# Chapter 18 - The Oscillator

**The Electronics Curse**
“Your amplifiers will oscillate, your oscillators won't!”

### Question, What is an Oscillator?

A Pendulum is an Oscillator...

“Oscillators are circuits that are used to generate A.C. signals. Although mechanical methods, like alternators, can be used to generate low frequency A.C. signals, such as the 50 Hz mains, electronic circuits are the most practical way of generating signals at radio frequencies.”

Comment: Hmm, wasn't always. In the time of Marconi, generators were used to generate a frequency to transmit. We are talking about kiloWatts! e.g. Grimeton L.F. Transmitter.

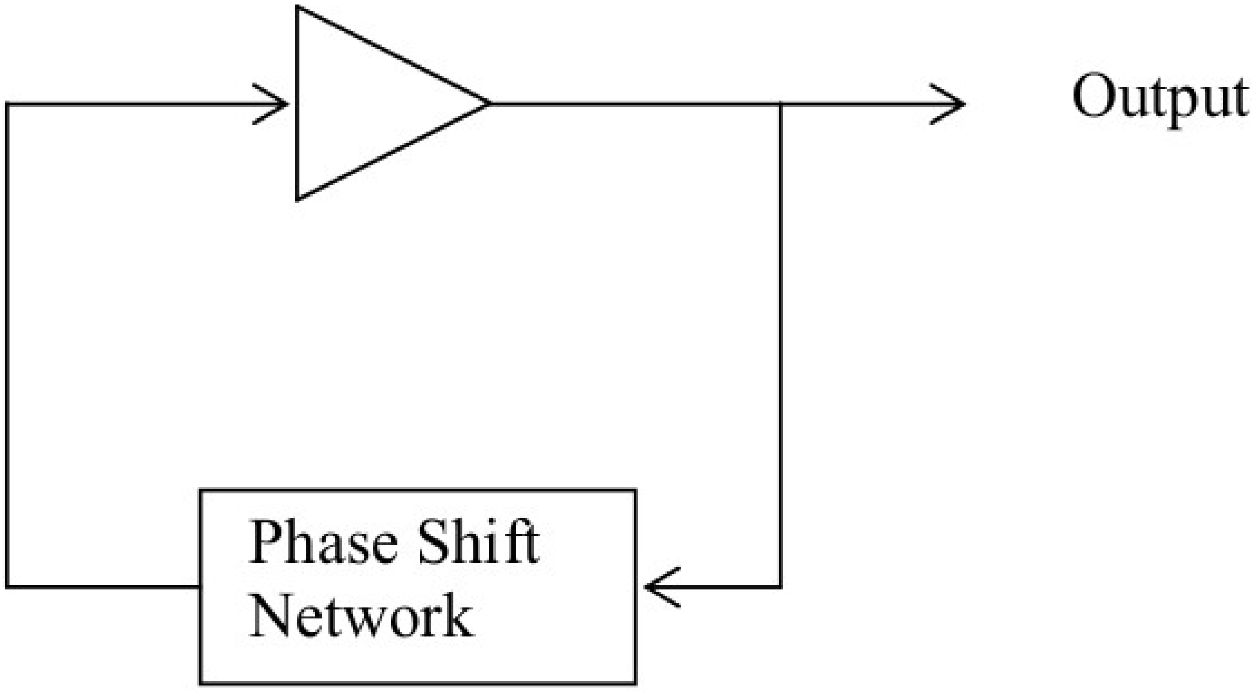
Oscillators are widely used in both transmitters and receivers. In transmitters they are used to generate the radio frequency signal that will ultimately be applied to the antenna, causing it to transmit. In receivers, oscillators are widely used in conjunction with mixers (a circuit that will be covered in a later module) to change the frequency of the received radio signal.

### Principal of Operation

The diagram below is a block diagram showing a typical oscillator. Block diagrams differ from the circuit diagrams that we have used so far in that they do not show every component in the circuit individually. Instead they show complete functional blocks – for example, amplifiers and filters – as just one symbol in the diagram. They are useful because they allow us to get a high level overview of how a circuit or system functions without having to show every individual component.

Comment: The author forgot the simplest form a multi-vibrator. Described as “an electronic see-saw”. He also 'forgot' the Pierce Oscillator, the simplest form of crystal oscillator...

# An Oscillator [Block Diagram]



*Block Diagram of an Oscillator*

**Block Diagram of an Oscillator**
The triangular symbol at the top represents an amplifier. The input of the amplifier is the blunt side of the triangle, on the left in this diagram; the output is the pointy side of the triangle. Since this symbol always represents an amplifier, there is no need to label it. The output of the amplifier is connected to the input of the block labelled “phase shift network”, and the output of the phase shift network is connected back to the input of the amplifier.

(Since the rectangular box of the phase shift network does not indicate the input and output, you must surmise this from the directions of the arrows on the connecting lines.) The output of the oscillator is taken from some point in the circuit - in this diagram We have shown it being taken from the output of the amplifier.

The lines connecting the symbols in the block diagram represent the flow of signals from one functional block to another. In this type of diagram, a line does not necessarily represent a single wire, as it would in a circuit diagram. A signal might flow along a single wire (with respect to earth), or it might flow in two wires, with the current flowing in opposite directions in both wires. In either case, it could be represented by a single line in a block diagram. The arrows at the end of the lines show the direction that the signal flows in – in this case, from the output of the amplifier to the input of the phase shift network, and from the output of the phase shift network back to the input of the amplifier. The direction in which the signal is flowing does not in general correspond with the direction in which current is flowing – after all, most of the signals we deal with will in any case be A.C. so current flows in both directions.

So how does this circuit oscillate? When it is initially turned on, there will be some (very small) thermal noise present in the circuit. This type of noise is generated by the random motion of electrons due to heat, and exists in all conductors. Thermal noise is broadband in nature, meaning that it includes frequency components at all possible frequencies. (When you turn the volume of a Hi-Fi amp up without any input signal, the hiss you hear is the audio frequency component of the thermal noise. If you hear a hum, this is mains pick-up, not thermal noise.)

Thermal noise at the input to the amplifier will be amplified, causing a larger noise signal at the output of the amplifier, some of which is bled off to the output, and some of which is applied to the phase shift network. The phase shift network does what its name implies – it changes the phase of the input signal, so the output of the network will have a phase that either leads or lags the input signal. The phase relationship between the output and the input depends on the precise frequency of the input signal.

At most frequencies, the output of the phase shift network, which is fed back into the amplifier, will not be at precisely the same phase as the noise component that caused it in the first place. In this case, the signal that is "fed back" to the input of the amplifier from the phase shift network will partially cancel out the signal that caused it, so the noise components at these frequencies will die out. However at one frequency, the output of the phase shift network will be exactly in phase with the noise component that caused it, and so it will reinforce that particular frequency component of the noise signal at the input to the amplifier.

This reinforced signal will again be amplified by the amplifier, phase shifted by the phase shift network, and fed back to the input of the amplifier. And once again, the output from the phase shift network is precisely in phase with the input signal from the "last round" that caused it, and so the signals reinforce each other and keep on growing.

Of course the signal cannot grow larger forever. As the signal grows bigger, ultimately the gain of the amplifier will be reduced (for example, it may be limited by the power supply voltage to the amplifier) until we reach the point that the amplified signal that is passed through the phase shift network and back to the input of the amplifier is only just as strong as the input to the amplifier that caused it. At this point, the signal is no longer growing, but remains constant and we have reached a stable oscillating state. If the oscillator has been designed correctly, then the output will be a constant amplitude signal at the desired frequency.

Feeding back some of the output of the amplifier back to the input in such a way that it reinforces the original input signal is called **positive feedback**. This is the same effect that you get when the audio output of a PA system is fed back to the microphone creating "howl-round" or "feedback".

## The Barkhausen Criteria for Oscillation [That's not dog box in German!]

**Comment:** In electronics, the **Barkhausen stability criterion** is a mathematical condition to determine when a linear electronic circuit will oscillate.[1][2][3] It was put forth in 1921 by German physicist Heinrich Georg Barkhausen (1881–1956).[4] It is widely used in the design of electronic oscillators, and also in the design of general negative feedback circuits such as op amps, to prevent them from oscillating..

The loop gain of an oscillator is the total gain that the signal experiences starting from any point in the circuit and going around the loop until it gets back to the starting point. For example, suppose the amplifier has a gain of 10 dB, that half the power is "bled off" to the output (resulting in a loss of 3 dB), and that the phase shift network also has a loss of 3 dB.

Converting the losses into negative gains, we get the following figures:

| | |
|---|---|
| Amplifier | 10dB |
| Loss of output signal | -3dB |
| Phase shift network | -3dB |
| Total loop gain 4 dB | |

Similarly, you can calculate the total phase shift around the loop. The amplifier will contribute some phase shift, and the phase shift network will contribute some more. Even the interconnecting wires may contribute significant phase shift at high frequencies – for example, the wavelength of a 100 MHz signal is 3 metres, so every centimetre of connecting wire would contribute a phase shift of about 1.2°!

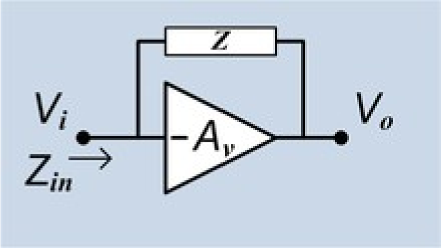
When the oscillator is oscillating stably – that is, with constant amplitude and frequency, the following criteria must be fulfilled:

The loop gain must be exactly 1. If the gain was more than 1, then the amplitude of the output would be increasing. If less than 1, then the amplitude would be decreasing.

The total phase shift around the loop must be 0 or an integer multiple of 360°. This is necessary for the signal to reinforce itself as it goes around the loop, so it does not cancel itself out.

These requirements are known as the Barkhausen criteria for oscillation.

It is entirely possible for these criteria to be met at more than one frequency. In particular, it is easy for the phase requirement to be met, since it only specifies a phase shift of 0 or any integer multiple of 360°, so it could be satisfied for different frequencies that had a total phase shift around the loop of say 0°, 360° and 720°. If both criteria are met for several frequencies, then oscillator will oscillate at all these frequencies simultaneously, which is usually not the desired result! Oscillations at undesired frequencies are called **parasitic oscillations**.



**Effect of parasitic capacitance *Z* = *C* between the input and output of an amplifier.**

**MILLER Capacitance.**

**Instability – in Oscillators**

In order to minimize the chance of this happening, the phase shift network is usually also made frequency selective, so that it will pass frequencies in the region of the desired frequency of oscillation, while attenuating frequencies that are higher or lower than this. In other words, it is made to be a band-pass filter as well as a phase shift network. The advantage of this is that even if the phase shift criterion is met for some other frequencies, as long as they are far enough away from the desired frequency, they can be attenuated sufficiently by the band-pass characteristic of the network to ensure that the loop gain remains less that 1 so oscillation will not occur at these unwanted frequencies.

Fortunately there is a simple circuit that provides both a phase shift and band-pass filter characteristics simultaneously: the parallel tuned circuit. At the resonant frequency the reactance of a parallel tuned circuit changes rapidly from being highly inductive just below the resonant frequency to being highly capacitive just above the resonant frequency. This sudden change in reactance results in a change in the phase relationship between the voltage across the tuned circuit and the current flowing through it (remember that for in inductive reactance, voltage leads current, while for a capacitive reactance current leads voltage). At the same time, the parallel tuned circuit can be used to provide good band-pass filter characteristics, minimizing the likelihood of parasitic oscillation.

An oscillator that uses a tuned circuit as its phase shift network will oscillate at (or very close to) the resonant frequency of the tuned circuit.

Comment: It also depends on the 'QUALITY' of the tuned circuit.

## The Colpitts Oscillator

Note: A **Colpitts oscillator**, invented in 1918 by American engineer Edwin H. Colpitts

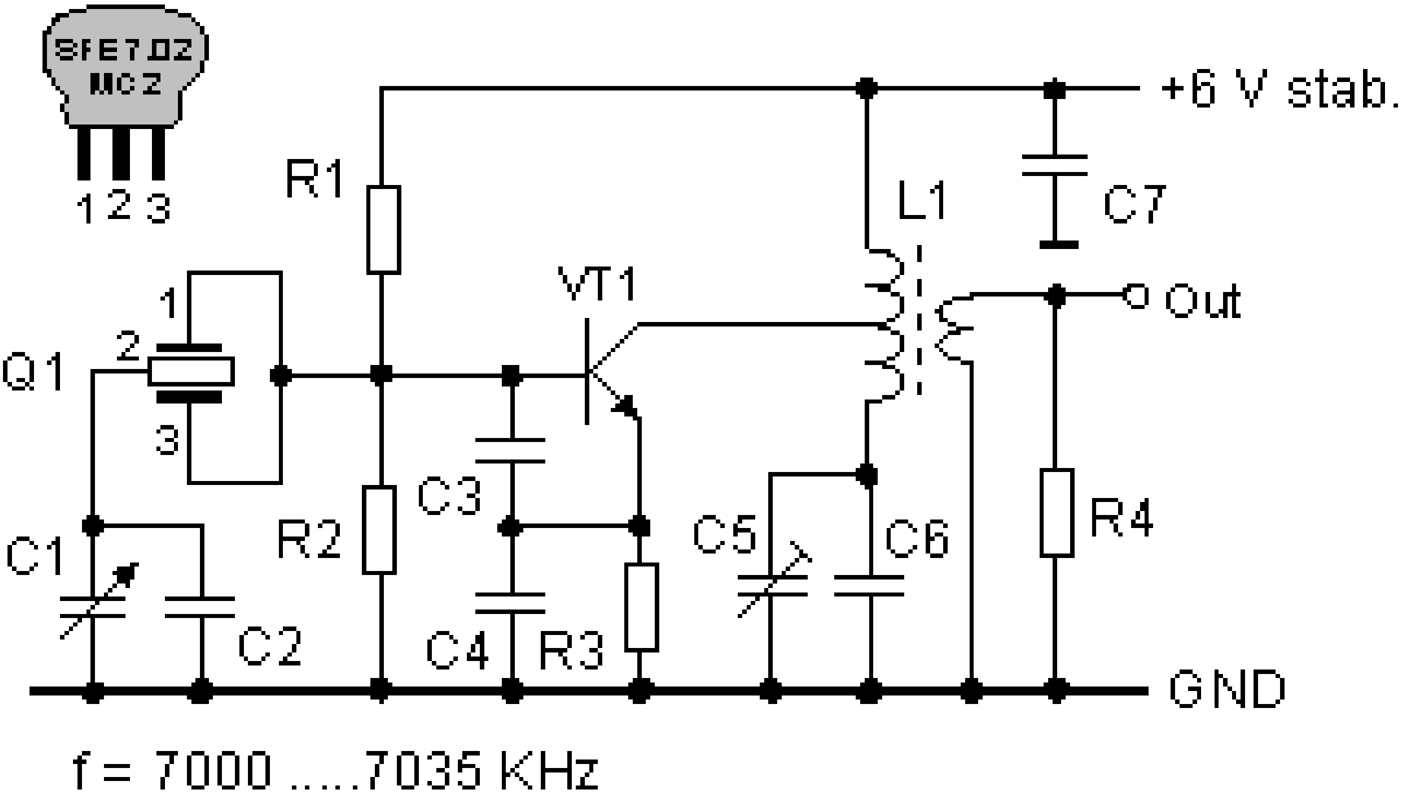
The Colpitts oscillator is typical of how these concepts can be implemented in a practical circuit.

### Circuit Diagram of a Colpitts Oscillator

Transistor Q1 and the associated components R1, R2, R3 and L1 form a common-emitter amplifier. The output of the amplifier, taken from the collector of Q1, is fed into a parallel tuned circuit consisting of L2, C2 and C3. The capacitor in this tuned circuit has been "split" into two capacitors, C2 and C3, to allow the output current from the collector of Q1 to flow to ground via C2. This causes a voltage across the whole parallel tuned circuit (also known as the tank circuit of the oscillator). This voltage is fed back to the input of the amplifier via C1.

The output of the oscillator is taken from the collector of the transistor via C4. The label "VCC" represents the positive power supply voltage.

The defining characteristic of the Colpitts oscillator – i.e. what makes it a Colpitts oscillator as opposed to any other type of oscillator – is the way the tank circuit (the parallel tuned circuit) uses a split capacitor to allow the output of the amplifier to be injected across one of the capacitors, while the input to the amplifier is taken from across the other capacitor.



**A 'real' Circuit – Colpitts Oscillator**

### Buffering

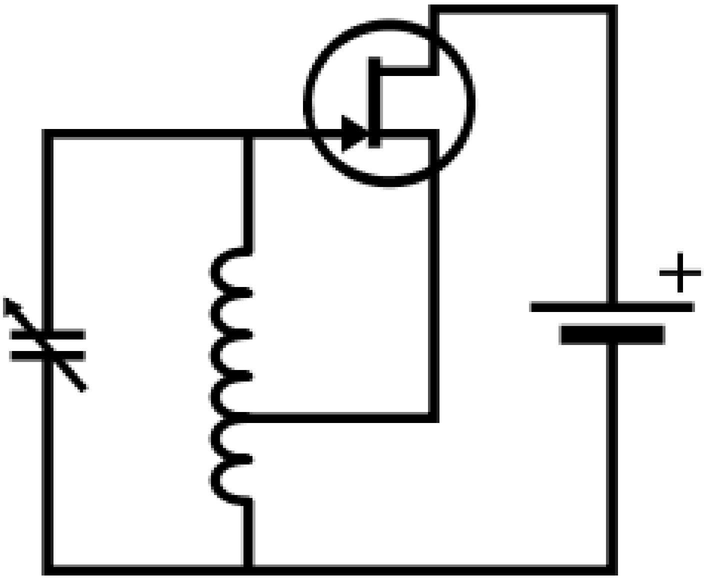
Because the amount of signal that is drawn off by the output of the oscillator affects the loop gain of the oscillator, it will also affect the frequency of the oscillator. For this reason it is important that the amount of signal drawn off does not change, for example in response to a Morse code (CW) transmitter being keyed, otherwise the frequency of the transmitter will change as it is keyed, a phenomenon known as "chirp". Most transmitter designs prevent this by having a buffer amplifier between the oscillator and the keyed stages of the transmitter.

The buffer amplifier is often a common-collector (emitter follower) amplifier, which shows constant high impedance to the oscillator while having a low output impedance that can supply sufficient current to drive the stages that follow.

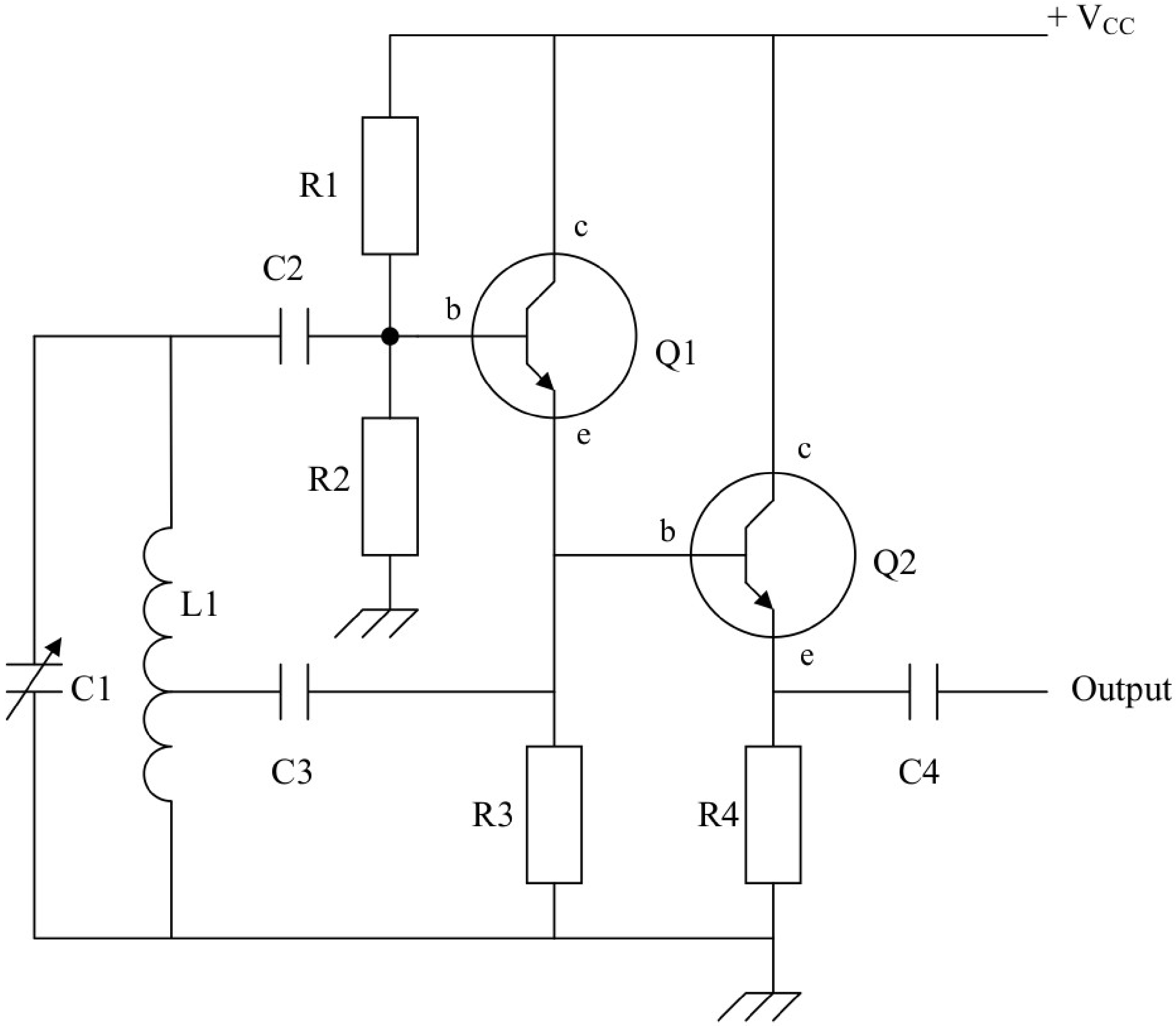
## The Hartley Oscillator

**Note: The circuit was invented in 1915 by American engineer Ralph Hartley.**

Another way of feeding the output of the amplifier into a parallel tuned circuit, and the output of the tuned circuit back to the input of the amplifier, is to use a centre-tapped inductor in the tank (tuned) circuit. This is the principal of the Hartley oscillator.



**Theoretical Circuit – Hartley Oscillator**



**Circuit Diagram of a Hartley Oscillator with a Buffer Amplifier – From Book**

In this circuit, transistor Q1 is a common-collector (emitter follower) amplifier that is biased by R1, R2 and R3. The output of the amplifier, at the emitter of Q1, is coupled via DC blocking capacitor C3 into the parallel tuned tank circuit consisting of L1 and C2 through a tap in the inductor. The tank circuit is coupled back to the input of the amplifier via C2, which serves as another DC blocking capacitor to prevent the base of Q1 from being shorted to earth via L1. The arrow through C1 indicates that it is a variable capacitor, so the resonant frequency of the tank circuit, and hence the oscillator frequency, can be changed by varying C1. The output of the oscillator at the emitter of Q1 is fed to Q2, which is a common-collector (emitter follower) buffer amplifier. R4 sets the emitter and collector current for Q2. The output of the buffer amplifier is taken from the emitter of Q2 via DC blocking capacitor C4.

An Oscillator where the frequency to be varied, typically by turning a control knob, is known as a Variable Frequency Oscillator (VFO).

In this circuit, the centre-tapped inductor L1 acts a bit like a step-up transformer, since an AC voltage applied between the centre tap and the chassis connection (the bottom of the inductor) generates a varying magnetic field, which causes a larger voltage to be generated between the “hot” side of L1 (the top of the inductor) and the chassis. This voltage step-up allows the common-collector amplifier to provide power gain in this circuit, despite the fact that the voltage gain between the base and emitter of the transistor is unity (1). A tapped inductor like this is also called an autotransformer.

## Other types of Oscillator

### Clapp

It was published by James Kilton Clapp in 1948.[1] According to Vačkář,[2] oscillators of this kind were independently developed by several inventors, and one developed by Gouriet had been in operation at the BBC since 1938.

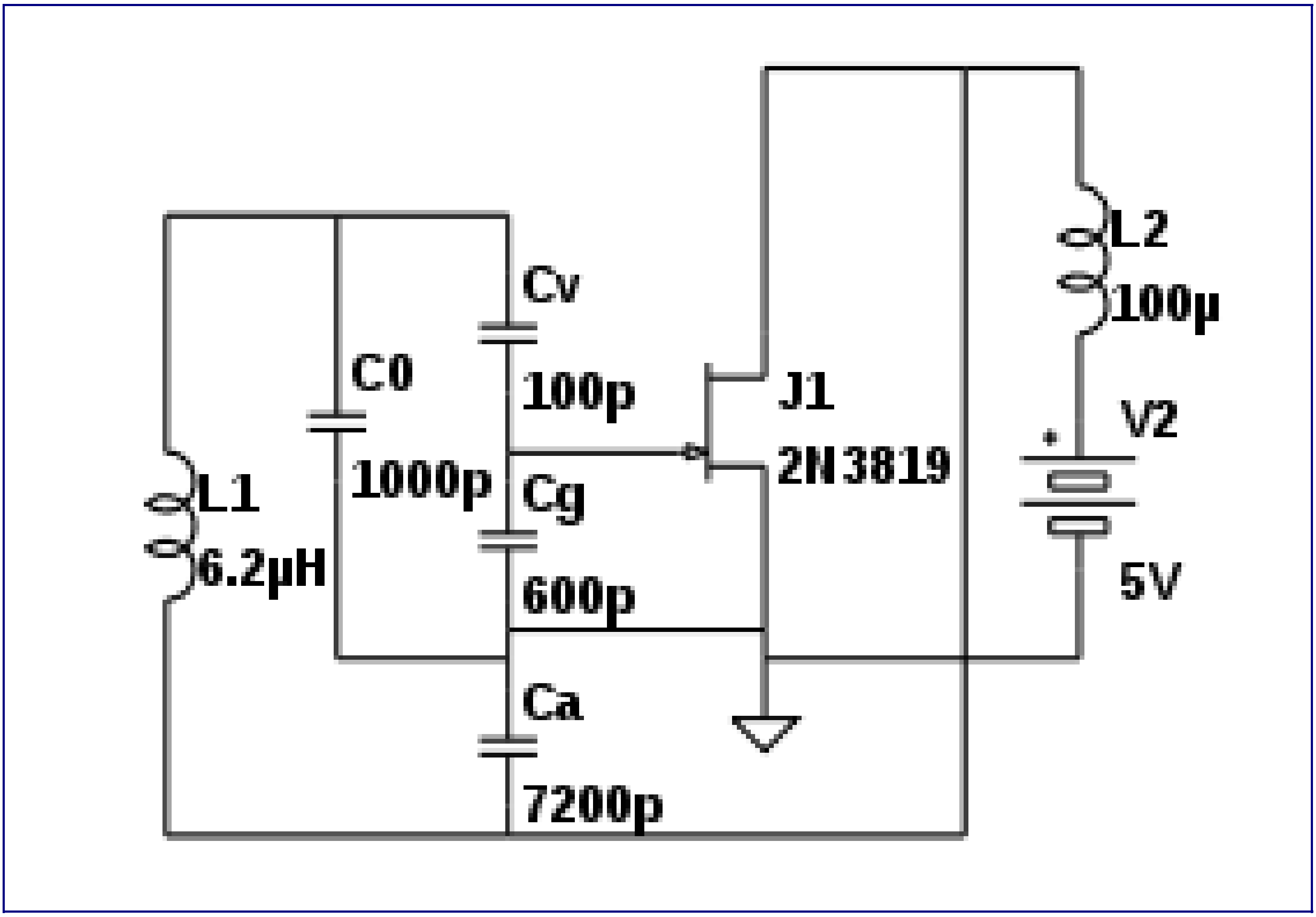
### Gouriet

**Geoffrey George Gouriet** M.I.E.E joined the Drive Section of the Transmitters Department of the BBC in 1937,[1][2] and in 1937/38 he was the inventor of a high stability crystal-controlled variant of the Colpitts oscillator. With the outbreak of war imminent, his circuit was put to immediate use by the BBC to drive its Medium Wave broadcast transmitters, allowing the implementation of Britain's wartime single-frequency synchronised radio services from multiple transmitters. This was a technique adopted to try to prevent the Luftwaffe conducting air raids on British cities using BBC transmitters for navigation.

Due to wartime security measures, Gouriet's oscillator design was kept secret until after WWII. Meanwhile, the same circuit was independently discovered by James Kilton Clapp of the USA, and published by him in 1948. Gouriet's oscillator is usually known as the Clapp oscillator as a result, although newer books use the term *Gouriet-Clapp oscillator*.[3]

## Vackář oscillator

From Wikipedia, the free encyclopaedia



Schematic of what is commonly called the Vackář oscillator. Vackář credited Radioslava with developing this circuit in 1945.[1]

A **Vackář oscillator** is a wide range variable frequency oscillator that strives for a near constant output amplitude over its frequency range. It is similar to a Colpitts oscillator or a Clapp oscillator, but those designs do not have a constant output amplitude when tuned.

## Stability [Very Important!]

In 1949, the Czech engineer Jiří Vackář published a paper on the design of stable variable-frequency oscillators (VFO).[2] The paper discussed many stability issues such as variations with temperature, atmospheric pressure, component ageing, and micro-phonics. For example, Vackář describes making inductors by first heating the wire and then winding the wire on a stable ceramic coil form. The resulting inductor has a temperature coefficient of 6 to 8 parts per million per degree Celsius.[3] Vackář points out that common air variable capacitors have a stability of 2 parts per thousand; to build a VFO with a stability of 50 parts per million requires that the variable capacitor is only 1/40 of the tuning capacity (.002/40 = 50ppm). The stability requirement also implies the variable capacitor may only tune a limited range of 1:1.025.[3] Larger tuning ranges require switching stable fixed capacitors or inductors.[4]

Vackář was interested in high stability designs, so he wanted the highest $Q$ for his circuits. It is possible to make wide range VFOs with stable output amplitude by heavily damping (loading) the tuned circuit. However, that tactic substantially reduces the $Q$.[5]

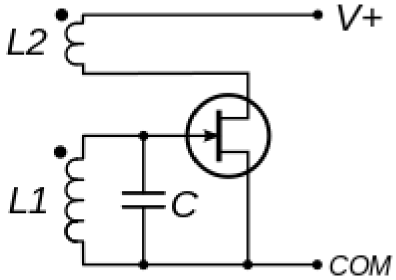
Vackář was also concerned with the amplitude variations of the variable-frequency oscillator as it is tuned through its range. Vackář assumes the tuned circuit has a constant $Q$ over the VFO's frequency range. Vackář reviewed several existing circuits for their amplitude stability.[1] The Clapp oscillator's transconductance requirement is proportional to $\omega^3$. If the Clapp transconductance is set to just oscillate at the lower frequency range, then the oscillator will be over-driven at its highest frequency. The Seiler and Lampkin oscillators have a transconductance requirement that is proportional to $\omega^{-1}$.

Vackář then describes an oscillator circuit due to Radioslava in 1945 that maintained "a comparatively constant amplitude over a wide frequency range."[6] Vackář reports that VFO circuit being used by the Czechoslovak Post Office since 1946. Vackář does not claim the circuit, but he analyses the circuit and explains how to get an approximately constant amplitude response. This circuit has become known as the Vackář VFO.[7] Vackář does refer to the circuit as "our circuit" and states that O. Landini independently discovered the circuit and published it (without an analysis) in Radio Rivista in 1948.[8] Vackář describes a VFO design using this circuit that covers a range of 1:1.17.[8]

Vackář then describes a variation of the Radioslavia circuit that can cover a range of 1:2.5.[9] The circuit need not assume the tuned circuit has a constant $Q$. Vackář patented this new circuit and two variations of it.[10]

## Armstrong Oscillator

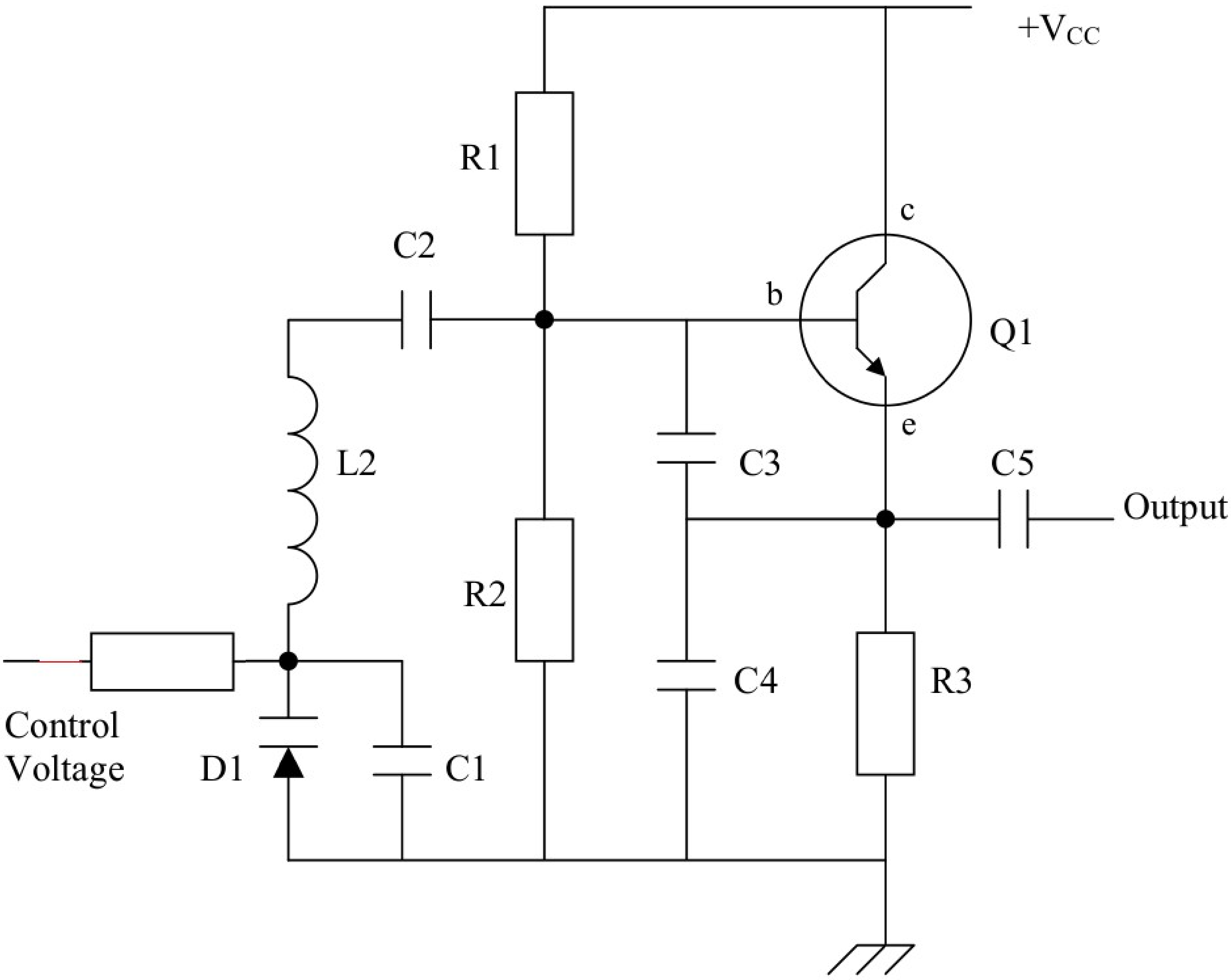
The **Armstrong oscillator**[1] (also known as the **Meissner oscillator**[2]) is an electronic oscillator circuit which uses an inductor and capacitor to determine the oscillation frequency; an LC oscillator. It is the earliest oscillator circuit, invented by US engineer Edwin Armstrong in 1912 and independently by Austrian engineer Alexander Meissner in 1913, and was used in the first vacuum tube radio transmitters. It is sometimes called a *tickler oscillator* because its distinguishing feature is that the feedback signal needed to produce oscillations is magnetically coupled into the tank inductor in the input circuit by a "tickler coil" *(L2, right)* in the output circuit. Assuming the coupling is weak, but sufficient to sustain oscillation, the oscillation frequency $f$ is determined primarily by the tank circuit *(L1 and C, right)* and is approximately given by



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

## The Voltage-Controlled Oscillator

If part of the capacitance forming the tuned circuit in an oscillator is made up of capacitance from a varicap diode, then the frequency of the oscillator can be varied by changing the reverse-bias voltage applied to the varicap diode. This is called a voltage-controlled oscillator (VCO). An example circuit, using a **Clapp** (series-tuned Colpitts) configuration is shown below:



**Circuit Diagram of a Voltage Controlled Oscillator**

The control voltage is applied through radio-frequency choke L1 to reverse-bias the varicap diode D1. This is in parallel with C1, which provides some additional capacitance (necessary since varicap diodes have fairly low capacitance). They are in series with L2, hence the name "series-tuned Colpitts" oscillator (also called a Clapp oscillator). C2 prevents the DC control voltage from interfering with the bias voltage generated by the voltage divider consisting of R1 and R2 (or vice-versa). Q1 is operated as a common collector (emitter follower) amplifier, and the output at the emitter of Q1 is fed back into the tank circuit at the junction between C3 and C4, which form the tank circuit along with C1, D1 and L2. The oscillator output is taken from the emitter of Q1 via DC blocking capacitor C5.

## The Crystal Oscillator

Quartz crystals exhibit the **piezoelectric effect** – a voltage applied across the crystal causes the crystal to distort ("bend") slightly, and when the crystal returns to its undistorted shape a voltage is generated across it. As a result, the crystal appears similar to a series tuned circuit and it can be used as the frequency-determining element in an oscillator. A typical circuit is shown below.

Comment: Gas cigarette lighter crystal generates a high-voltage spark to light the gas!

## Circuit Diagram of a Crystal Oscillator

Here the resonant circuit consists of crystal X1 with series capacitor C1 and capacitors C2 and C3. Q1 operates as a common-collector (emitter-follower) amplifier biased by R1, R2 and R3.

The output of the amplifier is fed back into the tank circuit at the junction between C2 and C3. This circuit also uses a "series-tuned Colpitts" or "Clapp" configuration.

Crystals have the advantage of providing very good frequency stability – that is, the frequency of a crystal controlled oscillator will remain stable with little tendency to "drift", which is a problem with oscillators using traditional inductor-capacitor tuned circuits. The disadvantage of crystal oscillators is that they cannot be tuned over any great range. The variable capacitor C1 in this circuit can varying the frequency slightly (which is known as "pulling" the crystal), but the tuning range is very limited. Crystal oscillators that allow the frequency to be varied are called "**v**ariable **c**rystal **o**scillators", abbreviated "VXO".

Comment: Crystals are EXPENSIVE. Also these days they have been replaced with CERAMIC RESONATORS and Surface Wave Acoustic (S.A.W.) devices.

## Summary

Oscillators are circuits that generate AC signals. Oscillators consist of an amplifier with positive feedback through a phase-shift network. The phase shift network usually also serves as a band-pass filter. An oscillator will oscillate at any frequency and amplitude where the Barkhausen criteria for oscillation are met:

- The loop gain is unity.
- The sum of the phase shifts around the feedback loop is zero or an integer multiple of 360°.
- The output of an oscillator should be buffered to prevent the frequency of the oscillator from changing as the load on the oscillator varies.

There are several different oscillator circuits, including the Colpitts, Hartley and Clapp oscillators, which differ in the precise arrangement of the tank circuit. An oscillator that allows the frequency to be varied is called a Variable Frequency Oscillator (VFO). If the frequency is varied by applying a control voltage, then it is a Voltage Controlled Oscillator (VCO).

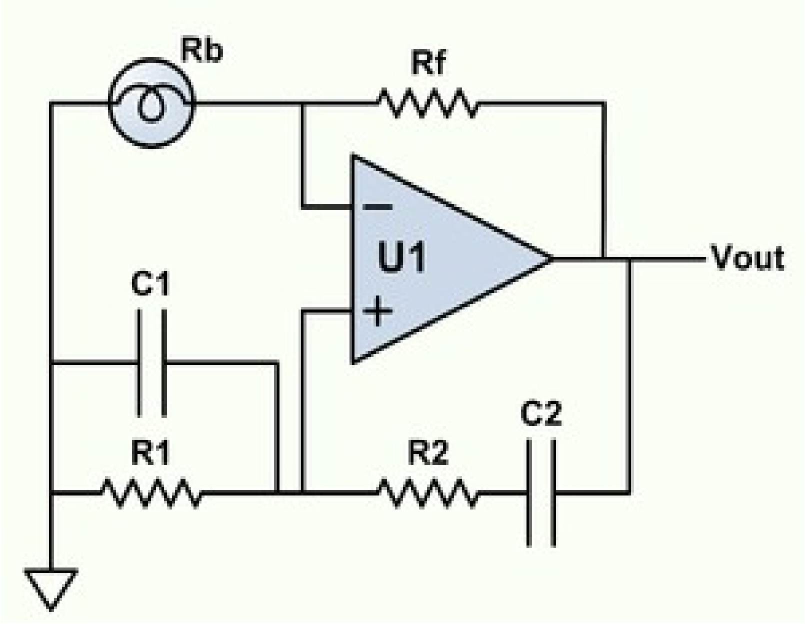
Quartz crystals exhibit the piezoelectric effect and act like series tuned circuits. They can be used to control the frequency of an oscillator. Crystal-controlled oscillators exhibit excellent frequency stability, with very little drift. However they are essentially fixed-frequency oscillators; although the frequency can be "pulled" slightly using a variable capacitor, the tuning range is not nearly as wide as for oscillators using ordinary tuned circuits. Crystal oscillators that allow the frequency to be varied are called "variable crystal oscillators", abbreviated "VXO".

Comment: BUT
Crystals can be 'cut' for specific high temperature operation. So that they can be used as a very stable frequency source. Usually inside a temperature controlled oven.

Crystals in general these days are used as "Frequency Reference" for a "Phase Locked Loop" or a "Direct Digital Synthesiser" [DDS].

We did not even mention "tone generator/oscillators"!

**Wien Bridge Oscillator**



A **Wien bridge oscillator** is a type of electronic oscillator that generates sine waves. It can generate a large range of frequencies. The oscillator is based on a bridge circuit originally developed by Max Wien in 1891.[1] The bridge comprises four resistors and two capacitors. The oscillator can also be viewed as a positive gain amplifier combined with a bandpass filter that provides positive feedback.

The modern circuit is derived from William Hewlett's 1939 Stanford University master's degree thesis. Hewlett figured out how to make the oscillator with a stable output amplitude and low distortion.[2][3] Hewlett, along with David Packard, co-founded **Hewlett-Packard**, and Hewlett-Packard's first product was the HP200A, a precision Wien bridge oscillator.

The frequency of oscillation is given by:

$$f = \frac{1}{2\pi RC}$$