1.5 HARTLEY OSCILLATOR

LC oscillator:

- The oscillators which use the elements L and C to produce the oscillations are called LC oscillators.
- The circuit using elements L and C is called tank circuit or oscillatory circuit, which is an important part of LC oscillators.
- These oscillators are used for high frequency range from 00 kHz up to few GHz.
- The LC tank circuit consists of elements L and C connected in parallel

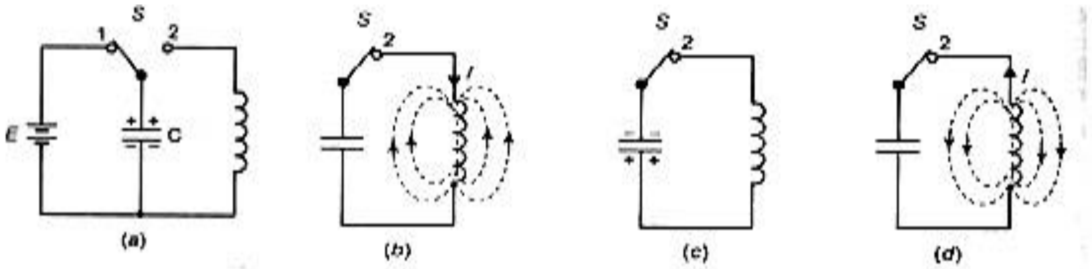

Figure 2.4.1 Operation of LC tank circuit

[Source: Microelectronics by J. Millman and A. Grabel, Page-395]

- The energy keeps oscillating between electric potential energy and magnetic field energy
- The capacitor stores energy in the form of an electrostatic field and which produces a potential (static voltage) across its plates, while the inductive coil stores its energy in the form of an electromagnetic field.
- The capacitor is charged up to the DC supply voltage, V by putting the switch in position 1.
- When the capacitor is fully charged the switch changes to position 2.
- The charged capacitor is now connected in parallel across the inductive coil so the capacitor begins to discharge itself through the coil.
- The voltage across C starts falling as the current through the coil begins to rise. This rising current sets up an electromagnetic field around the coil which resists this flow of current.
- When the capacitor, C is completely discharged the energy that was

originally stored in the capacitor, C as an electrostatic filed is now stored in the inductive coil, L as an electromagneticfield around the coils windings.

- As there is now no external voltage in the circuit to maintain the current within the coil, it starts to fall as the electromagnetic field begins to collapse. A back emf is induced in the coil (e=-Ldi/dt) keeping the current flowing in the original direction. This current now charges up the capacitor, c with the opposite polarity to its original charge.
- Capacitor continues to charge up until the current reduces to zero and the electromagnetic field ofthe coil has collapsed completely.
- The capacitor now starts to discharge again back through the coil and the whole process so repeated.
- The polarity of the voltage changes as the energy is passed back and forth between the capacitor and inductor producing an AC type sinusoidal voltage and current waveform.
- The frequency of oscillations generated by LC tank circuit depends on the values L and C is given by,

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

Hartley Oscillator:

- A LC oscillator which uses two inductive reactance and one capacitive reactance in its feedback network is called Hartley oscillator.

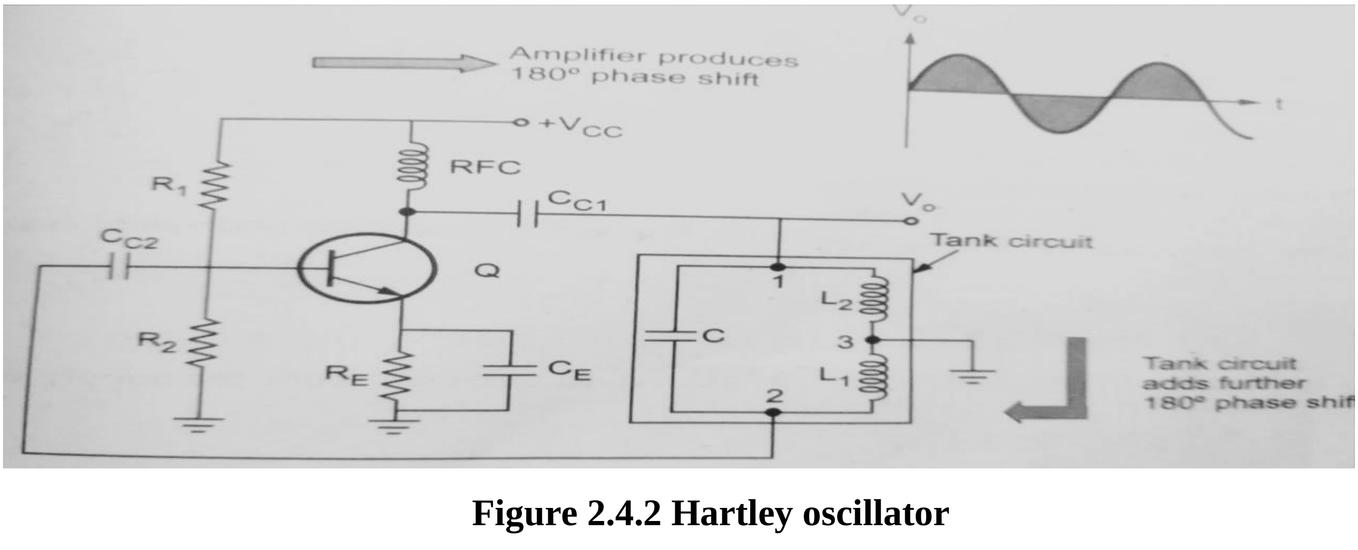

Figure 2.4.2 Hartley oscillator

[Source: Microelectronics by J. Millman and A. Grabel, Page-396]

- CE amplifier provides a phase shift of 180^0 and LC feedback network provides additional 180^0 phase shift.
- The resistance R1 and R2 are the biasing resistances. The RFC is the radio frequency choke.
- Its reactance value is very high frequencies; hence it can be treated as open circuit. While for d.c conditions, the reactance is zero hence cause no problem for d.c capacitors.
- Hence due to RFC, the isolation between a.c. and d.c operation is achieved.

Derivation of frequency of oscillations:

- Output current is collector current is

$$h_{fe}I_b$$

- As h_{ie} is the input impedance of the transistor. The output of the feedback is current I_b which is the input current of the transistor.

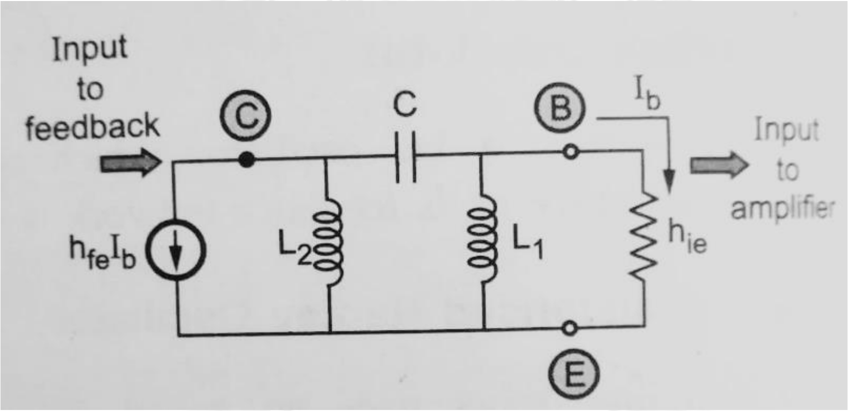

Figure 2.4.3 equivalent circuit

[Source: Microelectronics by J. Millman and A. Grabel, Page-396]

- 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

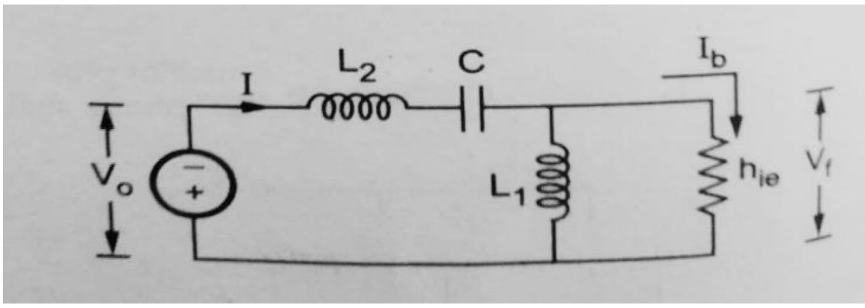

Figure 2.4.4 simplified equivalent circuit

[Source: Microelectronics by J. Millman and A. Grabel, Page-396]

$$V_0 = h_{fe} I_b X_{L2} = h_{fe} I_b j\omega L_2 - - - - - (1)$$

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

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

- Negative sign, as current direction shown in opposite to the polarities of V_o.

$$X_{L2} + X_c = j\omega L_2 + \frac{1}{j\omega C}$$

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

Substituting in the equation (2) we get,

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

According to current division in parallel circuit,

$$I_b = I\ X\ \frac{X_{L1}}{X_{L1} + h_{ie}} = I\ X\ \frac{j\omega L_1}{j\omega L_1 + h_{ie}} - - - - - (4)$$

Substituting in the equation (3) we get,

$$I_b = \frac{-h_{fe} I_b j\omega L_2}{\left[j\omega L_2 + \frac{1}{j\omega C}\right] + [\frac{j\omega L_1 h_{ie}}{(j\omega L_1 + h_{ie})}]}\ X\ \frac{j\omega L_1}{j\omega L_1 + h_{ie}}$$

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

Rationalizing R.H.S of the above equation.

$$1 = \frac{\omega^4 h_{fe} L_1^2 L_2 C(1 - \omega^2 L_2 C) + j\omega^3\ h_{fe} C\ L_1 L_2 [h_{ie} - \omega^2 C h_{ie}(L_1 + L_2)]}{[h_{ie} - \omega^2 C h_{ie}(L_1 + L_2)]^2 + \omega^2 L_1^2 (1 - \omega^2 L_2 C)^2} - - (5)$$

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

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

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

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

$$f = \frac{1}{2\pi\sqrt{C(L_1 + L_2)}}$$

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 (5)

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

At

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

$$h_{fe} = \frac{L_1}{L_2}$$

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

For mutual inductance of M

$$h_{fe} = \frac{L_1 + M}{L_2 + M}$$