LC Oscillators

LC Oscillators

Oscillators that uses LC network as Feedback:

i. **Tuned Collector Oscillator**
ii. **Colpitts Oscillator**
iii. **Clapp Oscillator**
iv. **Hartley Oscillator**
v. **Armstrong Oscillator**
vi. **Crystal Oscillator**

Tuned Collector Oscillator

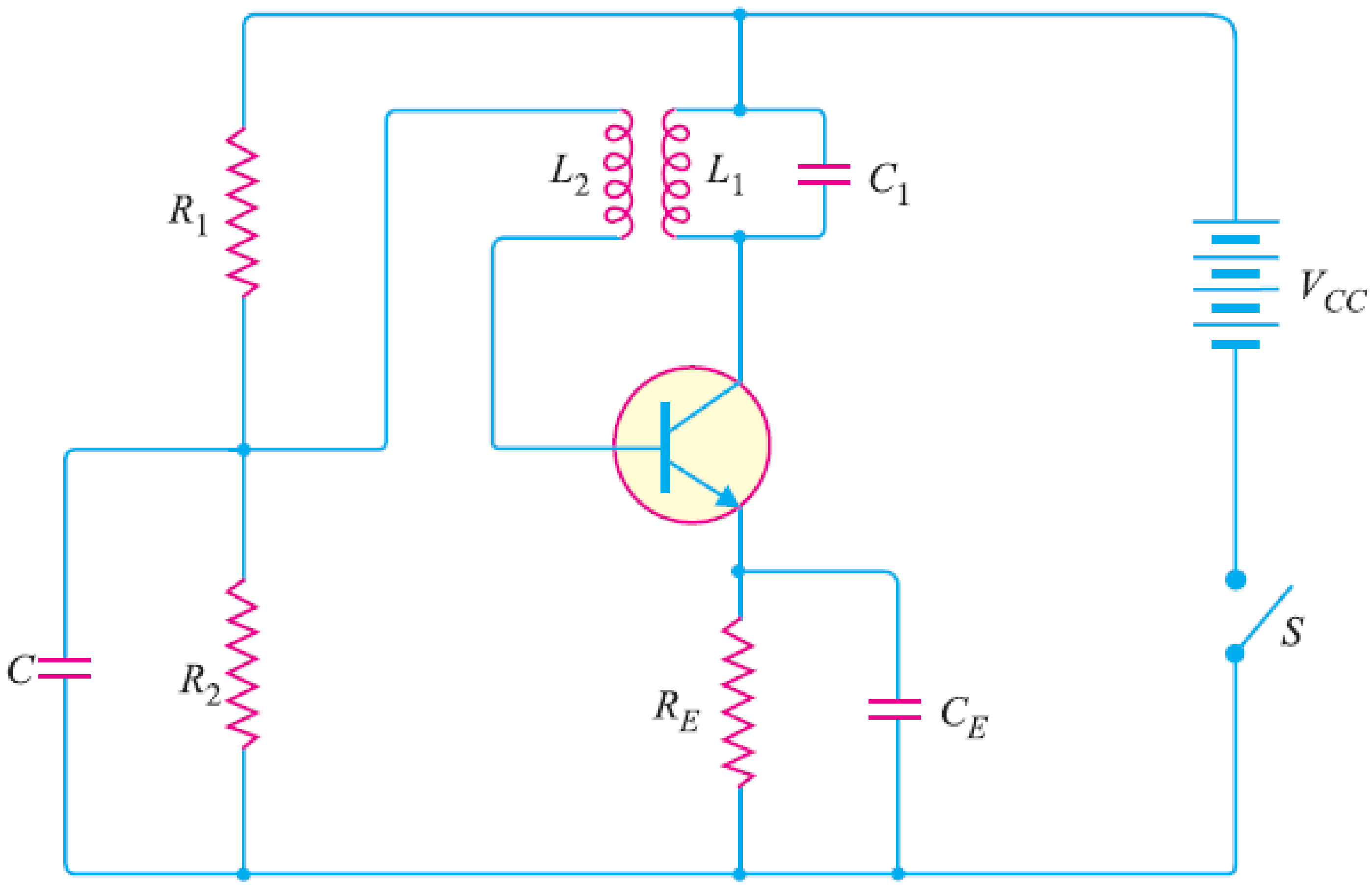
- It contains tuned circuit *L*1-*C*1 in the collector and hence the name.

Frequency of Oscillation:

$$f = \frac{1}{2\pi\sqrt{L_1 C_1}}$$

*The LC circuit is often called tuned circuit or tank circuit.

*Transformer provides 180° phase shift.



Circuit Operation

- The feedback coil L2 in the base circuit is magnetically coupled to the tank circuit coil L1.
- In practice, L1 and L2 form the primary and secondary of the transformer respectively.
- The biasing is provided by potential divider arrangement. The capacitor C connected in the base circuit provides low reactance path to the oscillations.
- When switch S is closed, collector current starts increasing and charges the capacitor $C1$. When this capacitor is fully charged, it discharges through coil $L1$, setting up oscillations of frequency.
- These oscillations induce some voltage in coil $L2$ by mutual induction. The frequency of voltage in coil $L2$ is the same as that of tank circuit but its magnitude depends upon the number of turns of $L2$ and coupling between $L1$ and $L2$.
- The voltage across $L2$ is applied between base and emitter and appears in the amplified form in the collector circuit, thus overcoming the losses occurring in the tank circuit.
- The number of turns of $L2$ and coupling between $L1$ and $L2$ are so adjusted that oscillations across $L2$ are amplified to a level just sufficient to supply losses to the tank circuit.

Circuit Operation

- It may be noted that the phase of feedback is correct i.e. energy supplied to the tank circuit is in phase with the generated oscillations.
- A phase shift of 180º is created between the voltages of L1 and L2 due to transformer *action.
- A further phase shift of 180º takes place between base-emitter and collector circuit due to transistor properties. As a result, the energy fedback to the tank circuit is in phase with the generated oscillations.

Sample Problem #1

The tuned collector oscillator circuit used in the local oscillator of a radio receiver makes use of an LC tuned circuit with $L1 = 58.6\ \mu H$ and $C1 = 300\ pF$. Calculate the frequency of oscillations.

Ans.

1.2 MHz

Sample Problem #2

Find the capacitance of the capacitor required to build an LC oscillator that uses an inductance of L1 = 1 mH to produce a sine wave of frequency 1000 GHz.

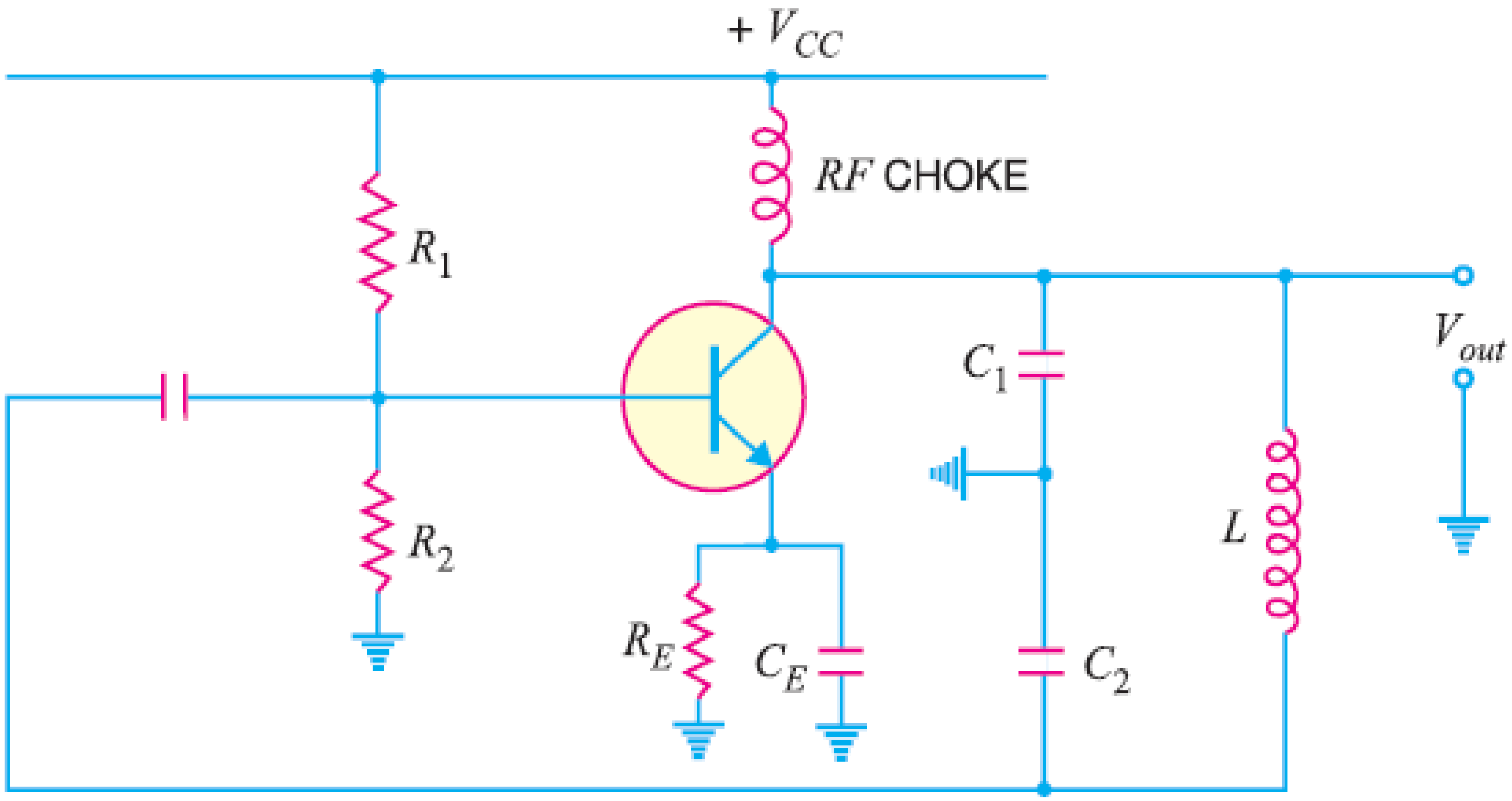
Ans.

$$25.33 \times 10^{-24}\ \mathrm{F}$$

Colpitts Oscillator

- It is one basic types of resonant circuit feedback oscillators.
- Named after its inventor, Edwin Henry Colpitts.
- Uses an LC circuit in the feedback loop to provide the necessary phase shift and to act as a resonant filter that passes only the desired frequency of oscillation.
- It uses two capacitors and placed across a common inductor L and the center of the two capacitors is tapped.
- The tank circuit is made up of C1, C2 and L.

Colpitts Oscillator



*The RF choke decouples any ac signal on the power lines from affecting the output signal.

Frequency of Oscillation:

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

Where:

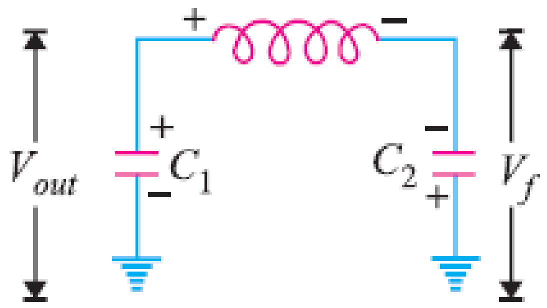
$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

C_T = total capacitance

*Note that C1 – C2 – L is also the feedback circuit that produces a phase shift of 180°.

Circuit Operation

- When the circuit is turned on, the capacitors *C*1 and *C*2 are charged.
- The capacitors discharge through *L*, setting up oscillations of frequency determined by the formula.
- The output voltage of the amplifier appears across *C*1 and feedback voltage is developed across *C*2.
- The voltage across it is 180° out of phase with the voltage developed across *C*1 (*Vout*) as shown in figure.
- It is easy to see that voltage fedback (voltage across *C*2) to the transistor provides positive feedback.
- A phase shift of 180° is produced by the transistor and a further phase shift of 180° is produced by *C*1 – *C*2 voltage divider.
- In this way, feedback is properly phased to produce continuous undamped oscillation.



FEEDBACK CIRCUIT

Feedback Fraction ($\boldsymbol{\beta}$)

The amount of feedback voltage in Colpitt's oscillator depends upon feedback fraction β of the circuit.

Feedback fraction (β):

$$\beta = \frac{V_f}{V_{out}} = \frac{X_{c2}}{X_{c1}} = \frac{C_1}{C_2}$$

Or

$$\boldsymbol{\beta = \frac{C_1}{C_2}}$$

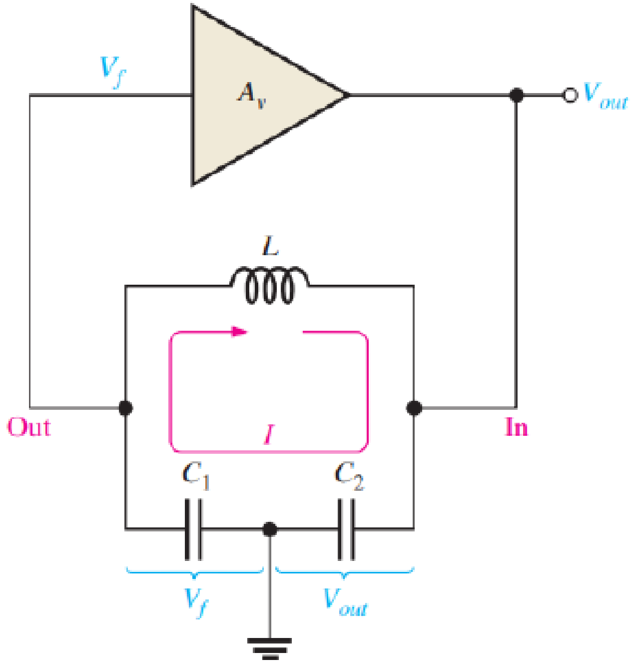
From Module

$$B = \frac{V_f}{V_{out}} \cong \frac{IX_{C1}}{IX_{C2}} = \frac{X_{C1}}{X_{C2}} = \frac{1/(2\pi f_r C_1)}{1/(2\pi f_r C_2)}$$

Cancelling the $2\pi f_r$ terms gives

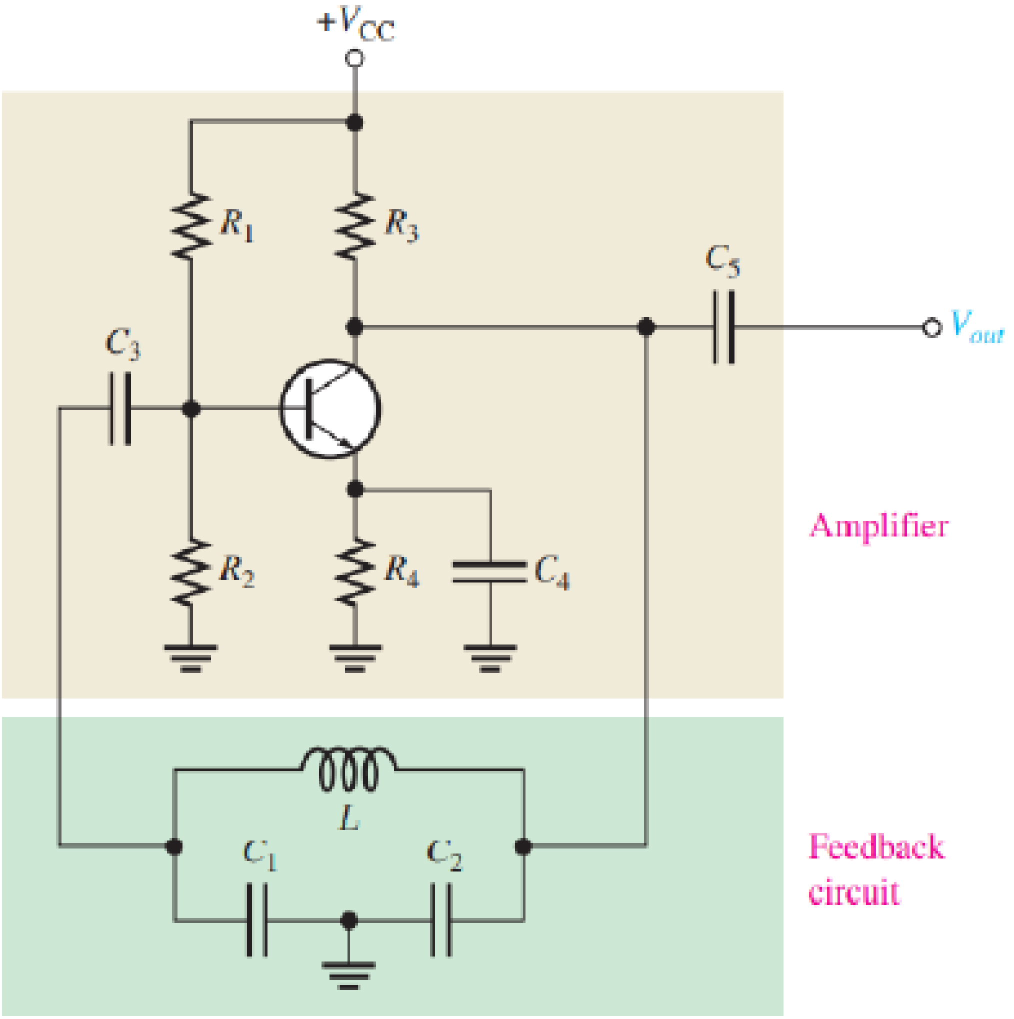
$$B = \frac{C_2}{C_1}$$

As you know, a condition for oscillation is Since $A_V B = 1$. Since $B = {C_2}/{C_1}$



$$\boldsymbol{A_V = \frac{C_1}{C_2}}$$

$$A_V > \boldsymbol{\frac{C_1}{C_2}}$$

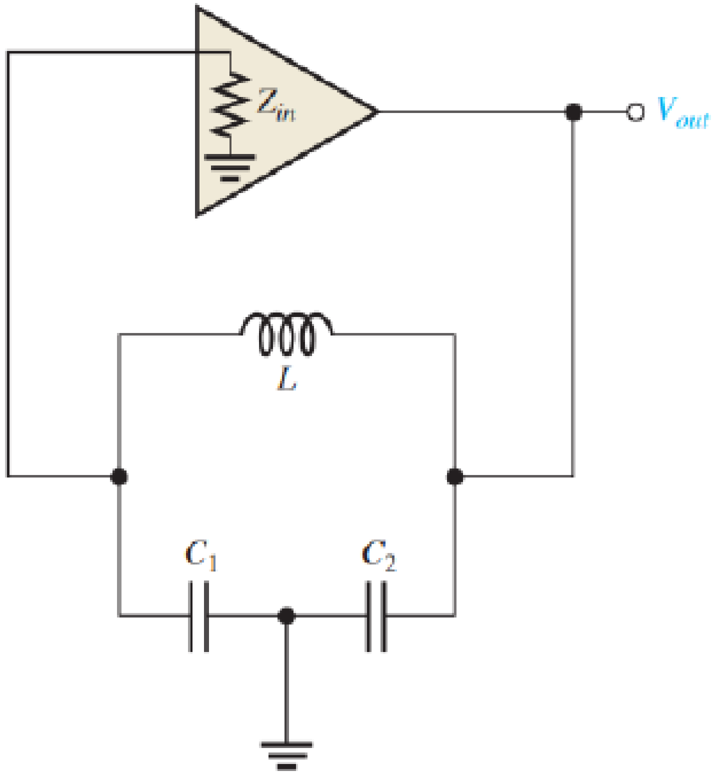


Loading of the Feedback Circuit Affects the Frequency of Oscillation

The input impedance of the amplifier acts as a load on the resonant feedback circuit and reduces the Q of the circuit.

The resonant frequency of a parallel resonant circuit depends on the Q, according to the following formula:

$$f_r = \frac{1}{2\pi\sqrt{LC_T}}\left(\sqrt{\frac{Q^2}{Q^2+1}}\right)$$

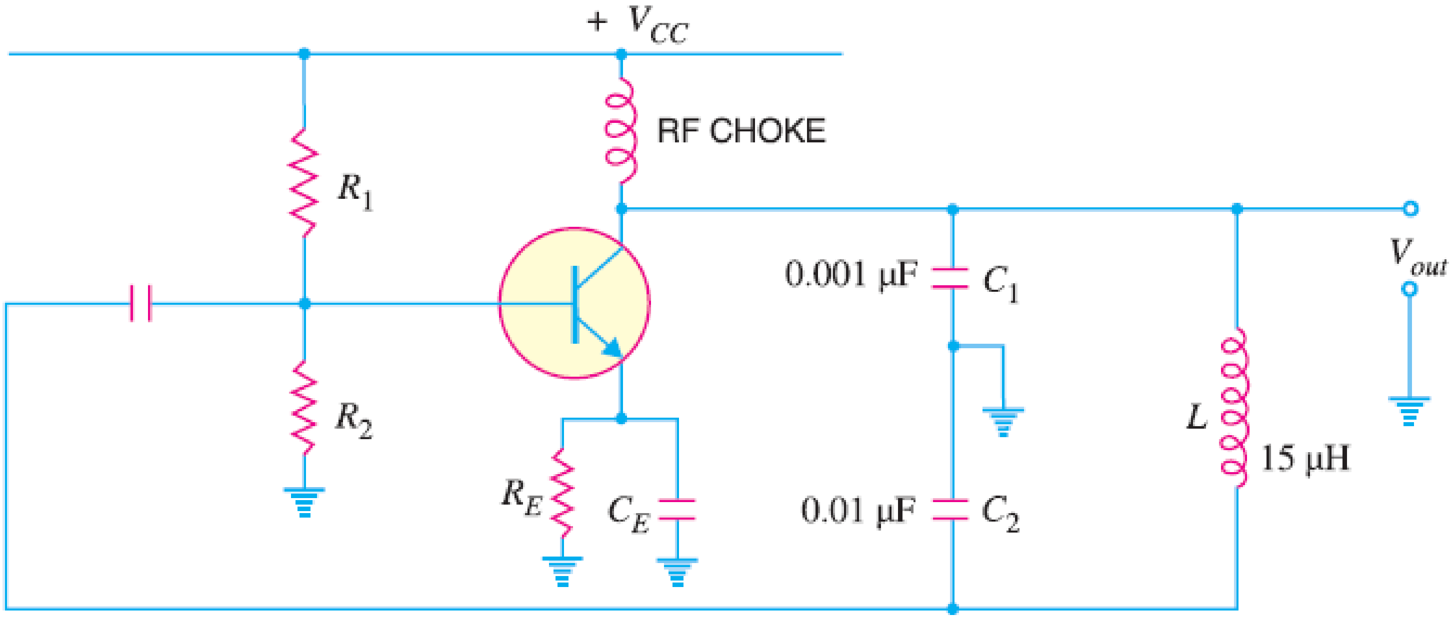


Problem #3

Determine the

(i) Operating frequency and

(ii) Feedback fraction for Colpitt's oscillator figure.



Ans.

(i) 1.363 MHz

(ii) 1/10 or 0.1

Problem #4

A 1 mH inductor is available. Choose the capacitor values in a Colpitts oscillator so that f = 1 MHz and β = 0.25.

Ans.

$C1 = 31.66$ pF

$C2 = 126.65$ pF

Clapp Oscillator

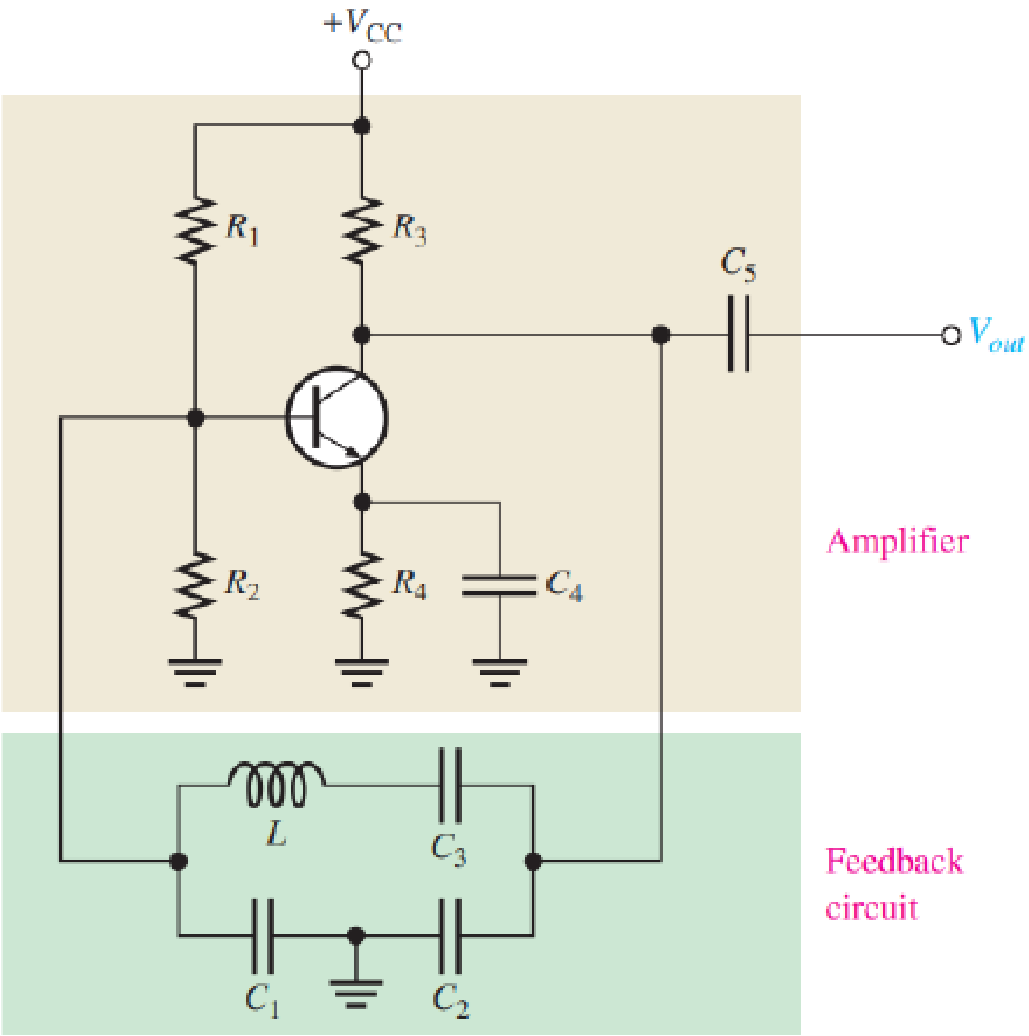
- By **James Kilton Clapp**
- The Clapp oscillator is a variation of the Colpitts
- The basic difference is an additional capacitor, C3 in series with the inductor in the resonant feedback circuit.

Frequency of Oscillation: $(\mathrm{Q} > 10)$

$$\boldsymbol{f \cong \frac{1}{2\pi\sqrt{L_1 C_T}}}$$

Where:

$$\boldsymbol{C_T = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$



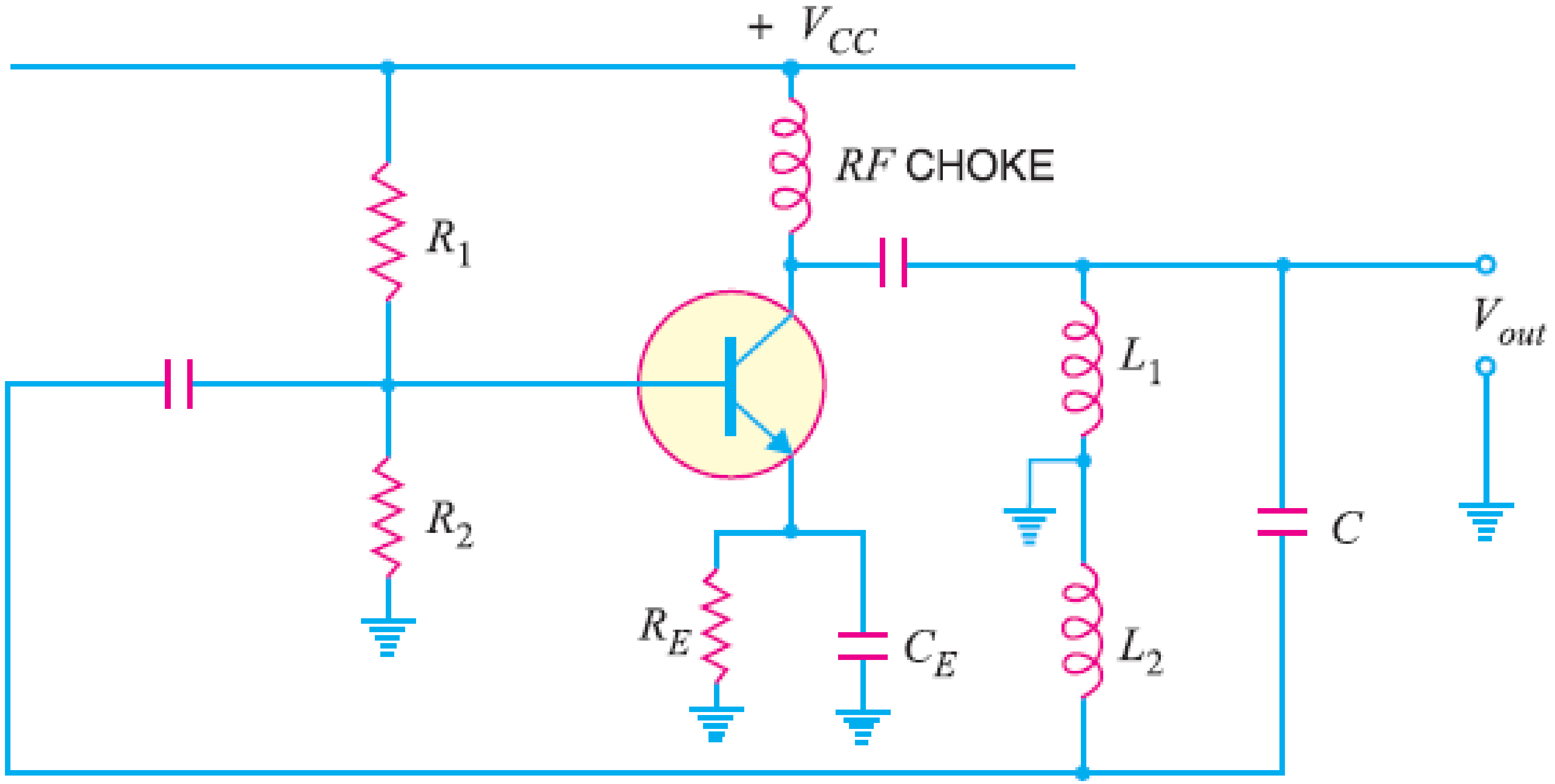
Clapp Oscillator

- If $C3$ is much smaller than $C1$ and $C2$, then $C3$ almost entirely controls the resonant frequency ($fr \cong 1/(2\pi\sqrt{LC3})$).
- Since $C1$ and $C2$ are both connected to ground at one end, the junction capacitance of the transistor and other stray capacitances appear in parallel with $C1$ and $C2$ to ground, altering their effective values.
- $C3$ is not affected, however, and thus provides a more accurate and stable frequency of oscillation.

Hartley Oscillator

- The Hartley oscillator is similar to Colpitt’s oscillator with minor modifications.
- Instead of using tapped capacitors, two inductors $L1$ and $L2$ are placed across a common capacitor C and the center of the inductors is tapped.
- It was named after **Ralph Hartley.**

Hartley Oscillator



Frequency of Oscillation:

$$\boldsymbol{f = \frac{1}{2\pi\sqrt{L_T C}}}$$

Where:

$$\boldsymbol{L_T = L_1 + L_2 \pm 2\mathrm{M}}$$

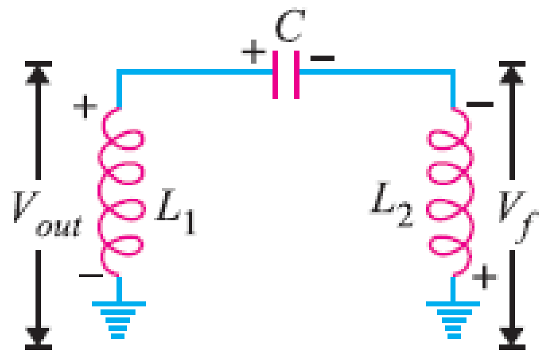
$M = mutual\ inductance$

$C_T = total\ capacitance$

**Note that L1 – L2 – C is also the feedback circuit that produces a phase shift of 180°.*

Circuit Operation

- When the circuit is turned on, the capacitor is charged.
- When this capacitor is fully charged, it discharges through coils $L1$ and $L2$ setting up oscillations of frequency determined by the formula.
- The output voltage of the amplifier appears across $L1$ and feedback voltage across $L2$.
- The voltage across $L2$ is 180° out of phase with the voltage developed across $L1$ (*Vout*) as shown in the figure.
- It is easy to see that voltage fedback (*i.e.*, voltage across $L2$) to the transistor provides positive feedback.
- A phase shift of 180° is produced by the transistor and a further phase shift of 180° is produced by $L1 – L2$ voltage divider.
- In this way, feedback is properly phased to produce continuous undamped oscillations.



FEEDBACK CIRCUIT

Feedback Fraction ($\boldsymbol{\beta}$)

In Hartley oscillator, the feedback voltage is across L2 and output voltage is across L1.

Feedback fraction (β):

$$\beta = \frac{V_f}{V_{out}} = \frac{X_{L2}}{X_{L1}} = \frac{L_2}{L_1}$$

Or

$$\boldsymbol{\beta = \frac{L_2}{L_1}}$$

From Module

In this circuit, the frequency of oscillation for Q > 10 is

$$f_r \cong \frac{1}{2\pi\sqrt{L_T C}}$$

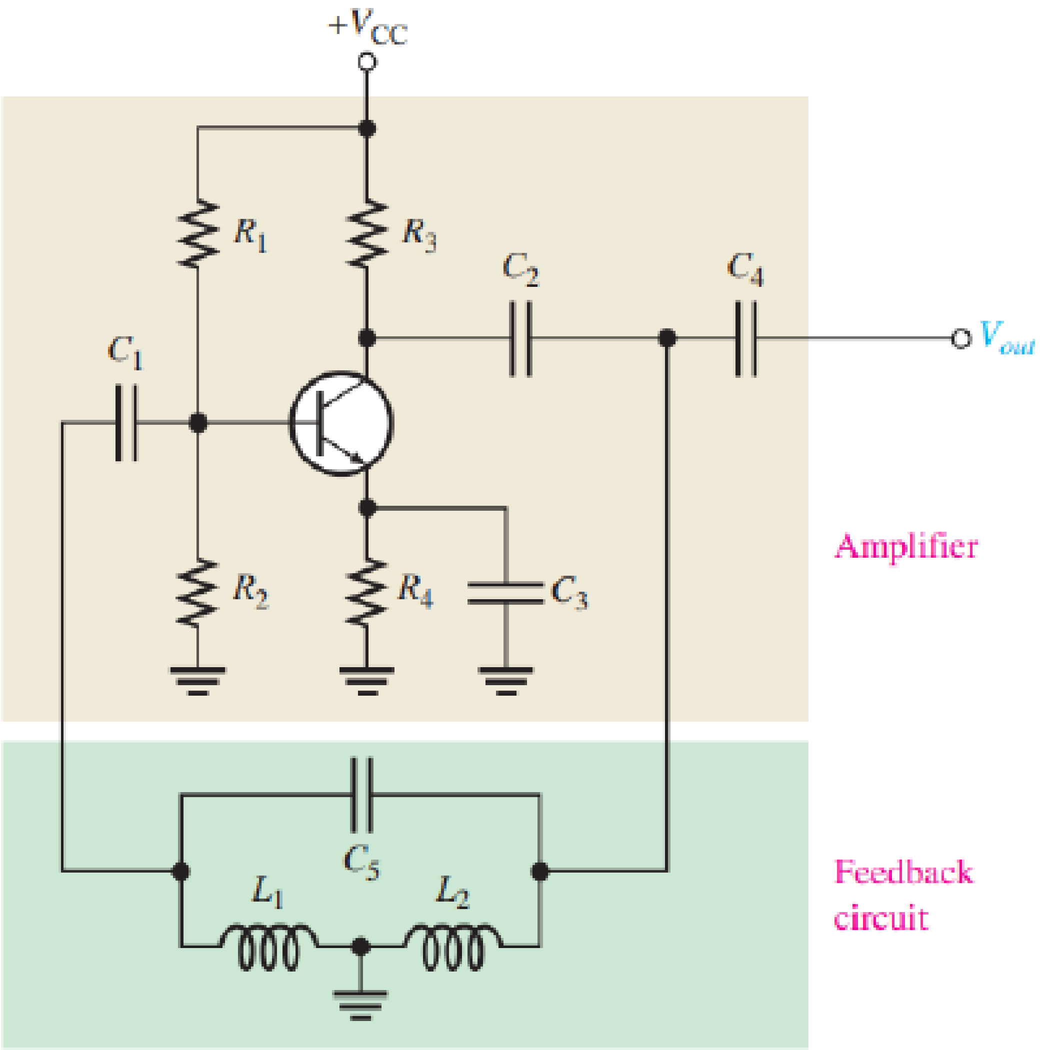
where $L_T = L_1 + L_2$ .The inductors act in a role similar to C_1 and C_2 in the Colpitts to determine the attenuation, *B*, of the feedback circuit.

$$B \cong \frac{L_1}{L_2}$$

To assure start-up of oscillation, A must be greater than 1/*B*.

$$A_v \cong \frac{L_2}{L_1}$$

Loading of the tank circuit has the same effect in the Hartley as in the Colpitts; that is, the Q is decreased and thus f_r decreases.

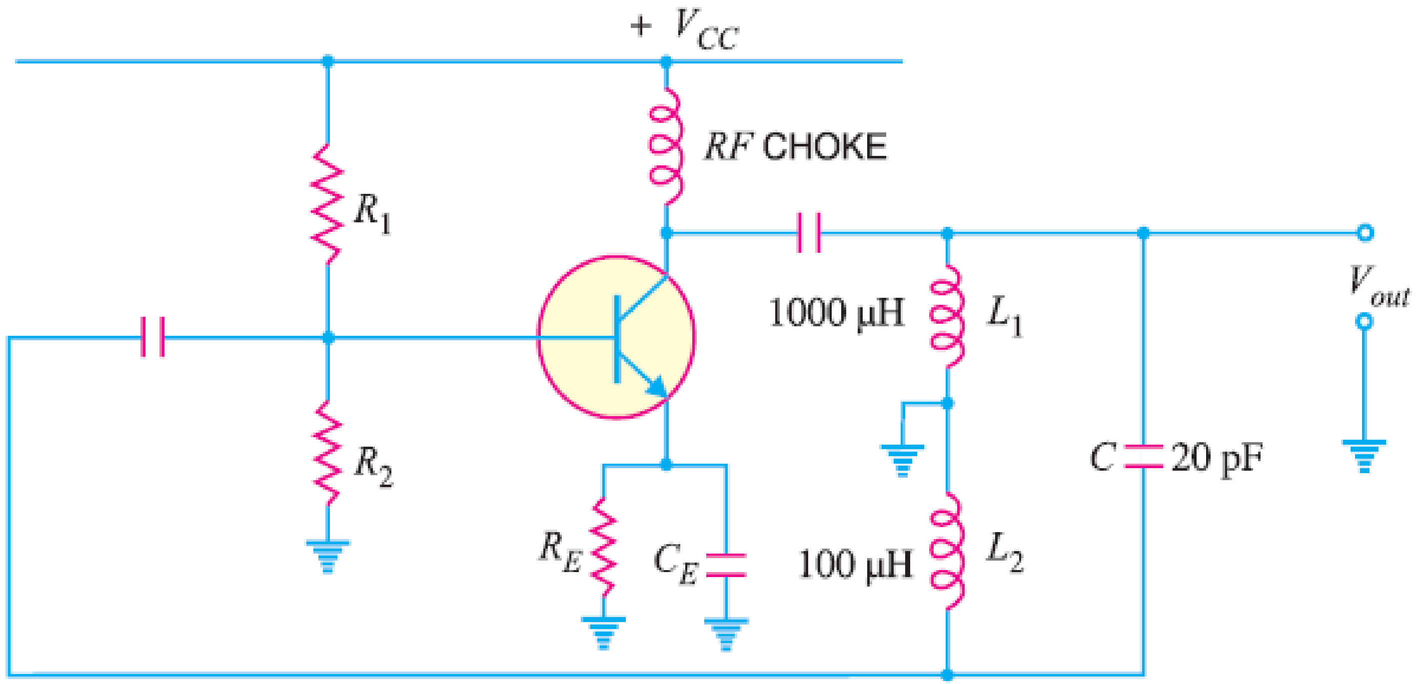


Problem #5

Calculate the

(i) Operating frequency and

(ii) Feedback fraction for Hartley oscillator shown in the figure. The mutual inductance between the coils, M = 20 μH. (Assume aiding inductance)



Ans.

(i) 1.054 MHz

(ii) 1/10 or 0.1

Problem #6

A 1 pF capacitor is available. Choose the inductor values in a Hartley oscillator so that f = 1 MHz and β = 0.2.

Ans.

L1 = 21.11 mH

L2 = 4.22 mH

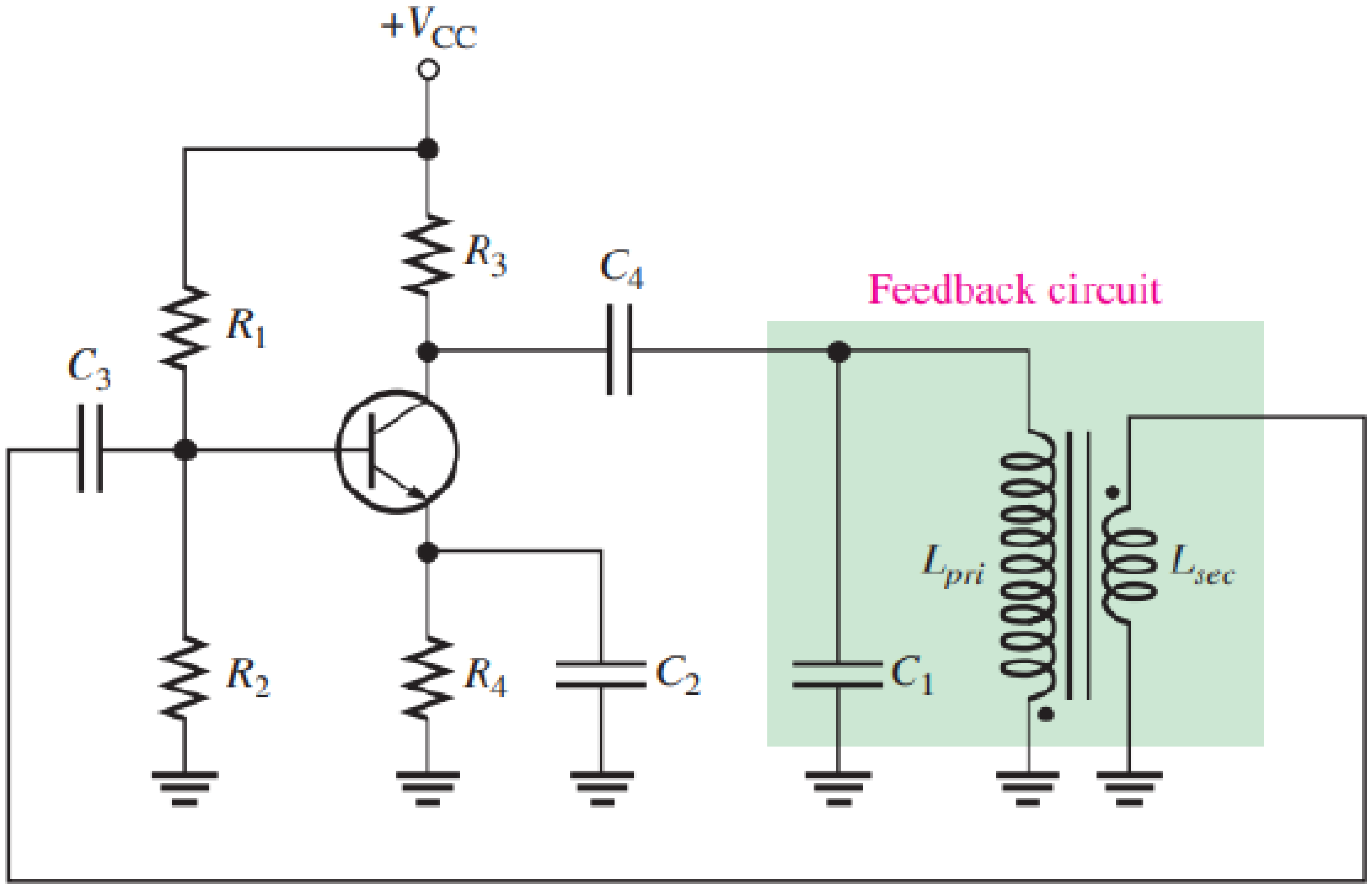
Armstrong Oscillator

- This type of LC feedback oscillator uses transformer coupling to feed back a portion of the signal voltage.
- It is sometimes called a "tickler" oscillator in reference to the transformer secondary or "tickler coil" that provides the feedback to keep the oscillation going.
- The Armstrong is less common than the Colpitts, Clapp, and Hartley, mainly because of the disadvantage of transformer size and cost.
- The frequency of oscillation is set by the inductance of the primary winding ($\boldsymbol{Lpri}$) in parallel with $\boldsymbol{C1}$.

Armstrong Oscillator

Frequency of Oscillation:

$$f = \frac{1}{2\pi\sqrt{L_T C}}$$

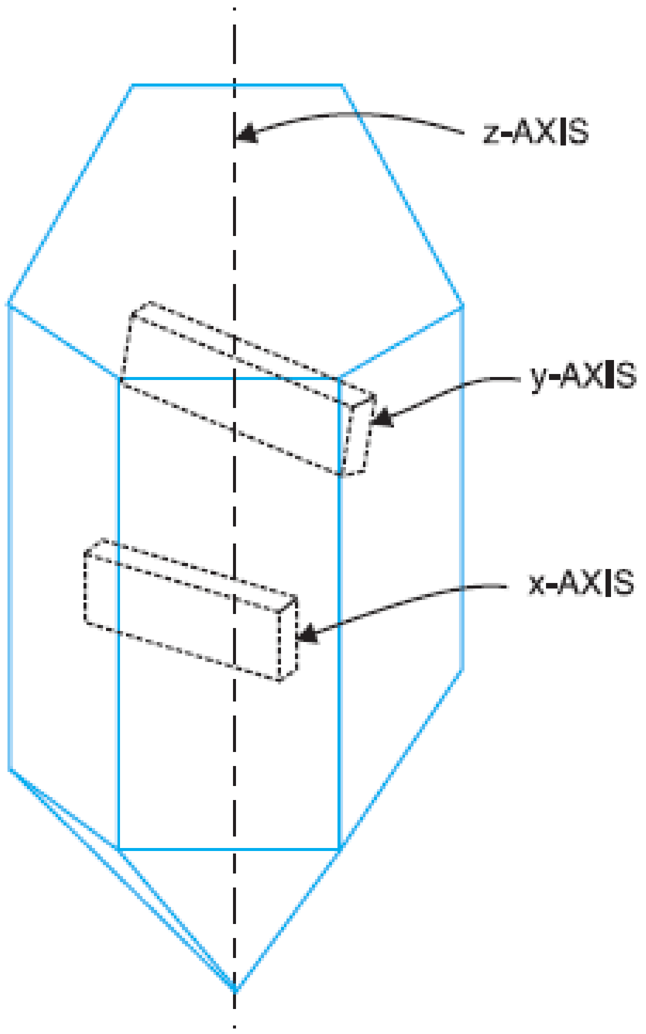


Crystal-Controlled Oscillator

- Certain crystalline materials, namely, Rochelle salt, quartz and tourmaline exhibit the *piezoelectric effect i.e.*, when we apply an a.c. voltage across them, they vibrate at the frequency of the applied voltage.
- Conversely, when they are compressed or placed under mechanical strain to vibrate, they produce an a.c. voltage.
- Such crystals which exhibit piezoelectric effect are called *piezoelectric crystals*.
- Of the various piezoelectric crystals, quartz is most commonly used because it is inexpensive and readily available in nature.

Quartz Crystal

- Quartz crystals are generally used in crystal oscillators because of their great mechanical strength and simplicity of manufacture.
- The natural shape of quartz crystal is hexagonal as shown in the figure.
- The three axes are shown : the z-axis is called the optical axis, the x-axis is called the electrical axis and y-axis is called the mechanical axis.
- Quartz crystal can be cut in different ways.
- Crystal cut perpendicular to the x-axis is called x-cut crystal whereas that cut perpendicular to y-axis is called y-cut crystal. The piezoelectric properties of a crystal depend upon its cut.



Frequency of Crystal

Each crystal has a natural frequency like a pendulum.

The natural frequency *f* of a crystal is given by :

$$f = \frac{K}{t}$$

Where

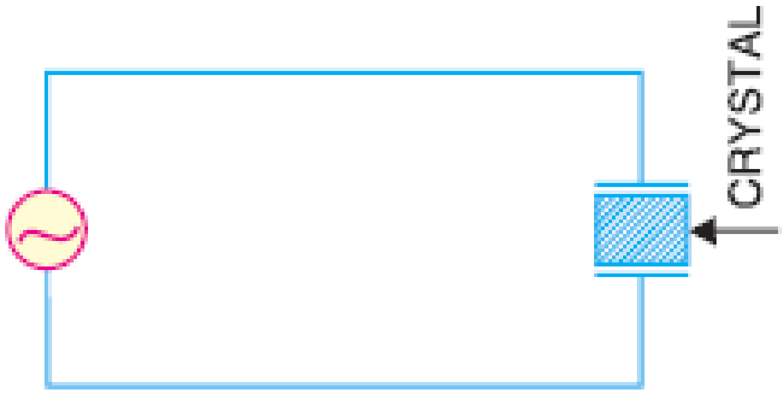
K is a constant that depends upon the cut and

t is the thickness of the crystal.

- It is clear that frequency is inversely proportional to crystal thickness.
- The thinner the crystal, the greater is its natural frequency and *vice-versa*.
- However, extremely thin crystal may break because of vibrations. This puts a limit to the frequency obtainable.
- In practice, frequencies between *25 kHz* to *5 MHz* have been obtained with crystals.

Working of Quartz Crystal

- In order to use crystal in an electronic circuit, it is placed between two metal plates.
- The arrangement then forms a capacitor with crystal as the dielectric as shown in the figure.
- If an a.c. voltage is applied across the plates, the crystal will start vibrating at the frequency of applied voltage.
- However, if the frequency of the applied voltage is made equal to the natural frequency of the crystal, resonance takes place and crystal vibrations reach a maximum value.
- This natural frequency is almost constant.
- Effects of temperature change can be eliminated by mounting the crystal in a temperature-controlled oven as in radio and television transmitters.

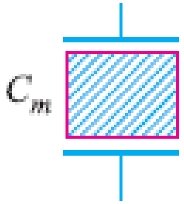


Equivalent Circuit of Crystal

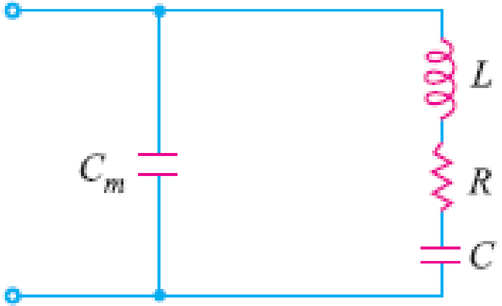
Although the crystal has electromechanical resonance, we can represent the crystal action by an equivalent electrical circuit.

i. When the crystal is not vibrating, it is equivalent to capacitance *Cm* because it has two metal plates separated by a dielectric. This capacitance is known as *mounting capacitance*.

ii. When a crystal vibrates, it is equivalent to R – L – C series circuit. Therefore, the equivalent circuit of a vibrating crystal is R – L – C series circuit shunted by the mounting capacitance Cm.

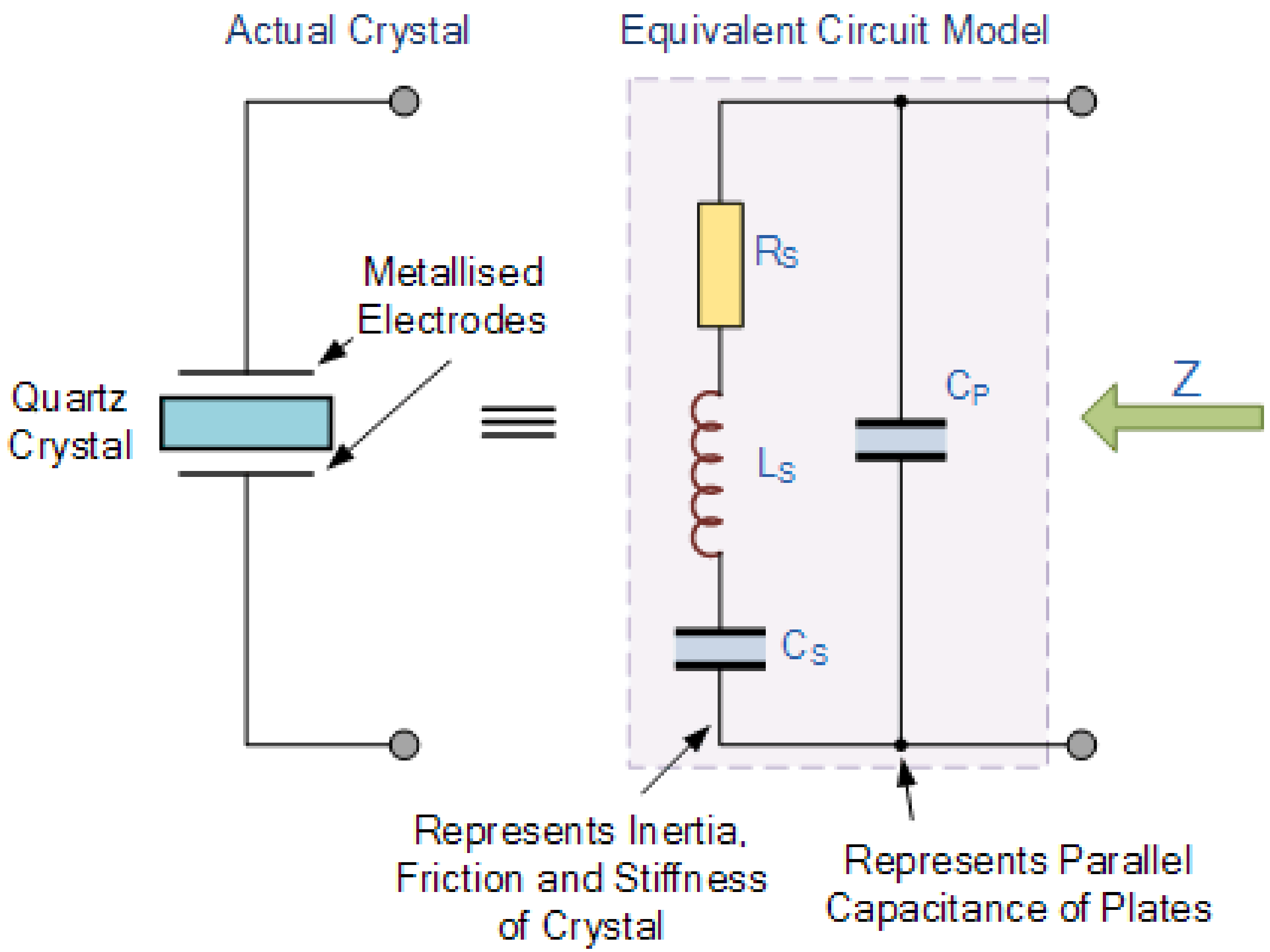


(i)



(ii)

Equivalent Circuit of Crystal

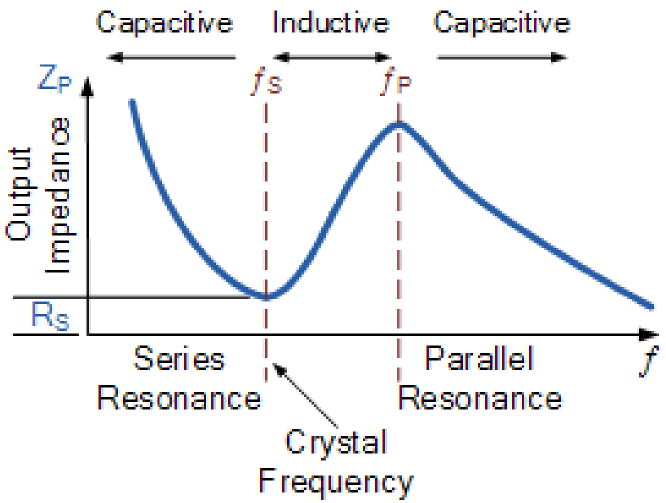


Frequency of Oscillation

- Quartz crystal oscillators tend to operate towards their "series resonance".
- The equivalent impedance of the crystal has a series resonance where Cs resonates with inductance, Ls at the crystals operating frequency. This frequency is called the crystals series frequency, ƒs.
- There is a second frequency point established as a result of the parallel resonance created when Ls and Cs resonates with the parallel capacitor Cp.

Frequency of Oscillation

- Crystal Impedance against Frequency



$$R = R \quad \text{and} \quad X_{LS} = 2\pi f L_S$$

$$X_{CS} = \frac{1}{2\pi f C_S} \quad \text{and} \quad X_{CP} = \frac{1}{2\pi f C_P}$$

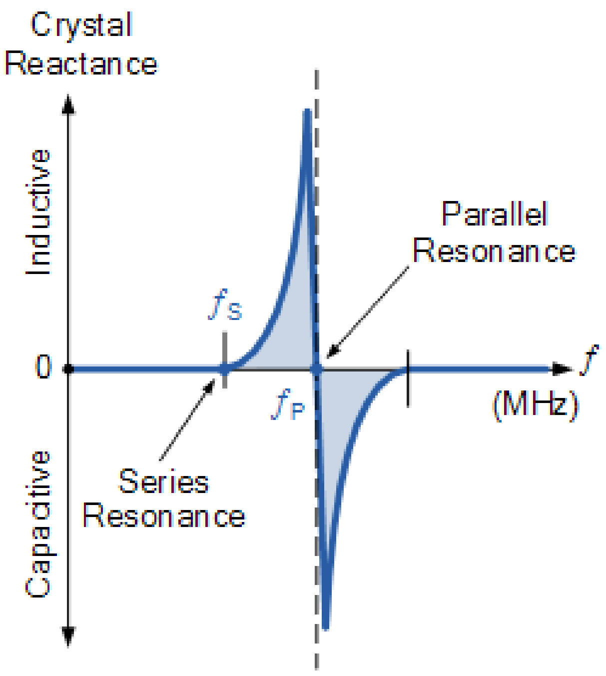
$$Z_S = \sqrt{R_S^2 + \left(X_{LS} - X_{CS}\right)^2}$$

$$\therefore Z_P = \frac{Z_S \times X_{CP}}{Z_S + X_{CP}}$$

As the frequency increases above the series resonance point, the crystal behaves like an inductor until the frequency reaches its parallel resonant frequency fp.
At this frequency point the interaction between the series inductor, Ls and parallel capacitor, Cp creates a parallel tuned LC tank circuit and as such the impedance across the crystal reaches its maximum value.

Frequency of Oscillation

- Crystal Reactance against Frequency



$$X_S = R^2 + (X_{LS} - X_{CS})^2$$

$$X_{CP} = \frac{-1}{2\pi f C_P}$$

$$X_P = \frac{X_S \times X_{CP}}{X_S + X_{CP}}$$

The slope of the reactance against frequency above, shows that the series reactance at frequency fs is inversely proportional to Cs because below fs and above fp the crystal appears capacitive.
Between frequencies fs and fp, the crystal appears inductive as the two parallel capacitances cancel out.

Frequency of Oscillation

- Series Resonant Frequency

$$f_s = \frac{1}{2\pi\sqrt{L_s C_s}}$$

- Parallel Resonant Frequency

The parallel resonance frequency, ƒp occurs when the reactance of the series LC leg equals the reactance of the parallel capacitor, Cp and is given as:

$$f_p = \frac{1}{2\pi\sqrt{L_s\left(\frac{C_s C_p}{C_s + C_p}\right)}}$$

Problem #7

- A quartz crystal has the following values: Rs = 6.4Ω, Cs = 0.09972pF and Ls = 2.546mH. If the capacitance across its terminal, Cp is measured at 28.68pF, Calculate the fundamental oscillating frequency of the crystal and its secondary resonance frequency.

Ans.

fs = 9.988 MHz

fp = 10.006 MHz

Problem #8

- Calculate the Q-factor of the previous problem (#7).

Ans.

$Q = 24965$ or 25000

Problem #9

- A quartz crystal has the following values after being cut, $R_s = 1k\Omega$, $C_s = 0.05pF$, $L_s = 3H$ and $C_p = 10pF$. Calculate the crystals series and parallel oscillating frequencies.

Ans.

$f_s = 410.94$ kHz

$f_p = 411.96$ kHz