Hartley Oscillator (Radio frequency generator)

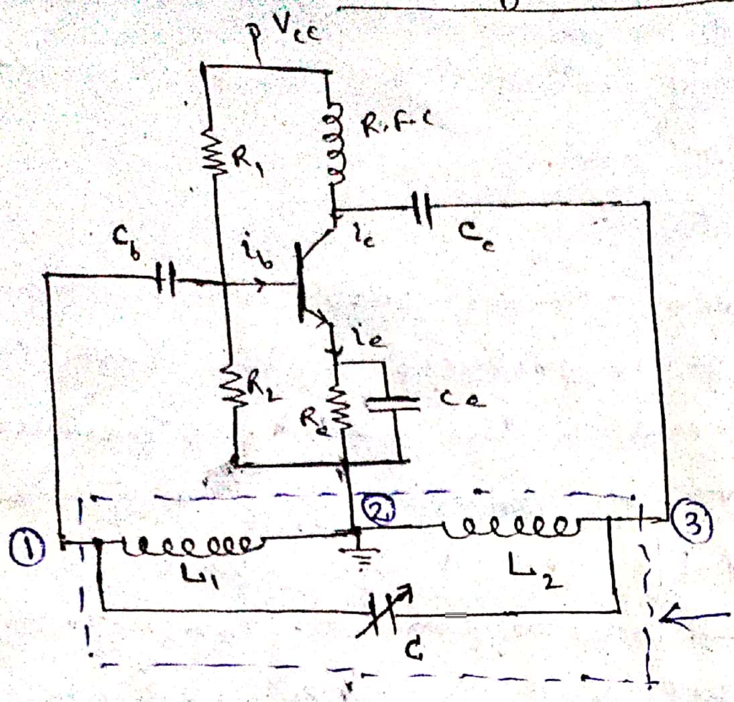

Fig-1.

Above fig-1 represents Hartley oscillator most commonly used as local oscillator in radio receivers. It can generates signal of frequency 10KHz to 100MHz.

The circuit consist of NPN-transistor with their biasing circuit elements R_1, R_2 and Re. The Radio frequency choke (R.F.C) connected betn supply and collector offeres very high impedance to high frequency current and acts like short-circuit for d.c component. The frequency determining network is a parallel resonant circuit consist of L_1, L_2 and a variable capacitor C. The junction of L_1 and L_2 is earthed. One side L_1 is connected to base via C_b. So, L_1 is in input side.

Similarly, one end of L_2 is connected to collector via C_c contributes into output side. These two parts are inductively coupled.

Working operation :-

When, collector supply is switched 'ON', a transient current is produced in the tank circuit. The oscillatory current in the tank ckt produces a.c voltage across L_1. In this way, a feedback between o/p and I/p circuit take place through inductive coupled arrangement. Consequently, there is a phase shift of 180° betn o/p and I/p. The common-emitter amplifier also produces further 180° phase shift betn I/p and o/p. Thus, total phase shift becomes 360° (2π). This makes feedback positive which is the essential condition for oscillation. When, $|A\beta|$ is slightly greater than unity, oscillation developed in the circuit.

Frequency of oscillation (Mathematical analysis)

For, the analysis, we made following assumptions

i) h_{re} of transistor is negligibly small, hence $h_{re}V_o \simeq 0$

ii) h_{oe} is very small and hence $\frac{1}{h_{oe}}$ is very large.

Now, circuit as in fig-1 can be equivalently redrawn as shown in fig-2.

(2)

(3)

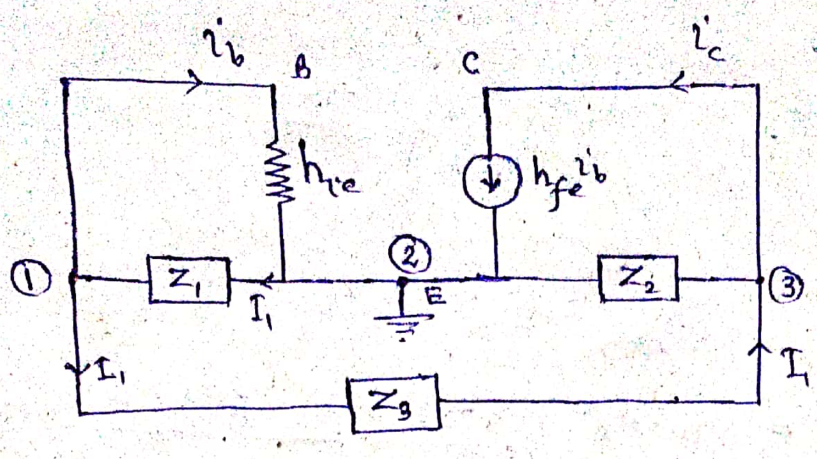

Fig-2

We, take load impedance Z_L betⁿ collector and emitter terminals. i.e betⁿ the terminals (2) and (3). It is clear, from fig-2 that, Z_1 and h_{ie} are parallel $(Z_1 \| h_{ie})$. Their impedance $(Z_1' = Z_1 \| h_{ie})$ is in series with Z_3. i.e $(Z_1' + Z_3)$ is in parallel with Z_2.

Now,
$$Z_1' = \frac{Z_1 h_{ie}}{Z_1 + h_{ie}} \quad \text{——— (i)}$$

$$\text{or } Z_1' + Z_3 = \left(\frac{Z_1 h_{ie}}{Z_1 + h_{ie}}\right) + Z_3 = \frac{Z_1 h_{ie} + Z_3(Z_1 + h_{ie})}{Z_1 + h_{ie}}$$

$$\text{or } Z_1' + Z_3 = \frac{h_{ie}(Z_1 + Z_3) + Z_1 Z_3}{Z_1 + h_{ie}} \quad \text{——— (ii)}$$

Now, load impedance Z_L is given by —

$$\frac{1}{Z_L} = \frac{1}{Z_2} + \frac{1}{(Z_1' + Z_3)}$$

(3)
or

$$\text{or } \frac{1}{Z_L} = \frac{1}{Z_2} + \frac{1}{\frac{h_{ie}(Z_1+Z_3)+Z_1Z_3}{Z_1+h_{ie}}}$$

$$\text{or } \frac{1}{Z_L} = \frac{1}{Z_2} + \frac{(Z_1+h_{ie})}{h_{ie}(Z_1+Z_3)+Z_1Z_3}$$

$$\text{or, } \frac{1}{Z_L} = \frac{[h_{ie}(Z_1+Z_3)+Z_1Z_2] + Z_2(Z_1+h_{ie})}{Z_2\cdot[h_{ie}(Z_1+Z_3)+Z_1Z_2]}$$

$$\text{or } \frac{1}{Z_L} = \frac{h_{ie}(Z_1+Z_2+Z_3)+Z_1Z_2+Z_1Z_3}{Z_2[h_{ie}(Z_1+Z_3)+Z_1Z_3]}$$

$$\text{or, } Z_L = \frac{Z_2[h_{ie}(Z_1+Z_3)+Z_1Z_3]}{h_{ie}(Z_1+Z_2+Z_3)+Z_1Z_2+Z_1Z_3} \quad \text{——— (iii)}$$

Since we know that, from h-parameter approximate analysis ———.

$$A_v = -\frac{h_{fe}Z_L}{h_{ie}} \quad \text{——— (iv)}; \text{ (see class notes)}$$

Now, feedback fraction 'β' can be calculated as:

The output voltage bet^n terminal (3) & (2); (fig-2)

$$V_o = (Z_1' + Z_3)I_1 = \left[\frac{h_{ie}(Z_1+Z_3)+Z_1Z_3}{Z_1+h_{ie}}\right]I_1$$

voltage feedback to the input terminals - (1) & (2)

$$V_f = Z_1' I_1 = \left(\frac{Z_1 h_{ie}}{Z_1+h_{ie}}\right)I_1$$

(a) Or

$$\therefore \beta = \frac{V_f}{V_o} = \left\{\left(\frac{Z_1 h_{ie}}{Z_1+h_{ie}}\right)I_1\right\} \div \left\{\frac{h_{ie}(Z_1+Z_3)+Z_1Z_3}{Z_1+h_{ie}}\right\}$$

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or $\beta = \dfrac{Z_1 h_{ie}}{Z_1 Z_3 + h_{ie}(Z_1+Z_3)}$ ——— (v)

From Barkhausen criterial, frequency to be sustain, $A\beta = 1$

Putting value of A from eqn (iv) and β from (v)

or $-\dfrac{h_{fe} Z_L}{\cancel{h_{ie}}} \cdot \dfrac{Z_1 \cancel{h_{ie}}}{Z_1 Z_3 + h_{ie}(Z_1+Z_3)} = 1$

or, $-\dfrac{h_{fe} Z_L Z_1}{Z_1 Z_3 + h_{ie}(Z_1+Z_3)} = 1$

Substituting value of Z_L from eqn (iii)

or $\dfrac{-h_{fe} Z_1}{\cancel{\{Z_1 Z_3 + h_{ie}(Z_1+Z_3)\}}} \times \dfrac{Z_2 \cancel{\{h_{ie}(Z_1+Z_3) + Z_1 Z_3\}}}{h_{ie}(Z_1+Z_2+Z_3) + Z_1 Z_2 + Z_1 Z_3} = +1$

or $-h_{fe} Z_1 Z_2 = h_{ie}(Z_1+Z_2+Z_3) + Z_1 Z_2 + Z_1 Z_3$

or $h_{ie}(Z_1+Z_2+Z_3) + Z_1 Z_3 + Z_1 Z_2(1+h_{fe}) = 0$ ——— (vi)

Eqn (vi) is called general eqn of oscillation.

Here for Hartley oscillator,

$Z_1 = j\omega L_1 + j\omega M = X_{L_1}$; M = Mutual inductance of coil

$Z_2 = j\omega L_2 + j\omega M = X_{L_2}$; (see in fig-1.)

$Z_3 = \dfrac{1}{j\omega C} = X_C \Rightarrow Z_3 = -\dfrac{j}{\omega C}$

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Substituting values of Z_1, Z_2 and Z_3 in eqⁿ (vi)

$$h_{ie}\left[(j\omega L_1 + j\omega M) + (j\omega L_2 + j\omega M) - \frac{j}{\omega C}\right] + (j\omega L_1 + j\omega M)(j\omega L_2 + j\omega M) \times (1 + h_{fe}) + (j\omega L_1 + j\omega M)\cdot\left(-\frac{j}{\omega C}\right) = 0$$

$$\text{or, } h_{ie}\left[j\omega(L_1 + M) + j\omega(L_2 + M) - \frac{j\omega}{\omega^2 C}\right] + j\omega(L_1 + M) \times j\omega(L_2 + M)(1 + h_{fe}) - j^2\cancel{\omega}(L_1 + M)\cdot\frac{1}{\cancel{\omega} C} = 0$$

$$\text{or, } j\omega h_{ie}\left[L_1 + M + L_2 + M - \frac{1}{\omega^2 C}\right] - \omega^2(L_1 + M)(L_2 + M)(1 + h_{fe}) - \times -1 \times \left(\frac{L_1 + M}{C}\right) = 0$$

$$\text{or, } j\omega h_{ie}\left[L_1 + L_2 + 2M - \frac{1}{\omega^2 C}\right] - \omega^2(L_1 + M)(L_2 + M)(1 + h_{fe}) + \left(\frac{L_1 + M}{C}\right) \times \frac{\omega^2}{\omega^2} = 0$$

$$\text{or, } -\omega^2(L_1 + M)\cdot\left\{(L_2 + M)(1 + h_{fe}) - \frac{1}{\omega^2 C}\right\} + j\omega h_{ie}\left[L_1 + L_2 + 2M - \frac{1}{\omega^2 C}\right] = 0 = 0 + j\cdot 0$$

Equating real part to real part, and imaginary part to imaginary part on both sides,

$$L_1 + L_2 + 2M - \frac{1}{\omega^2 C} = 0 \qquad \text{or } L_1 + L_2 + 2M = \frac{1}{\omega^2 C}$$

$$\text{or } \frac{1}{\omega^2} = (L_1 + L_2 + 2M)C \qquad \text{or } \omega^2 = \frac{1}{(L_1 + L_2 + 2M)C}$$

$$\text{or, } \omega = \frac{1}{\sqrt{(L_1 + L_2 + 2M)C}} \Rightarrow \boxed{f = \frac{1}{2\pi\sqrt{(L_1 + L_2 + 2M)C}}}$$

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∴ frequency of oscillation of Hartley oscillator is given by —

$$\boxed{f = \frac{1}{2\pi\sqrt{(L_1 + L_2 + 2M)C}}} \quad \text{—— (VII)}$$

<u>Condition for maintenance of oscillation</u>

Condition for maintenance of oscillation can be obtained from real part —

i.e $\omega^2 (L_1 + M)\left[(L_2 + M)(1 + h_{fe}) - \frac{1}{\omega^2 c}\right] = 0$

∵ $\omega \neq 0$, $L_1 + M \neq 0$.

$(1 + h_{fe})(L_2 + M) - \frac{1}{\omega^2 c} = 0$ or $(1 + h_{fe}) = \frac{1}{\omega^2 c (L_2 + M)}$

(7)

Om

From previous discussion, we have

$$\frac{1}{\omega^2 C} = L_1 + L_2 + 2M.$$

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

$$\text{or, } h_{fe} = \frac{L_1 + L_2 + 2M}{L_2 + M} - 1$$

$$\text{or, } \boxed{h_{fe} = \left(\frac{L_1 + M}{L_2 + M}\right)} \quad \text{—— (VIII)}$$

Eq^n (VIII) gives condition for maintenance of

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oscillation.