's material type and geometry (length-width-height dimensions); the thinner the crystal, the higher its resonant frequency.

The reverse effect is that, when a voltage is applied to the crystal lattice, the voltage potential difference causes the internal electric fields to polarize within each lattice cell. This electric field change in turn causes the physical structure of the crystal to deform slightly. So, applying pressure will affect the voltage across the crystal slightly, and applying a voltage across the crystal will affect its shape slightly, meaning the process is *reversible*.



The crystal oscillator

When a DC voltage is first applied to the crystal, it microscopically deforms, but then like a spring, bounces back-and-forth, and eventually levels off. This is kind of like connecting a ball to the middle of a long rubber band, stretching from your floor to your ceiling. When you strike the ball sideways, it bounces away, then back again, but eventually slows down to a standstill due to elasticity and air friction. So, by itself, a crystal is less-than-useful, except for a very short period of time. Then, when the voltage is removed, it re-deforms again, like a spring, back-and-forth, until it levels back to sitting still.

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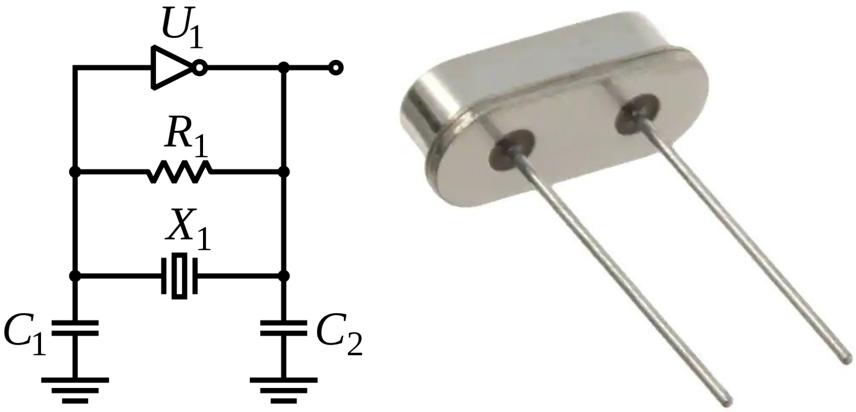
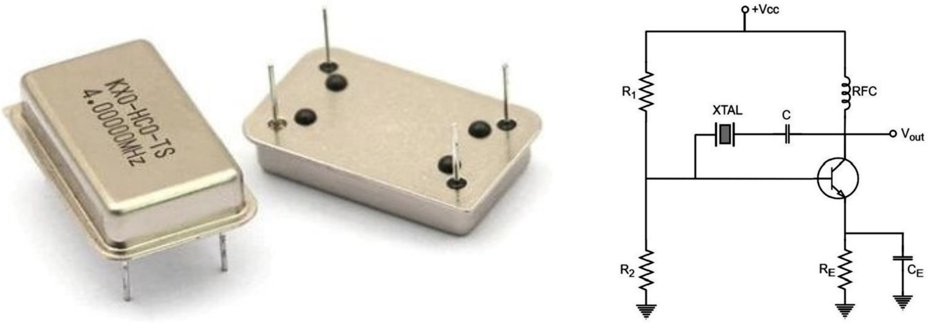
If an inverter is placed across the crystal, however, then when the DC signal is applied, the crystal deforms like before, and the deformation is reinforced by the signal from the inverter, acting like an amplifier. The combination of the inverting gain (180-degree phase shift) of the pi network (made by the capacitors) and the negative gain from the inverter and feedback resistor, provides *positive feedback*, the result of which is *oscillation*.



Resonator circuit, showing the inverter, and a commercial resonator

After that, the battery DC is only required to supply the little bit of energy lost in the inverter and resistor. This is known as a crystal resonator. Kind of like the same ball-and-rubber band setup you had, but after striking the ball, when it bounces back, you strike it again in the same direction, repeat the cycle, and the ball will keep going back-and-forth indefinitely, with you supplying the energy lost in air friction and elastic reformation.



Complete crystal oscillator, and oscillator schematic, showing a transistor inverter

Now, using the same crystal resonator, only changing the time it takes for the voltage to appear on the opposite side of the crystal, we can actually control its frequency. There are several ways to accomplish this, and one of the simplest is with a resistor and capacitor together, using them to control the time constant of the rising and falling voltages. This is known as a *crystal oscillator*.

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So, why use a crystal oscillator, over another type? Because crystal oscillators tend to be more stable, more resistant to temperature change, possess automatic amplitude control, are less expensive, occupy less circuit board space, easier by which to obtain a precision frequency, are available in very high frequencies, and exhibit high Q, requiring less energy to maintain a constant frequency. Also, raw crystal material, from which to manufacture crystal oscillators, are plentiful. With all those advantages, why use any other? Because crystal oscillators in very low (audio, for example) frequencies are not easily manufactured or available.

Applications

As mentioned, there are numerous uses for oscillators, and one of the most important uses for a reference crystal oscillator in the context of amateur radio is a frequency synthesizer. In the early days of radio, an operator could change bands by swapping out crystal resonators for one that supports the target band. (Using the term "rock" for an individual crystal, we often referred to those kinds of rigs as "rock-bound".) Then, using a bandspread or some other fine-tuning method, the operator could change frequencies within that band. Some channelized radios (military, commercial, aeronautical, marine) required the swapping of crystals for every frequency tuned to, since no fine-tuning control was needed.

Today, all the bands and individual frequencies required by each transceiver are provided by a frequency synthesizer, which uses a crystal oscillator for its reference frequency. The synthesizer uses digital logic to multiply and divide the oscillator frequency, and create (synthesize) all signals of the frequencies required by the rig.

Another major application of the crystal oscillator is the clock signal required by DSP (digital signal processing) and direct sampling in the modern amateur transceiver. These provide the mixing and filtering far less expensively than corresponding analog circuits, and can process incoming signals very efficiently, eliminating the need for expensive and complex (error-prone) superheterodyne circuitry.

Summary

An oscillator is used in many modern electronic devices, and provides a continuous clock signal of a very consistent frequency. We can take advantage of the piezoelectric nature of a quartz crystal, to create an oscillator by applying a DC voltage in repeated 180-deg phase shifts. One important application of an accurate oscillator is the frequency synthesizer in a radio, to produce our bands of frequencies that allow us to select on which one to communicate. Another is digital signal processing, which provides for very nice filtering of otherwise interfering signals.

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