Module

2

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# Oscillators

## 2.0 RF Sine Wave Oscillators

What you'll Learn in Module 2



### RF Oscillators


### Radio Frequency Oscillators

There are many different designs of sine wave oscillators used in radio and communication equipment, usually using some form of resonant circuit to generate signals at radio frequencies from several tens of kHz to 1GHz and above. A number of popular oscillator designs date back to the early 20th century when radio communication was being developed, and it has been the custom to name the various types of oscillator after their inventor. Any one particular design of oscillator can have several different forms, and each type of oscillator has certain advantages and disadvantages for any particular application. This module describes some popular types of LC and crystal sine wave oscillators, how they work and includes some practical projects showing how to build and test some RF oscillators.

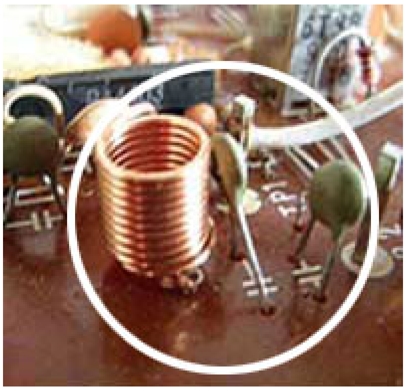
 

## Frequency Control in RF Oscillators

Several different types of frequency control networks are used in high frequency sine wave oscillators. Three of the most commonly found are:

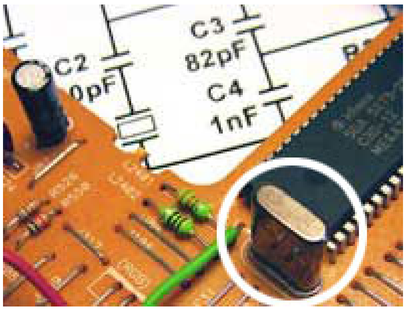
1. **LC Network, 2. Quartz Crystal, 3. Ceramic Resonator.**

### LC Networks



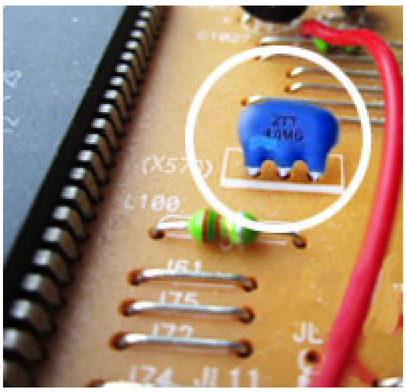
In networks, consisting of an inductors and capacitors the frequency of oscillation is inversely related to the values of L and C. (the higher the frequency, the smaller the values of L and C). LC oscillators generate a very good shape of sine wave and have quite good frequency stability. That is, the frequency does not change very much for changes in D.C. supply voltage or in ambient temperature. LC oscillators are extensively used for generating R.F. signals where good wave shape and reasonable frequency stability is required but is NOT of prime importance.

### Quartz Crystals




Crystal oscillators are used to generate both square and sine waves at frequencies around 1 or 2 MHz and higher, when a very high degree of frequency stability is needed. The component determining the frequency of oscillation is thin slice of crystalline quartz (Silicon Dioxide), usually sealed inside a metal can. The quartz crystal vibrates mechanically at a very precise frequency when subjected to an alternating voltage. The frequency depends on the physical dimensions of the slice and the angle at which the slice is cut in relation to the atomic structure of the crystal, and so once the crystal has been manufactured to specific dimensions, its frequency is extremely accurate, and constant. The frequency produced is typically accurate to around 0.001% of its design frequency and is almost wholly independent of changes in supply voltage and variations in temperature over its working range. Where even greater accuracy is required, the crystal may be mounted in a small, heated and temperature controlled enclosure. Crystals are manufactured in a wide range of specific frequencies. Sine wave crystal oscillators are commonly used to generate very accurate frequency carrier waves in radio and other communications transmitters.

### Ceramic Resonators



These components work in a similar way to quartz crystals, they vibrate when subjected to an AC signal, but are manufactured from a variety of ceramic materials. Thay are generally cheaper and physically smaller than equivalent quartz crystal resonators, but do not have such a high degreee of accuracy. They can be manufactured in either surface mount or through hole versions having either two or three connections.

## 2.1 The Hartley Oscillator

### What you'll learn in Module 2.1

**After Studying this section, you should be able to:**

- Understand the operation of The Tuned Tank Circuit.
- Understand the operation of Automatic (Sliding) Class C Bias.
- Understand the operation of Hartley Oscillators.
- Recognise Alternative Hartley Designs.

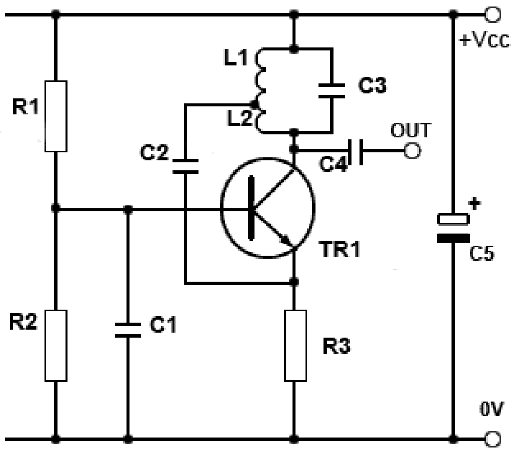



Fig. 2.1.1 The Hartley Oscillator

The Hartley Oscillator is a particularly useful circuit for producing good quality sine wave signals in the RF range, (30kHz to 30MHz) although at the higher limits of this range and above, The Colpitts oscillator is usually preferred. Although both these oscillators oscillator use an LC tuned (tank) circuit to control the oscillator frequency, The Hartley design can be recognised by its use of a tapped inductor (L1 and L2 in Fig. 2.1.1).

The frequency of oscillation can be calculated in the same way as any parallel resonant circuit, using:

$$f_r = \frac{1}{(2\pi\sqrt{LC})}$$

**Where L = L1 + L2**

This basic formula is adequate where the mutual inductance between L1 and L2 is negligible but needs to be modified when the mutual inductance between L1 and L2 is considerable.

### Mutual Inductance in Hartley Oscillators

Mutual inductance is an additional effective amount of inductance caused by the magnetic field created around one inductor (or one part of a tapped inductor) inducing a current into the other inductor. When both inductors are wound on a common core, as shown in Fig. 2.1.2 the effect of mutual inductance (M) can be considerable and the total inductance is calculated by the formula:

$$L_{TOT} = L_1 + L_2 \pm 2M$$

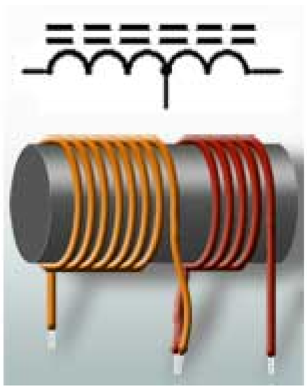


Fig. 2.1.2 Centre Tapped Inductors on a Common Core

The actual value of M depends on how effectively the two inductors are magnetically coupled, which among other factors depends on the spacing between the inductors, the number of turns on each inductor, the dimensions of each coil and the material of the common core.

With separate fixed inductors, as shown in Fig. 2.1.3a considerations of mutual inductance are simplified, the dimensions and number of turns for each inductor are fixed, therefore main considerations are the physical distance between the inductors and the direction of their magnetic fields. In practice the small values of inductance of the inductors needed at RF create very little magnetic field outside the component and only when mounted within a couple of millimetres of each other is the mutual inductance effect noticeable, as shown in Fig. 2.1.3b.

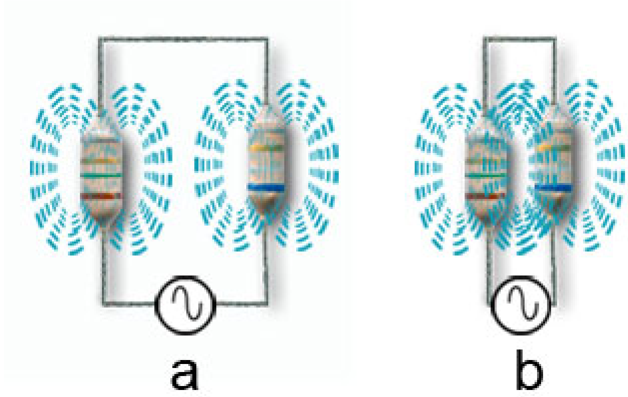


Fig. 2.1.3 Inductors with Adding Fields

Whether M, measured in Henrys or more likely micro Henrys (µH) in RF oscillators adds to or subtracts from the total inductance of very closely mounted tapped inductors depends on the North-South polarity of the fields around the individual coils $L_1$ and $L_2$, if the magnetic fields are both in the same direction, the mutual inductance will add to the total inductance but if the magnetic fields are arranged to oppose each other, as in Fig.2.1.4 the effect of the mutual inductance will be to reduce the total inductance and so increase the actual working frequency of the oscillator.

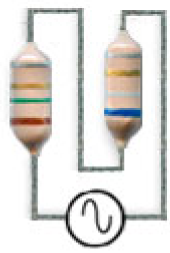


Fig. 2.1.4 Inductors with Opposing Fields

The amount of mutual inductance in a circuit using two small fixed inductors such as the circuit featured in Oscillators module 2.2 is minimal and experiments show that the inductors need to virtually touching to produce any noticeable effect. Whether the mutal inductance between small inductors of just a few micro Henrys add or subtract from the calculated oscillator frequency of a RF Hartley oscillator, this will generally only change the operating frequency by an amount similar to that which may be caused by the normal component value variation due to the values tolerances of the oscillator components.

In practical Hartley oscillators that use inductors sharing a common core however, the mutual induction effect can be much greater, and depends on the coefficient of coupling (k), which has a value between 1 when the mutual inductance is just about equal to 100% magnetic coupling, and 0 when there is no coupling between the two inductors.

Calculating a theoretical value for k involves some quite complex math, due to the number of factors affecting the mutual coupling and the process is often reduced to deciding either there is little mutual coupling, such that less than half of the magnetic flux produce by one coil affects the other coil. Then k is assumed to have a value less than 0.5, and the inductors are said to be ‘loosely coupled’ or if the inductors share a common core with zero spacing between them, they are said to be ‘tightly coupled’ and k is assumed to have a value between 0.5 and 1. In practice the core shared by such a tapped inductor working at RF frequencies will often be found to be a variable type as shown in Fig. 2.1.4 so that any frequency shift due to mutual inductance can be adjusted for by changing the position of the core and so correcting the oscillator frequency.

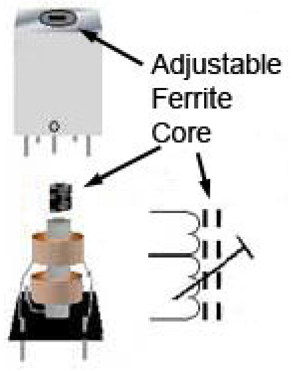


Fig. 2.1.5 Adjustable Ferrite Core

## The Hartley Circuit

Fig. 2.1.1 shows a typical Hartley oscillator. The frequency determining resonant tuned circuit is formed by L1/L2 and C3 and is used as the load impedance of the amplifier. This gives the amplifier a high gain only at the resonant frequency (Method 2 in Introduction to Oscillators). This particular version of the Hartley circuit uses a common base amplifier, the base of TR1 being connected directly to 0V (as far as AC the signal is concerned) by C1. In this mode the output voltage waveform at the collector, and the input signal at the emitter are in phase. This ensures that the fraction of the output signal fed back from the tuned circuit collector load to the emitter via the capacitor C2 provides the necessary positive feedback.

C2 also forms a long time constant with the emitter resistor R3 to provide an average DC voltage level proportional to the amplitude of the feedback signal at the emitter of Tr1. This is used to automatically control the gain of the amplifier to give the necessary closed loop gain of 1.

The emitter resistor R3 is not decoupled because the emitter terminal is used as the amplifier input. The base being connected to ground via C1, which will have a very low reactance at the oscillator frequency.

## The Tuned LC (Tank) Circuit

The LC circuit that controls the frequency of oscillation is often called the "TANK CIRCUIT" because it contains circulating currents much greater than the current supplying it (e.g. pulses of collector current supplied by the amplifier). Its operation is supposed to be rather like a water tank or cistern that can supply a continuous flow of water from an intermittently flowing external supply. The tank circuit in the oscillator contains high values of circulating current topped up regularly by smaller amounts of current from the amplifier.

Because most of the current flowing in the oscillator is flowing just around the resonant tank circuit rather than though the amplifier section of the oscillator, LC oscillators generally produce a sine wave with very little amplifier sourced distortion.

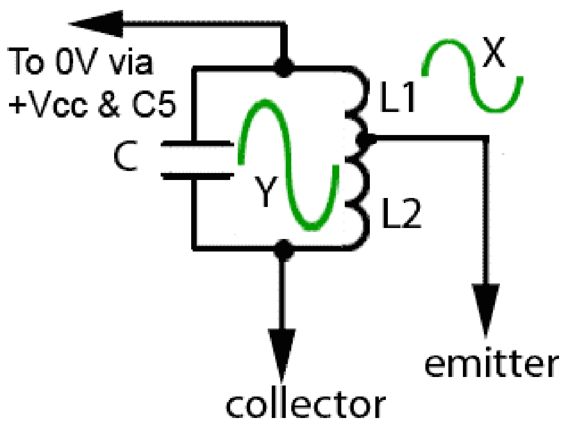


Fig. 2.1.6 The Tank Circuit

Another feature of the tank circuit is to provide the correct amount of positive feedback to keep the oscillator running. This is done by dividing the inductive branch of the circuit into two sections, each having a different value, the inductor therefore works in a similar manner to an autotransformer, the ratio of the two windings providing the appropriate amount of signal to be fed back to the input of the amplifier.

Because in Fig. 2.1.6 (and Fig. 2.1.1) the top of L1 is connected to +Vcc, it is, as far as AC signals are concerned, connected to ground via the very low impedance of C5. Therefore waveform X across L1, and waveform Y across the whole circuit are in phase. As a common base amplifier is being used, the collector and emitter signals are also in phase, and the tank circuit is therefore providing positive feedback. In other Hartley designs, using common emitter amplifiers for example, similar tank circuits are used but with different connections, so that the feedback signal is always in phase with the input signal, therefore providing the necessary positive feedback.

## Automatic 'Sliding' Class C bias

It is common in LC sine wave oscillators to use automatic class C bias. In class C the bias voltage, that is the base voltage of the transistor is more negative than the emitter voltage, making $V_{be}$ negative so that the average (centre) voltage of the input wave is located on the negative portion of the $V_{be}$ axis of the characteristic curve shown in Fig. 2.1.7 Therefore only a portion of each sine wave is amplified to produce pulses of collector current.

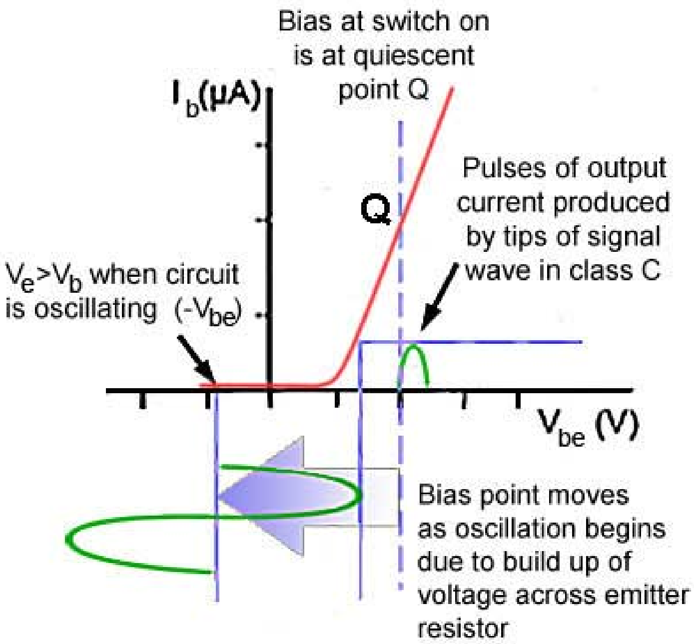



Fig. 2.1.7 Sliding Class C Bias

Because only the tips of the waveform are amplified in class C, the amplifier cannot produce an undistorted output wave. This does not matter however, in an LC oscillator. All the amplifier is required to do is to provide pulses of current to the LC resonant circuit at its resonating frequency. The sine wave output of the circuit is actually produced by the resonating action of the LC circuit. The amplitude of the signal produced will depend on the amount of current flowing in the LC tuned circuit.

As the amplifier provides this current it follows that, by automatically controlling the amount of collector current ($I_c$) flowing each time a pulse is produced, the amplitude of the output sine wave can be controlled at a constant level. The collector current of the transistor depends on the base/emitter voltage. In class C the base/emitter voltage is automatically varied so that the amplitude of the output wave remains stable.

## How the Hartley Oscillator Works

The oscillator in Fig. 2.1.1 uses a common base amplifier. When the oscillator is first powered up, the amplifier is working in class A with positive feedback. The LC tank circuit receives pulses of collector current and begins to resonate at its designed frequency. The current magnification provided by the tank circuit is high, which initially makes the output amplitude very large. However, once the first pulses are present and are fed back to the emitter via C2, a DC voltage, dependent to a large extent on the time constant of C2 and R3, which is much longer than the periodic time of the oscillator wave, builds up across R3.

As the emitter voltage increases, the bias point of the amplifier ‘slides’ from its class A position towards class C conditions, as shown in Fig 2.1.7, reducing the difference ($V_{be}$) between the relatively stable base voltage created by the potential diver Rl/R2 and the increasingly positive emitter voltage. This reduces the portion of the waveform that can be amplified by TR1, until just the tips of the waveform are producing pulses of collector current through the tank circuit and the closed loop gain circuit has reduced to 1. Effectively the positive feedback from the tank circuit and the negative and feedback created by C2 and R3 are in balance.

Any deviation from this balance creates a correcting effect. If the amplitude of the output wave reduces, the feedback via C2 also reduces causing the emitter voltage to decrease, making negative value of $V_{be}$ smaller, and so creating a correcting increase in collector current and a greater output wave produced across the tank circuit. As collector current increases, then so will TR1 emitter voltage. This will cause a larger voltage across R3 making the emitter more positive, effectively increasing the amount of negative base/emitter voltage of Tr1. This reduces collector current again, leading to a smaller output waveform being produced by the tank circuit and balancing the closed loop gain of the circuit at 1.

## Alternative Hartley Designs.

The circuit shown in Fig. 2.1.8 uses a common emitter amplifier and positive feedback from the top of the tuned circuit, via C2 (DC blocking and AC coupling capacitor) to the base.

The top and bottom ends of the tapped inductor L1/L2 are in anti-phase as in this design, the tapping point of the tank circuit is connected to the supply line, which in a common emitter amplifier it is exactly the same point as the transistor emitter due to the decoupling capacitors across the supply (not shown as they will be in the power supply), and C3 across the emitter resistor.

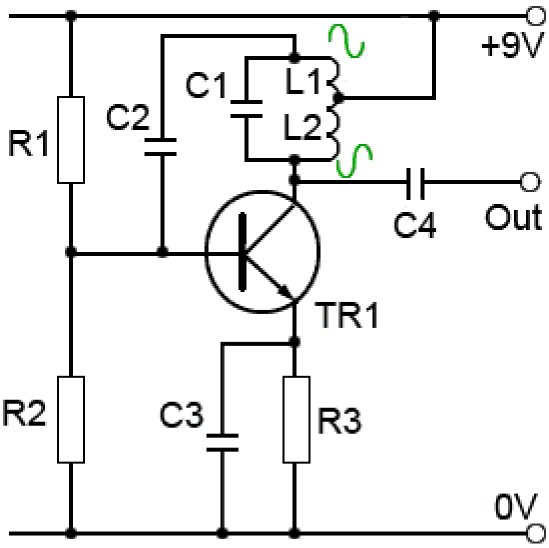


Fig. 2.1.8 Common Emitter Hartley Oscillator

The base in a common emitter amplifier is also in anti-phase with the collector waveform, resulting in positive feedback via C2. Automatic class C bias is again used but in this circuit the value of the emitter decoupling capacitor C3 will be critical, and smaller than in a normal class A amplifier. It will only partially decouple R3, the time constant of R3/C3 controlling the amount of class C bias applied.

In Fig. 2.1.9 the tapping on the inductor is conne
blocking capacitors are used to eliminate any DC
provided by a RF choke which simply provides a

Automatic class C bias is provided for the comm
2.1.8. In this variation however, rather than usin
frequency, the amplifier here will operate over a

However placing the tuned tank circuit in the fee
occurs at the resonant frequency of the tuned cir

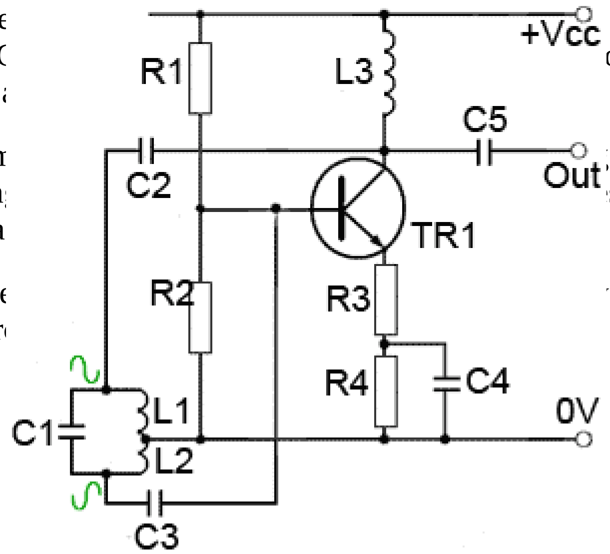


Fig. 2.1.9 Hartley Oscillator with Tuned Feedback

## 2.2 Hartley Oscillator Practical Project

### What you'll learn in Module 2.2

**After studying this section, you should be able to:**

- Build a Hartley Oscillator from given instructions.
- Test a Hartley Oscillator for correct operation.
- Take measurements on a Hartley Oscillator.

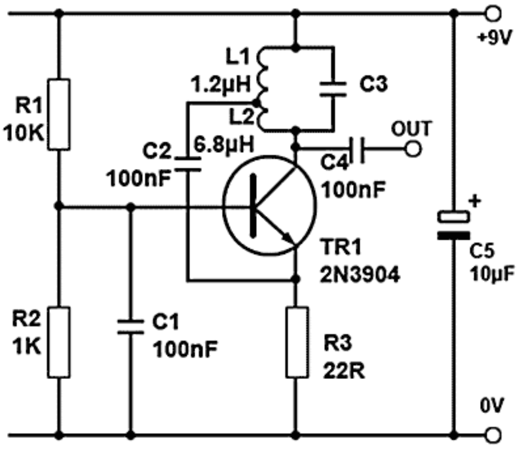


Fig. 2.2.1 Hartley Oscillator

### Building The Hartley Oscillator

Build The Hartley Oscillator shown in Fig 2.2.1 using either breadboard (proto board) as shown in Fig. 2.2.2 or on strip board as shown in Fig. 2.2.3. The frequency of the oscillator can be from around 560kHz to 1.7MHz depending on the value chosen for C3. Full constructional details to build the Hartley oscillator are given below. Test the oscillator by making the measurements described on the Hartley Oscillator Measurements sheet to verify the operation of the oscillator, using a multi-meter and oscilloscope. A really effective way to learn about Hartley oscillators!

This Hartley oscillator produces a sine wave output in excess of 12Vpp at an approximate frequency set by the value chosen for C3. Any of the C3 optional values shown below should give reliable oscillation.

The circuit will operate from a 9V battery, or a DC power supply of 9 to 12V. Supply current at 9V is around 20 to 30mA.

The circuit can be built on breadboard for testing purposes. It may be found that the value of R3 is fairly critical, producing either a large distorted waveform or intermittent low/no output. To find the best value for R3, it could be temporarily replaced by a 470 ohm variable resistor for experimentation to find the value that gives the best wave shape and reliable amplitude.

### Components List

TR1 = 2N3904

C1, C2 & C4 = 47nF

C3 = See C3 Options table.

R1 = 10KΩ

R2 = 1KΩ

R3 = 22Ω (or 470Ω variable)

L1 = 1.2µH

L2 = 6.8µH

**C3 Options**

| Value | Frequency |
|---|---|
| 1nF | 1.7MHz |
| 2.2nF | 1.2MHz |
| 4.7nF | 877kHz |
| 10nF | 563kHz |

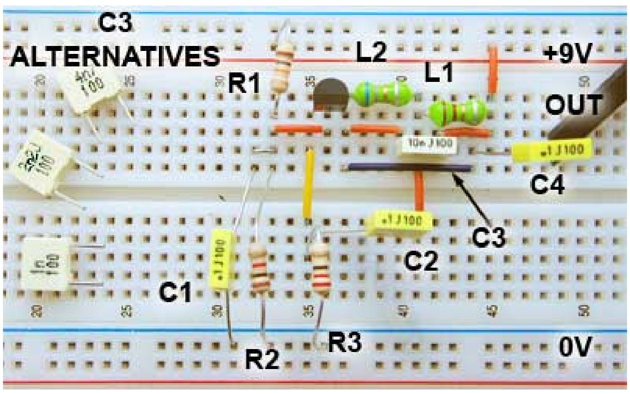


Fig. 2.2.2 Hartley Oscillator - Breadboard Version

## Stripboard Version

### Additional Components For Strip-board Version

Strip board 9x25 holes

3 way connection block (Optional)

9V battery connector (Optional)

Tinned copper wire (for links)

Insulated flexible wire (for external connections)

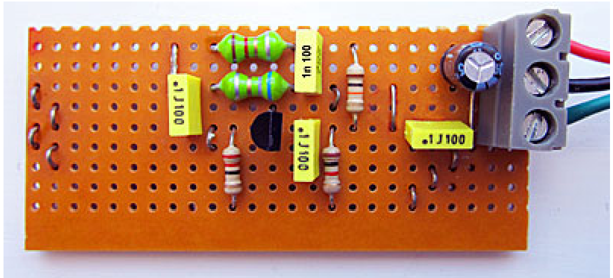


Fig. 2.2.3 Hartley Oscillator - Stripboard Version

## Construction on Stripboard

1. On a piece of 9 x 25 hole strip-board, mark hole A1 to ensure that counting the strips and holes for placing track cuts and components always starts from the same point
2. Mark the holes where track cuts are to be made. Double check their correct position before cutting.
3. Make the track cuts.
4. Solder the wire links in place.
5. Solder the components in place in the following order.
6. Resistors.
7. Inductors.
8. Polyester capacitors.
9. Transistor (check for correct e b c positions before soldering).
10. Electrolytic (check for correct polarity before soldering).
11. Terminal Block.(This may be replaced by a 9V battery connector & and an output lead if preferred).
12. Carefully check for any short circuits caused by solder bridging adjacent tracks, and for any poorly soldered joints.
13. Connect up the power supply and connect an oscilloscope to the output.
14. Adjust the 470Ω variable resistor (if used in place of R3) for best wave shape with reliable operation.
15. Once the best position is found, remove the variable resistor and measure its value. It can then be replaced with a fixed resistor having a preferred value closest to the measured value.

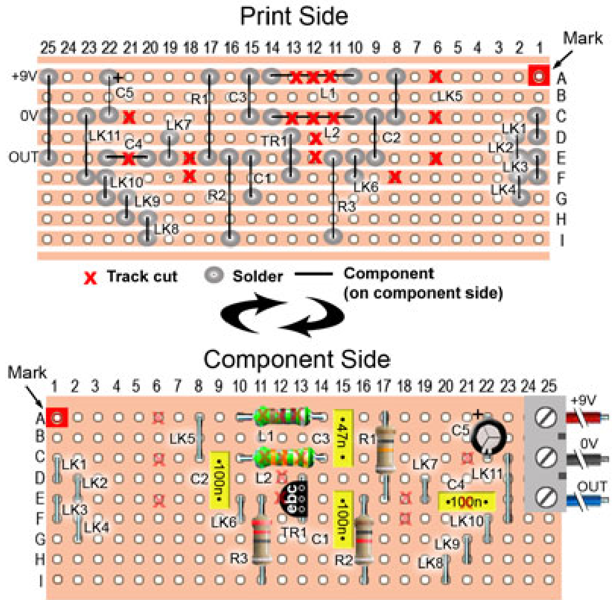



Fig. 2.2.4 Hartley Oscillator - Stripboard Layout

## Hartley Oscillator Measurements

Having built the Hartley oscillator, either on breadboard or strip-board, check that the circuit is oscillating satisfactorily by connecting the circuit to the 9V supply and. connecting an oscilloscope to the output terminals

## Voltage and Current Measurements

Ensure the oscillator is producing a sine wave output, and then measure and record the values listed in Tables 1 and 2.

| Table 1 | |
|---|---|
| Take the following measurements with the circuit oscillating in class C: | |
| The supply current | |
| The supply voltage | |
| TR1 collector voltage | |
| TR1 base voltage | |
| TR1 emitter voltage | |

| Table 2 | |
|---|---|
| Temporarily stop the oscillations by connecting a 0.47μF (non-polarised) capacitor across R3 and take the following measurements: | |
| The supply current | |
| TR1 collector voltage | |
| TR1 base voltage | |
| TR1 emitter voltage | |

| Table 3 | |
|---|---|
| The Peak to Peak Voltage | |
| DC Level of the Wave | |
| Periodic Time (T) of the Wave | |
| Frequency of the wave (1/T) | |
| Frequency of the wave calculated by $f = 1/ 2\pi\sqrt{(LC)}$ | |

## Waveform Measurements

Reconnect the oscilloscope to TR1 collector (not the circuit output terminal) and draw at least two cycles of the collector waveform on the grid.

Enter the volts/division and time/division settings of the CRO in the spaces provided.

From the waveform, calculate and record the values in Table 3.

_____V/Div ________µs/Div

## 2.3 The Colpitts Oscillator

### What you'll learn in Module 2.3

**After studying this section, you should be able to:**

- Understand the operation of a Common Base Colpitts Oscillator.
- Understand the operation of a Common Emitter Colpitts Oscillator.
- Understand the need for Output Buffering.

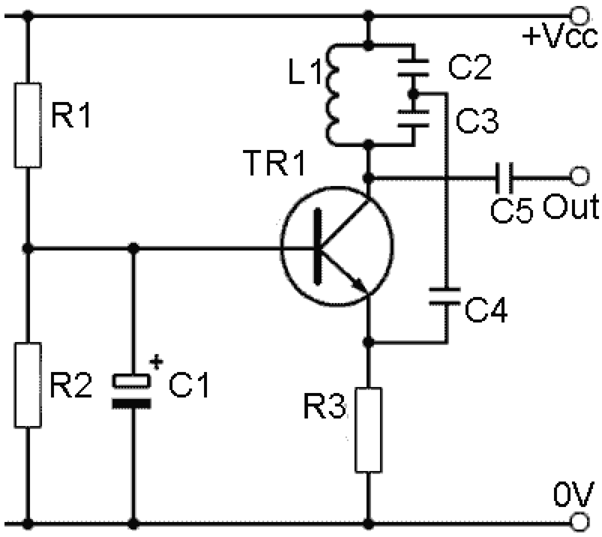



Fig. 2.3.1 The Common Base Colpitts Oscillator

### Common Base Colpitts Oscillator

Fig. 2.3.1 shows a typical Colpitts oscillator design. This circuit is very similar in operation to the Hartley oscillator described in Oscillators Module 2.1 but the Colpitts LC tank circuit consists of a single inductor and two capacitors. The capacitors form in effect, a single 'tapped' capacitor instead of the tapped inductor used in the Hartley. The values of the two capacitors (connected in series) are chosen so their total capacitance in series ($C_{TOT}$), is given by:

$$C_{TOT} = \frac{C_2 \times C_3}{C_2 + C_3}$$

This gives the total capacitance necessary for the tank circuit to achieve parallel resonance at the required frequency. The frequency of oscillation is given by the same formula as for the Hartley oscillator:

$$f_r = \frac{1}{(2\pi\sqrt{LC})}$$

But here the value C is the calculated value of C2 and C3 in series ($C_{TOT}$).

The individual values of C2 and C3 are chosen so that the ratio of the values produces the necessary proportion of feedback signal. However, the ratio of voltages across two capacitors in series is in inverse proportion to the ratio of the values, i.e. the smaller capacitor has the larger signal voltage across it. The main advantage of the Colpitts arrangement is that the single inductor in the tuned circuit removes the effect of any mutual inductance between two coils where the alternating magnetic field built up around one inductor induces a current into the their inductor. This would affect the total inductance of the coils and so changes the resonant frequency of the tuned circuit.

### Common Emitter Colpitts Oscillator

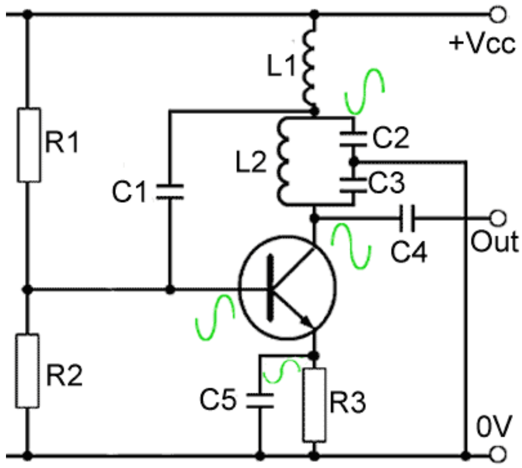


Fig. 2.3.2 A Colpitts Oscillator using a Common Emitter Amplifier

The circuit in Fig. 2.3.2 is the Colpitts equivalent of the Common Emitter Hartley Oscillator described in Oscillators Module 2.1 (Fig.2.1.8). It uses a common emitter amplifier, and as the tuned (tank) circuit tapping point in this configuration is connected to ground, the tank circuit produces anti-phase waves at top and bottom of L2, which ensures the correct phase relationships for positive feed back between collector and base. The feedback is applied to the base via C1, which also acts as a DC block, preventing the higher voltage on L1 upsetting the base bias voltage.

Note that the tank circuit (L2, C2 and C3) is connected to the supply rail (+Vcc) via L1. If the tank circuit were connected directly to the supply there could be no anti-phase AC signal present at the top of the tank circuit, due to the DC supply being heavily decoupled by large capacitors in the DC power supply. An RF choke (L1) having a high impedance at the frequency of oscillation is therefore included between the tuned circuit and the supply. This allows for a signal voltage for feedback purposes to be developed across L1.

Automatic class C bias is used, with the emitter in this circuit only partially decoupled by a small value of C5 to give the 'sliding bias' previously described.

The Colpitts oscillator, like the Hartley is capable of giving an excellent sine wave shape, and also has the advantage of better stability at very high frequencies. It can be recognised by always having a "tapped capacitor"

**Remember:**

HartLey = tapped L

Colpitts = tapped C

Sine wave oscillator design is complicated by the fact that any load placed on the output, by circuits that the output is supplying, effectively places a damping resistance across the tank circuit. As well as reducing the amplitude of the oscillator output by having the effect of reducing the Q factor of the tuned tank circuit, this can adversely affect both the wave shape and the frequency stability of the oscillator waveform.

## Buffered Colpitts Oscillator

A common solution is to feed the oscillator output into an emitter follower buffer amplifier, as shown in Fig. 2.3.2. The oscillator section of this circuit is a slightly different version of the Colpitts oscillator in shown in Fig. 2.3.1.

The RF choke is now the load impedance for TR1 and the tank circuit is isolated from TR1 by two DC blocking capacitors, C1 and C4. Therefore this version of the Colpitts oscillator uses a tuned feedback path (Method 1 in Oscillators Module 1.1) rather than a tuned amplifier (Method 2) as in Fig. 2.3.1

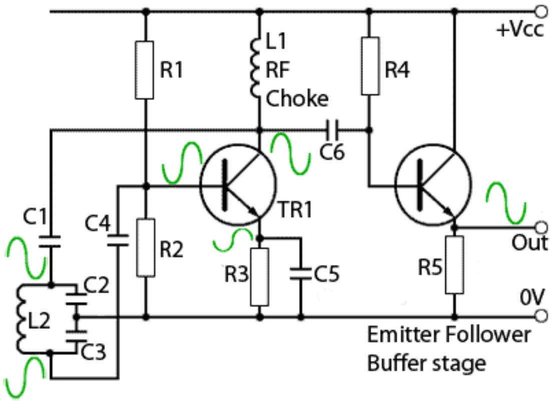


Fig. 2.3.2 Colpitts Oscillator with Buffer Stage

The emitter follower stage (R4, TR2 and R5) has a very high input impedance, thus having little loading effect on the oscillator, and a very low output impedance allowing it to drive loads of only a few tens of ohms impedance.

The frequency stability of oscillators can also be affected by variations in supply voltage. It is common therefore, where good frequency stability is required, to use a stabilised power supply. Oscillator supplies may also need extra decoupling capacitors to remove unwanted 'noise' from the supply. Stable amplitude is normally achieved by using automatic class C bias, provided in this circuit by only partially decoupling the emitter of TR1 by C5.

## 2.4 Colpitts Oscillator Practical Project

**What you'll learn in Module 2.4**
**After studying this section, you should be able to:**
- Build a Colpitts Oscillator from given instructions.
- Test the Colpitts Oscillator for correct operation.
- Take measurements on a Colpitts Oscillator.

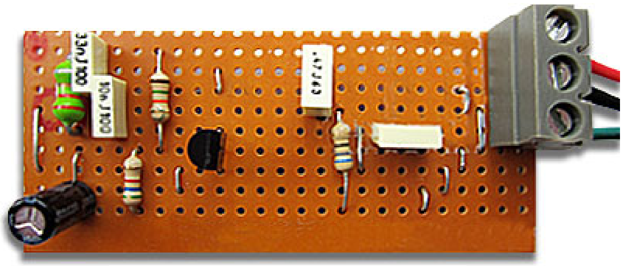


Fig. 2.4.1 Colpitts Oscillator

### Build a Colpitts Oscillator

Build the Colpitts oscillator shown using either breadboard (proto board) or strip board, and then test the oscillator's operation using a multi meter and oscilloscope.

Building and testing your own circuit is a really effective way to learn about oscillators!

### The Oscillator Circuit

This Colpitts oscillator produces a sine wave output in excess of 12Vpp at an approximate frequency set by the values chosen for L1, C2 and C3. It will operate from a 9V battery, or a DC power supply up to 12V. Supply current at 9V is around 20mA. The circuit can be built on breadboard for testing purposes, where it will be found that the value of R3 is fairly critical. This 68 ohm resistor could be replaced by a slightly higher or lower value to alter the amplifier gain for experimentation. The values given for the circuit should work reliably when built on strip-board.

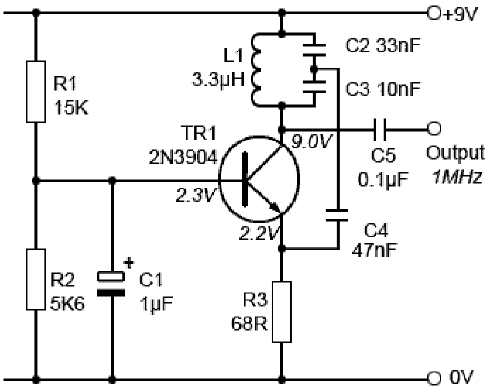


Fig. 2.4.2 Colpitts Circuit

### Components List

TR1 = 2N3904
C1 = 1μF
C2 = 33nF
C3 = 10nF
C4 = 47nF
C5 = 100nF
R1 = 15KΩ
R2 = 5.6KΩ
R3 = 22Ω (or 470Ω variable)
L1 = 3.3μH

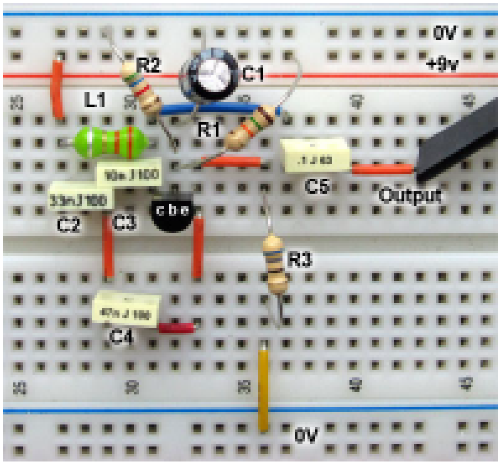


Fig. 2.4.3 Colpitts Oscillator - Breadboard Version

### Construction on Breadboard (Protoboard)

Construct the circuit on breadboard and experiment with different component values. The values shown on the circuit schematic above should give reliable oscillation. Note how some values produce different amplitudes or better wave shapes. It should be possible to obtain a good sine wave with a peak to peak output amplitude even greater than the supply voltage. This is a particular feature of LC oscillators as the AC output voltage depends on the amount of current circulating around the tuned circuit at resonance. But remember that a larger output voltage will also mean a higher collector current.

## Colpitts Oscillator Construction on Stripboard

**Additional Components For Stripboard Version**
Strip board 9x25 holes
3 way connection block (Optional)
9V battery connector (Optional)
Tinned copper wire (for links)
Insulated flexible wire(for external connections)

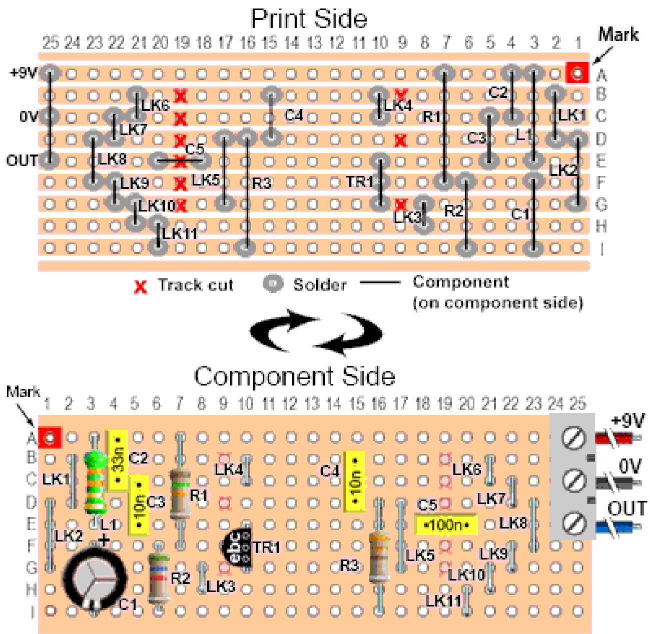


Fig. 2.4.2 Colpitts Oscillator - Stripboard Version

## Construction - Stripboard Version

1. On a piece of 9 x 25 hole strip-board, mark hole A1 to ensure that counting the strips and holes for placing track cuts and components always starts from the same point.
2. Mark the holes where track cuts are to be made. Double check their correct position before cutting.
3. Make the track cuts.
4. Solder the wire links in place.
5. Solder the components in place in the following order.
6. Resistors.
7. Inductor.
8. Polyester capacitors.
9. Transistor (check for correct e b c positions before soldering).
10. Electrolytic (check for correct polarity before soldering).
11. Terminal Block.

Double check for correct positions and values of components

Carefully check for any short circuits made by solder bridging adjacent tracks, and for any poorly soldered joints.

Connect up the power supply and connect an oscilloscope to the output.

## Colpitts Oscillator Measurements

Having built the Colpitts oscillator, either on breadboard or strip-board, check that the circuit is oscillating satisfactorily by connecting the circuit to the 9V supply and. connecting an oscilloscope to the output terminals.

## Voltage and Current Measurements

Ensure the oscillator is producing a sine wave output, and then measure and record the values listed in Tables 1 and 2.

| **Table 1** | |
|---|---|
| Take the following measurements with the circuit oscillating in class C: | |
| The supply current | |
| The supply voltage | |
| TR1 collector voltage | |
| TR1 base voltage | |
| TR1 emitter voltage | |

| **Table 2** | |
|---|---|
| Temporarily stop the oscillations by connecting a 0.47µF (non-polarised) capacitor across L1 and take the following measurements: | |
| The supply current | |
| TR1 collector voltage | |
| TR1 base voltage | |
| TR1 emitter voltage | |

| **Table 3** | |
|---|---|
| The Peak to Peak Voltage | |
| DC Level of the Wave | |
| Periodic Time (T) of the Wave | |
| Frequency of the wave (1/T) | |
| Frequency of the wave calculated by $f = 1/2\pi\sqrt{(LC)}$ | |

## Waveform Measurements

Reconnect the oscilloscope to TR1 collector (not the circuit output terminal) and draw at least two cycles of the collector waveform on the grid.

Enter the volts/division and time/division settings of the CRO in the spaces provided.

From the waveform, calculate and record the values in Table 3.

______V/Div ________µs/Div

## 2.5 Crystal Sine Wave Oscillators

### What you'll learn in Module 2.5

**After studying this section, you should be able to:**

- Understand the need for Frequency control in LC Oscillators.
- Understand the application of Quartz Crystals in LC Oscillators.
- Understand the operation of Quartz Crystals.
- Understand the application of Quartz Crystals in both serial and parallel modes.
- Recognise Integrated Crystal Oscillator Modules.

### Crystal Sine Wave Oscillators

Where good frequency stability is required, in applications such radio transmitters, basic LC oscillators cannot guarantee to hold their frequency without some drifting, which can be caused by quite small changes in supply voltage (although stabilised power supplies help avoid this) and changes in temperature.

The effects of resistance and stray capacitance within the circuit can also cause the oscillator to operate at a slightly different frequency from that calculated using just the values of L and C. In most cases this can be overcome by making the tuned 'tank' circuit have as high a Q factor as possible. With ordinary inductors and capacitors, Q factors more than a few hundred are not possible, but by using quartz crystals Q factors well in excess of 10,000 can be achieved.

Crystals may be used increase frequency stability in RF oscillators such as Hartley and Colpitts. The crystal may be used either in 'parallel mode' e.g. as an inductor operating at a frequency between $f_1$ and $f_2$ as part of the resonating tuned circuit, as shown in the crystal controlled Colpitts oscillator in Fig 2.5.1, or in 'series mode' where the crystal is acting as a highly selective low impedance at $f_1$ in the feedback path as shown in a Hartley oscillator in Fig. 2.5.2.

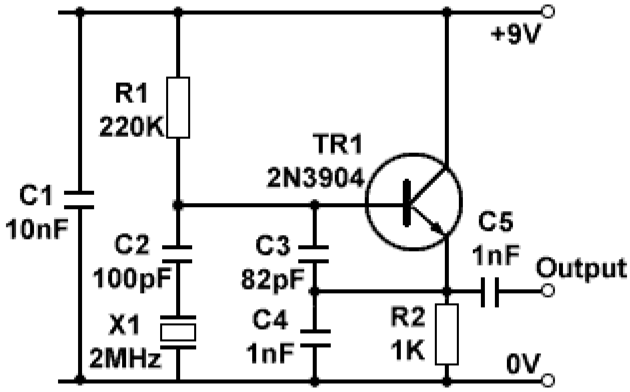



Fig. 2.5.1 Colpitts Oscillator using a Crystal in Parallel Mode

### The Quartz Crystal

The quartz crystal is a piezo-electric device, and will both produce a voltage across it when it is subjected to some mechanical distortion such as slight bending, or will distort slightly when a voltage is applied across it. Therefore applying regular voltage pulses will cause the crystal to bend, and the bending will in turn create voltage pulses in phase with the applied pulses, that will reinforce them and cause oscillation.

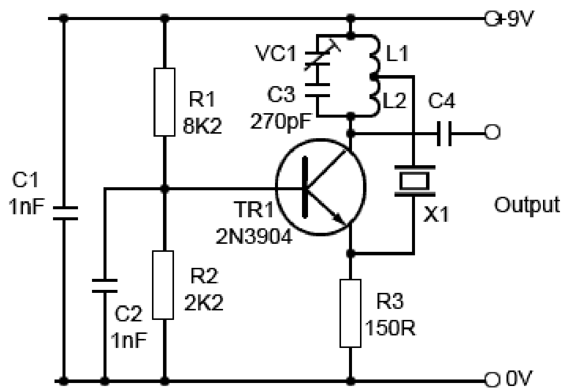



Fig. 2.5.2 Hartley Oscillator using a Crystal in Series Mode

The frequency at which this reinforcing effect occurs is the resonant frequency of the crystal, and this is determined by the physical size of the crystal and by the way the crystal is cut in relation to its atomic structure. When a quartz crystal is accurately cut and prepared, it is almost perfectly elastic. This means that once oscillations start, they take a long time to die away.

Fig 2.5.3 shows the circuit (schematic) symbol for a quartz crystal and its equivalent circuit. Notice that in effect it contains all of the properties (L, C and R) normally associated with a tuned circuit. It can therefore be used to replace either a series tuned circuit or a parallel tuned circuit, and the graph of its impedance (Z) shows two resonant frequencies $f_1$ and $f_2$. When used in series mode the crystal exhibits very low impedance at $f_1$, and in parallel mode, a very high impedance at $f_2$. In practice, because of the extremely narrow bandwidth caused by the crystal's very high Q factor, these frequencies are close enough together to be considered the same for many purposes.

Crystal oscillators can produce either sine wave or square wave outputs over a very wide range of frequencies, usually from one or two MHz up to several hundred MHz. Crystals are produced to resonate at many different specific frequencies for particular applications, but the range of available frequencies is made much greater by various techniques such as frequency division, where the frequency of a crystal oscillator is sequentially divided by 2 many times by digital dividers, to a much lower frequency. Because any slight errors are also reduced by the same division process, the final low frequency is much more accurate.

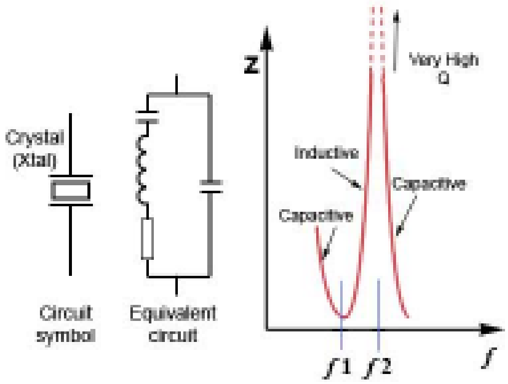



Fig. 2.5.3 The Quartz Crystal

Crystals can also be made to resonate at higher multiples of their basic resonant frequency. One of these higher multiples, called overtones) can then be selected using a conventional LC circuit. By using these frequency division and overtone techniques a much wider range of crystal frequencies can be achieved.

## Integrated Crystal Oscillator Modules

In modern circuitry it is far less common to find crystal oscillators constructed from discrete components, as many ready-made crystal oscillators are available. Both square wave and sine wave oscillators are available as DIL (dual in line) or SMT (surface mount) modules with a wide variety of specifications and frequencies.

In sine wave oscillators for use in radio transmission, the oscillator is the source of the transmitted radio wave, so frequency accuracy and stability are of vital importance as radio bands are usually crowded with many transmitters operating in a given radio band. Transmitters therefore must not allow their transmission frequency to wander and interfere with adjacent transmissions. Receivers must be able to tune to known reliable frequencies.

Fig. 2.5.4 14pin DIL Crystal Oscillator Module

Many crystal oscillators are capable of maintaining their set frequency to within a few parts per million e.g +/- 5 to 50Hz for each MHz of their intended frequency, over temperature ranges typically from 0 to 70 degrees for consumer applications and -85 to +85 degrees for some military and aerospace specifications.

Very low harmonic distortion is also an important factor. That is, the oscillator must not output frequencies at harmonics of the design frequency, as these would create extra transmissions at these frequencies. To avoid harmonic distortion, the sine wave must be as pure as possible and oscillators are available with a total harmonic distortion (the percentage of power in generated harmonics compared to the power generated in the fundamental sine wave) of just a few percent.

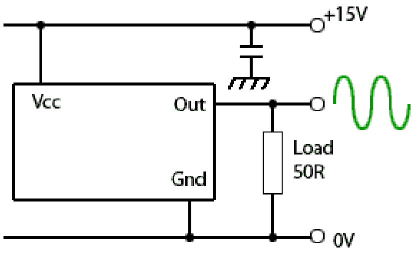


Fig. 2.5.5 Typical Oscillator Module Connections

Many oscillator modules have only 3 pins for +Vcc Ground and output, though some have extra pins for control options and typically drive loads such as 50 ohms with an output of 500mV to 1V as shown in Fig. 2.5.5.

Because many of the characteristics of an oscillator vary with temperature, special oven controlled crystal oscillators (OCXOS) are made for the most critical applications. These oscillators are contained within a heated, thermostatically controlled case, so that in operation their temperature is kept at a constant level. This allows frequency variations to be kept typically below 1 part per million and harmonic distortion to less than 1%.

## 2.6 RF Oscillators Quiz

Try our quiz, based on the information you can find in Oscillators Module 2.

You can check your answers by using the online version at:

http://www.learnabout-electronics.org/Oscillators/osc26.php

**1. Refer to Fig. 2.6.1. Which of the following component combinations are responsible for providing Sliding Class C bias?**

a) R1, R2

b) C1, R2

c) C2, L2

d) C2, R3

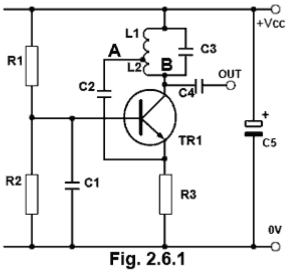


Fig. 2.6.1

**2. Refer to Fig. 2.6.1. A typical frequency of oscillation for this circuit would be most likely to be in which of the following ranges?**

a) AF 20Hz to 20kHz

b) RF 30kHz to 30MHz

c) VHF 30MHz to 300MHz

d) UHF 300MHz to 3GHz

**3. Which formula in Fig 2.6.2 should be used for finding the frequency of oscillation of a LC oscillator?**

a)

b)

c)

d)

a. $$f_o = \frac{1}{1.4\,LC}$$

b. $$f_o = \frac{1}{2\pi(\sqrt{6})LC}$$

c. $$f_{osc} = \frac{1}{2\pi LC}$$

d. $$f_o = \frac{1}{2\pi\sqrt{LC}}$$

Fig. 2.6.2

**4. Refer to Fig. 2.6.1. What will be phase relationship between the waveforms at points A and B?**

a) They will be in phase.

b) They will be in antiphase.

c) A will lead B by 90°.

d) B will lead A by 90°.

**5. Refer to Fig. 2.6.3. Which of the following governs the proportion of signal used as positive feedback?**

a) The reactance of C1.

b) The impedance of C4 at the frequency of oscillation.

c) The time constant of R3,C4

d) The value ratio of C2 to C3

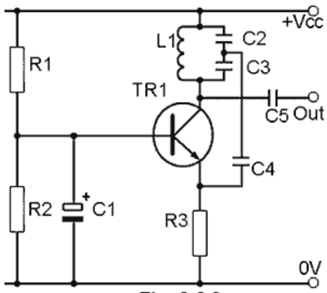


Fig. 2.6.3

**6.The output of a LC oscillator is often fed into a common collector amplifier stage. The reason for this is:**

a) To provide extra voltage gain.

b) To provide negative feedback.

c) To reduce loading on the tank circuit.

d) To convert the sine wave output to a square wave.

**7. Refer to Fig. 2.6.3. Which of the following actions would increase the frequency of the oscillator?**

a) Increase the value of C2

b) Decrease the value of C4

c) Increase the value of R2

d) Decrease the value of L1

**8. Refer to Fig. 2.6.4. What is the purpose of L1?**

a) To provide an antiphase signal for positive feedback.

b) To provide an in phase signal for positive feedback.

c) To correct the 90° phase shift produced by the tank circuit.

d) To provide a load impedance for the output signal.

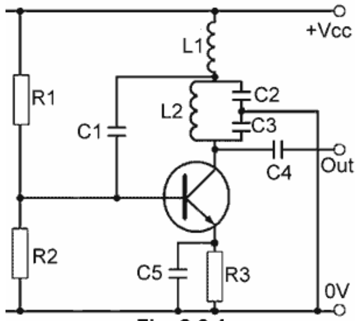


Fig. 2.6.4

**9. A typical specification for a quartz crystal oscillator would indicate a Q factor of:**

a) Less than 500

b) About 1,000

c) About 5,000

d) More than 10,000

**10. Refer to Fig. 2.6.5. In which of the following modes is the quartz crystal X1 operating?**

a) A high impedance parallel resonant circuit.

b) A low impedance parallel resonant circuit.

c) A high impedance series resonant circuit.

d) A low impedance series resonant circuit.

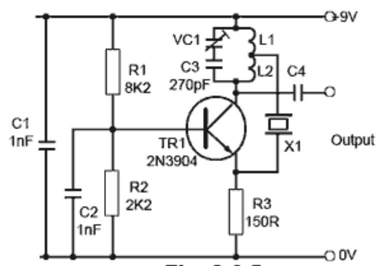


Fig. 2.6.5