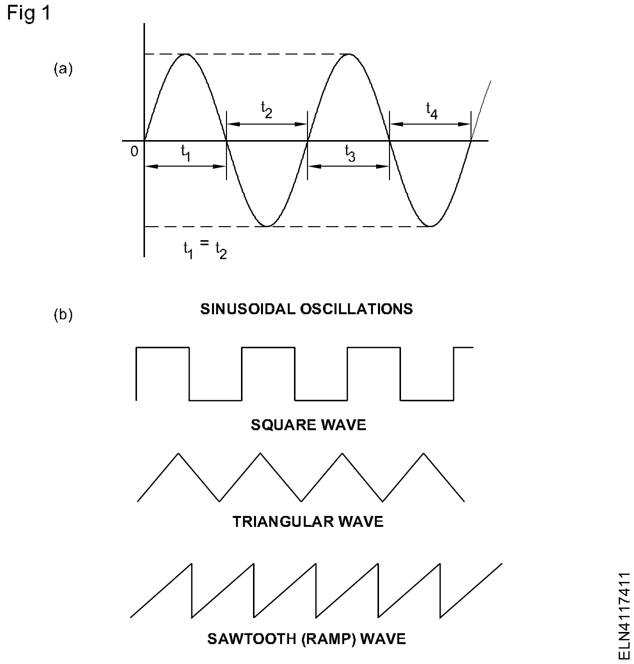
Wave shapes - oscillators and multivibrators

Objectives: At the end of this lesson you shall be able to
- **state the working principle and gain of oscillator**
- **explain the RC phase-shift oscillator and frequency calculation**
- **state the features, gain and frequency of Hartley, colpitts and crystal oscillators**
- **state the working principle and frequency calculation of bistable and monostable multivibrator using CRO.**

Oscillator: An oscillator is a circuit for producing voltages that vary in a regular fashion with respect to time. The output wave forms of oscillators are repeated exactly in equal successive intervals of time as in Fig 1a and Fig 1b.

Fig 1



The output wave-form of an oscillator may be sinusoidal as in Fig 1a. Such oscillators are known as sine wave oscillators or harmonic oscillators.

The output of oscillators may be square, triangular or saw-tooth wave forms as in Fig 1b. Such oscillators are known as non-sinusoidal oscillators or relaxation oscillators.

It was discussed earlier that positive feedback results in converting an amplifier into an oscillator. To provide positive feedback the feedback signal should be inphase with the input signal such that it adds up with the input signal.

In practice, an oscillator will have no input AC signal at all, but it still generates AC signal. An oscillator will have only a DC supply. The oscillator circuit, makes use of the noise generated in resistors at the switching on time of dc supply and sustains the oscillations.

To build an oscillator, the following are essential;

– An amplifier

– A circuit which provides positive feedback from output to input.

The gain of an amplifier with feedback is given by,

$$A_{vf} = \frac{A_V}{1 - kA_V}$$

kA_v is known as the loop gain of the amplifier. In the case of the amplifiers when the sign associated with kA_v is negative, the denominator has value more than 1. And, hence the value of Avt will always be less than A_v (negative feedback). But, if the value of kA_v is made larger, such that, it approaches unity, and, if the sign associated with kA_v is negative then the value of the denominator decreases to less than 1, and hence, A_{vf} will be larger than A_v.

In case of oscillators, if the loop gain kA_v is made positive, i.e. by feeding back signal which is in-phase with the input signal, then there will be an output signal even though there is no external input signal. In other words, an amplifier is modified to be an oscillator by positive feedback such that it supplies its own input signal.

Example

An amplifier has a voltage gain of 40 without feedback. Determine the voltage gains when positive feedback of the following amounts is applied.

i) k = 0.01

ii) k = 0.02

iii) k = 0.025

Solution

i) $A_{vf} = \frac{A_V}{1 - kA_V} = \frac{40}{1 - 0.01 \text{ x } 40} = \frac{40}{0.6} = 66.7$

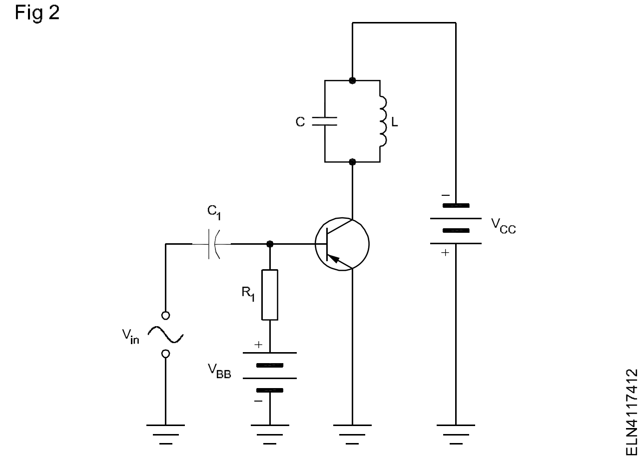
ii) $A_{vf} = \frac{A_V}{1 - kA_V} = \frac{40}{1 - 0.02 \text{ x } 40} = \frac{40}{0.2} = 200$

(iii) $A_{vf} = \dfrac{A_V}{1-kA_V} = \dfrac{40}{1-0.025 \times 40} = \dfrac{40}{0} = \infty$ (Infinity)

In (iii) the gain of the amplifier become infinite when the loop gain kA_v = +1. This is known as the critical value of the loop gain kA_v. It is important to note that the output voltage cannot be infinite. Instead the amplifier will start working as an oscillator without the need of any separate input. If the feedback path contains a frequency selective network, the requirement of kA_v = 1 can be met at only one particular frequency, such that, the output of the oscillator will be a sinusoidal signal of a particular frequency. Such oscillators are known as sine wave oscillators.

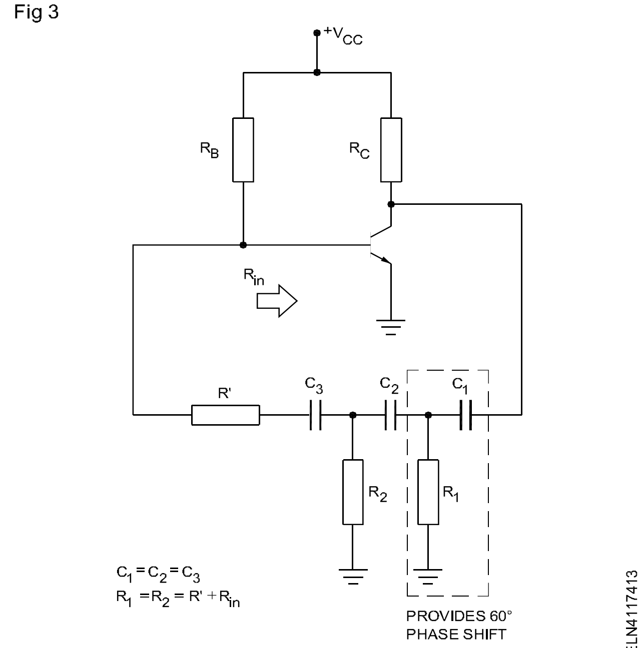
One of the simplest form of sine wave oscillators is the phase shift oscillator. Fig 2 shows the principle behind an RC phase shift oscillator.

Fig 2



The feedback network shown in Fig 3 consists of resistors and capacitors which provide the required phase shift of 180°. Due to the presence of capacitors in the feedback network, the feedback network can be so designed to provides the required phase shift of exactly 180° at a particular frequency f given by,

Fig 3



$$f = \frac{1}{2\pi RC\sqrt{6}}$$

The other condition to be satisfied oscillations to occur is that the loop gain KA_v should be equal to unity. To satisfy this condition, using classical network analysis, it can be found that, the value of K should be, $k = 1/29$. Therefore, the voltage gain of the amplifier A_v stage must be greater than $1/k$ or greater than 29 so that kA_v becomes equal to 1.

Transistor RC phase shift oscillator: Fig 3 shows a single transistor phase shift oscillator using resistors and capacitors in a feedback network.

There are three sections of R and C in the feedback network. Each RC section provides a 60° phase shift at a specific frequency, resulting in a 180° phase shift as required for positive feedback. This satisfies one of the two required conditions for oscillations.

In Fig 3, the feedback signals coupled through a feedback resistor R^1 in series with the amplifier stage input Resistance R_{in}. resistor R^1 can be made variable for adjusting the oscillator frequency. For each of three sections of R_C phase shift network to produce 60° phase shift, it is necessary that $C_1 = C_2 = C_3$ and $R_1 = R_2 = R' + R_{in}$.

The other required condition for oscillation, i.e. loop gain kA_v to be unity is satisfied by the circuit at Fig 2, when β of the transistor used in the circuit is,

$$h_{fe} = \beta = 23 + 29\frac{R}{R_C} = +4\frac{R_C}{R} \quad ......(2)$$

where, $R_1 = R_2 = R$

When β is atleast the value given by equation (2) or greater than, the circuit at Fig 2 it will oscillate.

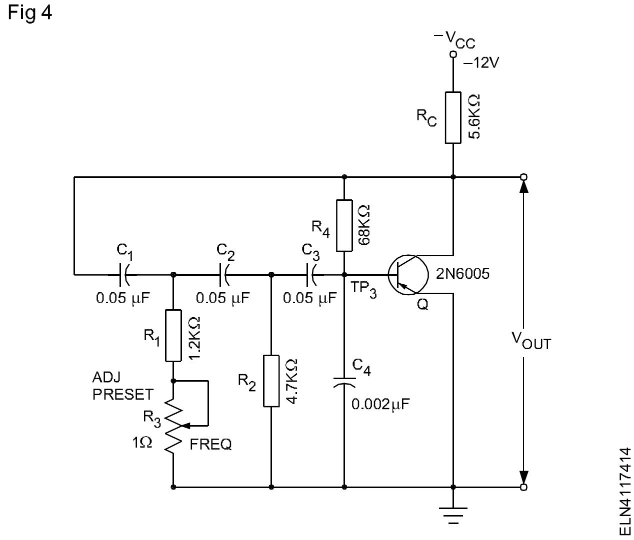
Practical transistor RC phase shift oscillator

Fig 4 shows a practical transistor RC phase shift oscillator which is similar to that shown in Fig 2.

In Fig 4 note that resistor R_3 (in Fig 2 it is denoted as R') used for frequency adjustments is connected in series with one of the resistors of the RC section. Resistor R_4 provides the necessary bias stabilisation for the transistor operation. Note that a small value capacitor C_4 is connected in parallel with the input. The purpose of C_4 is to bypass the unwanted high frequency oscillations to ground. The value of R_3 can be varied to adjust the frequency of oscillations. However, the variation that can be obtained by R_3 is limited.

For the circuit at Fig 3, the frequency of oscillation is given by,

Fig 4



$$f = \frac{1}{2\pi C\sqrt{6R_1^2 + 4R_1R_C}} \qquad ......(3)$$

where, $C = C_1 = C_2 = C_3$

The minimum value of hfe or β of the transistor used in the circuit at Fig 3 should be,

$$h_{fe} = \beta = 23 + 29\frac{R_1}{R_C} + 4\frac{R_C}{R1}$$

using the component values at Fig 3, the β of the transistor used should be a minimum of,

$$\beta = 23 + 29\frac{1.2K}{5.6K} + 4\frac{5.6K}{1.2K} = 47.89$$

The frequency of oscillations can be increased by decreasing the value of R or by decreasing the value of C.

In the practical circuit at Fig 3, collector feedback bias is employed to ensure that the transistor will never go to saturation. Other biasing techniques such as voltage divider bias can also be used for DC biasing of the transistor. Since the frequency of oscillations is decided only by the feedback phase shift network, biasing resistors will not have any effect of the frequency of oscillations. The important point to be noted is that the β of the transistor should be higher than the minimum β given in equation 2 to have sustained oscillations.

Hartley oscillator

Principle of sinusoidal or harmonic oscillations: Fig 5a shows an inductor and a capacitor connected in parallel as a parallel LC resonant circuit. A parallel LC circuit is also known as tuned circuit or tank circuit.

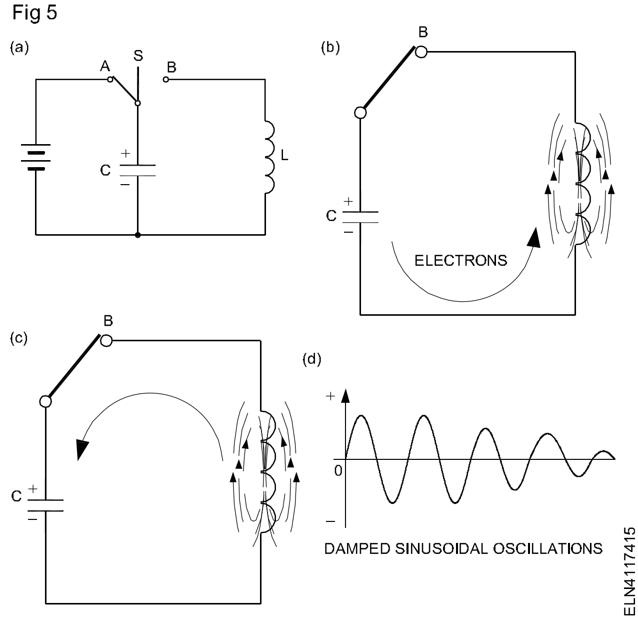
In Fig 5a, when switch S is put into position A, the capacitor gets charged with the bottom plate being negative and the top plate positive. This means, energy is stored in the capacitor in the form of an electric charge.

When switch S is put into position B, as in Fig 5b, the capacitor starts discharging through the inductor, creating an expanding magnetic field around L. Since the inductor has the property of opposing any sudden change in current through it, the current builds up slowly.

Once the capacitor gets fully discharged, the magnetic field around L begins to collapse. The collapsing magnetic field, induces a voltage (back-emf) in L. This back emf tends to maintain the electron flow through L in the same direction as when C was discharging. Hence, this back emf in the inductor starts charging the capacitor with opposite polarity as in Fig 5c. After the magnetic field has totally collapsed, C would have got charged in the opposite direction as in Fig 5c.

Sinusoidal wave form: However, owing to the resistance in a practical inductor and the losses in the capacitor due to resulting I^2R (heat loss) the amplified of the oscillation decreases gradually (damped) and ultimately the oscillations die down as in Fig 5d.

Fig 5



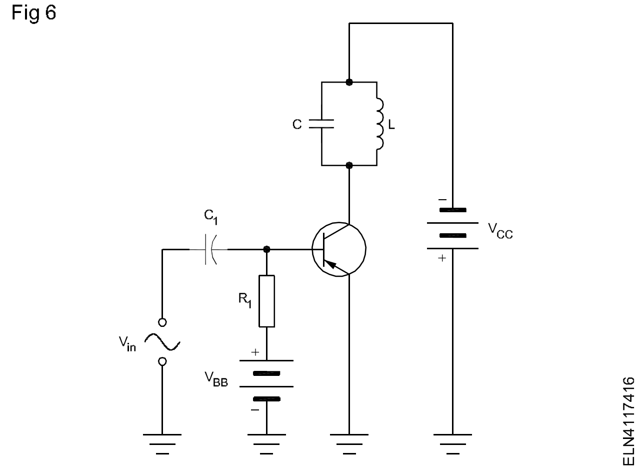
The frequency of oscillation produced by the resonant frequency is given by,

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

Overcoming losses in tank circuit for sustained oscillations: To avoid the damping of oscillations, when the energy fed into the circuit has been used up, it is necessary to supply more energy by charging the capacitor again. As shown in Fig 5a, by switching S between A and B at proper time, the oscillations can be maintained thus obtaining sinusoidal waveform of constant amplitude and frequency.

Another method of making the LC tank circuit to give undamped oscillations is, to connect the tank circuit in the output of an amplifier as in Fig 6.

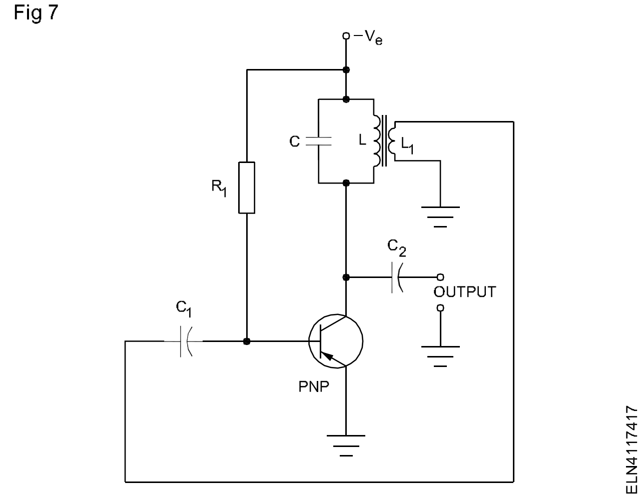
Fig 6



The amplifier is kept at cut-off by the dc supply V_{BB} which reverse-biases the base-emitter circuit. A sine wave is injected to the base circuit with such an amplitude that the collector current flows at the peak of the negative alterations of the input sine wave. This excites the LC circuit in the collector of the transistor and the tank keeps oscillating. If the input sine wave has the same frequency as the frequency of oscillations of the tank circuit, the oscillations in the LC tank is maintained.

Fig 7 shows a modified form of circuit at Fig 6. In Fig 5a transistor amplifier connected in such a way that it will cause undamped oscillations without requiring any external signal. Such a circuit is known as an oscillator.

Fig 7



The oscillator circuit at Fig 7 is known as tickler-coil oscillator. Here L1 is inductively coupled to L. When power is first switched ON to the circuit, current flows in the transistor. As the current flows through L, it induces a voltage in L1 which is coupled to the base of the transistor and is amplified.

If the phase of the feedback voltage is adding, then there is an increase in the collector current. This action builds up a large current pulse which excites the LC tank into oscillations. The signal fed by L1 to the base of the transistor is a sine wave of the same frequency as that in the LC circuit and of proper phase to sustain the oscillations.

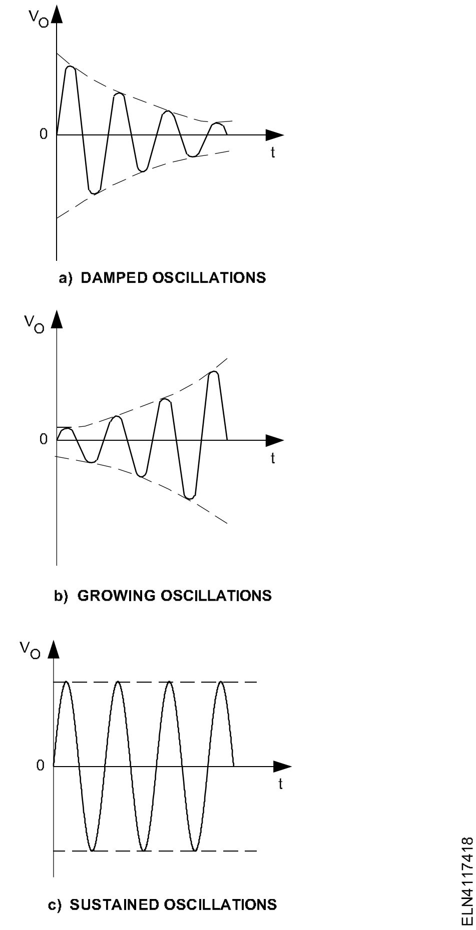
The signal induced in the base thus eliminates the need for an external input to the oscillator and the LC tank will oscillate as long as the DC power to the circuit is ON.

The feedback given to the amplifier in Fig 7 in the proper phase so as to sustain (keep going) oscillations is referred to as positive feedback or regenerative feedback.

Barkhausen criterion: The mathematical analysis for an amplifier to oscillate on its own is given below:

- In the amplifier shown in Fig 7, assume that the gain of the amplifier is A and the feedback factors is β. If the product of $A\beta$ is less than 1 ($A\beta<1$), then the output signal will be a damped oscillations which will die down as is shown in Fig 8a.
- If $A\beta>1$, the output voltage builds up as shown in Fig 8b. Such oscillations are called growing oscillations.
- If $A\beta=1$, the output amplitude of oscillations remains constant as in Fig 8c.

Fig 8



When the feedback is positive (regenerative), the overall gain of the amplifier with feedback (A_f) is given by,

$$A_f = \frac{A}{1 - A\beta}$$

When $A\beta = 1$, the denominator of the equation will be zero, and hence A_f = Infinity. The gain becoming infinity means, there is output without any input. i.e. the amplifier becomes an oscillator. This condition $A\beta = 1$, is known as Barkhausen criterion for oscillations.

Summarizing, the basic requirements for an oscillator are;

- A stable DC power supply source
- An amplifier
- A regenerative (positive) feedback from output to input
- A LC tank circuit to determine the frequency of oscillations

Starting signal for oscillators: As discussed above an oscillator gives alternating output voltage without an input signal once the amplifier is given a regenerative feedback. But in a practical oscillator circuit, to start off oscillations, no starting input signal is provided. However, the starting signal of an oscillator is generated by the noise voltage while switching on the oscillator circuit. Such noise voltages are produced due to the random motion of electrons in resistors used in the circuit.

Noise voltage contains almost all the sinusoidal frequencies of small amplitude. However, it gets amplified and appears at the output terminals. The amplified noise now drives the feedback network, which is a resonant tank circuit. Because of this tuned tank circuit, the feedback voltage $A\beta$ is maximum at a particular frequency f_r, which will be the frequency of oscillations.

Further more, the phase shift required for positive feedback is correct at this frequency f_r only. Thus although the noise voltage contains several frequency components, the output of the oscillator will contain a single sinusoidal frequency f_r the resonant frequency of the tank circuit.

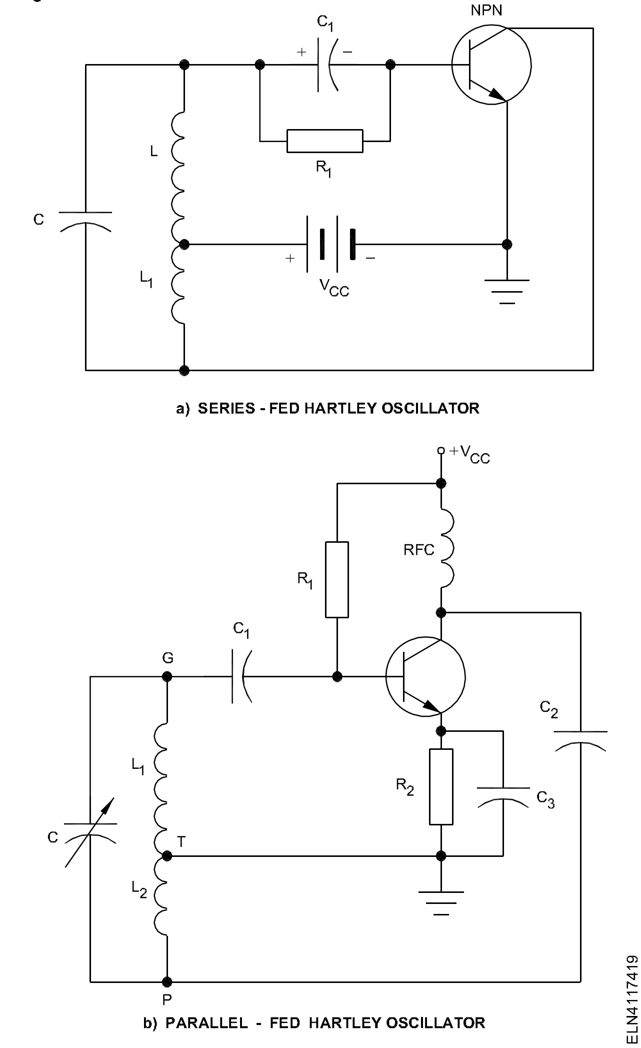
To summarize, the following are the requirements of an oscillator circuit to take-off with oscillations and have sustained oscillations,

- there must be positive feedback.
- Initially the loop gain product $A\beta$ must be >1.
- After the circuit starts oscillating, the loop gain product $A\beta$ must decrease to 1 and remain at 1.

Hartley oscillator: One of the simplest of sinusoidal oscillators is the Hartley oscillator shown in Figs 9a and 9b.

As in Fig 9a is a series fed Hartley oscillator. This circuit is similar to the tickler coil oscillator shown in Fig 7, but the tickler circuit coil L_1 is physically connected to L, and is hence a part of L (like an auto-transformer). This oscillator is called series-fed because, the high frequency oscillations generated and the DC paths are the same, just as they would be in a series circuit. Series fed Hartley oscillators are not preferred due to their poor stability of oscillations.

Fig 9



a) SERIES - FED HARTLEY OSCILLATOR

b) PARALLEL - FED HARTLEY OSCILLATOR

Fig 9b is parallel fed Hartley oscillator commonly used in radio receivers. Parallel fed Hartley oscillators are known for their high stability of oscillations.

The circuit at Fig 9b is actually an amplifier with positive (regenerative) feedback to have sustained oscillations. The capacitor C_2 and inductor L_2 form the path for RF current in the collector to ground circuit.

RF current through L_2 induces a voltage in L_1 in proper phase and amplitude to sustain oscillations.

The position of the tap at the junction of L_1 and L_2 determines how much signal is fed back to the base circuit.

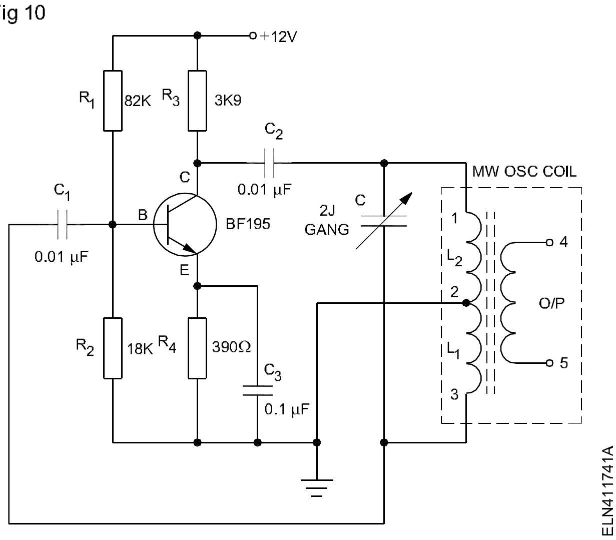
The capacitor C and the inductors $L_1 + L_2$ forms the resonant tank circuit of the oscillator which determines the frequency of oscillations. Capacitor C can be made variable capacitor for tuning the oscillator to different frequencies. C_1 and R_1 form the RC circuit which develops the bias voltage at the base.

The RF choke at the collector keeps the high frequency ac signal out of the V_{cc} supply. In cheaper oscillator circuits the RF choke is omitted and is replaced by a resistor.

Resistor R_2 connected in the emitter provides DC stabilization. R_2 is by-passed by C_3 to prevent AC degeneration.

The Hartley oscillator coil has three connections. These are usually coded on the coil. If they are not, it is generally possible to identify them by a resistance check. The resistance between the taps T and P as in Fig 10, is small compared with the resistance between T and G., If the coil connections are not made properly, the oscillator will not work.

Fig 10



Checking oscillator frequency: The frequency of an oscillator can be computed if the values of L ($L = L_1 + L_2$) and C are known using the formula,

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

where, f is in hertz, L in henry, and C in farad.

The frequency of an oscillator may be measured in two ways,

- Using a direct read-out frequency meter also known as frequency counter which is most accurate, popular and easy to use.
- Using an oscilloscope with a calibrated time base to measure the period of the wave-form. From the measured period, 'T' frequency is calculated using the formula

$$f = \frac{1}{T}$$

where, f is the frequency in Hz and 'T' the time period in seconds.

A practical Hartley oscillator circuit using medium-wave oscillator coil as L is shown in Fig 10.

The advantage of using a medium wave oscillator coil for L is that the output can be taken out of the secondary winding (4 and 5) of the coil.

The transistor used is a silicon high frequency transistor (BF series) as the oscillator frequency is in the range of 1 MHz.

The divider biasing is provided to make the DC conditions such that the amplifier works as Class A. With the heavy feedback (large β), the large feedback signal drives the base of the transistor into saturation and cut-off. This large feedback signal produces negative DC clamping at the base, changing the operation from Class A to Class C. This negative clamping automatically adjusts the value of Aβ to 1. If the feedback is too large, it may result in loss of some of the output voltage because of the stray power loses.

When you build an oscillator, you can adjust the amount of feedback to maximize the output voltage. The trick is to use enough feedback to start under all conditions (different transistors, temperature, voltage etc.), but not so much that you lose more output than necessary.

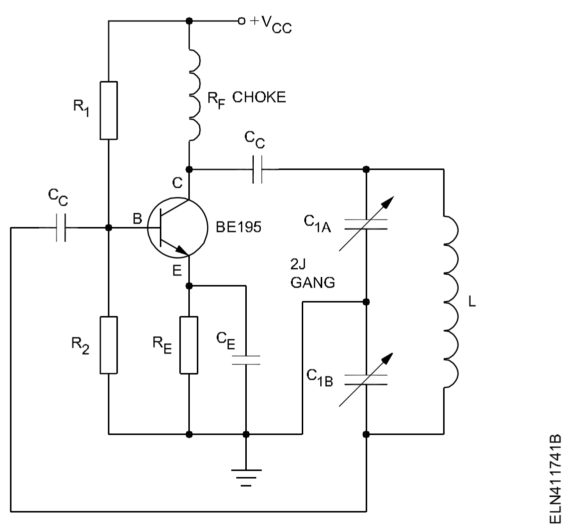
The frequency of oscillations of the oscillator circuit at Fig 10 can be varied by varying the position of the shaft of the gang of the gang capacitor (C_4).

Colpitt's oscillator: Colpitt's oscillator is another type of sinusoidal oscillator or harmonic oscillator which uses a tank circuit for oscillations. Colpitt's oscillators are very popular and are widely used in commercial signal generators and communication receivers.

A typical Colpitt's oscillator is in Fig 11 is similar to a Hartley oscillator. The only difference is that the Colpitt's oscillator uses a split capacitor for the tank instead of a split inductor used in Hartley oscillators.

The parallel-fed or shunt-fed Colpitt's oscillator is in Fig 11, uses the common emitter configuration. The capacitors C_{1A} & C_{1B} from the voltage divider used to provide the feedback signal. The voltage drop across C_{1B} determines the feedback voltage. All other components in this circuit have the same function as in the Hartley circuit.

Fig 11



The frequency of oscillations of the Colpitt's oscillator is given by,

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

where,

f is the frequency of oscillation in hertz,

L is the inductance of the coil in henry

C is the total capacitance in farad given by,

$$C = \frac{C_{1A} \times C_{1B}}{C_{1A} + C_{1B}}$$

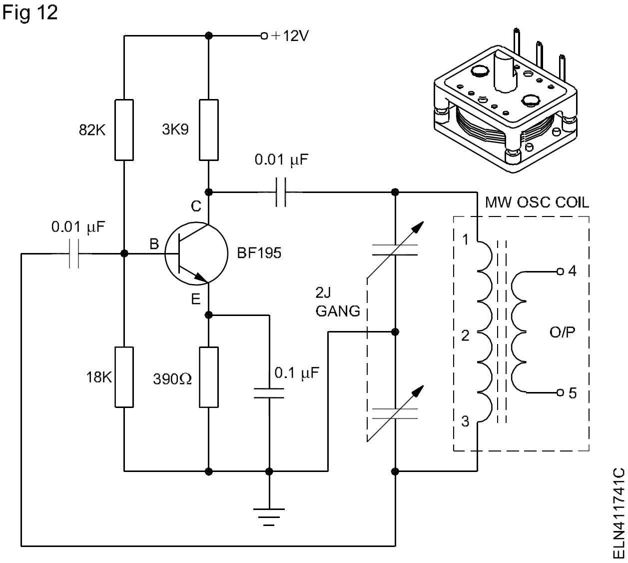
The frequency of oscillations can be changed by using a miniature ganged capacitor for C_{1A} & C_{1B}.

By varying the shaft of the ganged capacitor, both the capacitances C_{1A} and C_{1B} get varied, and hence, the frequency of oscillations of the oscillator varies.

Colpitt's oscillators are generally used for generating frequencies above 1 MHz.

A practical Colpitts oscillator circuit using a ganged capacitor for C_{1A} and C_{1B} and a medium wave oscillator coil for L is in Fig 12.

Fig 12



Crystal oscillators: The LC oscillator circuits such as Hartley and Colpitts have the problem of frequency instability. The most important reason for the frequency drift in LC oscillators is, the change in value of capacitance and inductance of the tank circuit that occurs when temperature changes.

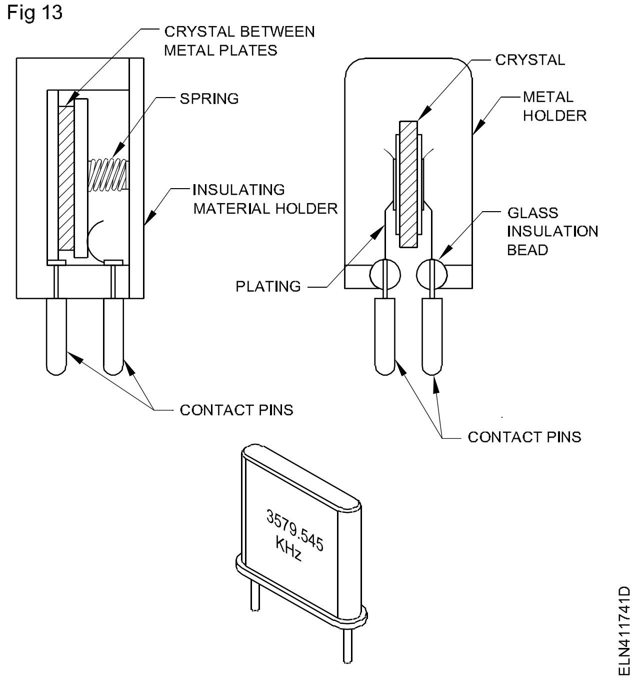
As the temperature increases or decreases, the values of L and C deviate causing the circuit to oscillate at a frequency different from the desired resonant frequency. Other reasons for frequency deviation are, the leads of transistor, inter electrode and wiring capacitances.

The problem of frequency drift can be largely overcome by using high Q coils and good quality capacitors. But, with ordinary inductors and capacitors, Q-values in excess of a few hundred is very difficult or impossible to achieve.

Large improvements in frequency stability can be achieved by using a quartz crystal in the place of the conventional tuned circuit. Such oscillator circuits are referred to as crystal controlled oscillators.

Piezo-electric effect: It was discovered that certain crystals such as quartz and Rochelle salt, exhibit a special property known as piezo-electric property. A quartz crystal looks like a piece of thin frosted glass usually cut into 1/4 to 1 inch squares as in Fig 13.

Fig 13



When such a crystal is held between two flat metal plates and pressed together, a small emf will be developed between the plates as if the crystal became a battery for an instant. When the plates are released, the crystal springs brings back to its original shape and an emf of opposite polarity is developed between the two plates. In this way, mechanical energy/force is converted to electrical energy by the crystal.

This property is made use of in the pick-ups for gramophone records. In a gramophone record, small mechanical vibrations are produced when the stylus tracks the groove on the gramophone plate. This vibrating force gives rise to corresponding voltages representing the recorded sound at the pick-up terminals.

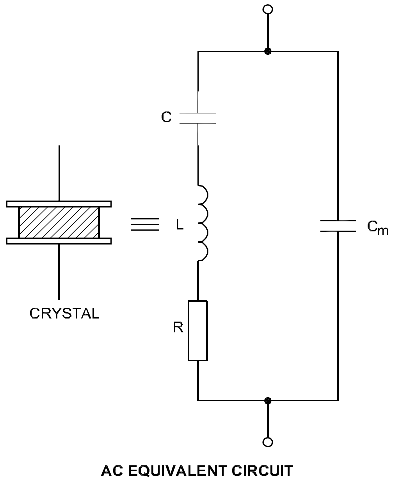
In addition to the above property of the crystal, when an emf is applied across the two plates of the crystal, the crystal will distort from its normal shape. If an opposite polarity emf is applied, the crystal will reverse its physical distorted shape. In this way, these crystals also convert electrical energy into mechanical energy.

The above two reciprocal actions of a crystal are known as piezo-electric effect. Such crystals are housed in crystal holders as in Fig 13.

Amongst several crystals having this piezo-electric property, the quartz crystal is most popular because, mechanical oscillations are started in this crystal it takes a long time for the oscillations to die away. Quartz crystals therefore, have a very high mechanical Q.

So far as the electrical properties are concerned, a quartz crystal is equivalent to the LC resonant circuit is in Fig 14.

Fig 14



The values of L,R,C and C_m depend upon the physical size of the crystal and how the crystal is cut from the original mass. Capacitance C_m represents the mounting capacitance. For using the crystal in electronic circuits, two conducting electrodes are placed onto its two faces. Connecting leads are then joined to these electrodes. When the leads are connected to a source of oscillating voltage, mechanical vibrations are set up within the crystal.

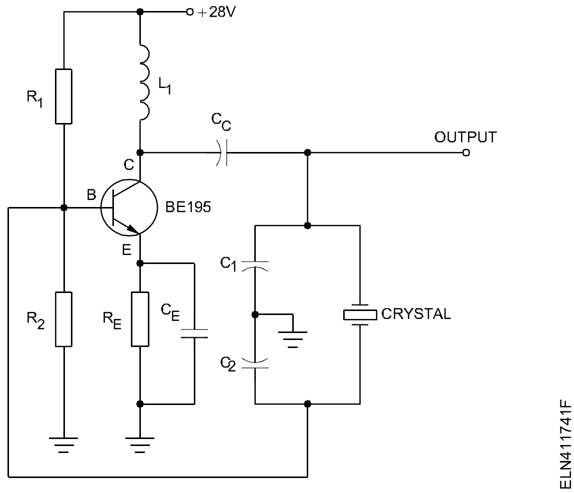
If the frequency of the oscillating voltage is close to a resonant frequency of the crystal, then the crystal forces the oscillating voltage to coincide with the oscillating frequency of the crystal. Hence, in an oscillator, by using the crystal in the place of an LC resonant circuit, the frequency of oscillation is determined almost entirely by the crystal. Q values in excess of 20,000 are easily obtained with readily available crystals resulting in highly stable oscillating frequency.

Hence, when accuracy and stability of the oscillation frequency are important, a quartz crystal oscillator is used instead of Hartley or Colpitt's oscillators. The frequency range of crystals is usually between 0.5 to 30 MHz.

Pierce crystal oscillator: The pierce crystal controlled oscillator is in Fig 15 is often used because it requires very few components and has good frequency stability.

The pierce crystal oscillator is similar to the Colpitts oscillator but for the inductance coil replaced by a crystal. Here the crystal across the collector and the base terminals of the transistor determines the oscillating frequency. As in a colpitts oscillator, capacitors C_1 and C_2 form a capacitive voltage divider for feedback. The ac voltage across C_2 provides the necessary positive feedback to the base.

Fig 15



In Fig 15, the crystal acts like an inductor that resonates with C_1 and C_2. In the base circuit, the R_1R_2 divider supplies forward bias voltage from the V_{CC}. Bias stabilization is provided by the R_EC_E combination in the emitter circuit.

In Fig 15, if the crystal resonant frequency is, say 3579.545 Hz, then the oscillator oscillates at the same frequency and gives a sinusoidal output of 3579.545 Hz.

Crystal oscillators are generally used in,

- mobile radio transmitters and receivers
- broadcast transmitters
- test equipments such as signal generators where exact frequency and very high frequency stability are of utmost importance. The frequency drift in crystal controlled oscillators will be less than 1 Hz per 10^6 Hz.

Multivibrator

It is a free running oscillator which gives repetitive pulse wave form output, and other types of multi-vibrators which are classified depending upon the manner in which the two stages of the multi-vibrator interchange their ON and OFF states. They are:

- **Mono-stable multivibrator** (having one stable state).
- **Bistable multivibrator** (having two stable states).

Mono-stable Multivibrator

Fig 16 shows a typical mono-stable multi-vibrator also known as **mono-shot** or **one-shot**.

A mono-shot has one stable state with one transistor conducting and the other off. This state can be changed only temporarily by giving an input pulse generally known as **trigger** pulse to the transistor which is off. But this changed state returns back to its original stable state after a period decided by the values of R and C.

Fig 16

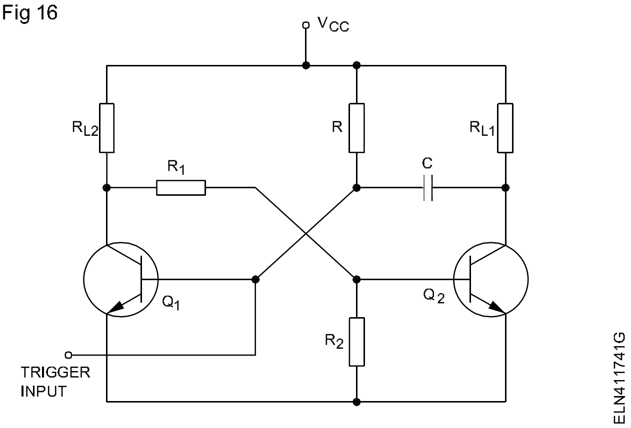
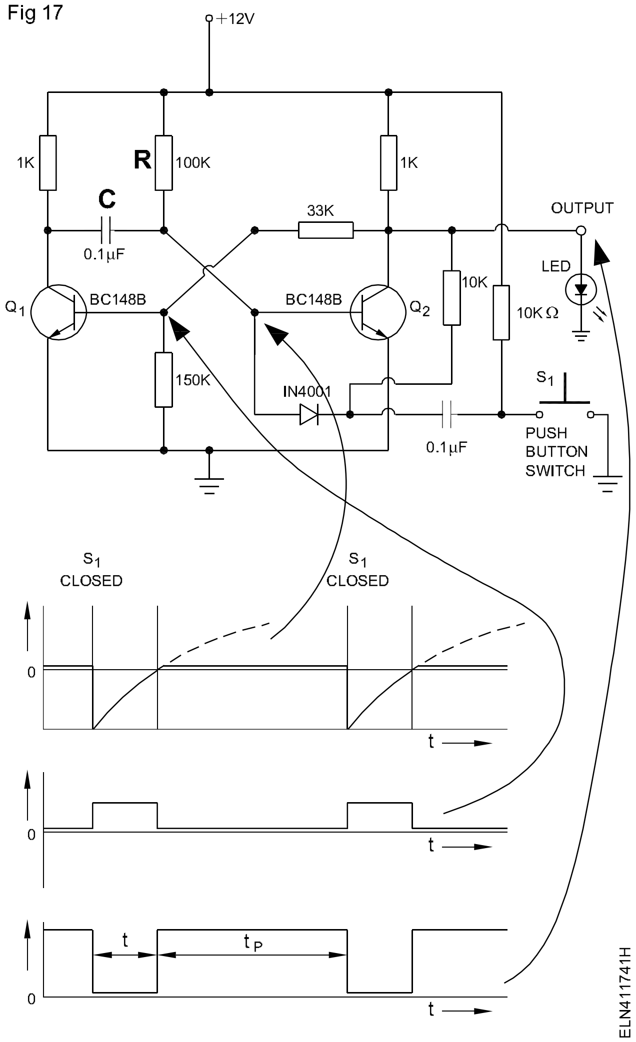


Fig 17 shows a practical mono-stable multi-vibrator with trigger input. Fig 17 also shows the wave-forms at different points of the circuit.

Fig 17



The period t for which Q_2 is kept off temporarily is given by,

$$t = 0.69\ RC.$$

Mono-stable multi-vibrators are extensively used as timers in electronic timing control circuits.

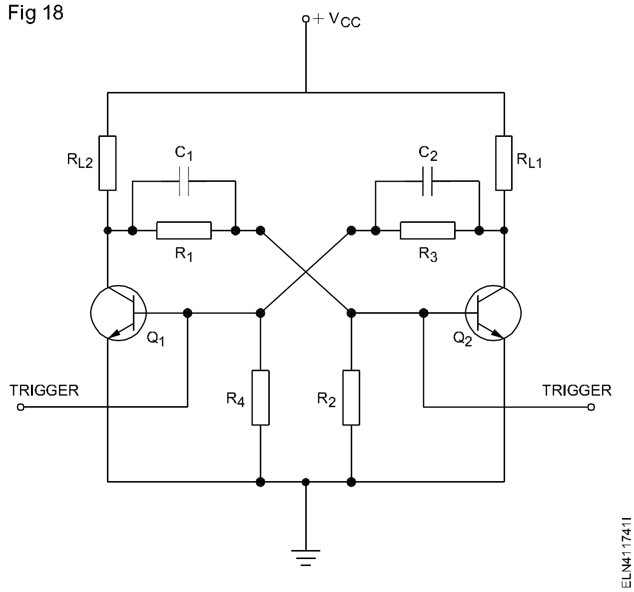
Bistable multivibrator

An astable multi-vibrator automatically switches from one state to other (ON-to-OFF or OFF-to-ON...). Whereas, a bistable multi-vibrator will change the state(ON to OFF or OFF to ON) when triggered and remain in the new state (ON or OFF). This means, a bistable multi-vibrator has two stable states. Fig 18 shows a typical bistable multi-vibrator circuit.

The circuit at Fig 18 is completely symmetrical. The potential dividers R_1, R_2 and R_3, R_4 form identical bias network at the base of transistors. Each transistor is biased from the collector of the other transistor. Due to the slightest difference in parameters of the transistor, when the circuit is switched ON, any one of the two transistors will turn-ON, and the other remain in OFF condition.

In the circuit at Fig 18, the two identical CE amplifier stages are so connected that the output of one is fed to the input of the other, through resistors R_1, R_3 and shunted by capacitors C_1, C_2. The purpose of the capacitor is nothing but to speed up the switching characteristic of the circuit to get distortion-less output wave-form. Capacitors C_1 & C_2 are also known as **commutating capacitors**.

Fig 18



A bistable multi-vibrator is also known as a **flip-flop**. The output terminals are generally identified as Q & $\overline{Q}$ (Q-bar) as in Fig 19.

When Q is in high state (also known as **Logic-1** state in digital electronics), $\overline{Q}$ (Q-bar) will be in low state (also known as **Logic-0** state), and vice versa. This circuit is known as a flip-flop circuit because, if one output flips(high/ logic-1) the other output automatically flops(low/logic-0). A flip-flop can be switched from one state to the other by applying a suitable triggering input. Flip-flops are used as a basic **memory cell** in digital computers for storing information. Flip-flops are used in various forms in almost all digital system as counters, frequency dividers and so on.

Fig 19

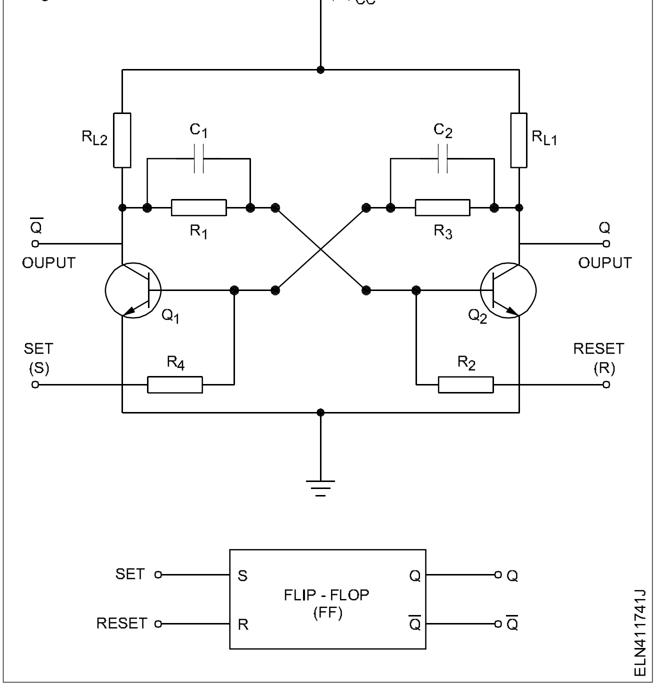
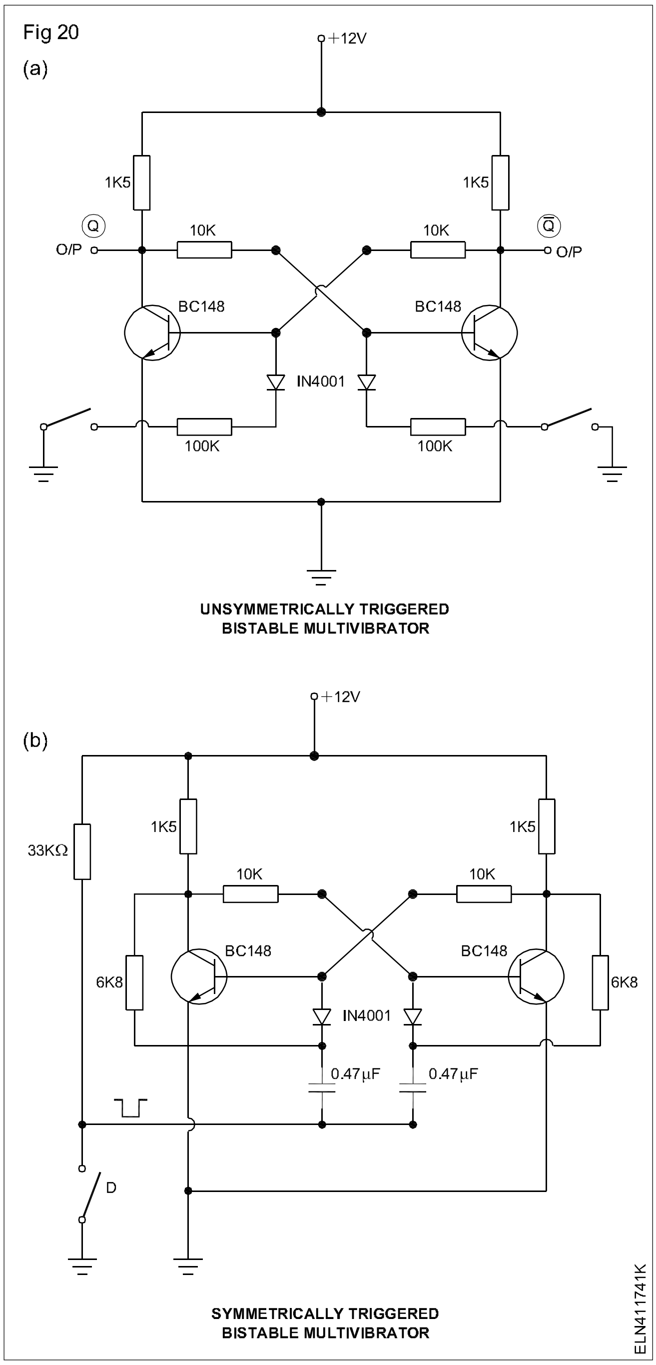


Fig 20



Practical bistable multi-vibrators with unsymmetrical and symmetrical triggering arrangement are shown in Fig 20a and 20b.