UNIT (2)::EC 2::Long Answers

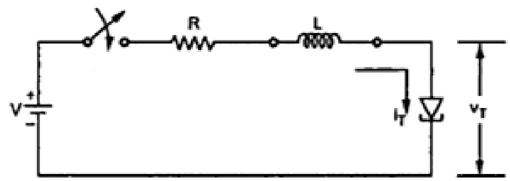
1.Explain the operation of Negative resistance oscillator using Tunnel Diode with neat diagram ?

5.2.6 Negative Resistance Oscillator Using Tunnel Diode

The Fig. 5.13 shows a negative resistance oscillator using tunnel diode.

▶ Figure 5.13

Negative resistance oscillator using tunnel diode



The network elements are so designed to obtain the operating Q point at position 'O' as shown in the Fig. 5.14. This is the intersection point of load line with Tunnel diode characteristics. The design is such that the load line intersects the characteristics only at one point which is the Q point. A stable operating point is not at all defined.

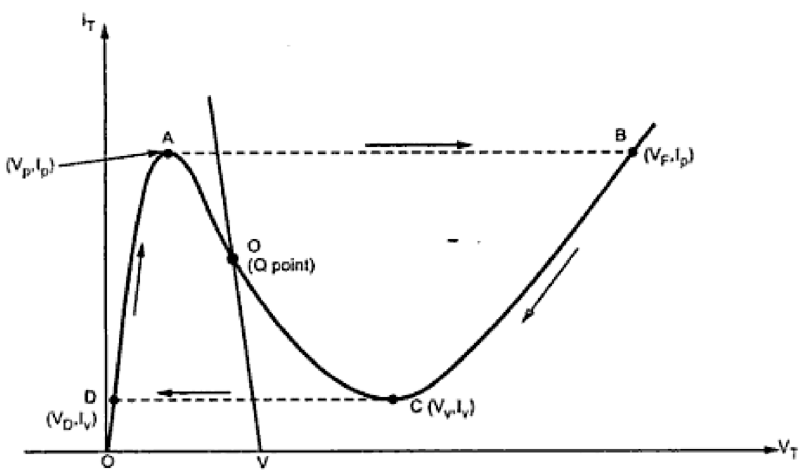
Initially when switch is closed, the supply voltage starts increasing and at $V=V_p$, the current attains maximum value I_p. Now for $V>V_p$, according to the characteristics current must decrease.

But $$V = I_T R + I_T(-R_T) \quad \dots (2)$$

As tunnel diode is operating with Q point in negative resistance region hence R_T is taken negative.

$$\therefore \quad V = I_T(R - R_T) \quad \dots (3)$$

▶ Figure 5.14

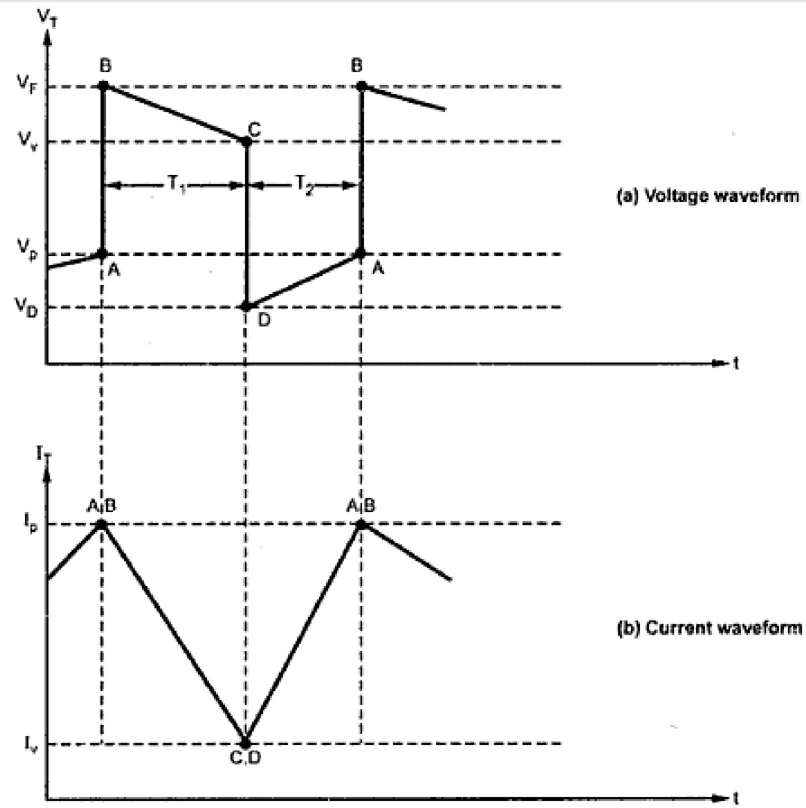


Hence I_T is decreasing and $R-R_T$ is also decreasing. But V is increasing beyond V_p. This is contradictory according to equations (3). Hence diode operating point switches from A to B, in that region where current can increase as voltage increases. But at point B, $V = V_F$ which is greater than V. To achieve this, the polarity of the transient voltage across the coil must reverse and current starts decreasing from B to C. Energy stored in the inductor while current has reached I_p, starts decreasing.

This decrease in current continues till the point of operation shifts to point C where current is I_v while voltage is V_v. Now this voltage is still more than V and hereafter current starts increasing again. But as inductor is discharging, current must decrease as voltage decreases. Hence it is not possible in practice to increase the current after point C but the point of operation shifts from point C to D where voltage is V_D and current is I_v. This is a stable region where current can further decrease rather than increasing. But from point D onwards, tunnel current can again increase to I_p. Thus the process repeats on its own again and again, never settling at an operating point defined in an unstable region of characteristics. The result is the oscillator circuit with the help of a fixed supply and negative resistance characteristics of a Tunnel diode.

The voltage and current waveforms are shown in the Fig. 5.15 (a) and (b).

Thus the square type waveform can be obtained using tunnel diode. The oscillator waveforms are not necessarily exactly symmetrical i.e. $T_1 \neq T_2$. This is because portions DA and BC are not identical.



<u>Voltage and Current Waveform</u>

2.RC Pahse shift Oscillator

In a practical RC phase shift oscillator, a common emitter (CE) single stage amplifier is used as a basic amplifier. This produces 180° phase shift. The feedback network consists of 3 RC sections each producing 60° phase shift. Such a RC phase shift oscillator using BJT amplifier is shown in the Fig. 4.9.

The output of amplifier is given to feedback network. The output of feedback network drives the amplifier. The total phase shift around a loop is 180° of amplifier and 180° due to 3 RC section, thus 360°. This satisfies the required condition for positive feedback and circuit works as an oscillator.

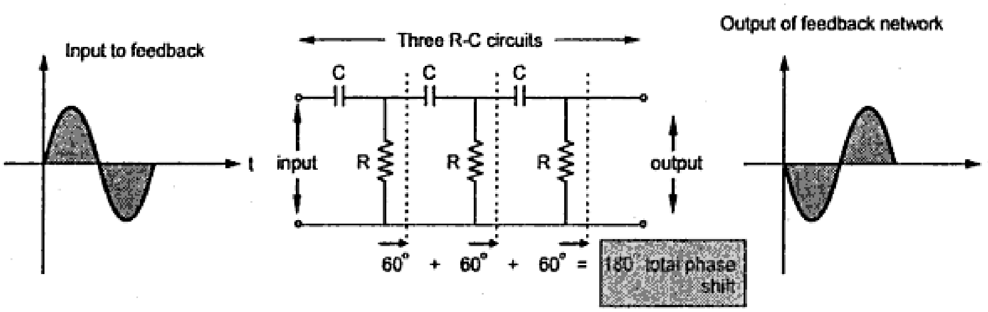


Fig. 4.8 Feedback network in RC phase shift oscillator

The network is also called the **ladder network.** All the resistance values and all the capacitance values are same, so that for a particular frequency, each section of R and C produces a phase shift of 60°.

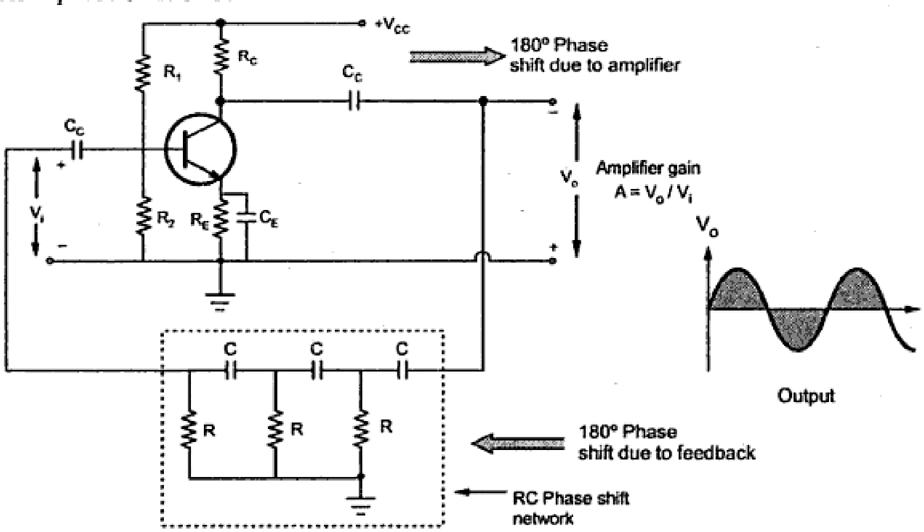


Fig. 4.9 Transistorised RC phase shift oscillator

The frequency of sustained oscillations generated depends on the values of R and C and is given by,

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

The frequency is measured in Hz.

Actually to satisfy the Barkhausen condition, the expression for the frequency of oscillations is given by,

$$f = \frac{1}{2\pi RC} \cdot \frac{1}{\sqrt{6+4K}}$$

where $K = \frac{R_C}{R}$

As practically R_C/R is small, K is neglected,

The condition of h_{fe} for the transistor to obtain the oscillations is given by,

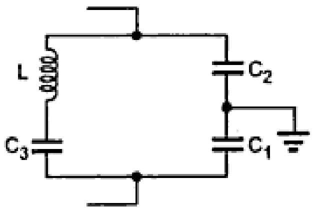
$$h_{fe} > 4K + 23 + \frac{29}{K}$$

And value of K for minimum h_{fe} is 2.7 hence minimum h_{fe} = 44.5. So transistor with h_{fe} less than 44.5 cannot be used in phase shift oscillator.

But for most of practical circuits, the expression for the frequency is considered as,

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

3.Explain Clapp's Osc. & Derive the exp. for freq. of oscillation.Also explain how frequency stability can be improved Clapp's Oscillator ?



To achieve the frequency stability, Colpitts oscillator circuit is slightly modified in practice, called Clapp oscillator. The basic tank circuit with two capacitive reactances and one inductive reactance remains same. But the modification in the tank circuit is that **one more capacitor C_3 is introduced in series with the inductance** as shown in the Fig. 2.46.

Fig. 2.46 Modified tank circuit

Key Point : *The value of C_3 is much smaller than the values of C_1 and C_2.*

Now the equivalent capacitance becomes,

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \quad \dots (1)$$

While the oscillator frequency is given by the same expression as,

$$f = \frac{1}{2\pi\sqrt{L\,C_{eq}}} \quad \dots (2)$$

Suppose $C_1 = C_2 = 0.001\ \mu F$, $L = 15\ \mu H$ and the new capacitor $C_3 = 50$ pF

so, $$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$\therefore$ $$C_{eq} = 4.545 \times 10^{-11}$$

$\therefore$ $$f = \frac{1}{2\pi\sqrt{L\,C_{eq}}} = \frac{1}{2\pi\sqrt{15\times 10^{-6} \times 4.545 \times 50 \times 10^{-11}}}$$

$$= 6.09\ \text{MHz}$$

If C_1 and C_2 are neglected then $C_{eq} = C_3$

$\therefore$ $$f = \frac{1}{2\pi\sqrt{L\,C_3}} = \frac{1}{2\pi\sqrt{15\times 10^{-6} \times 50 \times 10^{-12}}} = 5.82\ \text{MHz}$$

The frequencies are almost same, hence in practice the C_1, C_2 values are neglected and C_3 is assumed to be C_{eq}. Hence the frequency is given by,

$$f = \frac{1}{2\pi\sqrt{L\,C_3}} \quad \dots (3)$$

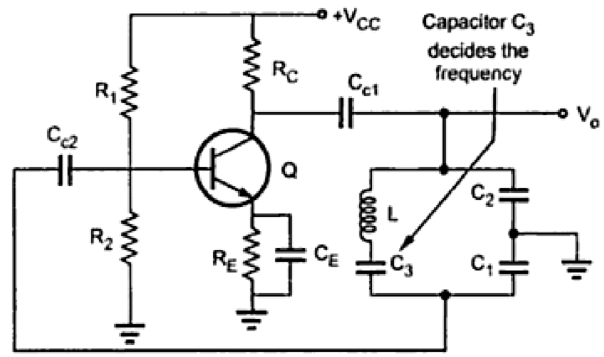


Fig. 2.47 Transistorised Clapp oscillator

Now across C_3, there is no transistor parameter and hence the frequency of the Clapp oscillator is stable and accurate. The transistor and stray capacitances have no effect on C_3 hence good frequency stability is achieved in Clapp oscillator. Hence practically Clapp oscillator is preferred over Colpitts oscillator. The transistorised Clapp oscillator is shown in the Fig. 2.47.

Another advantage of C_3 is that it can be kept variable. As frequency is dependent on C_3, the frequency can be varied in the desired range.

2.12.1 Derivation of Frequency of Oscillations

The derivation is similar to the Colpitt's oscillator with C_3 in series with L in the equivalent circuit of transistorised Clapp oscillator. The equivalent circuit is shown in the Fig. 2.48.

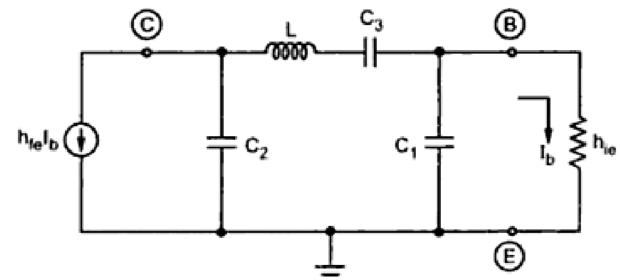


Fig. 2.48

Converting current source to voltage source we get the equivalent circuit as shown in the Fig. 2.49.

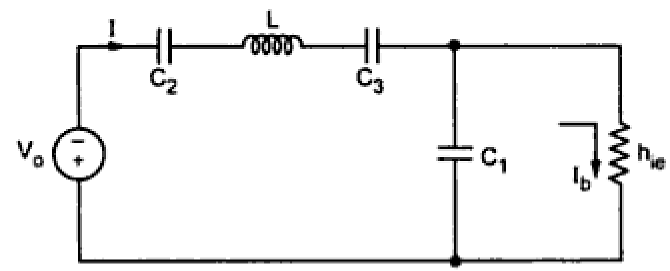


Fig. 2.49

$$V_o = h_{fe} I_b X_{C2}$$

$$\therefore \quad \boxed{V_o = h_{fe} I_b \cdot \frac{1}{j\omega C_2}} \quad \text{... (4)}$$

$$\therefore \quad I = \frac{-V_o}{[X_{C2} + X_{C3} + X_L] + [X_{C1} \| h_{ie}]} \quad \text{... (5)}$$

The negative sign as the direction of I is assumed opposite to that which voltage source will force the current I through the circuit.

$$X_{C2} + X_{C3} + X_L = \frac{1}{j\omega C_2} + \frac{1}{j\omega C_3} + j\omega L$$

$$X_{C1} \| h_{ie} = \frac{\frac{1}{j\omega C_1} \times h_{ie}}{\frac{1}{j\omega C_1} + h_{ie}}$$

$$\therefore \quad I = \frac{-h_{fe} I_b \cdot \frac{1}{j\omega C_2}}{\frac{1}{j\omega C_2} + \frac{1}{j\omega C_3} + j\omega L + \left[\frac{\frac{1}{j\omega C_1} h_{ie}}{\frac{1}{j\omega C_1} + h_{ie}}\right]} \quad \text{...(6)}$$

Replacing $j\omega$ by s,

$$I = \frac{-h_{fe} I_b \cdot \frac{1}{s C_2}}{\frac{1}{s C_2} + \frac{1}{s C_3} + sL + \left[\frac{\frac{h_{ie}}{s C_1}}{\frac{1}{s C_1} + h_{ie}}\right]} \quad \text{... (7)}$$

$$= \frac{-h_{fe} I_b}{1 + \frac{C_2}{C_3} + s^2 L C_2 + \frac{s C_2 h_{ie}}{(1 + s C_1 h_{ie})}}$$

...multiplying by sC_2 to denominator

$$= \frac{-h_{fe} I_b \cdot C_3}{C_3 + C_2 + s^2 L C_2 C_3 + \frac{s C_2 C_3 h_{ie}}{(1 + s C_1 h_{ie})}}$$

$$= \frac{-h_{fe} I_b C_3 (1 + s C_1 h_{ie})}{C_3 + sC_1 C_3 h_{ie} + C_2 + sC_1 C_2 h_{ie} + s^2 L C_2 C_3 + s^3 L C_1 C_2 C_3 h_{ie} + s C_2 C_3 h_{ie}}$$

Substituting $s = j\omega$, $s^2 = j^2\omega^2 = -\omega^2$, $s^3 = -j\omega^3$

$$1 = \frac{-h_{fe} C_3}{-j\omega^3 L C_1 C_2 C_3 h_{ie} - \omega^2 L C_2 C_3 + j\omega h_{ie} [C_1 C_2 + C_2 C_3 + C_3 C_1] + C_2 + C_3}$$

$$\therefore 1 = \frac{-h_{fe} C_3}{C_2 + C_3 - \omega^2 L C_2 C_3 + j\omega h_{ie} [(C_1 C_2 + C_2 C_3 + C_3 C_1] - \omega^2 L C_1 C_2 C_3]} \quad \text{... (10)}$$

As there is no imaginary part in numerator, to satisfy Barkhausen criterion, imaginary part in the denominator must be zero. But ω and h_{ie} are not zero hence,

$$\therefore \quad C_1 C_2 + C_2 C_3 + C_3 C_1 - \omega^2 L C_1 C_2 C_3 = 0$$

$$\therefore \quad \omega^2 = \frac{C_1 C_2 + C_2 C_3 + C_3 C_1}{L C_1 C_2 C_3}$$

$$\therefore \quad \omega^2 = \frac{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}{L} = \frac{\frac{1}{C_{eq}}}{L}$$

$$\therefore \quad \omega^2 = \frac{1}{L C_{eq}}$$

$$\therefore \quad \boxed{\omega = \frac{1}{\sqrt{L C_{eq}}}} \quad \text{... (11)}$$

$$\therefore \quad \boxed{f = \frac{1}{2\pi\sqrt{L C_{eq}}}} \quad \text{... (12)}$$

where $\boxed{\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$

But as $C_3 << C_1$ and C_2, $C_{eq} = C_3$

$$\therefore \quad \boxed{f = \frac{1}{2\pi\sqrt{L C_3}}} \quad \text{... (13)}$$

This is the required frequency of oscillations for the Clapp oscillator.

2.12.2 Advantages

1. The frequency is stable and accurate.
2. The good frequency stability.
3. The stray capacitances have no effect on C_3 which decides the frequency.
4. Keeping C_3 variable, frequency can be varied in the desired range.

4.Explain Hartley Oscillator and derive the equation for oscillation .

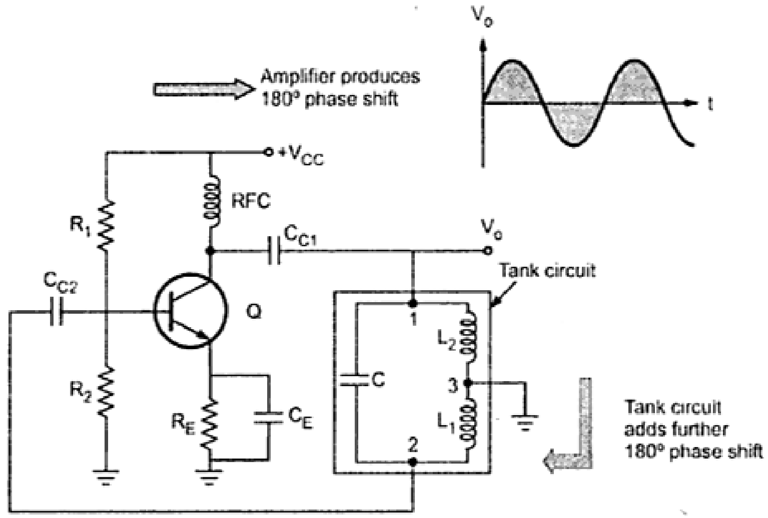


Fig. 2.35 Transistorised Hartley oscillator

The resistances R_1 and R_2 are the biasing resistances. The RFC is the radio frequency choke. Its reactance value is very high for high frequencies, hence it can be treated as open circuit. While for d.c. conditions, the reactance is zero hence causes no problem for d.c. capacitors.

Hence due to RFC, the isolation between a.c. and d.c. operation is achieved. R_E is also a biasing circuit resistance and C_E is the emitter bypass capacitor. C_{C1} and C_{C2} are the coupling capacitor.

The common emitter amplifier provides a phase shift of 180°. As emitter is grounded, the base and the collector voltages are out of phase by 180°. As the centre of L_1 and L_2 is grounded, when upper end becomes positive, the lower becomes negative and viceversa. So the LC feedback network gives an additional phase shift of 180°, necessary to satisfy oscillation conditions.

2.10.2 Derivation of Frequency of Oscillations

The output current which is the collector current is $h_{fe}I_b$ where I_b is the base current. Assuming coupling condensers are short, the capacitor C is between base and collector. The inductance L_1 is between base and emitter while the inductance L_2 is between collector and emitter. The equivalent circuit of the feedback network is shown in the Fig. 2.36.

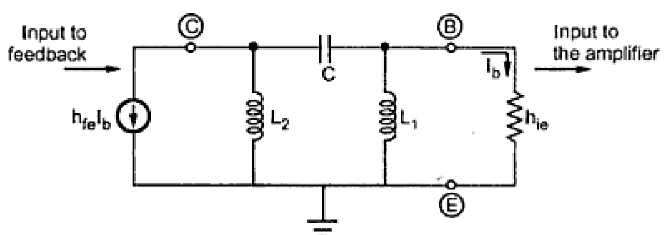


Fig. 2.36 Equivalent circuit

As h_{ie} is the input impedance of the transistor. The output of the feedback is the current I_b which is the input current of the transistor. While input to the feedback network is the output of the transistor which is $I_c = h_{fe}I_b$, converting current source into voltage source we get,

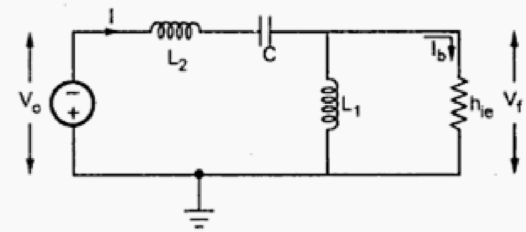


Fig. 2.37 Simplified equivalent circuit

$$V_o = h_{fe}I_b X_{L2} = h_{fe}I_b\, j\omega L_2 \quad \text{... (1)}$$

Now L_1 and h_{ie} are in parallel, so the total current I drawn from the supply is,

$$I = \frac{-V_o}{[X_{L2}+X_C]+[X_{L1} \| h_{ie}]} \quad \text{... (2)}$$

Now $\quad X_{L2} + X_C = j\omega L_2 + \dfrac{1}{j\omega C}$

and $\quad X_{L1} \| h_{ie} = \dfrac{j\omega L_1 h_{ie}}{(j\omega L_1 + h_{ie})}$

Substituting in the equation (2) we get,

$$I = \frac{-h_{fe} I_b\, j\omega L_2}{\left[j\omega L_2 + \frac{1}{j\omega C}\right] + \frac{j\omega L_1 h_{ie}}{(j\omega L_1 + h_{ie})}} \quad \text{... (3)}$$

Replacing $j\omega$ by s,

$$I = \frac{-s\, h_{fe} I_b L_2}{\left[s L_2 + \frac{1}{sC}\right] + \frac{s L_1 h_{ie}}{(s L_1 + h_{ie})}}$$

$$= \frac{-s\, h_{fe} I_b L_2}{\frac{[1+s^2 L_2 C]}{sC} + \frac{s L_1 h_{ie}}{(s L_1 + h_{ie})}}$$

$$= \frac{-s\, h_{fe} I_b L_2 (sC)(s L_1 + h_{ie})}{[1+s^2 L_2 C][s L_1 + h_{ie}] + (sC)(s L_1 h_{ie})}$$

$$= \frac{-s^2 h_{fe} I_b L_2 C(sL_1 + h_{ie})}{s^3 L_1 L_2 C + sL_1 + h_{ie} + s^2 L_2 C h_{ie} + s^2 L_1 C h_{ie}}$$

$$= \frac{-s^2 h_{fe} I_b L_2 C(sL_1 + h_{ie})}{s^3 L_1 L_2 C + s^2 C h_{ie}(L_1 + L_2) + sL_1 + h_{ie}}$$

According to current division in parallel circuit,

$$I_b = I \times \frac{X_{L1}}{XL_1 + h_{ie}}$$

$$= I \times \frac{j\omega L_1}{(j\omega L_1 + h_{ie})}$$

$$\boxed{I_b = I \times \left[\frac{sL_1}{(sL_1 + h_{ie})}\right]} \quad \ldots (4)$$

Substituting value of I from equation (3) in equation (4),

$$I_b = \frac{-s^2 h_{fe} I_b L_2 C(sL_1 + h_{ie})}{[s^3(L_1 L_2 C) + s^2 C h_{ie}(L_1 + L_2) + sL_1 + h_{ie}]} \times \frac{sL_1}{(sL_1 + h_{ie})}$$

$$= \frac{-s^3 h_{fe} I_b C L_1 L_2}{s^3(L_1 L_2 C) + s^2 C h_{ie}(L_1 + L_2) + sL_1 h_{ie}}$$

$$\therefore \quad 1 = \frac{-s^3 h_{fe} C L_1 L_2}{s^3(L_1 L_2 C) + s^2 C h_{ie}(L_1 + L_2) + sL_1 + h_{ie}} \quad \ldots (5)$$

Substituting $s = j\omega$, $s^2 = -\omega^2$, $s^3 = -j\omega^3$ we get,

$$\therefore \quad 1 = \frac{j\omega^3 h_{fe} C L_1 L_2}{-j\omega^3 L_1 L_2 C - \omega^2 C h_{ie}(L_1 + L_2) + j\omega L_1 + h_{ie}}$$

$$= \frac{j\omega^3 h_{ie} C L_1 L_2}{[h_{ie} - \omega^2 C h_{ie}(L_1 + L_2)] + j\omega L_1(1 - \omega^2 L_2 C)} \quad \ldots (6)$$

Rationalising the R.H.S of the above equation,

$$\therefore \quad 1 = \frac{j\omega^3 h_{fe} C L_1 L_2 [h_{ie} - \omega^2 C h_{ie}(L_1 + L_2) - j\omega L_1(1 - \omega^2 L_2 C)]}{[h_{ie} - \omega^2 C h_{ie}(L_1 + L_2)]^2 + \omega^2 L_1^2 (1 - \omega^2 L_2 C)^2}$$

$$= \frac{\omega^4 h_{fe} L_1^2 L_2 C(1 - \omega^2 L_2 C) + j\omega^3 h_{fe} L_1 L_2 C [h_{ie} - \omega^2 C h_{ie}(L_1 + L_2)]}{[h_{ie} - \omega^2 C h_{ie}(L_1 + L_2)]^2 + \omega^2 L_1^2 (1 - \omega^2 L_1^2 L_2 C)^2} \quad \ldots (7)$$

To satisfy this equation, imaginary part of R. H. S. must be zero.

$$\therefore \quad \boxed{\omega^3 h_{fe} L_1 L_2 C [h_{ie} - \omega^2 h_{ie} C (L_1 + L_2)] = 0}$$

$$\therefore \quad \omega^3 h_{fe} h_{ie} L_1 L_2 C [1 - \omega^2 C (L_1 + L_2)] = 0$$

$$\therefore \quad 1 - \omega^2 C (L_1 + L_2) = 0$$

$$\therefore \quad \omega^2 = \frac{1}{C(L_1 + L_2)}$$

$$\therefore \quad \boxed{\omega = \frac{1}{\sqrt{C(L_1 + L_2)}}}$$

$$\therefore \quad \boxed{f = \frac{1}{2\pi\sqrt{C(L_1 + L_2)}}} \quad \ldots (8)$$

This is the frequency of the oscillations. At this frequency, the restriction of the value of h_{fe} can be obtained, by equating the magnitudes of the both sides of the equation (7)

$$\therefore \quad 1 = \frac{\omega^4 h_{fe} L_1^2 L_2 C(1 - \omega^2 L_2 C)}{0 + \omega^2 L_1^2 (1 - \omega^2 L_2 C)^2} \text{ at } \omega = \frac{1}{\sqrt{C(L_1 + L_2)}}$$

$$\therefore \quad 1 = \frac{h_{fe} L_2}{(1 - \omega^2 L_2 C)} \text{ at } \omega = \frac{1}{\sqrt{C(L_1 + L_2)}}$$

$$\therefore \quad 1 = \frac{h_{fe} L_2}{\left[1 - \frac{L_2 C}{C(L_1 + L_2)}\right]} = \frac{h_{fe} L_2}{L_1}$$

$$\therefore \quad \boxed{h_{fe} = \frac{L_1}{L_2}} \quad \ldots (9\text{ a})$$

This is the value of h_{fe}, required to satisfy the oscillating conditions.

For a mutual inductance of M,

$$\boxed{h_{fe} = \frac{L_1 + M}{L_2 + M}} \quad \ldots (9\text{ b})$$

Now $L_1 + L_2$ is the equivalent inductance of the two inductances L_1 and L_2, connected in series denoted as

$$\boxed{L_{eq} = L_1 + L_2} \quad \ldots (10)$$

Hence the frequency of oscillations is given by,

$$\boxed{f = \frac{1}{2\pi\sqrt{C L_{eq}}}} \quad \ldots (11)$$

so if the capacitor C is kept variable,freq. can be varied over a large range as per the requirement.

5.Explain the resonance frequency of crystal.And Draw the Pierce crystal Oscillator ckt. and Derive the equation for Oscillation.

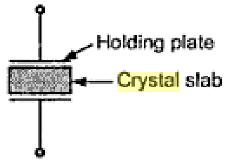


Fig. 2.55 Symbolic representation of a crystal

2.17.2 A.C. Equivalent Circuit

When the crystal is not vibrating, it is equivalent to a capacitance due to the mechanical mounting of the crystal. Such a capacitance existing due to the two metal plates separated by a dielectric like crystal slab, is called **mounting capacitance** denoted as C_M or C′.

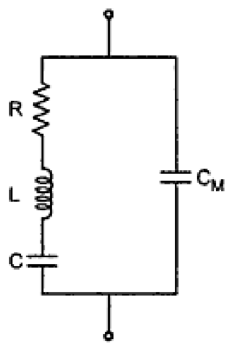


Fig. 2.56 A.C. equivalent circuit of a crystal

When it is vibrating, there are internal frictional losses which are denoted by a resistance R. While the mass of the crystal, which is indication of its inertia is represented by an inductance L. In vibrating condition, it is having some stiffness, which is represented by a capacitor C. The mounting capacitance is a shunt capacitance. And hence the overall equivalent circuit of a crystal can be shown as in the Fig. 2.56.

RLC forms a resonating circuit. The expression for the resonating frequency f_r is,

$$f_r = \frac{1}{2\pi\sqrt{LC}}\sqrt{\frac{Q^2}{1+Q^2}} \quad ...(1)$$

Where

Q = Quality factor of crystal

$$\therefore \quad Q = \frac{\omega L}{R} \quad ...(2)$$

The Q factor of the crystal is very high, typically 20,000. Value of Q upto 10^6 also can be achieved. Hence $\sqrt{\frac{Q^2}{1+Q^2}}$ factor approaches to unity and we get the resonating frequency as,

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad ...(3)$$

The crystal frequency is infact inversely proportional to the thickness of the crystal.

$$f \propto \frac{1}{t}$$ where t = Thickness

So to have very high frequencies, thickness of the crystal should be very small. But it makes the crystal mechanically weak and hence it may get damaged, under the vibrations. Hence practically crystal oscillators are used upto 200 or 300 kHz only.

The crystal has two resonating frequencies, series resonant frequency and parallel resonant frequency.

Series resonance, , $f_S = \frac{1}{2\pi\sqrt{LC}}$

Parallel resonance,; $f_P = \frac{1}{2\pi\sqrt{LC_{eq}}}$

- <u>Derivtion for the equation of oscillation :-</u>