Lecture-2

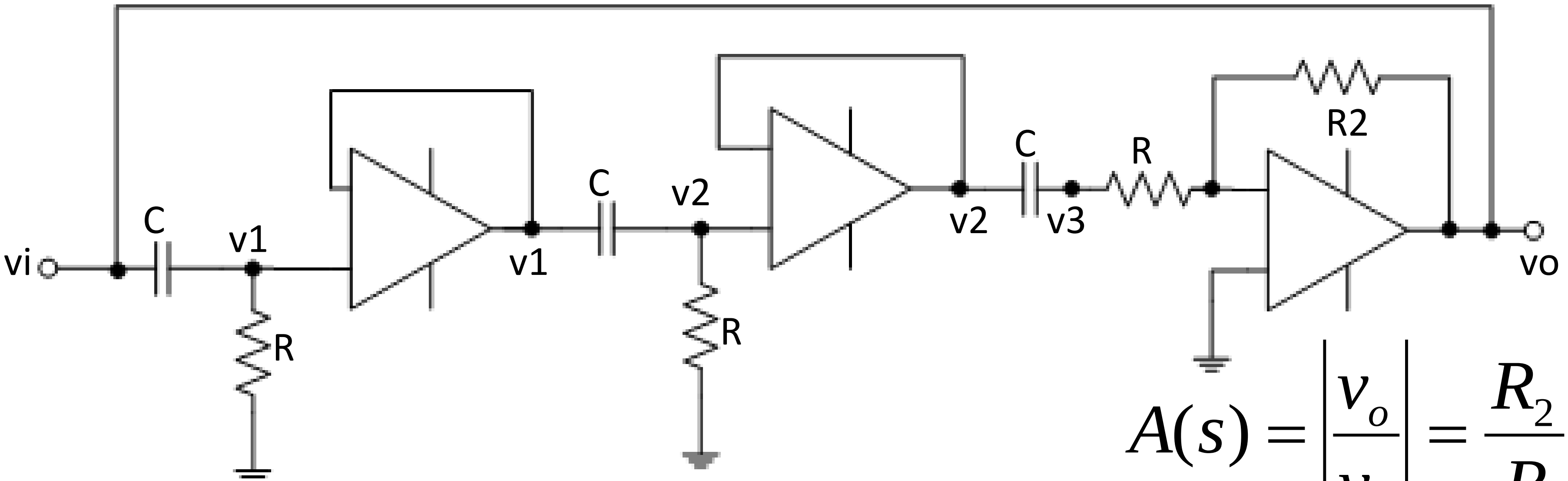
Phase Shift, LC and Crystal Oscillator

Phase-Shift Oscillator

- The phase shift oscillator utilizes three RC circuits to provide 180º phase shift that when coupled with the 180º of the op-amp itself provides the necessary feedback to sustain oscillations.
- The gain must be at least 29 to maintain the oscillations.
- The frequency of resonance for the this type is similar to any RC circuit oscillator:

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

Phase-Shift Oscillator



$$A(s) = \left| \frac{v_o}{v_3} \right| = \frac{R_2}{R}$$

$$v_1 = \left(\frac{sRC}{1+sRC} \right) v_i \qquad v_3 = \left(\frac{sRC}{1+sRC} \right)^3 v_i$$

$$v_2 = \left(\frac{sRC}{1+sRC} \right)^2 v_i \qquad \frac{v_3}{v_i} = \beta(s) = \left(\frac{sRC}{1+sRC} \right)^3$$

Phase-Shift Oscillator

- Loop gain, T(s):

$$T(s) = A(s)\beta(s) = \left(\frac{R_2}{R}\right)\left(\frac{sRC}{1+sRC}\right)^3$$

- Set s=jw

$$T(j\omega) = \left(\frac{R_2}{R}\right)\left(\frac{j\omega RC}{1+j\omega RC}\right)^3$$

$$T(j\omega) = -\left(\frac{R_2}{R}\right)\frac{(j\omega RC)(\omega RC)^2}{\left[1-3\omega^2 R^2 C^2\right] + j\omega RC\left[3-\omega^2 R^2 C^2\right]}$$

Phase-Shift Oscillator

- To satisfy condition T(jw$_o$)=1, real component must be zero since the numerator is purely imaginary.

$$1-3\omega^2R^2C^2=0$$

- the oscillation frequency: $\omega_0=\dfrac{1}{\sqrt{3}RC}$
- Apply w$_o$ in equation:

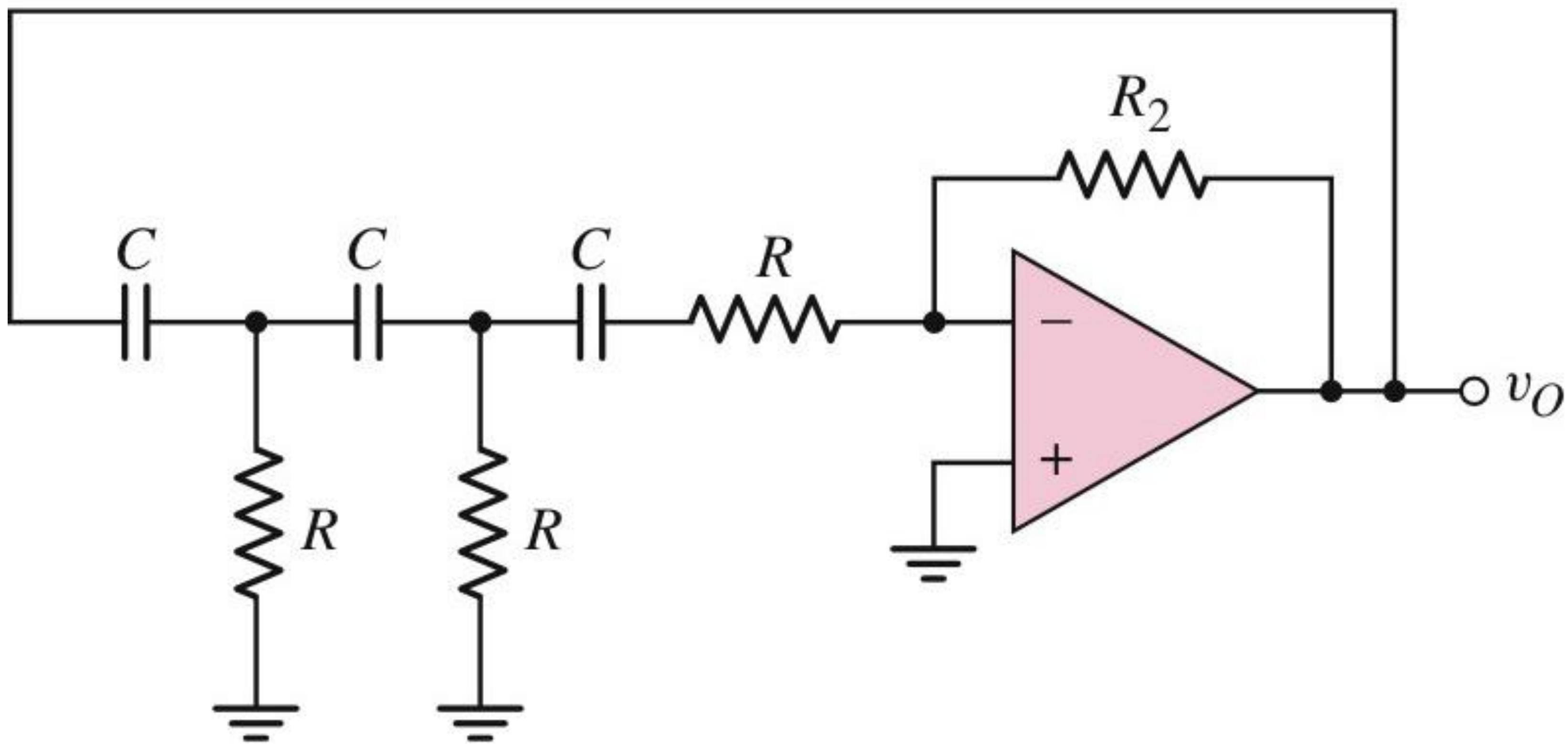
$$T(j\omega_o)=-\left(\frac{R_2}{R}\right)\frac{(j/\sqrt{3})(1/3)}{0+(j/\sqrt{3})\left[3-(1/3)\right]}=-\left(\frac{R_2}{R}\right)\left(\frac{1}{8}\right)$$

- To satisfy condition T(jw$_o$)=1

$$\frac{R_2}{R}=8$$

The gain greater than 8, the circuit will spontaneously begin oscillating & sustain oscillations

Phase-Shift Oscillator



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

$$\frac{R_2}{R} = 29$$

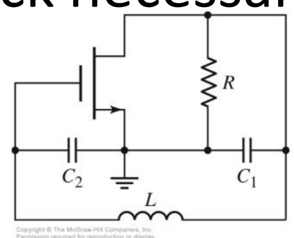
The gain must be at least 29 to maintain the oscillations

LC Oscillators

- Use transistors and LC tuned circuits or crystals in their feedback network.
- For hundreds of kHz to hundreds of MHz frequency range.
- Examine Colpitts, Hartley and crystal oscillator.

Colpitts Oscillator

- The Colpitts oscillator is a type of oscillator that uses an LC circuit in the feed-back loop.
- The feedback network is made up of a pair of ***tapped capacitors (C_1 and C_2)*** and ***an inductor L*** to produce a feedback necessary for oscillations.



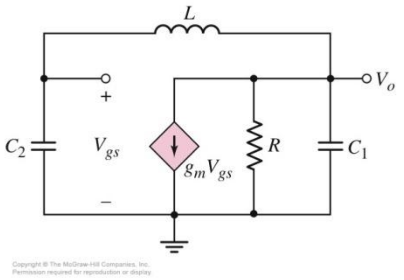
- The output voltage is developed across C_1.
- The feedback voltage is developed across C_2.

Colpitts Oscillator

- KCL at the output node:

$$\frac{V_o}{\frac{1}{sC_1}} + \frac{V_o}{R} + g_m V_{gs} + \frac{V_o}{sL + \frac{1}{sC_2}} = 0 \quad \text{- Eq (1)}$$

- voltage divider produces:



$$V_{gs} = \left(\frac{\frac{1}{sC_2}}{\frac{1}{sC_2} + sL} \right) \bullet V_o \quad \text{- Eq (2)}$$

- substitute eq(2) into eq(1):

$$V_o \left[g_m + sC_2 + \left(1 + s^2 LC_2\right)\left(\frac{1}{R} + sC_1\right) \right] = 0$$

Colpitts Oscillator

- Assume that oscillation has started, then Vo≠0

$$s^3LC_1C_2 + \frac{s^2LC_2}{R} + s(C_1 + C_2) + \left(g_m + \frac{1}{R}\right) = 0$$

- Let s=jω

$$\left(g_m + \frac{1}{R} + \frac{\omega^2LC_2}{R}\right) + j\omega\left[(C_1 + C_2) - \omega^2LC_1C_2\right] = 0$$

- both real & imaginary component must be zero
  - Imaginary component: $\omega_o = \dfrac{1}{\sqrt{L\left(\dfrac{C_1C_2}{C_1 + C_2}\right)}}$ - Eq (3)

Colpitts Oscillator

- both real & imaginary component must be zero
  - Imaginary component:

$$\frac{\omega^2 L C_2}{R} = g_m + \frac{1}{R}$$ - Eq (4)

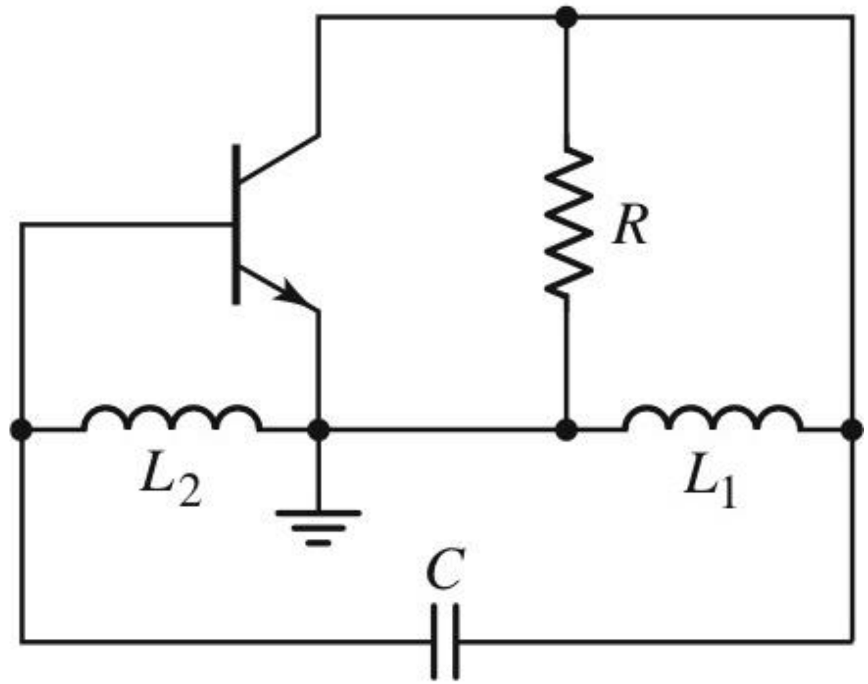
- Combining Eq(3) and Eq(4):

$$\frac{C_2}{C_1} = g_m R$$

- to initiate oscillations spontaneously: $g_m R > \left(\frac{C_2}{C_1} \right)$

Hartley Oscillator

- The Hartley oscillator is almost identical to the Colpitts oscillator.
- The primary difference is that the feedback network of the Hartley oscillator uses *tapped inductors (L_1 and L_2)* and *a single capacitor C*.



Hartley Oscillator

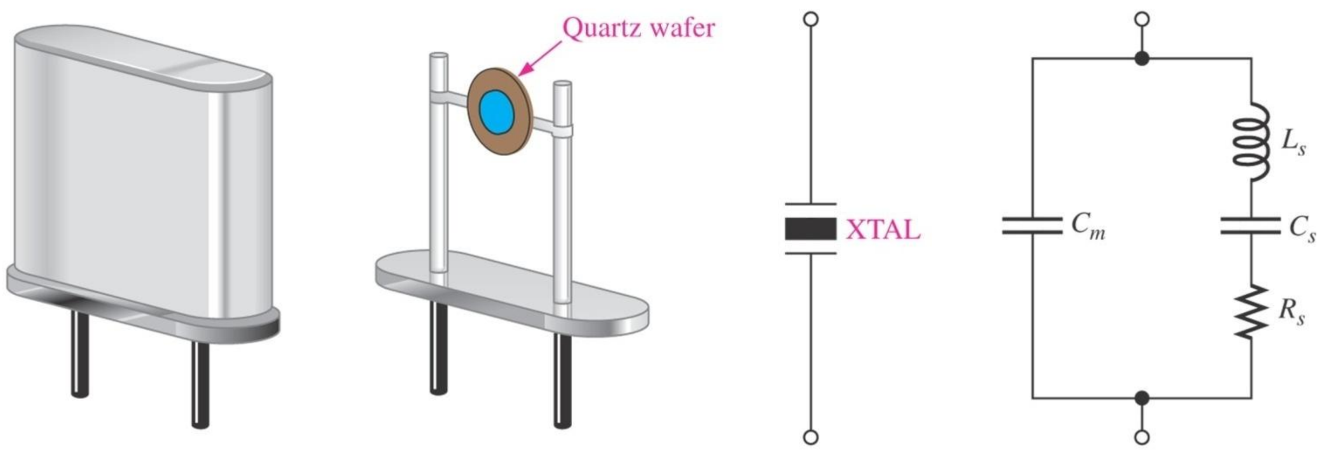
- the analysis of Hartley oscillator is identical to that Colpitts oscillator.
- the frequency of oscillation:

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

Crystal Oscillator

- Most communications and digital applications require the use of oscillators with extremely stable output. Crystal oscillators are invented to overcome the output fluctuation experienced by conventional oscillators.

- Crystals used in electronic applications consist of a quartz wafer held between two metal plates and housed in a a package as shown in Fig. 9 (a) and (b).



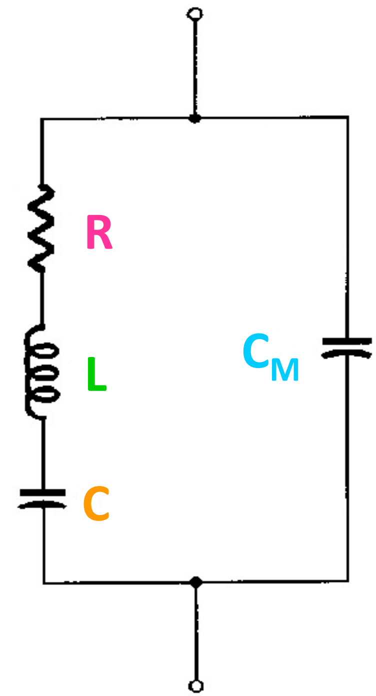
(a) Typical packaged crystal (b) Basic construction (without case) (c) Symbol (d) Electrical equivalent

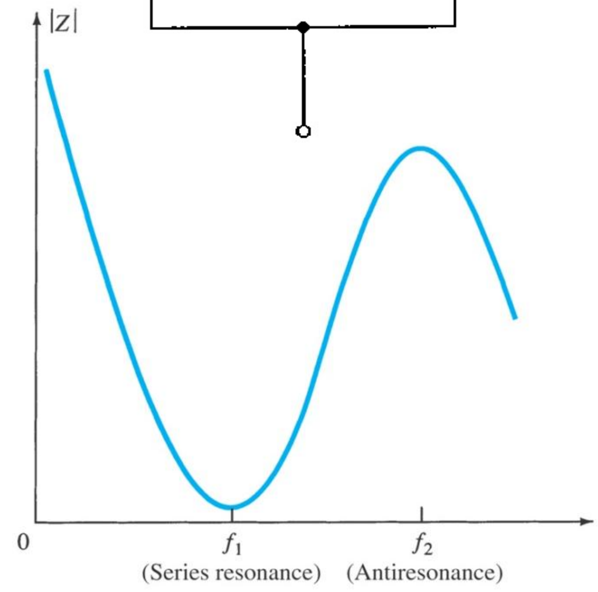
Crystal Oscillator

- Piezoelectric Effect
  - The quartz crystal is made of silicon oxide (SiO_2) and exhibits a property called the *piezoelectric*
  - When a changing an alternating voltage is applied across the crystal, it vibrates at the frequency of the applied voltage. In the other word, the frequency of the applied ac voltage is equal to the natural resonant frequency of the crystal.
  - The thinner the crystal, higher its frequency of vibration. This phenomenon is called piezoelectric effect.

Crystal Oscillator

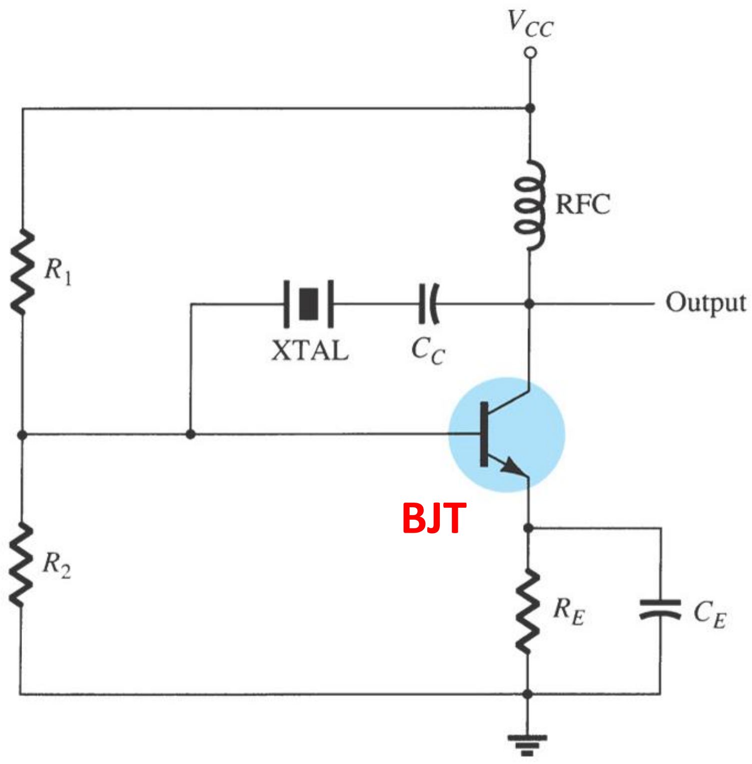
- Characteristic of Quartz Crystal
  - The crystal can have two resonant frequencies;
  - One is the series resonance frequency f_1 which occurs when $X_L = X_C$. At this frequency, crystal offers a very low impedance to the external circuit where $Z = R$.
  - The other is the parallel resonance (or antiresonance) frequency f_2 which occurs when reactance of the series leg equals the reactance of C_M. At this frequency, crystal offers a very high impedance to the external circuit



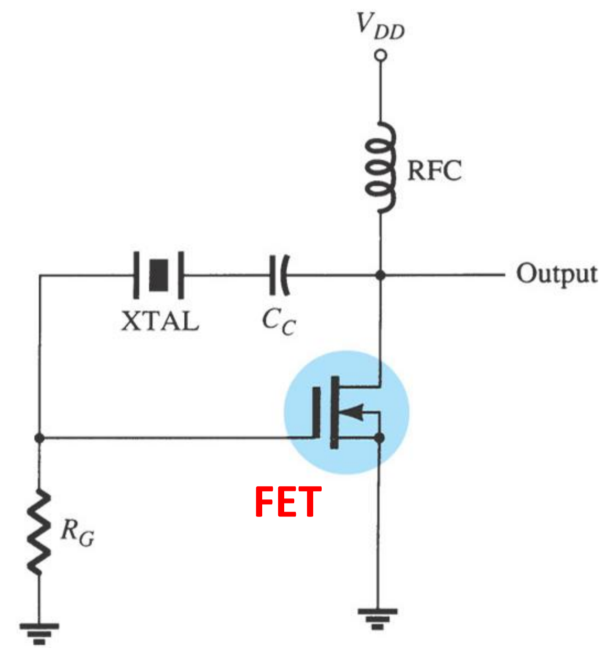


Crystal Oscillator

- The crystal is connected as a series element in the feedback path from collector to the base so that it is excited in the series-resonance mode



(a)



(b)

Crystal Oscillator

- Since, in series resonance, crystal impedance is the smallest that causes the crystal provides the largest positive feedback.
- Resistors R_1, R_2, and R_E provide a voltage-divider stabilized dc bias circuit. Capacitor C_E provides ac bypass of the emitter resistor, R_E to avoid degeneration.
- The RFC coil provides dc collector load and also prevents any ac signal from entering the dc supply.
- The coupling capacitor C_C has negligible reactance at circuit operating frequency but blocks any dc flow between collector and base.
- The oscillation frequency equals the series-resonance frequency of the crystal and is given by:

$$f_o = \frac{1}{2\pi\sqrt{LC_C}}$$