INTEGRATED TECHNICAL EDUCATION CLUSTER
AT ALAMEERIA

J-601-1448
Electronic Principals

Lecture #12
Sine wave oscillators

Instructor:
Dr. Ahmad El-Banna

JANUARY 2015

Agenda

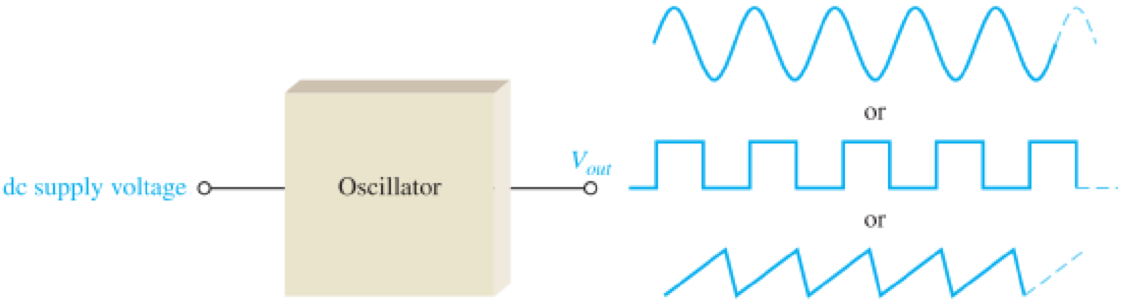
- Introduction
- Feedback Oscillators
- Oscillators with RC Feedback Circuits
- Oscillators with LC Feedback Circuits
- Crystal-Controlled Oscillators

INTRODUCTION

Introduction

- An **oscillator** is a circuit that produces a periodic waveform on its output with only the dc supply voltage as an input.
- The output voltage can be either **sinusoidal** or **non sinusoidal**, depending on the type of oscillator.
- Two major classifications for oscillators are **feedback** oscillators and **relaxation** oscillators.

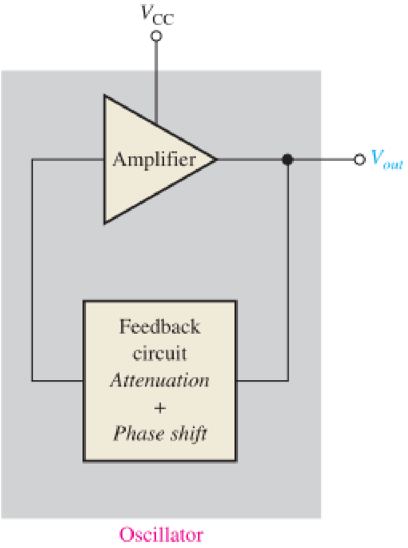
○ an oscillator converts electrical energy from the dc power supply to periodic waveforms.



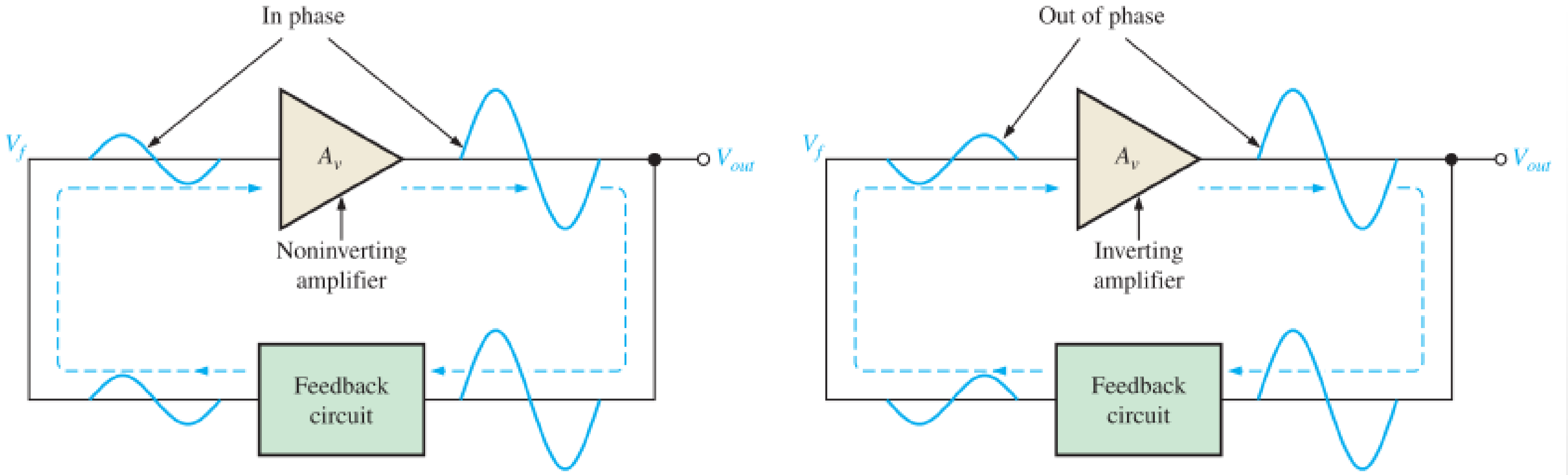
FEEDBACK OSCILLATORS

Positive feedback

- Positive feedback is characterized by the condition wherein a portion of the output voltage of an amplifier is fed back to the input with no net phase shift, resulting in a reinforcement of the output signal.



Basic elements of a feedback oscillator.

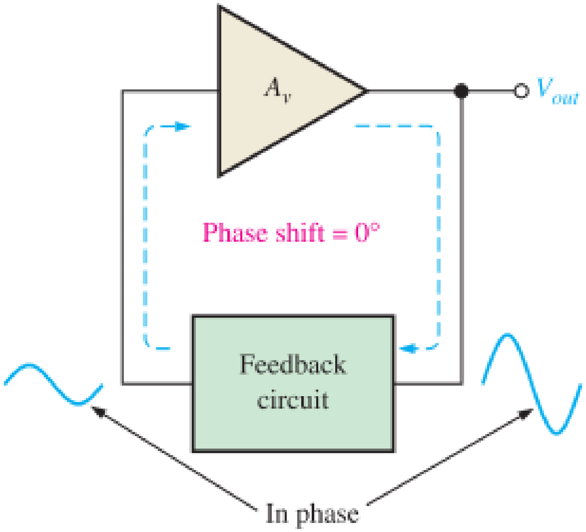


Conditions for Oscillation

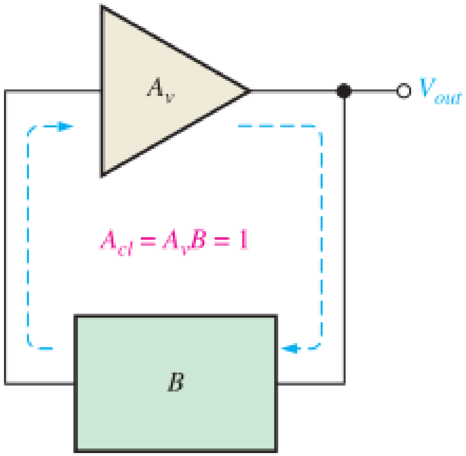
- Two conditions:

1. The phase shift around the feedback loop must be effectively 0°.
2. The voltage gain, A_{cl} around the closed feedback loop (loop gain) must equal 1 (unity).

$$A_{cl} = A_v B$$



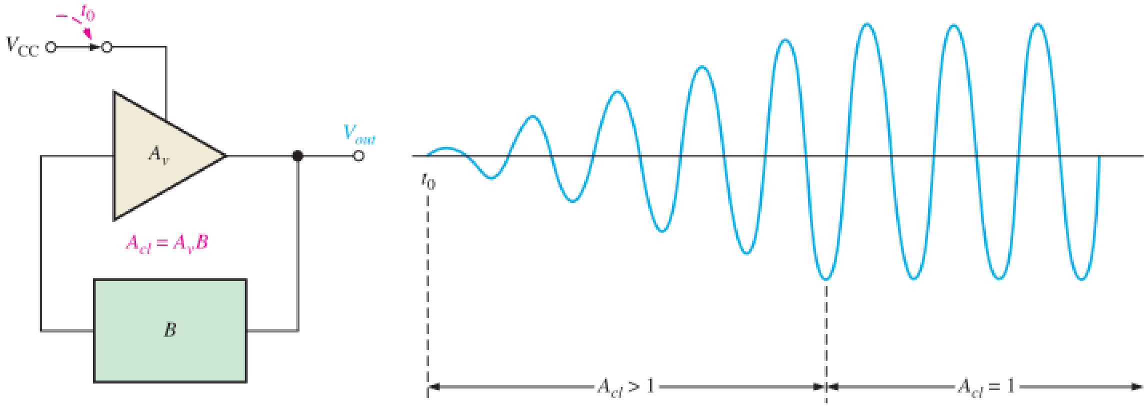
(a) The phase shift around the loop is 0°.



(b) The closed loop gain is 1.

Start-Up Conditions

- For oscillation to begin, the voltage gain around the positive feedback loop must be greater than 1 so that the amplitude of the output can build up to a desired level.
- The gain must then decrease to 1 so that the output stays at the desired level and oscillation is sustained.
- Initially, a small positive feedback voltage develops from thermally produced broad-band noise in the resistors or other components or from power supply turn-on transients.



Wien-bridge oscillator

Phase-shift oscillator

Twin-T oscillator

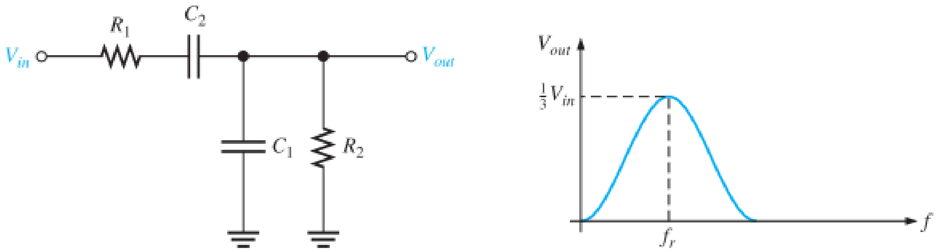
OSCILLATORS WITH RC FEEDBACK CIRCUITS

The Wien-Bridge Oscillator

- Generally, RC feedback oscillators are used for frequencies up to about 1 MHz.
- The Wien-bridge is by far the most widely used type of RC feedback oscillator for this range of frequencies.

$R_1 = R_2$ and $X_{C1} = X_{C2}$

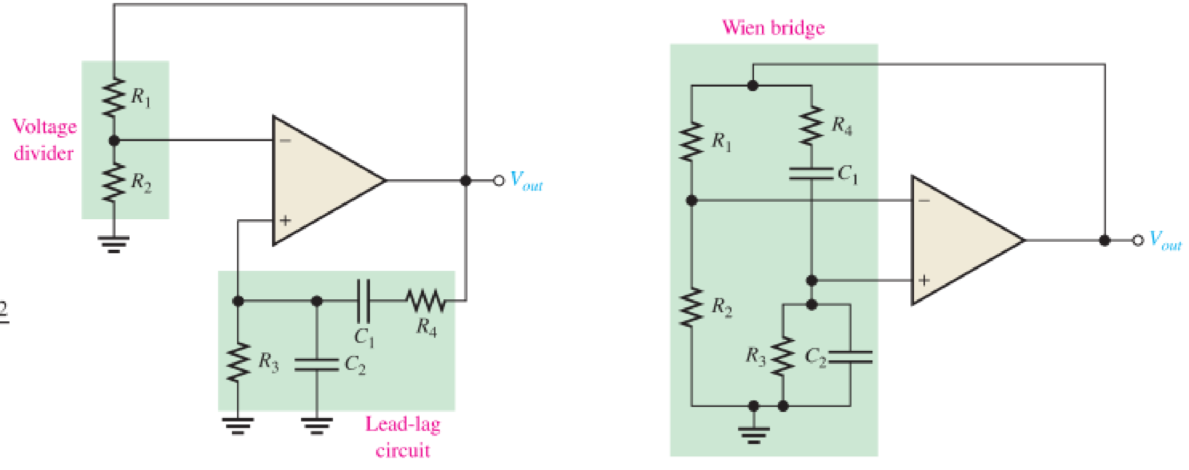
$$\frac{V_{out}}{V_{in}} = \frac{1}{3} \qquad f_r = \frac{1}{2\pi RC}$$



Lead-lag circuit and its response curve

- **Basic Circuit**

$$A_{cl} = \frac{1}{B} = \frac{1}{R_2/(R_1 + R_2)} = \frac{R_1 + R_2}{R_2}$$



(a)

(b) Wien bridge circuit combines a voltage divider and a lead-lag circuit.

▲ FIGURE 16–7

The Wien-bridge oscillator schematic drawn in two different but equivalent ways.

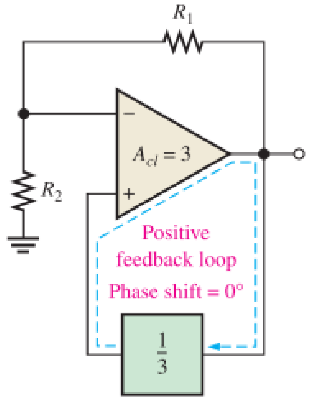
The Wien-Bridge Oscillator..

- Positive Feedback Conditions for Oscillation

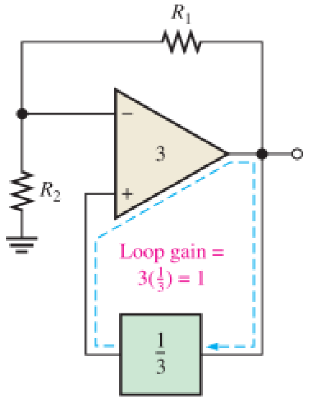
$A_{cl} = 3 \longrightarrow A_{cl} = 1 + (R_1/R_2)$

choose $R_1 = 2R_2$

$$A_{cl} = \frac{R_1 + R_2}{R_2} = \frac{2R_2 + R_2}{R_2} = \frac{3R_2}{R_2} = 3$$



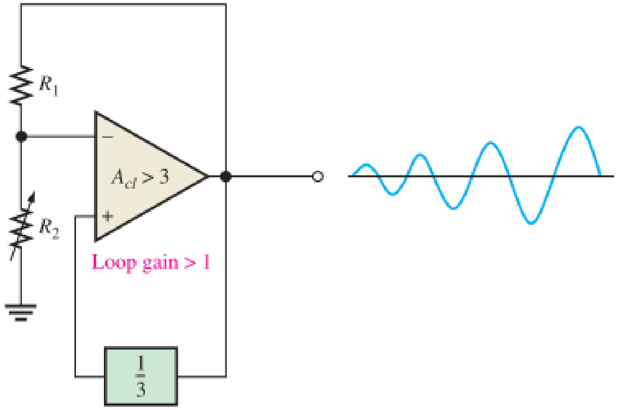
(a) The phase shift around the loop is 0°.



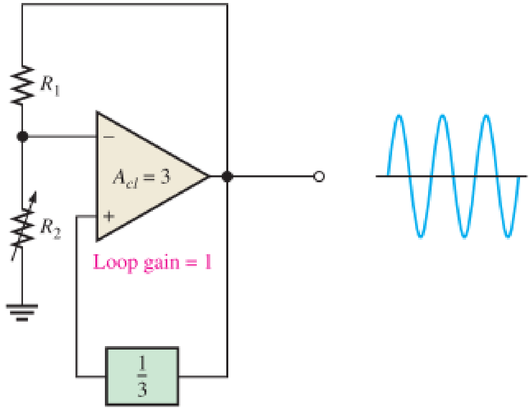
(b) The voltage gain around the loop is 1.

- Start-Up Conditions

$(A_{cl} > 3)$



(a) Loop gain greater than 1 causes output to build up.



(b) Loop gain of 1 causes a sustained constant output.

Self-starting Wien-bridge oscillator

Using a form of automatic gain control (AGC)

1- When dc power is first applied, both zener diodes appear as opens.

$$A_{cl} = \frac{R_1 + R_2 + R_3}{R_2} = \frac{3R_2 + R_3}{R_2} = 3 + \frac{R_3}{R_2}$$

2- When the zeners conduct, they short out R_3 and $A_{cl} = 3$

- The zener feedback is simple, it suffers from the nonlinearity of the zener diodes that occurs in order to control gain.

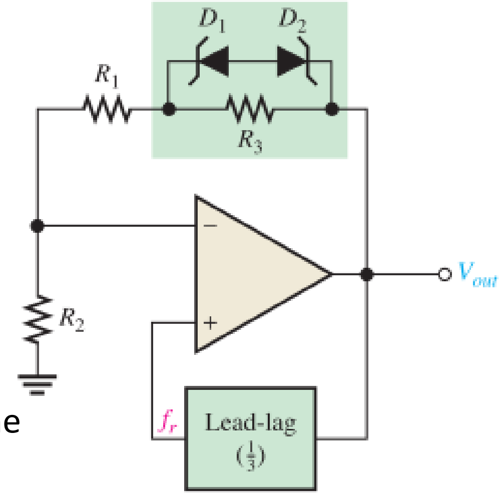
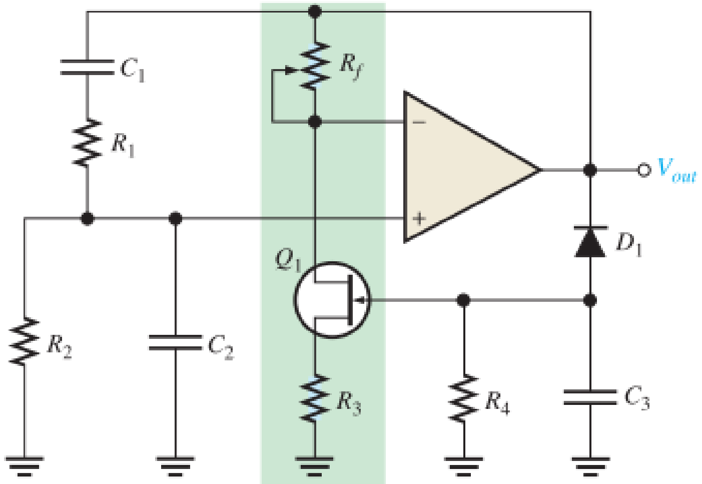


FIGURE 16–10

Self-starting Wien-bridge oscillator using back-to-back zener diodes.

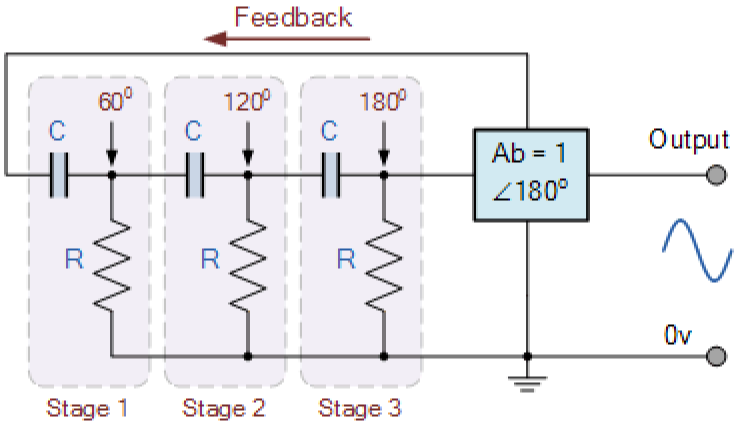
FIGURE 16–11

Self-starting Wien-bridge oscillator using a JFET in the negative feedback loop.

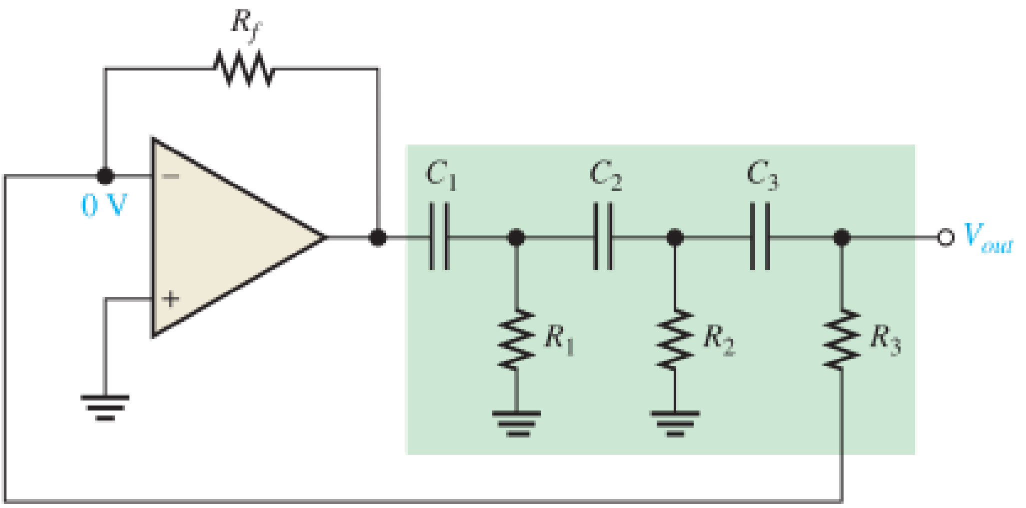


- In some older designs, a tungsten lamp was used in the feed-back circuit to achieve stability.
- A better method to control the gain uses a JFET as a voltage-controlled resistor in a negative feedback path.
- As the voltage increases, the drain-source resistance increases.

The Phase-Shift Oscillator



- Each of the three RC circuits in the feedback loop can provide a maximum phase shift approaching 90°.
- Oscillation occurs at the frequency where the total phase shift through the three RC circuits is 180°.
- The inversion of the op-amp itself provides the additional 180° to meet the requirement for oscillation of a 360° (or 0°) phase shift around the feedback loop.



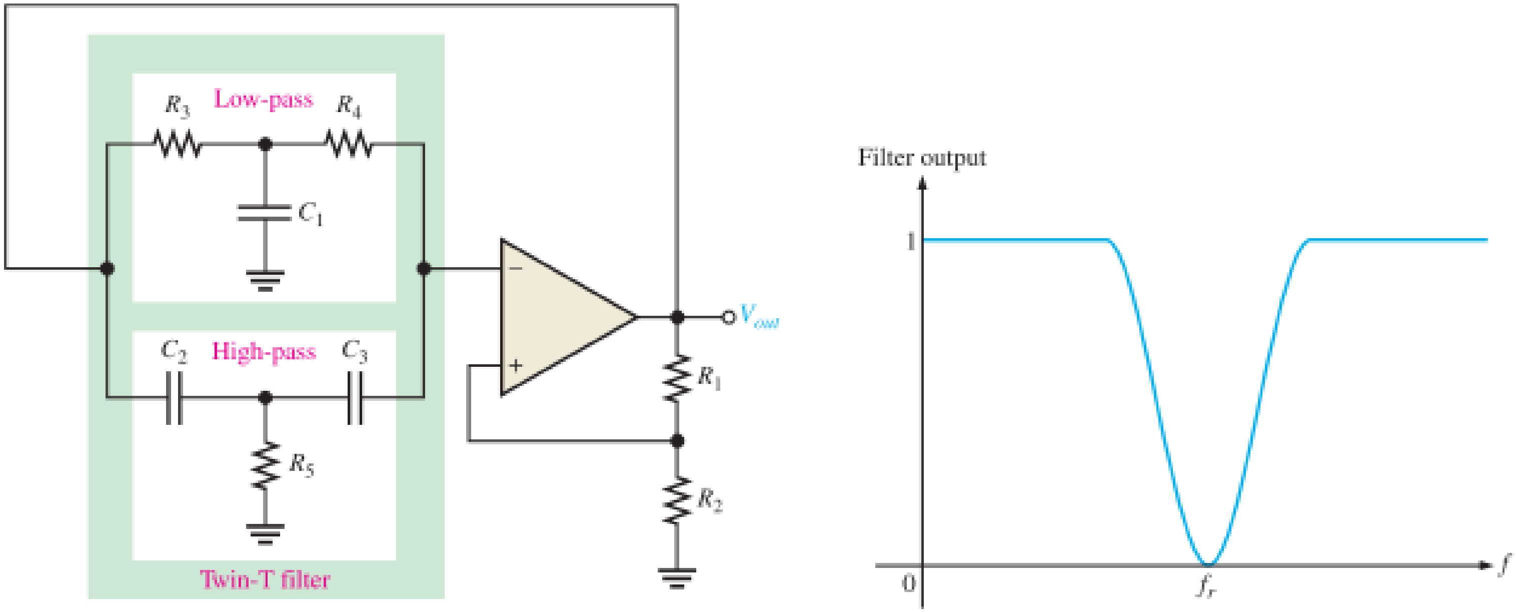
$$B = \frac{1}{29} \qquad \text{where } B = R_3/R_f.$$

$$R_1 = R_2 = R_3 = R \text{ and } C_1 = C_2 = C_3 = C.$$

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

Twin-T Oscillator

- One of the twin-T filters has a low-pass response, and the other has a high-pass response.
- The combined parallel filters produce a band-stop or notch response with a center frequency equal to the desired frequency of oscillation.



(a) Oscillator circuit

(b) Twin-T filter's frequency response curve

▲ FIGURE 16–15

Twin-T oscillator and twin-T filter response.

THE COLPITTS OSCILLATOR

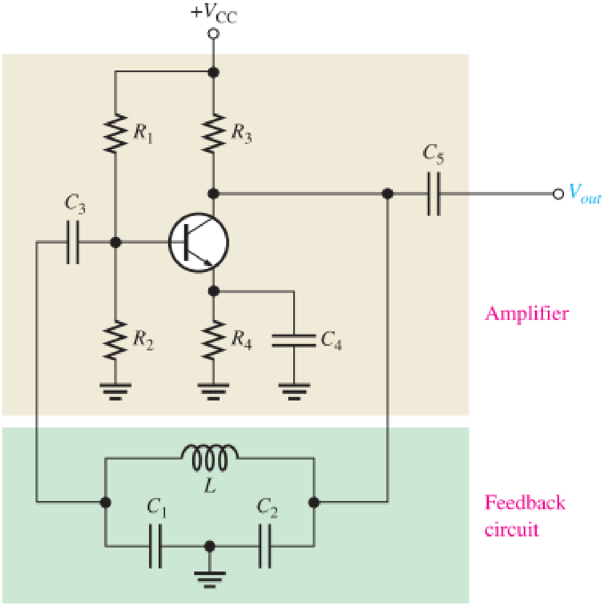
Colpitts Oscillator

- LC feedback elements are normally used in oscillators that require higher frequencies of oscillation.
- Also, because of the frequency limitation (lower unity-gain frequency) of most op-amps, discrete transistors (BJT or FET) are often used as the gain element in LC oscillators.

- Colpitts oscillator 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.

$$f_r \cong \frac{1}{2\pi\sqrt{LC_T}}$$

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



Conditions for Oscillation and Start-Up

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

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

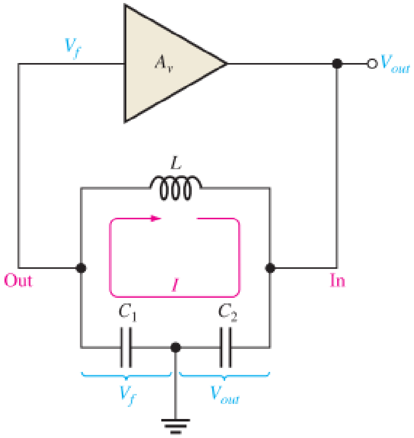


FIGURE 16–17

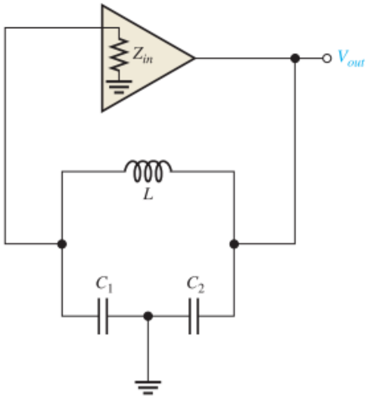
The attenuation of the tank circuit is the output of the tank (V_f) divided by the input to the tank (V_{out}). $B = V_f/V_{out} = C_2/C_1$. For $A_vB > 1$, A_v must be greater than C_1/C_2.

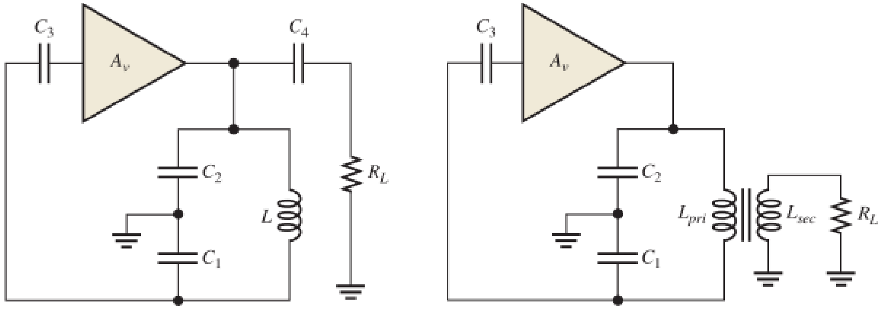
- Loading of the Feedback Circuit Affects the Frequency of Oscillation

→ Z_{in} of the amplifier loads the feed-back circuit and lowers its Q, thus lowering the resonant frequency.

→ A FET can be used in place of a BJT, as shown in Figure 16–19, to minimize the loading effect of the transistor's input impedance.

$$f_r = \frac{1}{2\pi\sqrt{LC_T}}\sqrt{\frac{Q^2}{Q^2 + 1}}$$





(a) A load capacitively coupled to oscillator output can reduce circuit Q and f_r.

(b) Transformer coupling of load can reduce loading effect by impedance transformation.

FIGURE 16–20

Oscillator loading.

THE CLAPP OSCILLATOR

Clapp Oscillator

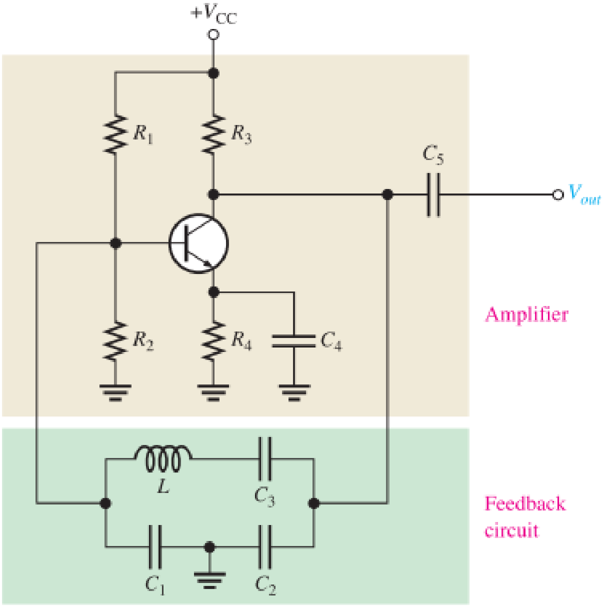
- The Clapp oscillator is a variation of the Colpitts with addition of C_3.

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

$$(Q > 10) \longrightarrow \qquad f_r \cong \frac{1}{2\pi\sqrt{LC_T}}$$

If C_3 is much smaller than C_1 and C_2,

$$(f_r \cong 1/(2\pi\sqrt{LC_3})).$$



- Since C_1 and C_2 are both connected to ground at one end, the junction capacitance of the transistor and other stray capacitances appear in parallel with C_1 and C_2 to ground, altering their effective values.
- C_3 is not affected, however, and thus provides a more accurate and stable frequency of oscillation.

THE HARTLEY OSCILLATOR

Hartley Oscillator

- The Hartley oscillator is similar to the Colpitts except that the feedback circuit consists of two series inductors and a parallel capacitor

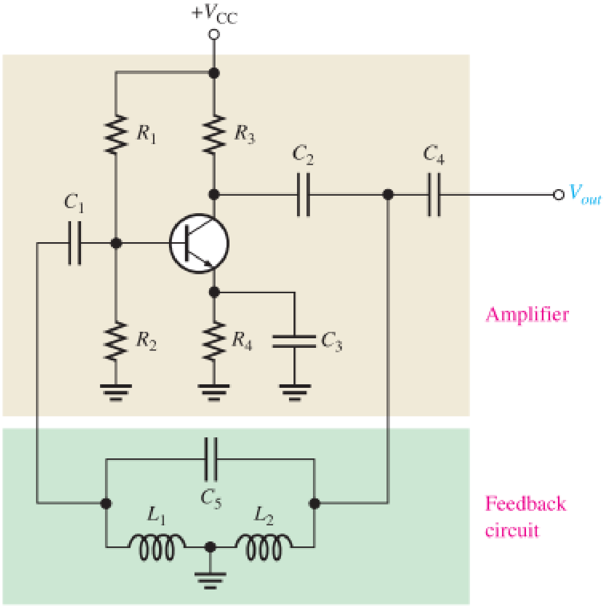
$Q > 10$

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

$$L_T = L_1 + L_2.$$

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

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



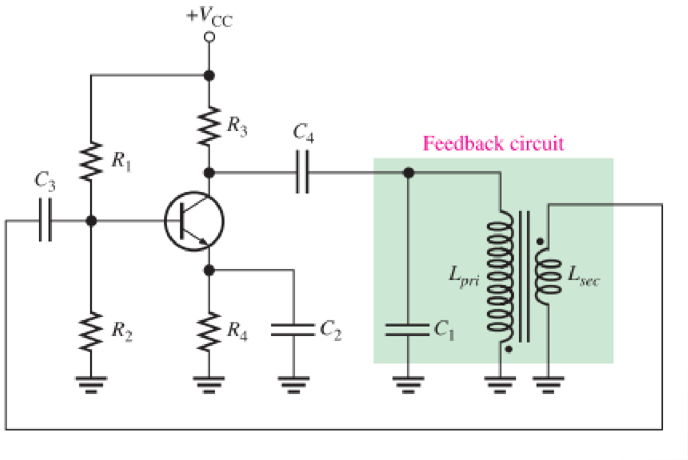
- Loading of the tank circuit has the same effect in the Hartley as in the Colpitts; that is, the Q is decreased and thus f_r decreases.

THE ARMSTRONG OSCILLATOR

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.

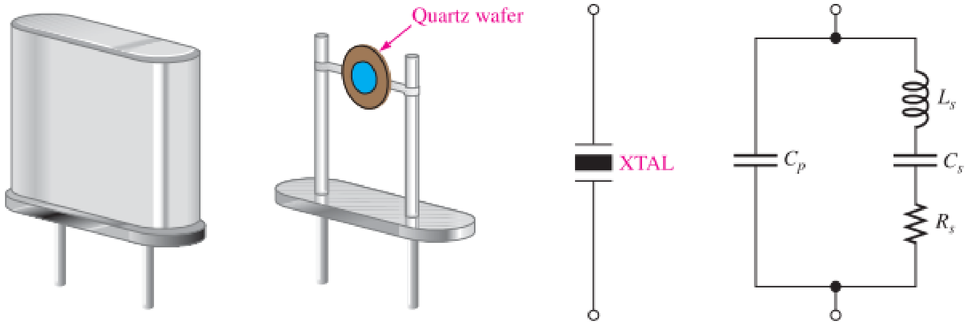
$$f_r = \frac{1}{2\pi\sqrt{L_{pri}C_1}}$$



CRYSTAL-CONTROLLED OSCILLATORS

Crystal-Controlled Oscillators

- The most stable and accurate type of feedback oscillator uses a **piezoelectric crystal** in the feedback loop to control the frequency.
- Quartz is one type of crystalline substance found in nature that exhibits a property called the piezoelectric effect.
- When a changing mechanical stress is applied across the crystal to cause it to vibrate, a voltage develops at the frequency of mechanical vibration.
- Conversely, when an ac voltage is applied across the crystal, it vibrates at the frequency of the applied voltage.
- The greatest vibration occurs at the crystal’s natural resonant frequency, which is determined by the physical dimensions and by the way the crystal is cut.



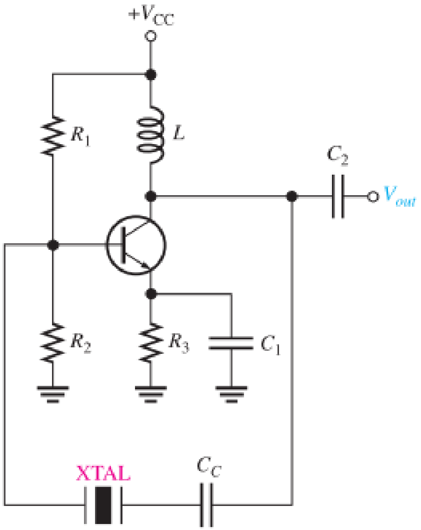
(a) Typical packaged crystal (b) Basic construction (without case) (c) Symbol (d) Electrical equivalent

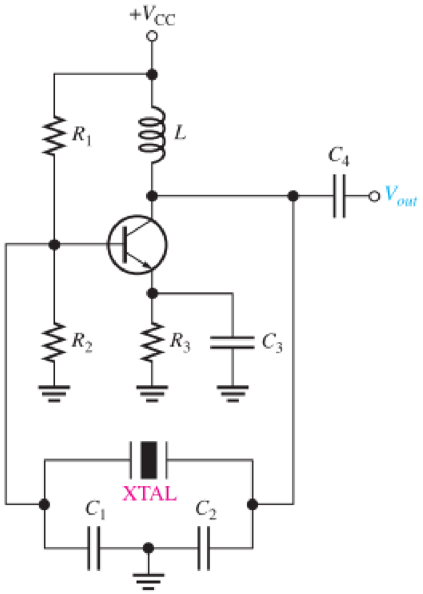
Basic crystal oscillators

- A great advantage of the crystal is that it exhibits a very high Q.
- The impedance of the crystal is minimum at the series resonant frequency, thus providing maximum feedback.
- a crystal is used as a series resonant tank circuit.
- The crystal tuning capacitor, C_c is used to “fine tune” the oscillator frequency by “pulling” the resonant frequency of the crystal slightly up or down.

Modes:

- Piezoelectric crystals can oscillate in either of two modes—fundamental or overtone.
- The **fundamental** frequency of a crystal is the lowest frequency at which it is naturally resonant.
- The fundamental frequency depends on the crystal’s mechanical dimensions, type of cut, .. etc.
- Usually it’s less than 20 MHz.
- **Overtones** are approximate integer multiples of the fundamental frequency.
- Many crystal oscillators are available in integrated circuit packages.





Fall 2014 Course Feedback

Select your course *

○ Mobile Communication Systems
○ Electronic Circuits (A)
○ Electronic Principals
○ Engineering Legislations
○ Active Circuits
○ CAD of Electronics

The course lies in your area of interest *

○ Yes
○ No

The course contents had been successfully covered *

○ totally agree
○ agree
○ disagree
○ totally disagree

Your evaluation for the instructor *

○ excellent
○ good
○ not bad

Feedback link:

http://goo.gl/forms/ghjNGxQpaj

- For more details, refer to:
  - Chapter 16 at T. Floyd, **Electronic Devices**,9th edition.
  - http://www.electronics-tutorials.ws/oscillator/rc_oscillator.html
  - http://www.electronics-tutorials.ws/oscillator/oscillators.html
- The lecture is available online at:
  - https://speakerdeck.com/ahmad_elbanna
- For inquires, send to:
  - ahmad.elbanna@feng.bu.edu.eg