Applied Electronics

Instructor:

Dr. Ahmad El-Banna

DAY#5
SUMMER 2016

Agenda

Active Filters

- Basic Filter Responses
- Active LPF, HPF, BPF & BSF
- Filter Response Measurements

Oscillators

- Sinusoidal Oscillators
- Non-Sinusoidal Oscillators

Troubleshooting

Practical Applications

BASIC FILTER RESPONSES

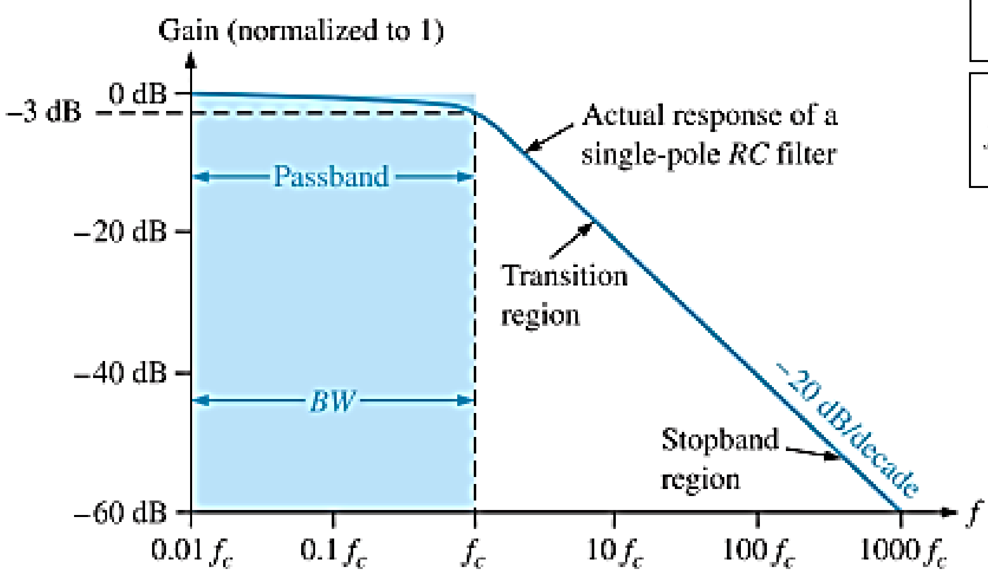
Intro.

- **Filters** are circuits that are capable of **passing** signals with certain selected **frequencies** while **rejecting** signals with **other** frequencies.
- This property is called **selectivity**.
- **Active** filters use **transistors** or **op-amps** combined with passive RC, RL, or RLC circuits.

- The **passband** of a filter is the range of frequencies that are allowed to pass through the filter with **minimum attenuation** (usually defined as less than of attenuation).
- The **critical frequency**, (also called the **cutoff frequency**) defines the **end of the passband** and is normally specified at the point where the response drops (**70.7%**) from the passband response.
- Following the passband is a region called the **transition region** that leads into a region called the **stopband**.
- There is **no precise point** between the transition region and the stopband.

Basic Filter Responses

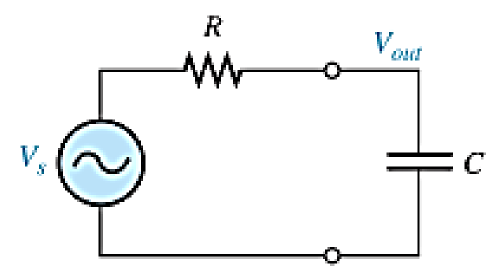
- **Low-Pass Filter Response**
  - Actual filter responses depend on the **number of poles**, a term used with filters to describe the **number of RC circuits** contained in the filter.
  - The -20 dB/decade **roll-off** rate for the gain of a basic RC filter means that at a frequency of $10 f_c$, the output will be -20dB (10%) of the input.
  - This roll-off rate is **not a good filter characteristic** because too much of the unwanted frequencies (beyond the passband) are allowed through the filter.



(a) Comparison of an ideal low-pass filter response (blue area) with actual response. Although not shown on log scale, response extends down to $f_c = 0$.

$$BW = f_c$$

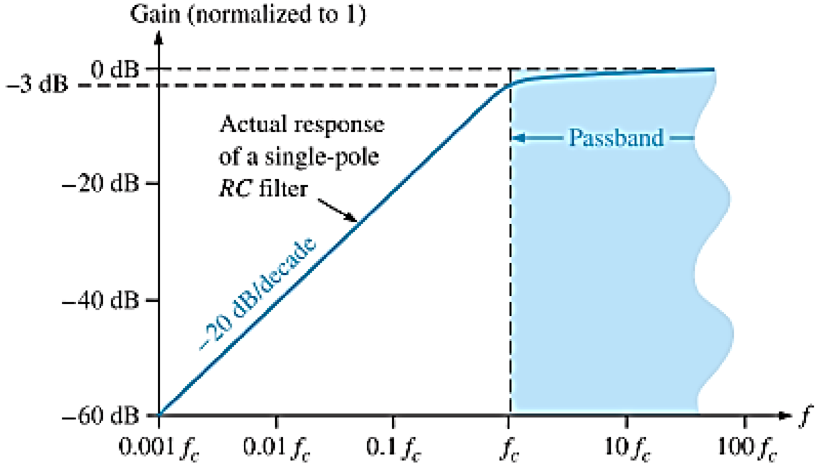
$$f_c = \frac{1}{2\pi RC}$$



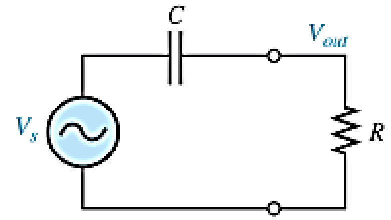
(b) Basic low-pass circuit

Basic Filter Responses..

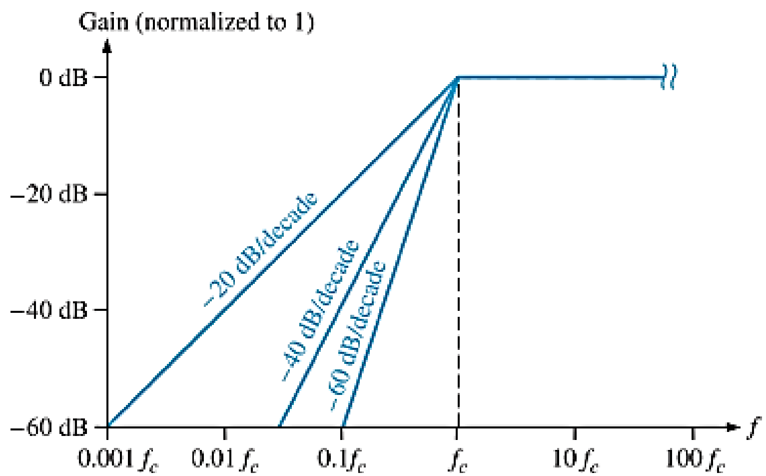
- **High-Pass Filter Response**



(a) Comparison of an ideal high-pass filter response (blue area) with actual response



(b) Basic high-pass circuit



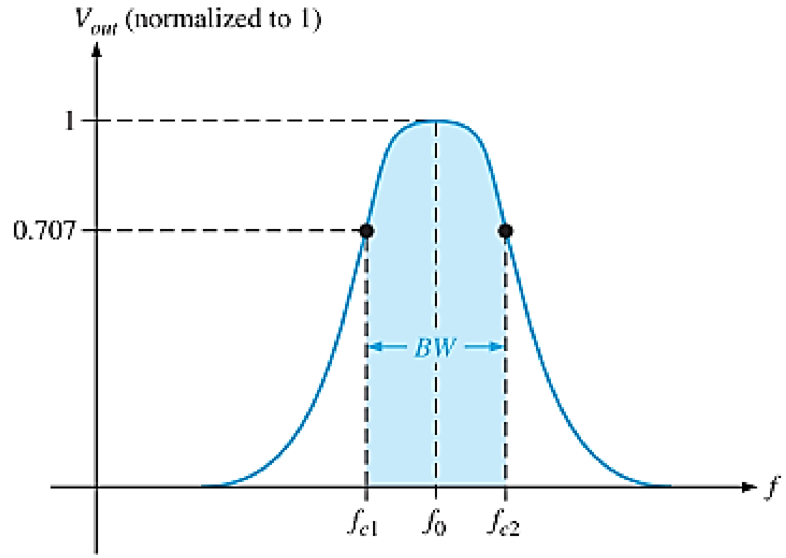
$$f_c = \frac{1}{2\pi RC}$$

Basic Filter Responses...

- **Band-Pass Filter Response**

$$BW = f_{c2} - f_{c1}$$

$$f_0 = \sqrt{f_{c1} f_{c2}}$$



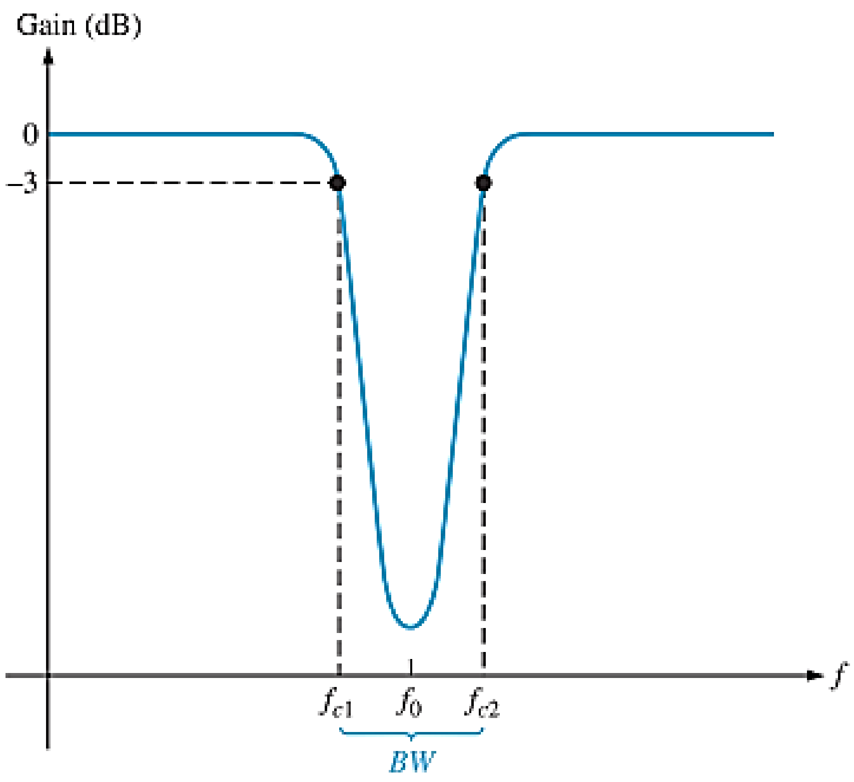
- The **quality factor** (Q) of a band-pass filter is the ratio of the center frequency to the bandwidth.
- The higher the value of Q, the narrower the bandwidth and the better the selectivity for a given value of f_0.
- Band-pass filters are sometimes classified as **narrow-band** (Q>10) or **wide-band** (Q<10).
- The quality factor (Q) can also be expressed in terms of the **damping factor** (DF) of the filter

$$Q = \frac{f_0}{BW} \qquad Q = \frac{1}{DF}$$

Basic Filter Responses....

- **Band-Stop Filter Response**

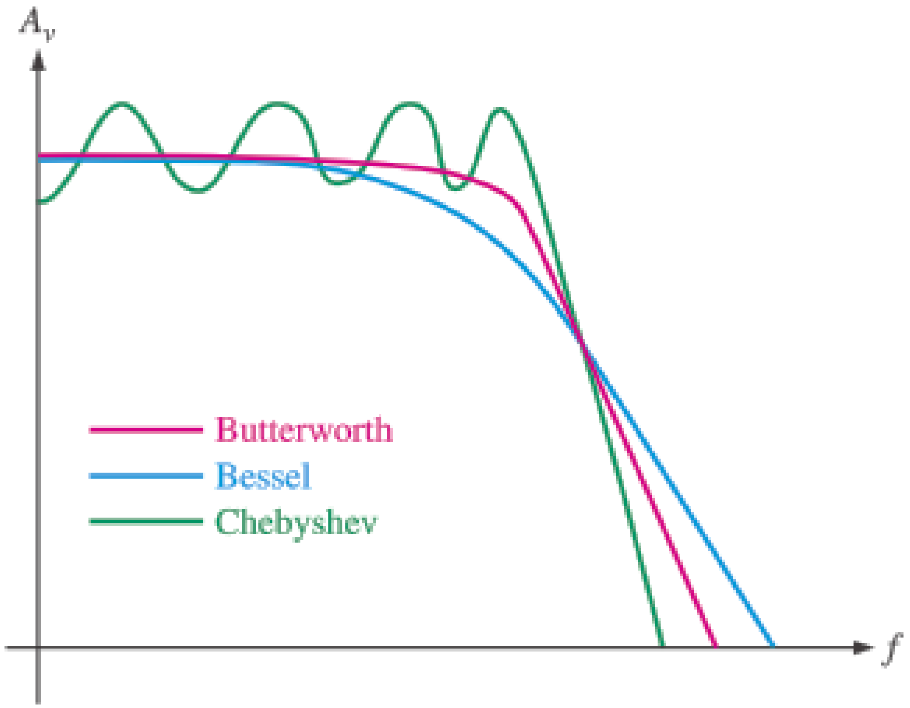
  also known as notch, band-reject, or band-elimination filter.



FILTER RESPONSE CHARACTERISTICS

FILTER RESPONSE CHARACTERISTICS

- Each type of filter response (low-pass, high-pass, band-pass, or band-stop) can be tailored by ***circuit component values*** to have either a
  - **Butterworth,**
  - **Chebyshev, or**
  - **Bessel** characteristic.
- Each of these characteristics is identified by the **shape of the response curve**, and each has an advantage in certain applications.



The Butterworth Characteristic

- The Butterworth characteristic provides a **very flat amplitude response** in the passband and a roll-off rate of -20 dB/decade/pole.
- The **phase response is not linear**, and the phase shift (thus, time delay) of signals passing through the filter varies nonlinearly with frequency.
- Therefore, a **pulse** applied to a Butterworth filter will **cause overshoots** on the output because each frequency component of the pulse's rising and falling edges experiences a different time delay.

FILTER RESPONSE CHARACTERISTICS..

The Chebyshev Characteristic

- Filters with the Chebyshev response characteristic are useful when a **rapid roll-off** is required because it provides a roll-off rate greater than -20 dB/decade/pole.
- This is a **greater rate** than that of the Butterworth, so filters can be implemented with the Chebyshev response with **fewer poles** and **less complex** circuitry for a given roll-off rate.
- This type of filter response is characterized by overshoot or **ripples in the passband** (depending on the number of poles) and an even **less linear phase response** than the Butterworth.

The Bessel Characteristic

- The Bessel response exhibits a **linear phase characteristic**, meaning that the phase shift increases linearly with frequency.
- The result is almost **no overshoot on the output** with a pulse input.
- It has the **slowest roll-off** rate.

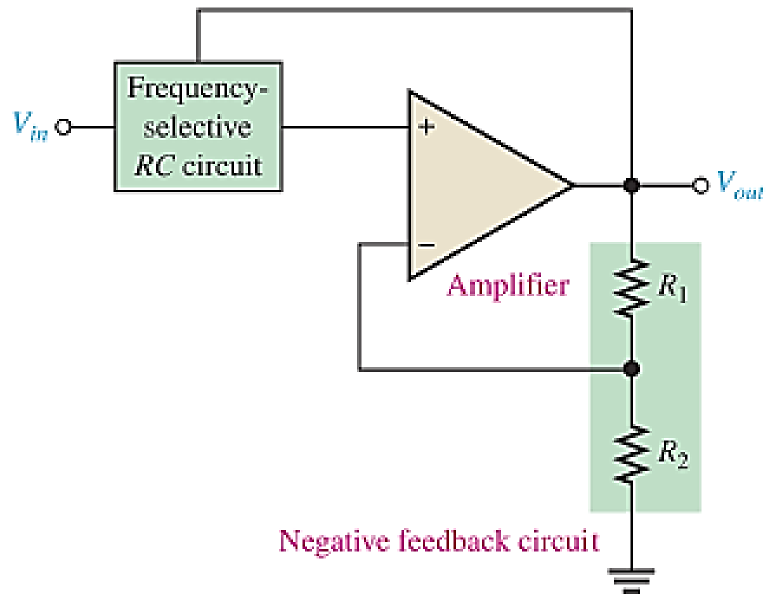
The Damping Factor

- The damping factor (**DF**) of an active filter circuit determines which **response characteristic** the filter exhibits.
- It affects the filter response by **negative feedback action**.
- Any attempted increase or decrease in the output voltage is offset by the **opposing effect** of the negative feedback.
- This **tends to** make the **response** curve **flat** in the passband of the filter if the value for the damping factor is precisely set.

$$DF = 2 - \frac{R_1}{R_2}$$

- The **value of the damping factor** required to produce a desired response characteristic **depends on the order** (number of poles) of the filter.
- ***Example:*** 2nd order → DF=1.4

$$\frac{R_1}{R_2} = 2 - DF = 2 - 1.414 = 0.586$$

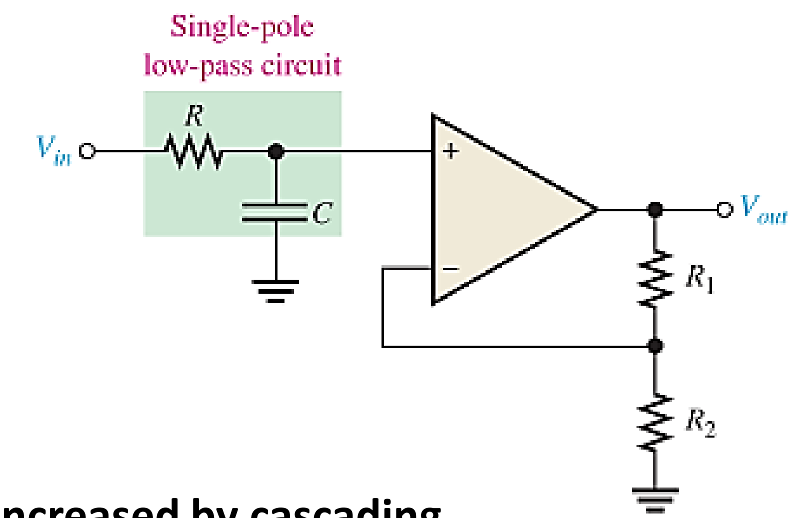


Values for the Butterworth response

ORDER	ROLL-OFF DB/DECADE	1ST STAGE			2ND STAGE			3RD STAGE		
		POLES	*DF*	R_1/R_2	POLES	*DF*	R_3/R_4	POLES	*DF*	R_5/R_6
1	−20	1	Optional							
2	−40	2	1.414	0.586						
3	−60	2	1.00	1	1	1.00	1			
4	−80	2	1.848	0.152	2	0.765	1.235			
5	−100	2	1.00	1	2	1.618	0.382	1	0.618	1.382
6	−120	2	1.932	0.068	2	1.414	0.586	2	0.518	1.482

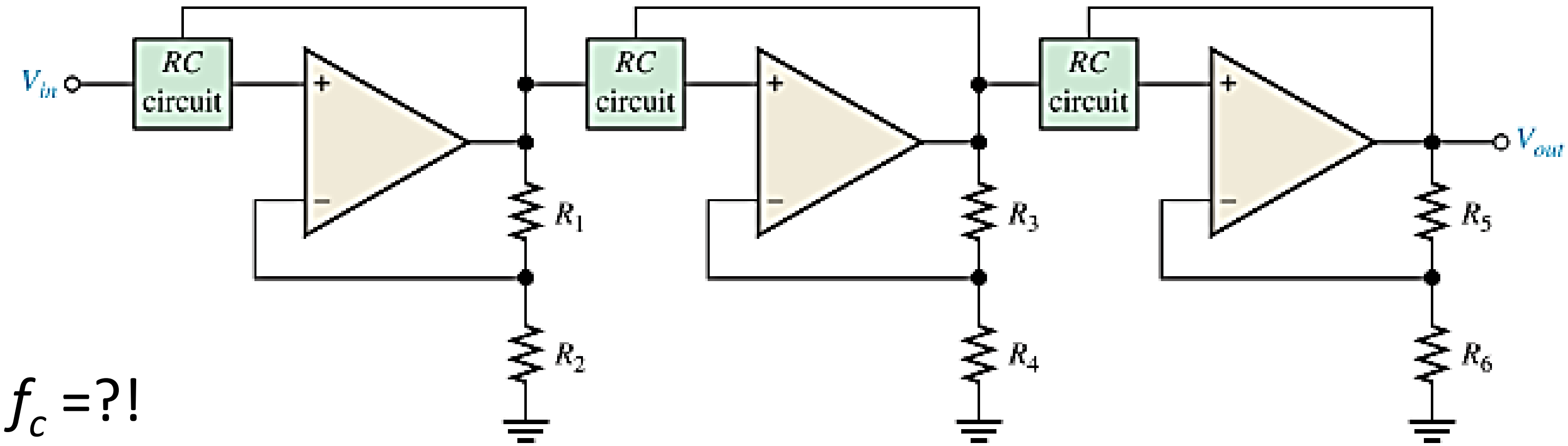
Critical Frequency and Roll-Off Rate

$$f_c = \frac{1}{2\pi RC}$$



- The number of filter **poles** can be **increased by cascading**.

<u>Example:</u> Third-order (three-pole) filter



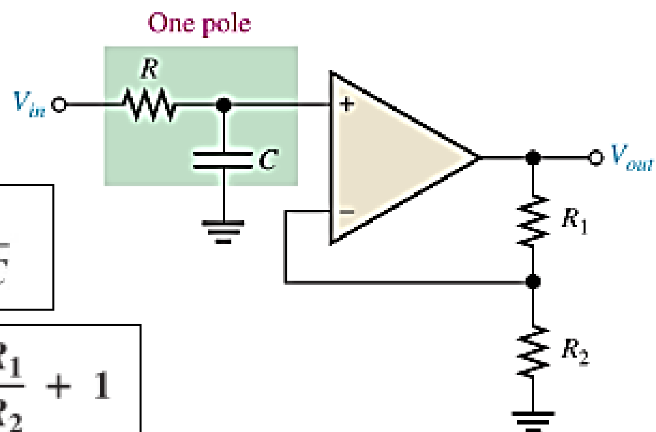
f_c =?!

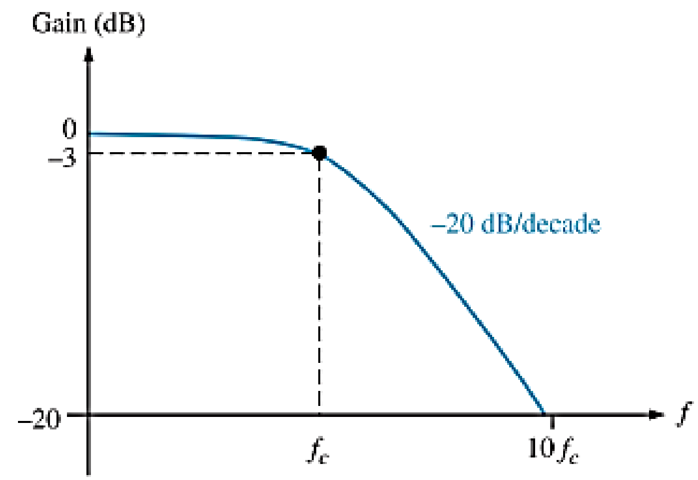
ACTIVE LOW-PASS FILTERS

Advantages of Op-Amp Active Filters

- Filters that use **op-amps** as the **active element** provide several **advantages** over passive filters (R, L, and C elements only).
  - The op-amp provides **gain**, so the **signal is not attenuated** as it passes through the filter.
  - The high input impedance of the op-amp **prevents excessive loading of the driving source**.
  - The low output impedance of the op-amp **prevents the filter from being affected by the load** that it is driving.
  - Active filters are also **easy to adjust over a wide frequency range** without altering the desired response.

Single-Pole LPF



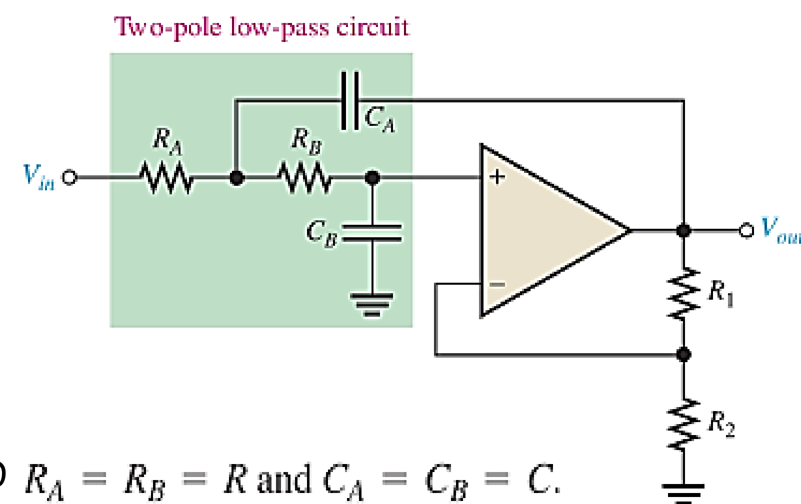


$$f_c = \frac{1}{2\pi RC}$$

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

The Sallen-Key LPF (2^{nd} Order)

- It is used to provide **very high Q factor and passband gain without the use of inductors**.
- It is also known as a **VCVS** (voltage-controlled voltage source) filter.

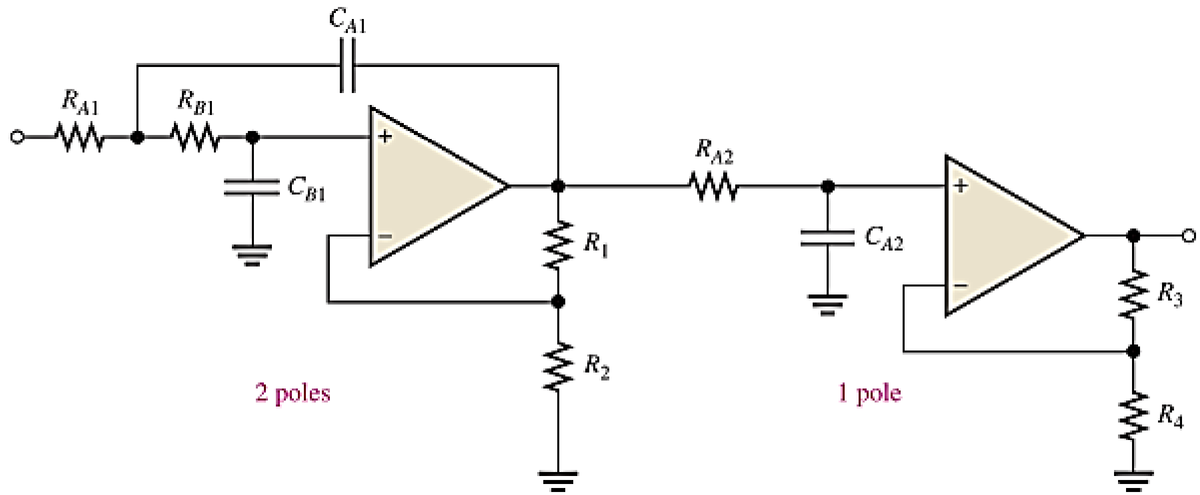


$$f_c = \frac{1}{2\pi\sqrt{R_A R_B C_A C_B}}$$

$$f_c = \frac{1}{2\pi RC} \quad @\ R_A = R_B = R \text{ and } C_A = C_B = C.$$

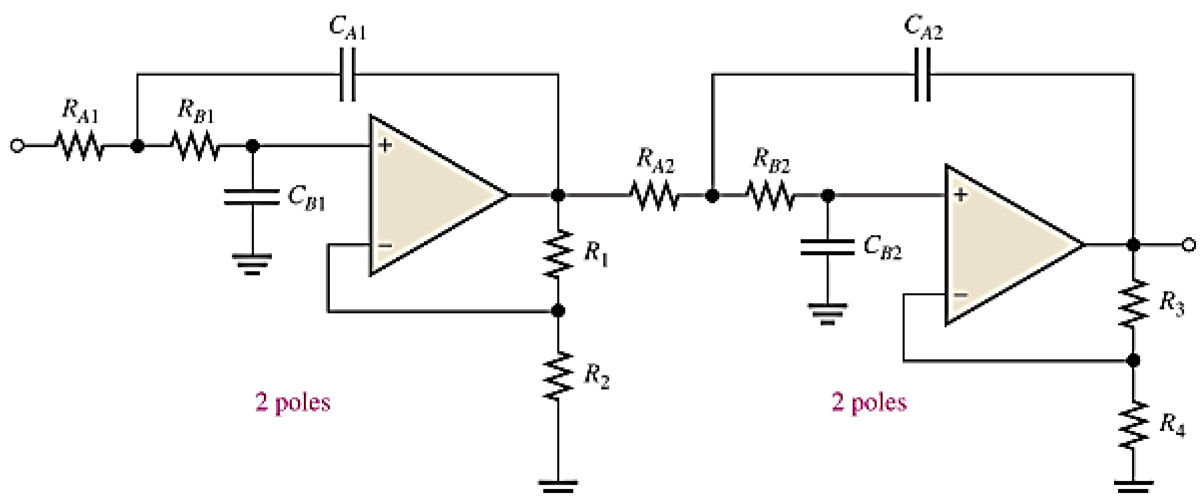
Cascaded LPF

- A **three-pole** filter is required to get a **third-order** low-pass response.



(a) Third-order configuration

- A **four-pole** filter is **preferred** because it uses the same number of op-amps to achieve a faster roll-off.

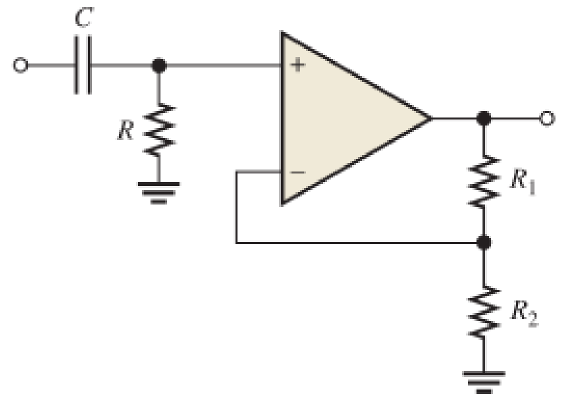


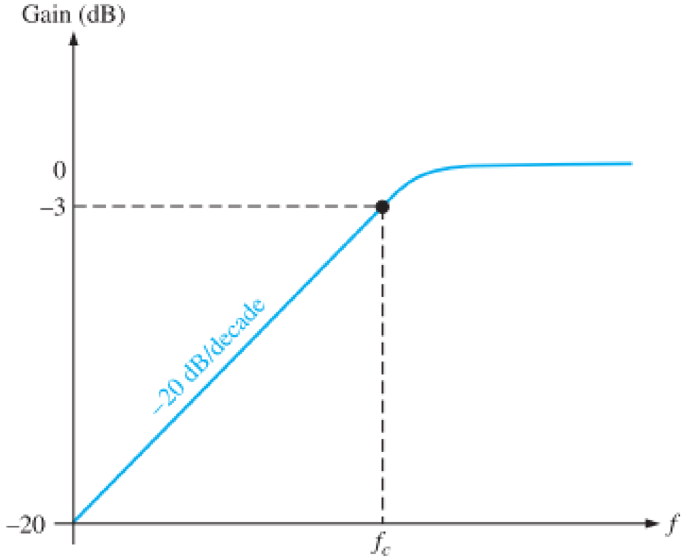
(b) Fourth-order configuration

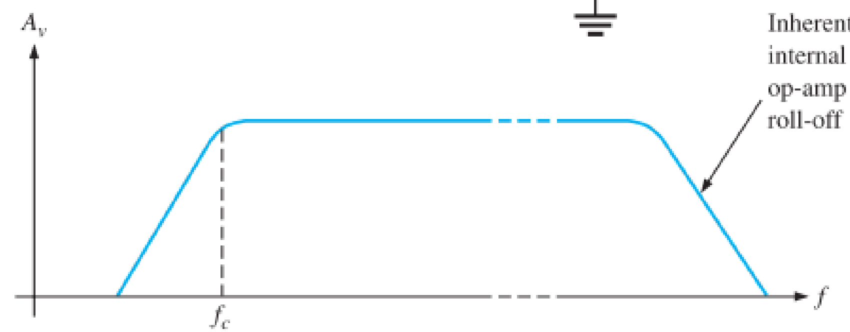
In high-pass filters, the roles of the capacitor and resistor are reversed in the RC circuits.

ACTIVE HIGH-PASS FILTERS

Single Pole HPF

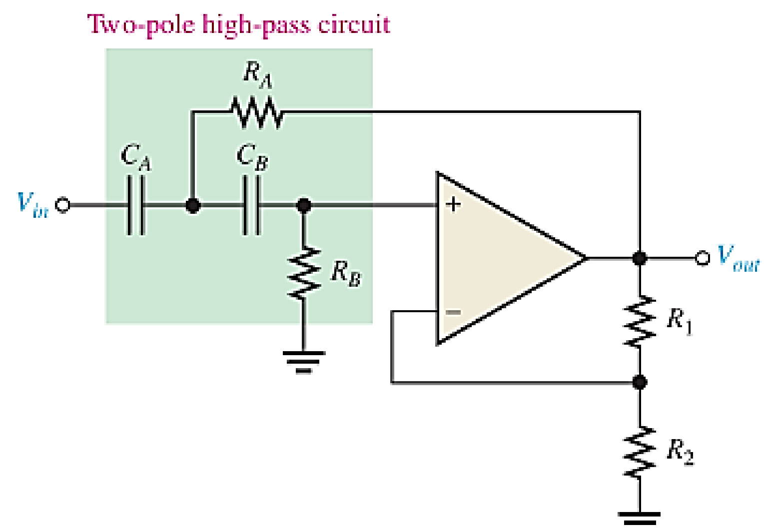




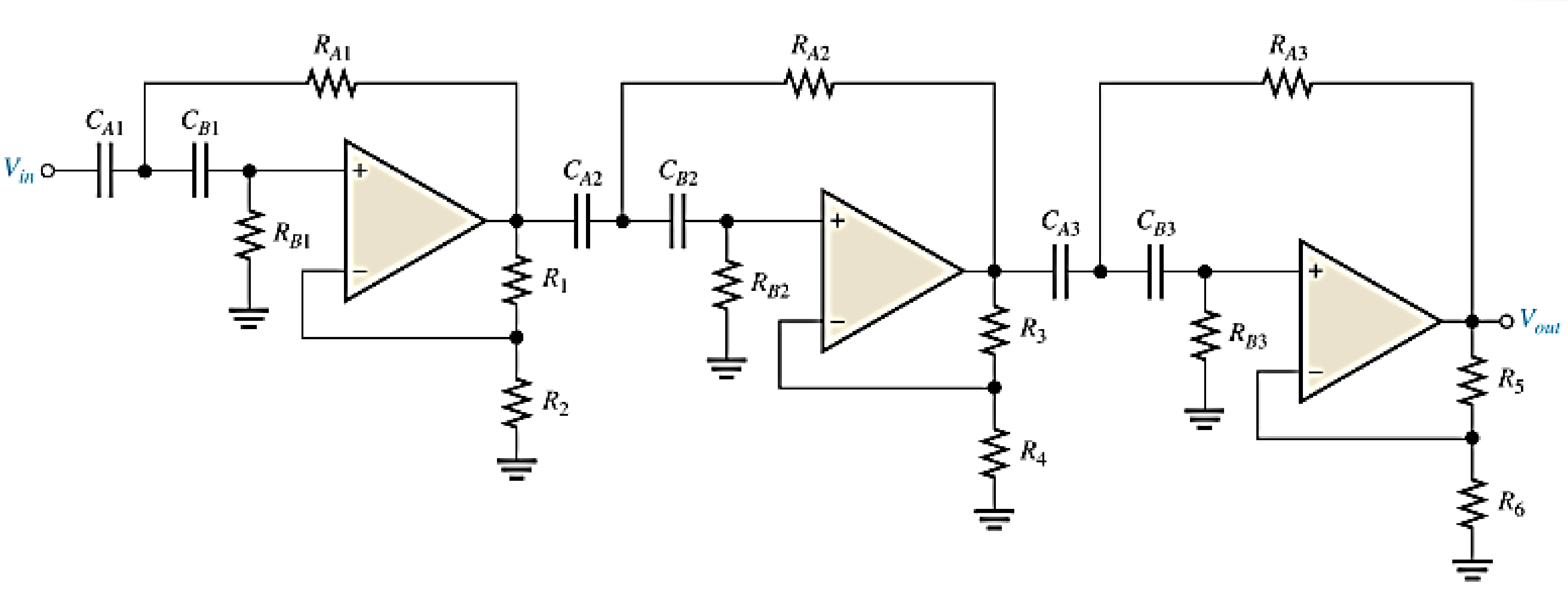


(b) Nonideal

Sallen-Key HPF



Cascaded HPF

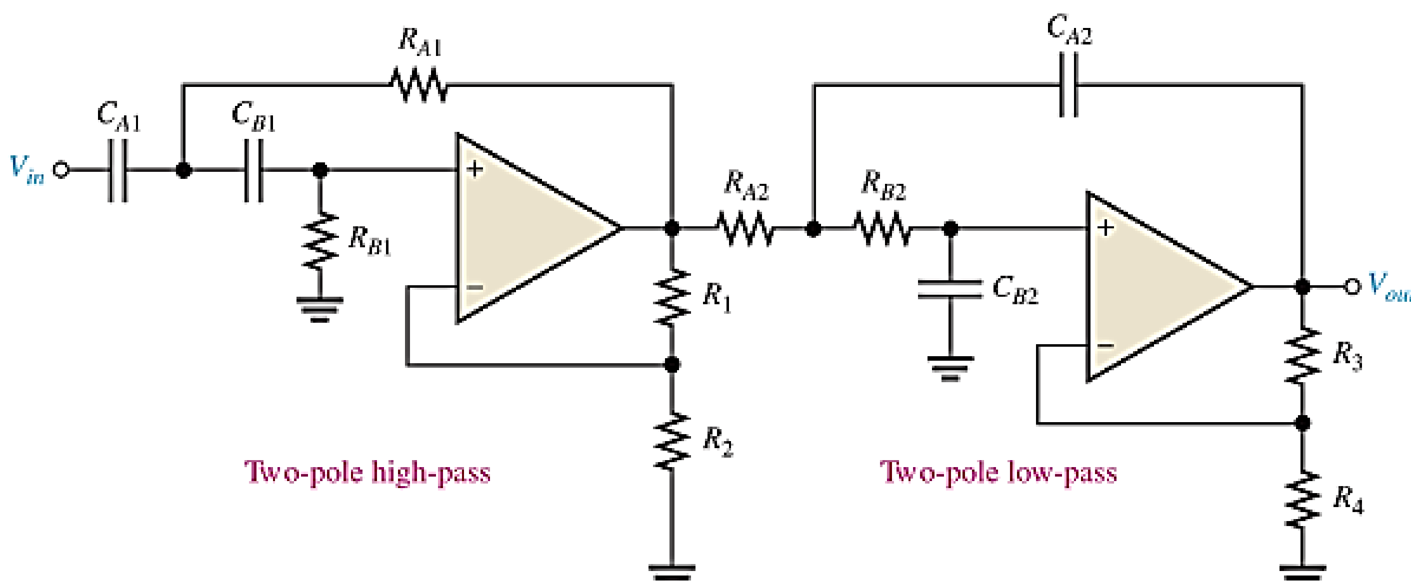


Order = ?

roll-off = ?

ACTIVE BAND-PASS FILTERS

Cascaded Low-Pass and High-Pass Filters



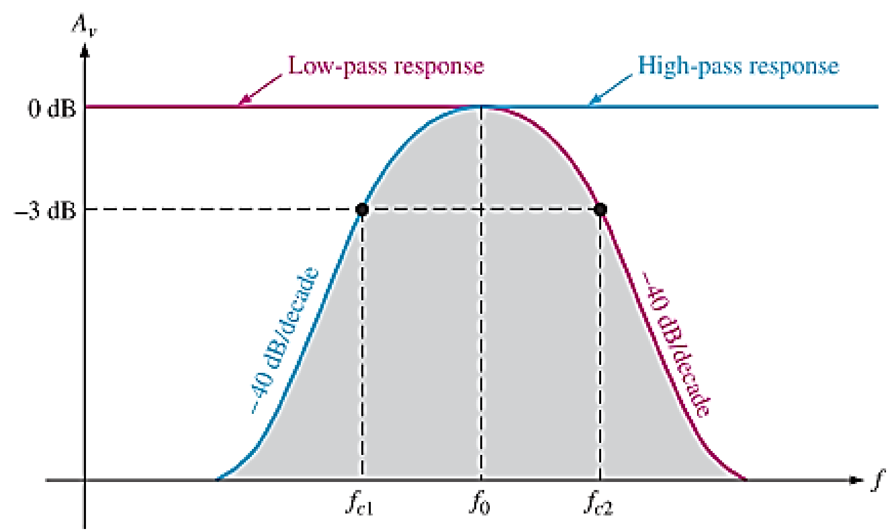
$$f_{c1} = \frac{1}{2\pi\sqrt{R_{A1}R_{B1}C_{A1}C_{B1}}}$$

$$f_{c2} = \frac{1}{2\pi\sqrt{R_{A2}R_{B2}C_{A2}C_{B2}}}$$

$$f_0 = \sqrt{f_{c1}f_{c2}}$$

If equal components:

$$f_c = 1/(2\pi RC).$$



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Multiple-Feedback Band-Pass Filter

- The center frequency expression is:

$$f_0 = \frac{1}{2\pi C}\sqrt{\frac{R_1 + R_3}{R_1 R_2 R_3}}$$

- A value for the capacitors is chosen and then the three resistor values are calculated using the expressions:

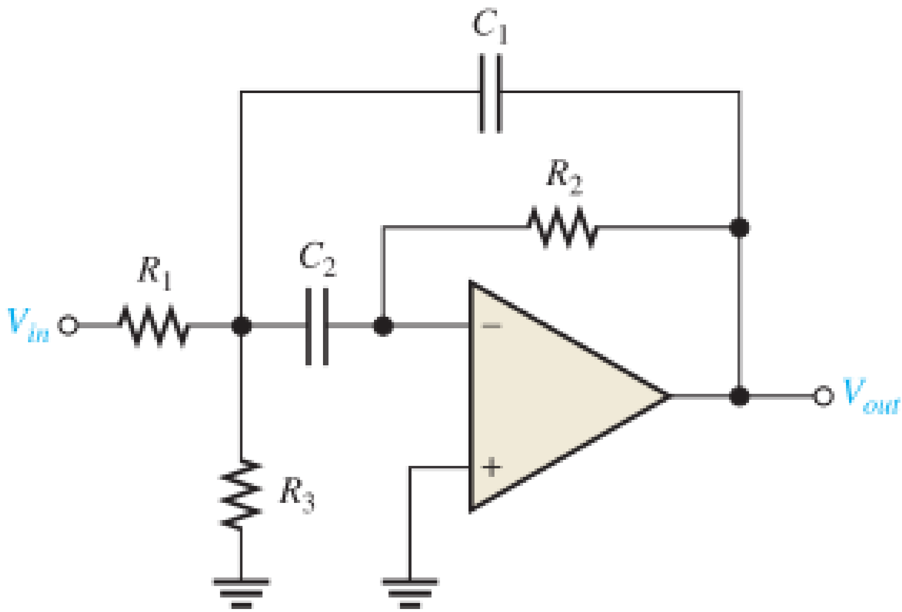
$$R_1 = \frac{Q}{2\pi f_0 C A_0}$$

$$R_2 = \frac{Q}{\pi f_0 C}$$

$$R_3 = \frac{Q}{2\pi f_0 C(2Q^2 - A_0)}$$

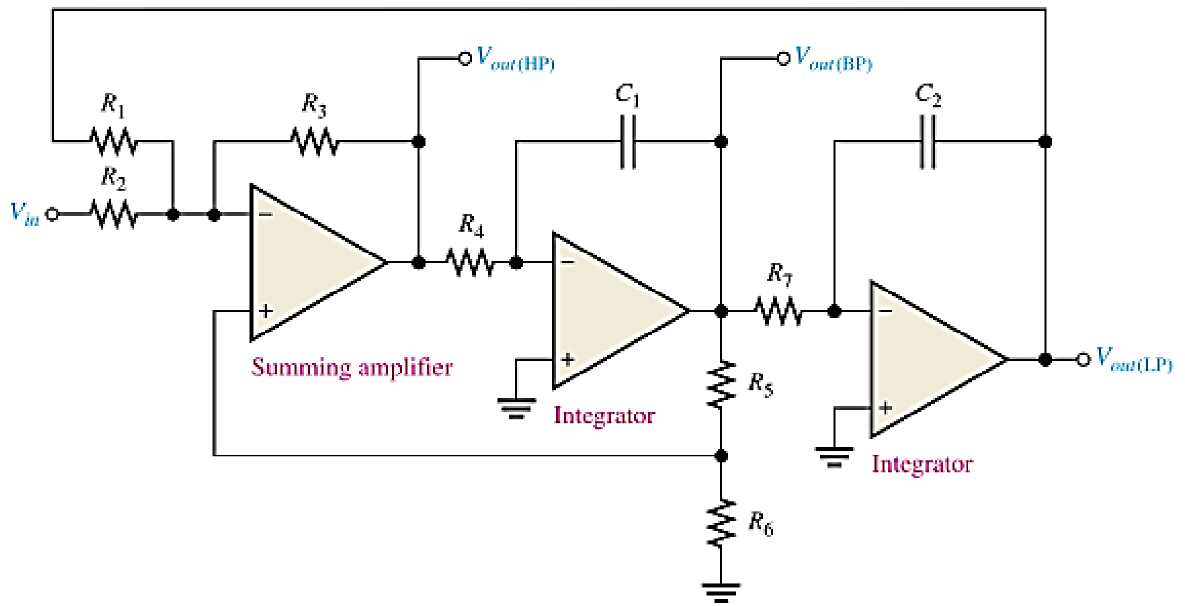
- The gain expression

$$A_0 = \frac{R_2}{2R_1}$$



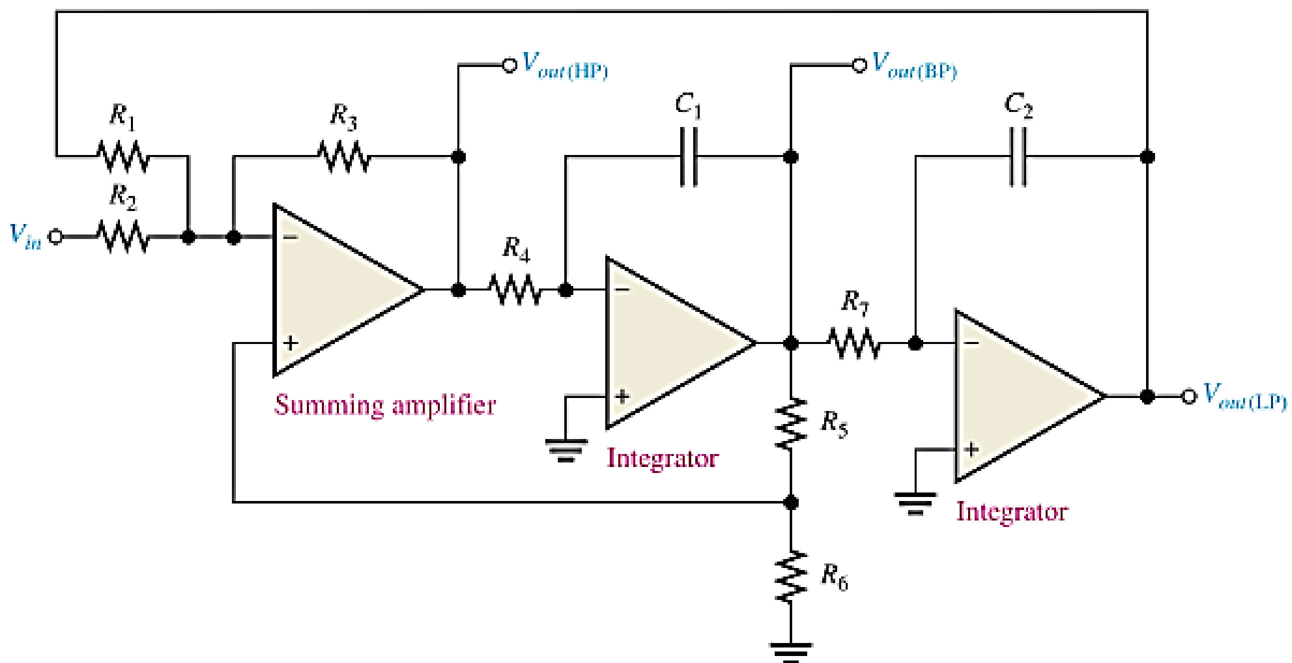
State-Variable Filter **(universal active filter)**

- It consists of **one or more integrators**, connected in some feedback configuration.
- It realizes the ***state-space model*** with n state variables for an n^{th} order system.
- The **instantaneous output** voltage of one of the integrators **corresponds to one of** the state-space model's **state variables**.
- The **center frequency** is set by the **RC** circuits in both **integrators**.



State-Variable Filter..

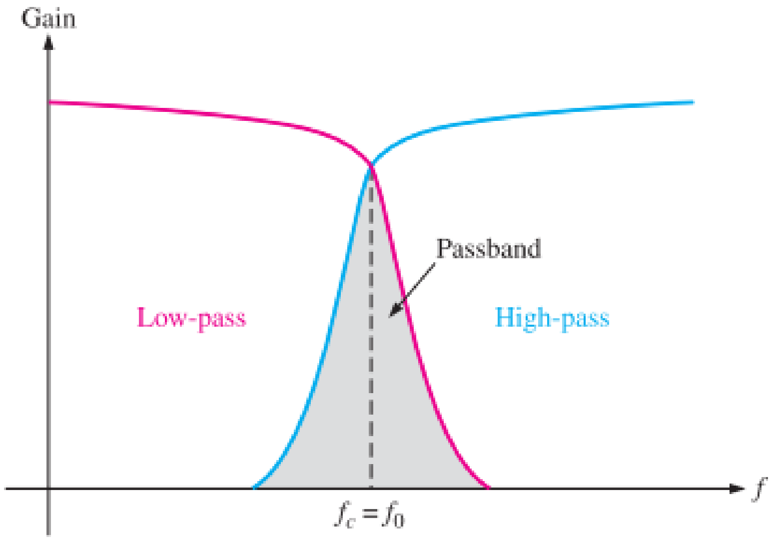
- At **<u>f < f_c</u>**, the input signal passes through the summing amplifier and integrators and is **fed back 180º** out of phase. Thus, the feedback signal and **input signal cancel** for all frequencies < fc.
- As the **low-pass response of the integrators rolls off**, the feedback signal diminishes, thus **allowing the input to pass** through to the band-pass output.
- **<u>Above f_c</u>**, the **low-pass response disappears**, thus preventing the input signal from passing through the integrators.
- As a **<u>result</u>**, the band-pass filter output **peaks sharply at f_c**.



State-Variable Filter…

- Stable **Qs** up to 100 can be obtained with this type of filter.

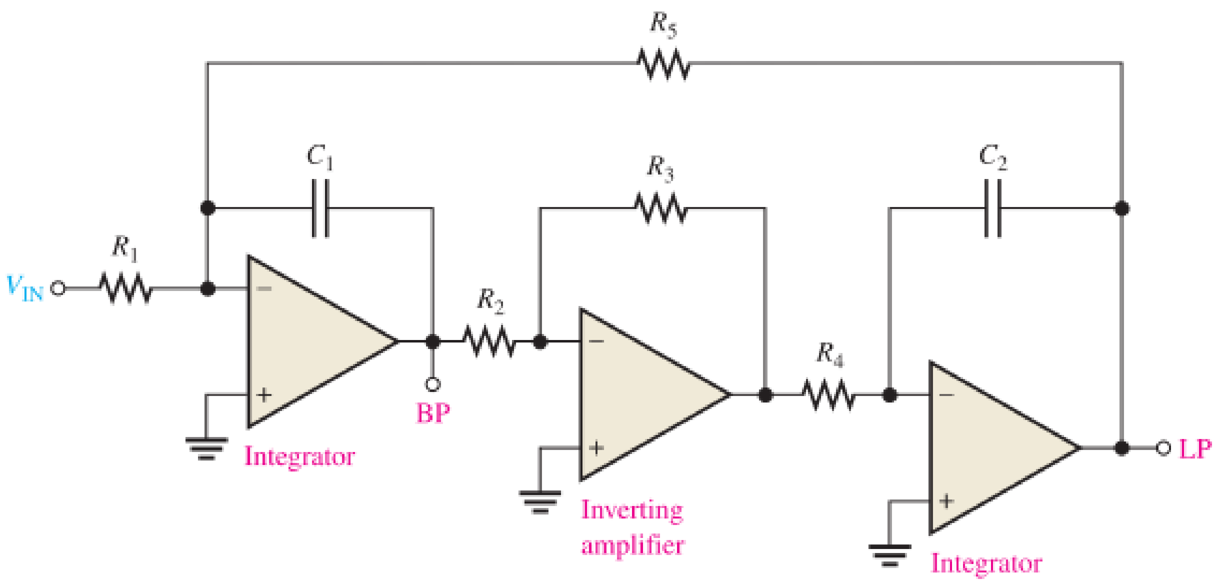
$$Q = \frac{1}{3}\left(\frac{R_5}{R_6} + 1\right)$$



- The state-variable filter **cannot be optimized for low-pass, high-pass, and narrow band-pass performance simultaneously**.
- To optimize for a low-pass or a high-pass Butterworth response, DF must equal 1.414. Since Q = 1/DF, a Q of 0.707 will result.
- Such a low Q provides a very wide band-pass response (large BW and poor selectivity).
- For optimization as a narrow band-pass filter, the Q must be set high.

Biquad Filter

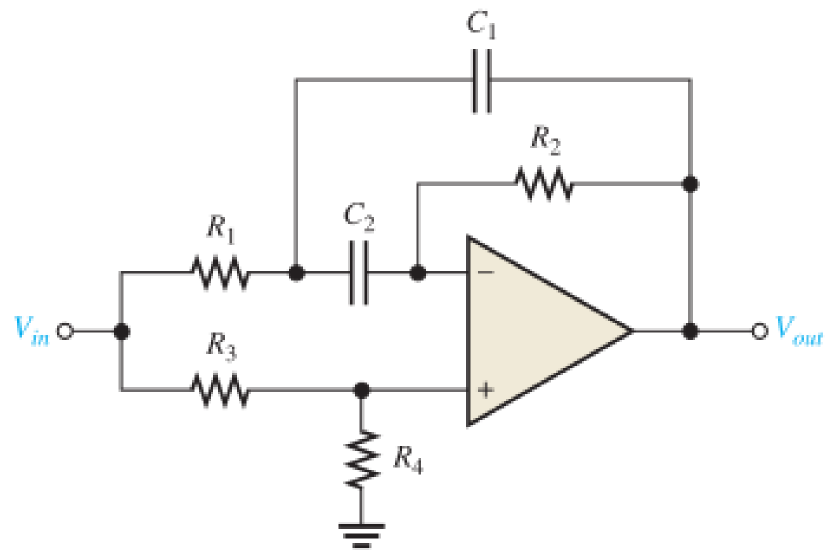
- "Biquad" is an abbreviation of "**biquadratic**", which refers to the fact that in the Z domain, its **transfer function** is the ratio of two quadratic functions.



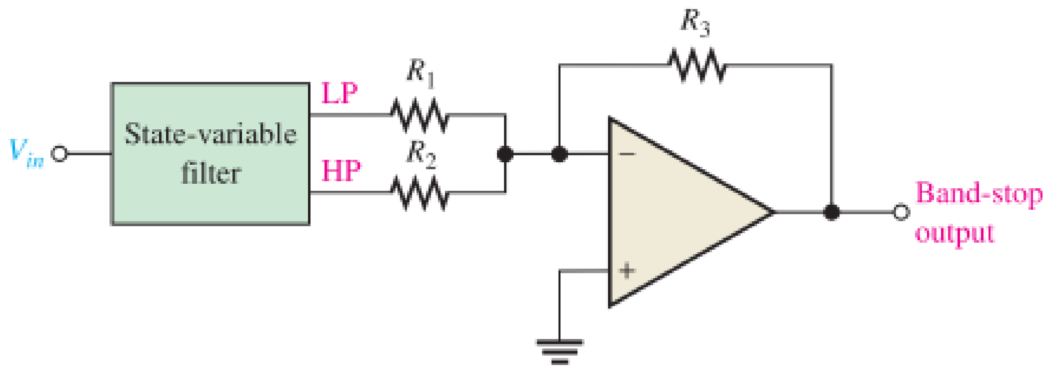
State-Variable Filter	Biquad Filter
Sum. Amp. → Integrator → Integrator	Integrator →Inv. Amp. → Integrator
very high Q value	very high Q value
B.W. depends on f_c	B.W. independent on f_c
Q independent on f_c	Q depends on f_c
HP, BP & LP outputs	BP & LP outputs

ACTIVE BAND-STOP FILTERS

Multiple-Feedback Band-Stop Filter



State-Variable Band-Stop Filter

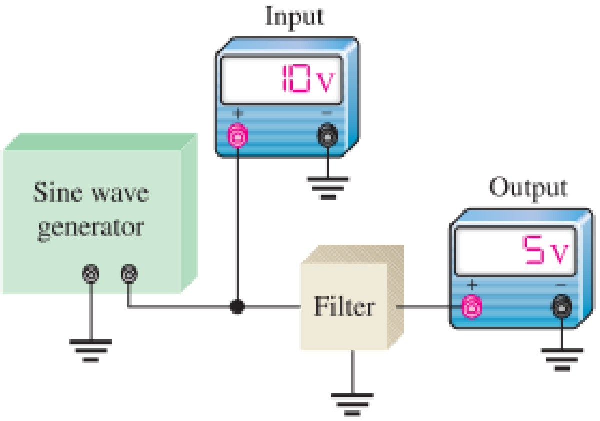


FILTER RESPONSE MEASUREMENTS

Discrete Point Measurement

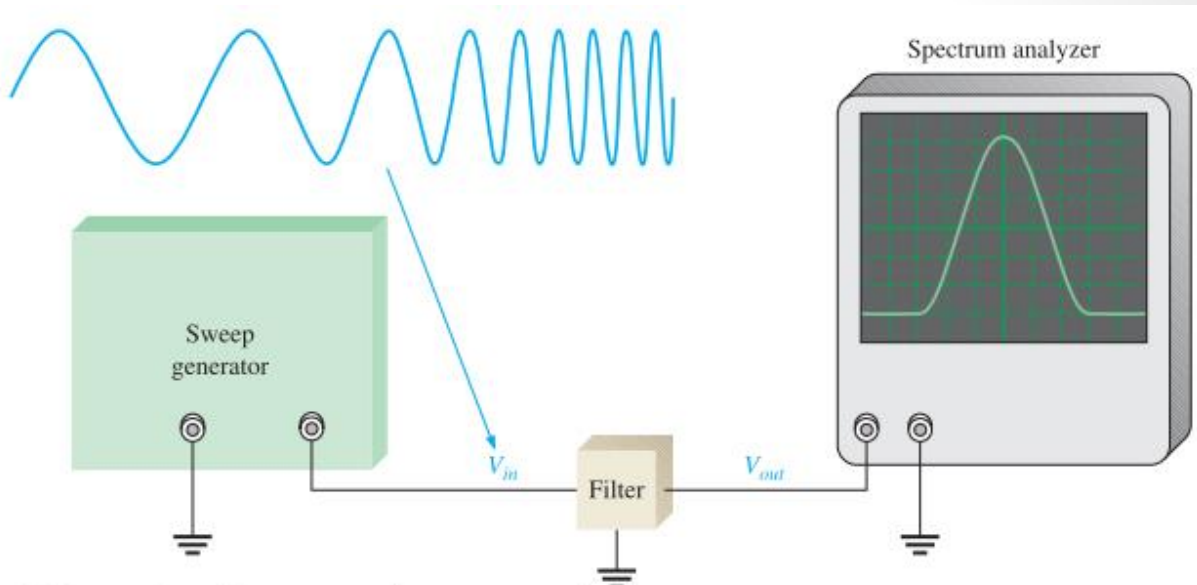
The **general procedure** is as follows:

1. **Set the amplitude** of the sine wave generator to a desired voltage level.
2. **Set the frequency** of the sine wave generator to a value well below the expected critical frequency of the filter under test.
    - For a **low-pass** filter, set the frequency as near as possible to **0 Hz**.
    - For a **band-pass** filter, set the frequency well **below the expected lower** critical frequency.
3. **Increase the frequency** in predetermined **steps** sufficient to allow enough data points for an accurate response curve.
4. **Maintain** a **constant input** voltage **amplitude** while **varying** the **frequency**.
5. **Record** the **output voltage** at each value of frequency.
6. After recording a sufficient number of points**, plot a graph** of output voltage versus frequency.

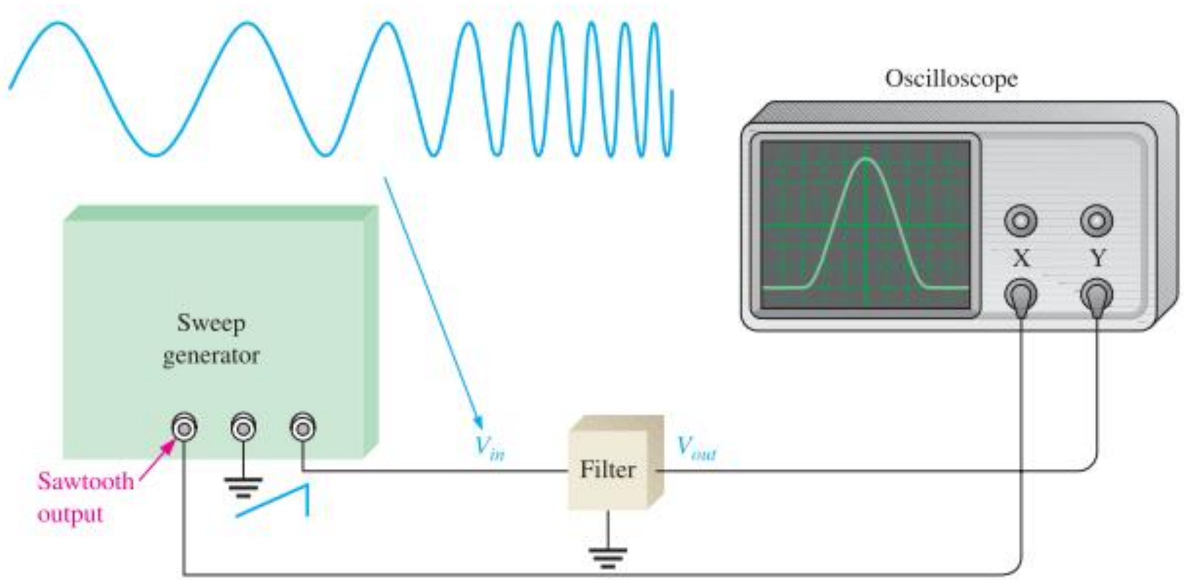


Swept Frequency Measuremen

- requires more elaborate test equipment
- but it is much more efficient



(a) Test setup for a filter response using a spectrum analyzer



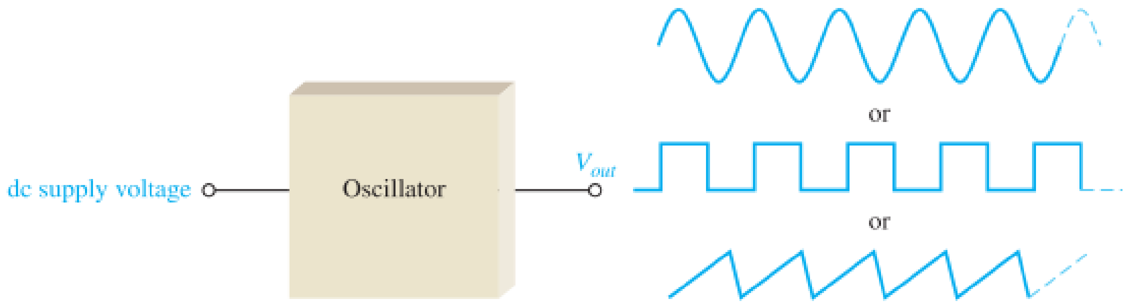
(b) Test setup for a filter response using an oscilloscope. The scope is placed in X-Y mode. The sawtooth waveform from the sweep generator drives the X-channel of the oscilloscope.

OSCILLATORS

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.

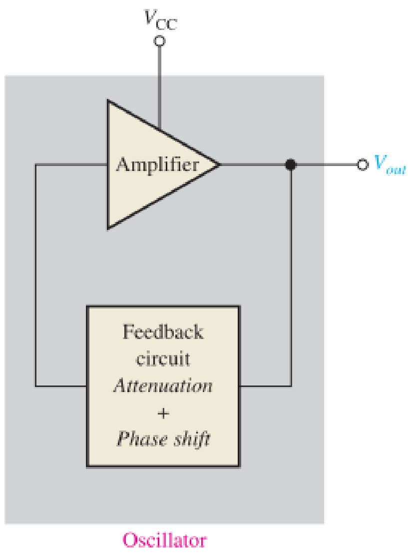
○ an oscillator converts electrical energy from the dc power supply to periodic waveforms.



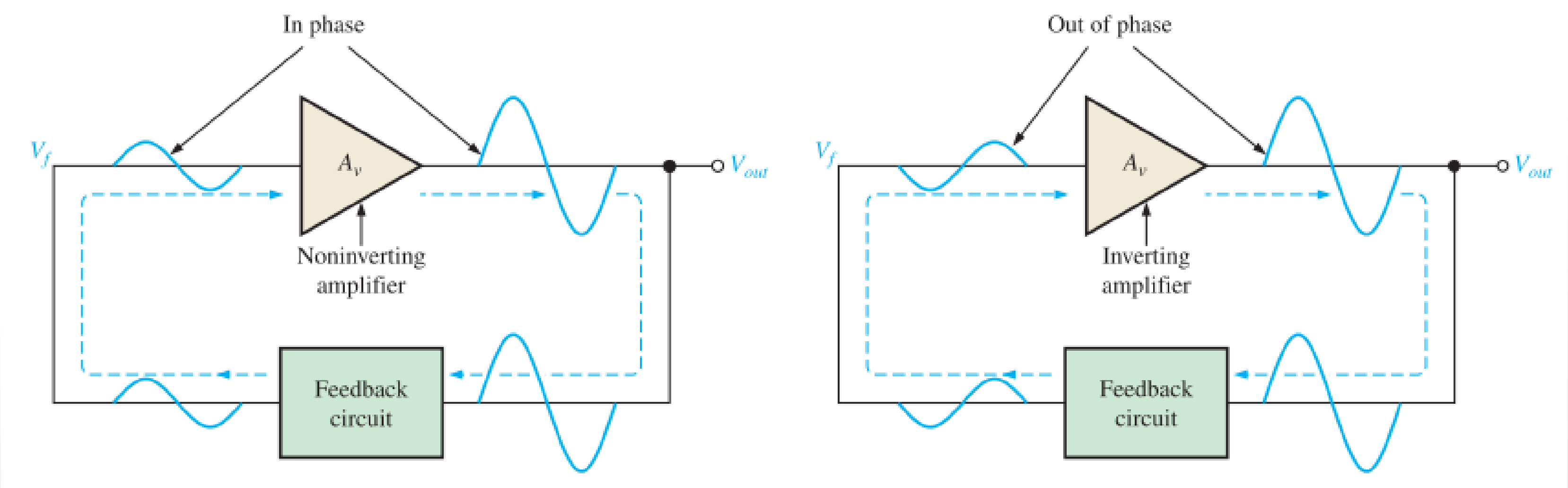
FEEDBACK OSCILLATORS

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.

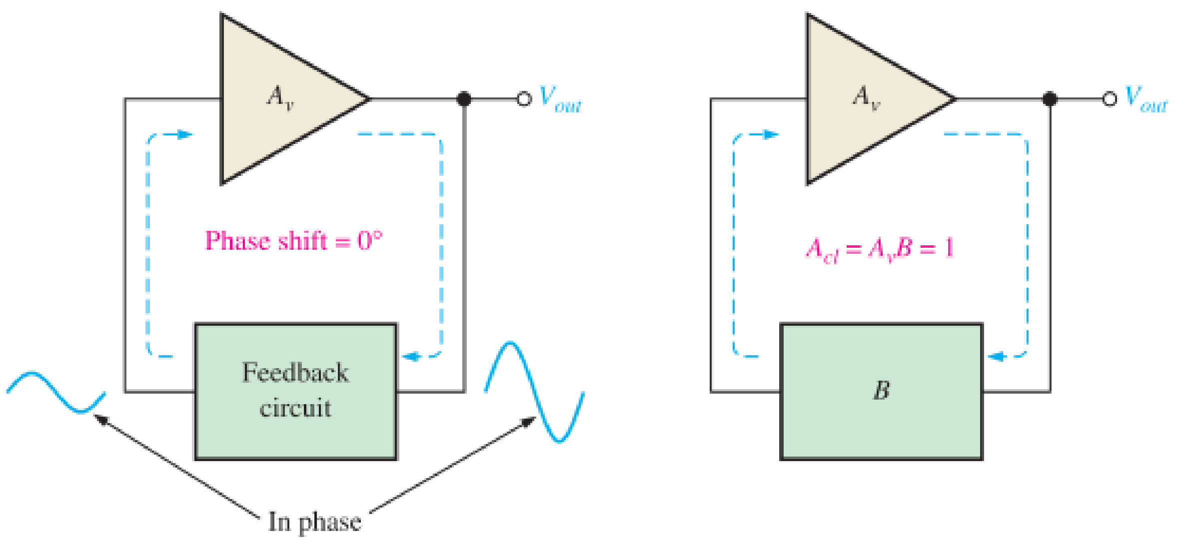


Conditions for Oscillation

- 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).

$$A_{cl} = A_v B$$

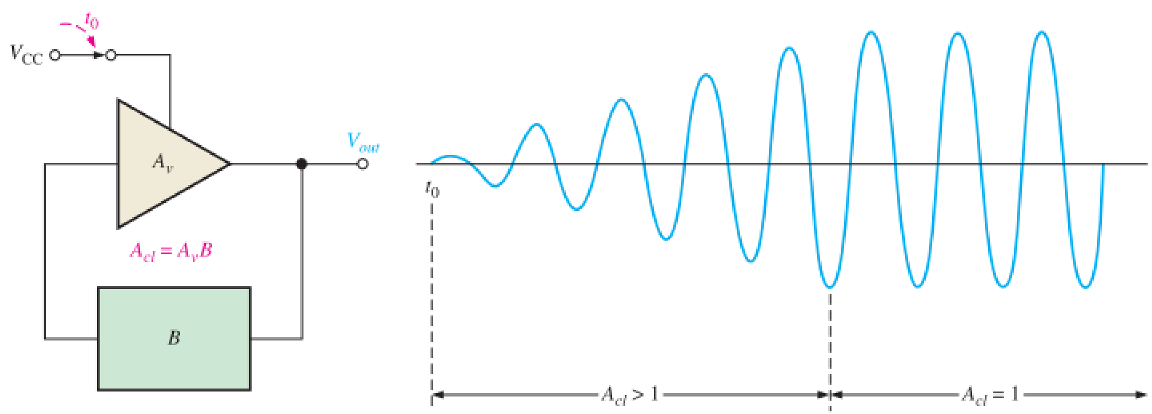


(a) The phase shift around the loop is 0°.

(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

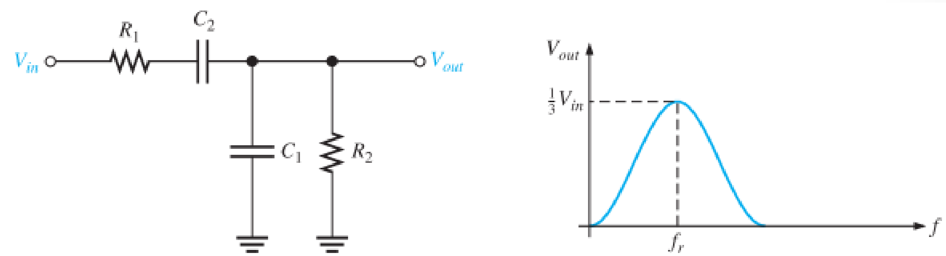
OSCILLATORS WITH RC FEEDBACK CIRCUITS

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 $X_{C1} = X_{C2}$

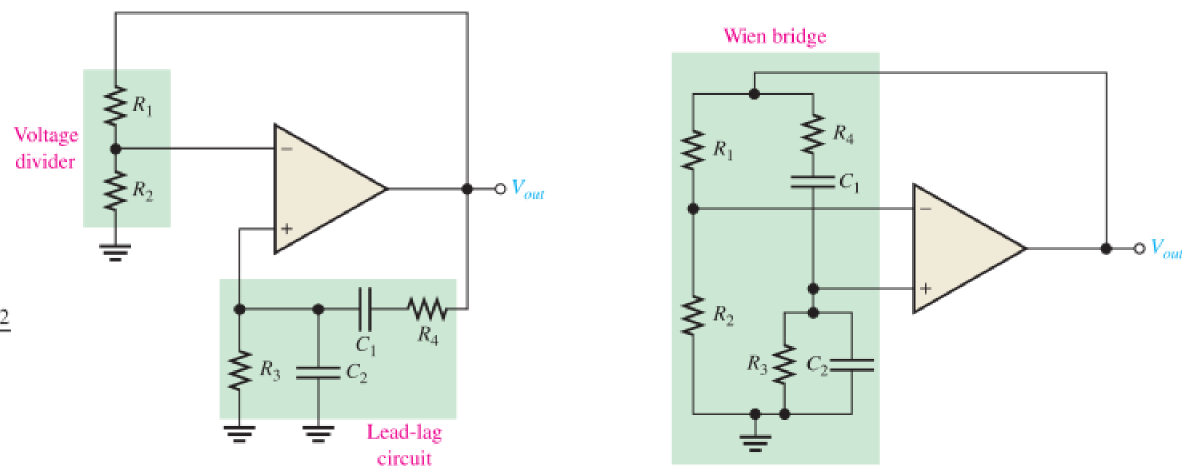
$$\frac{V_{out}}{V_{in}} = \frac{1}{3} \qquad f_r = \frac{1}{2\pi RC}$$



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.

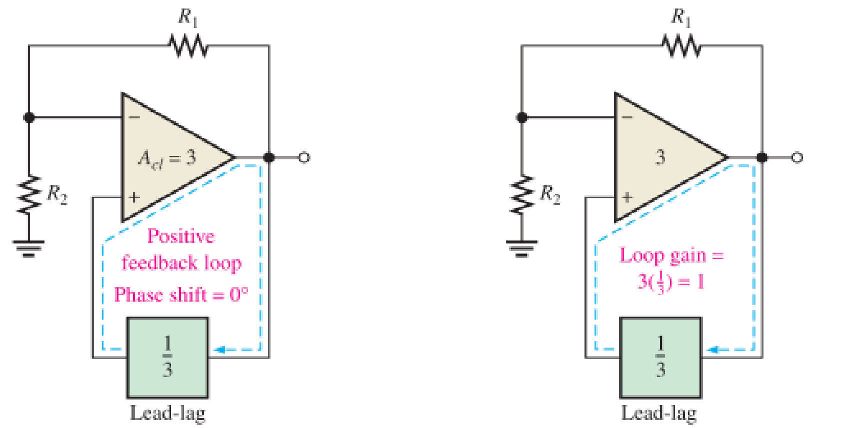
The Wien-Bridge Oscillator..

- Positive Feedback Conditions for Oscillation

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

choose $R_1 = 2R_2$

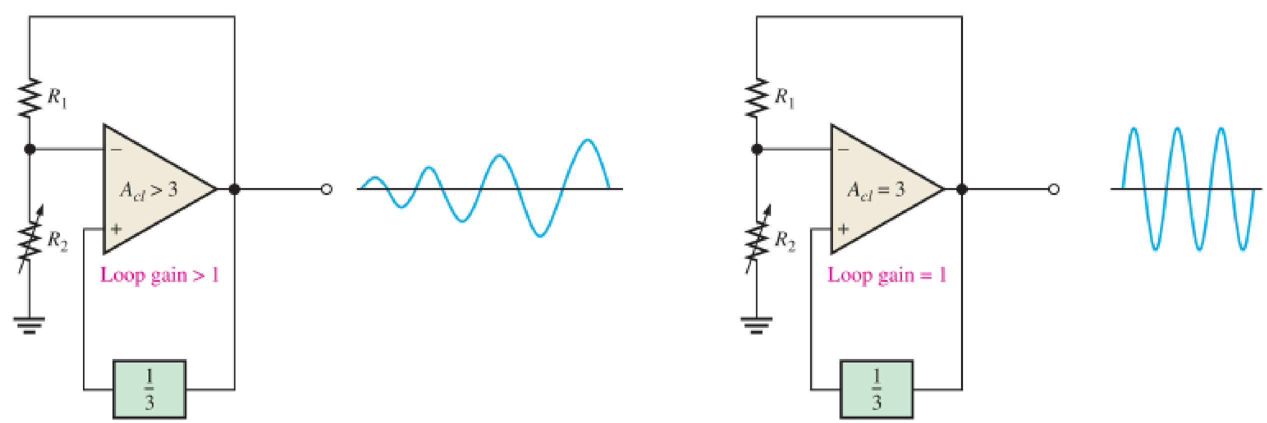
$$A_{cl} = \frac{R_1 + R_2}{R_2} = \frac{2R_2 + R_2}{R_2} = \frac{3R_2}{R_2} = 3$$



(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.

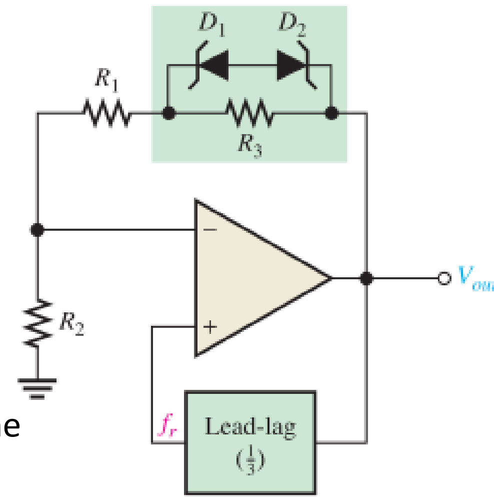
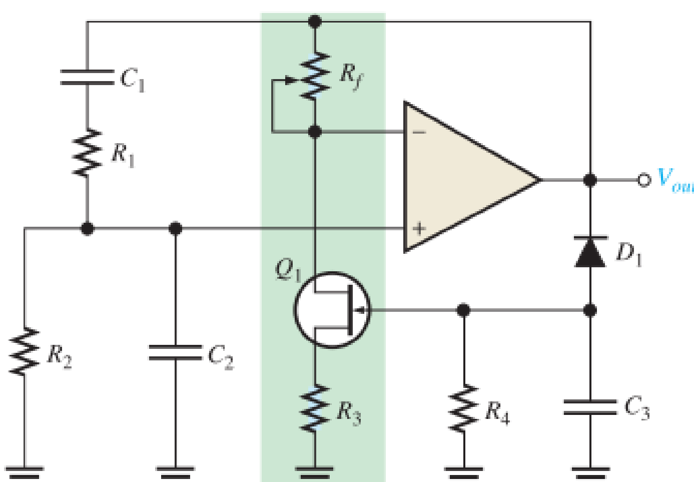


FIGURE 16–10

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

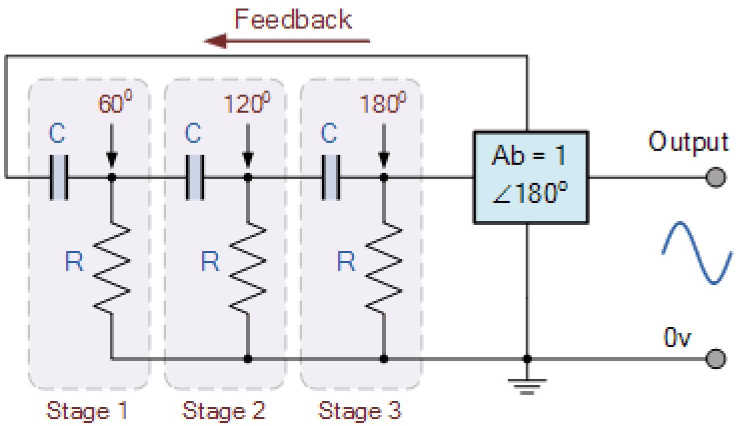
FIGURE 16–11

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

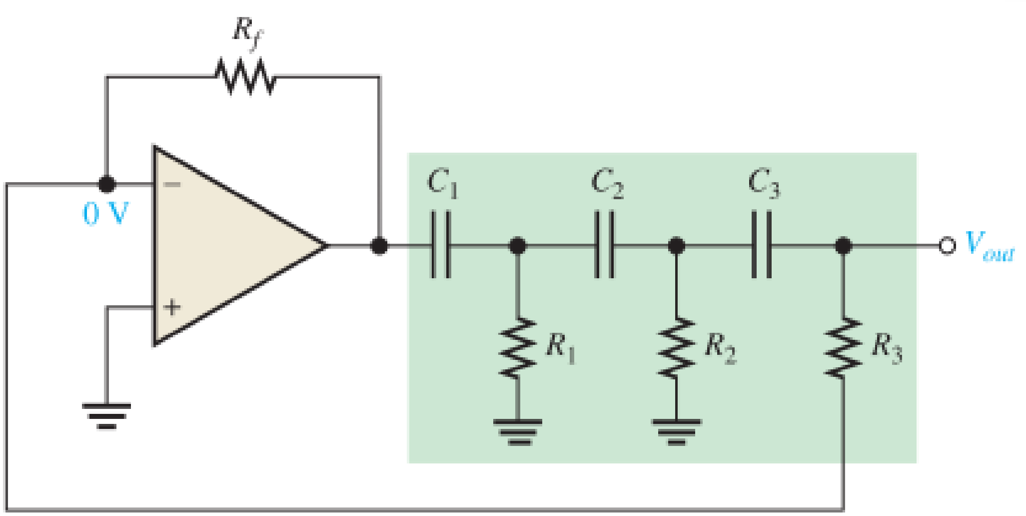


- In some older designs, a tungsten lamp was used in the feed-back circuit to achieve stability.
- A better method to control the gain uses a JFET as a voltage-controlled resistor in a negative feedback path.
- As the voltage increases, the drain-source resistance increases.

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.



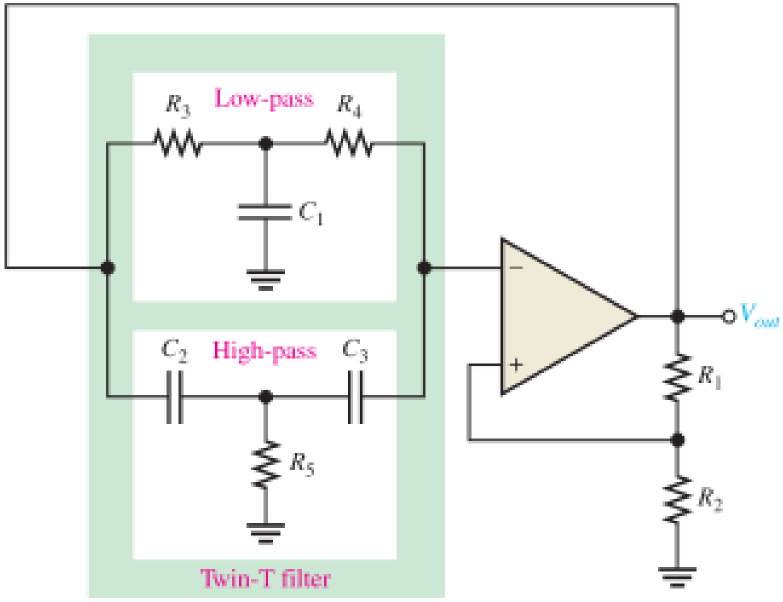
$$B = \frac{1}{29} \qquad \text{where } B = R_3/R_f.$$

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

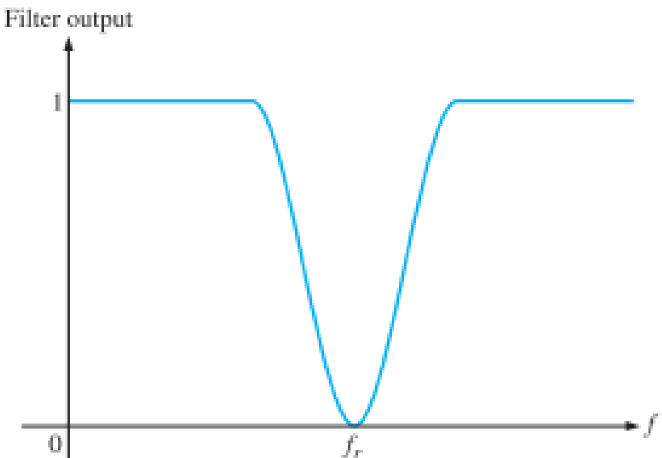
$$f_r = \frac{1}{2\pi\sqrt{6}RC}$$

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.

LC OSCILLATOR

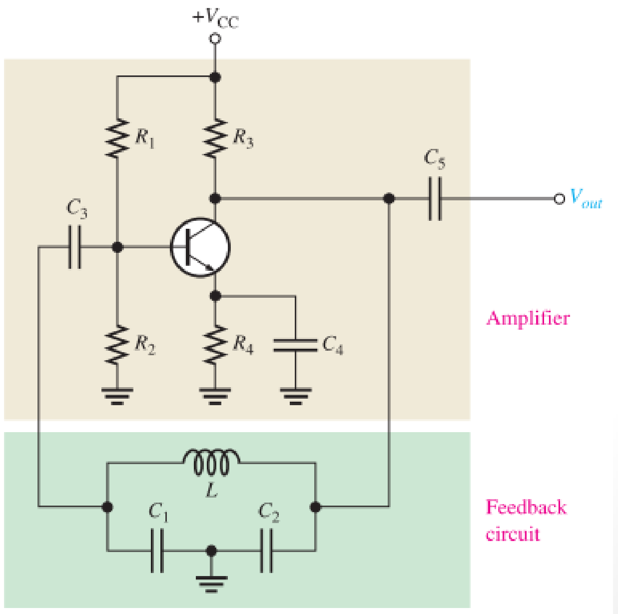
Colpitts Oscillator

- 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

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

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

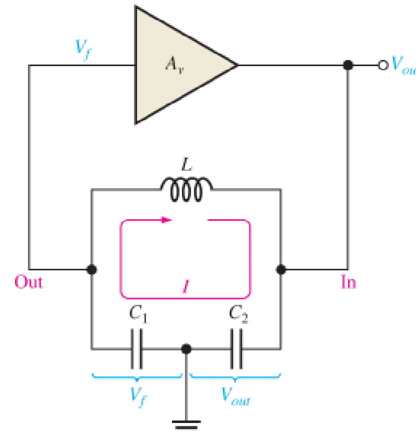


FIGURE 16–17

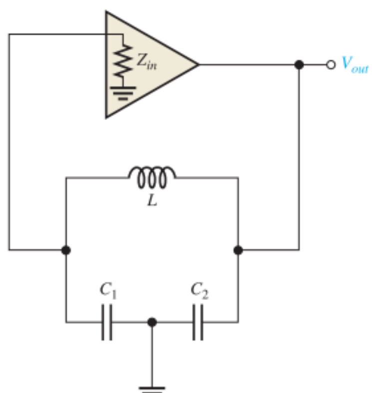
The attenuation of the tank circuit is the output of the tank (V_f) divided by the input to the tank (V_{out}). $B = V_f/V_{out} = C_2/C_1$. For $A_vB > 1$, A_v must be greater than C_1/C_2.

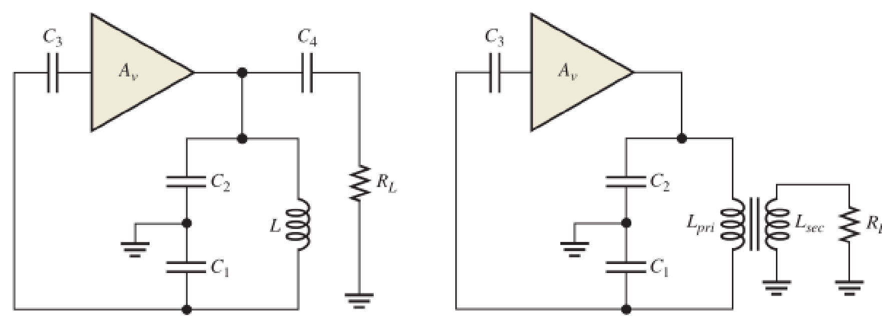
- Loading of the Feedback Circuit Affects the Frequency of Oscillation

→ 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.

Clapp Oscillator

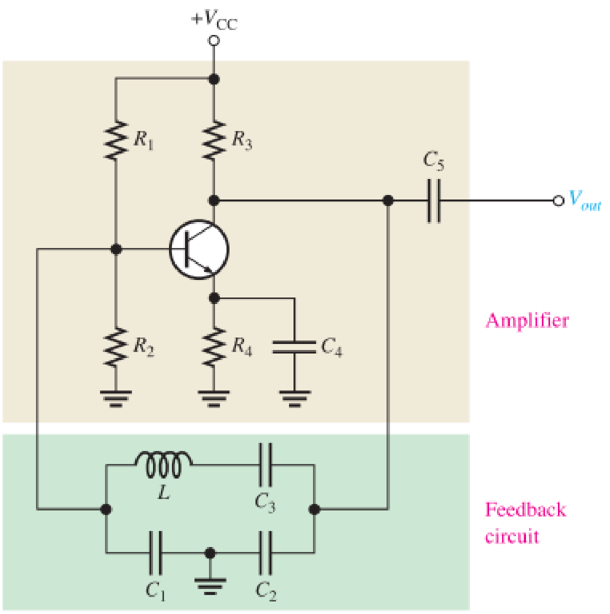
- The Clapp oscillator is a variation of the Colpitts with addition of C_3.

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

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

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.

Hartley Oscillator

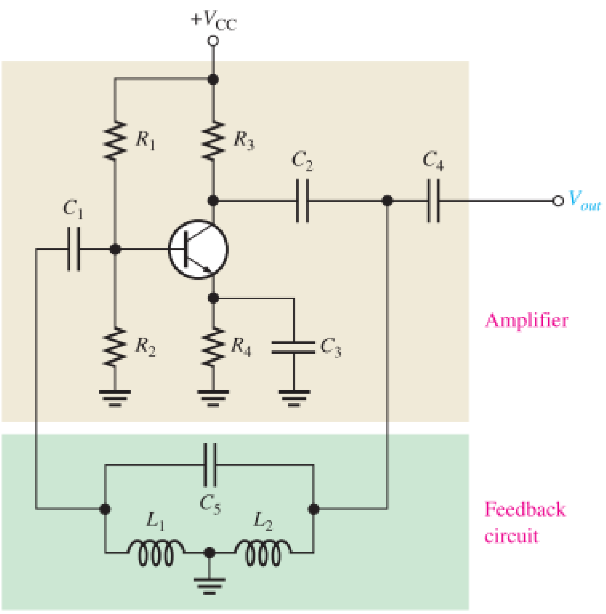
- The Hartley oscillator is similar to the Colpitts except that the feedback circuit consists of two series inductors and a parallel capacitor

$Q > 10 \qquad f_r \cong \frac{1}{2\pi\sqrt{L_T C}}$

$L_T = L_1 + L_2.$

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

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

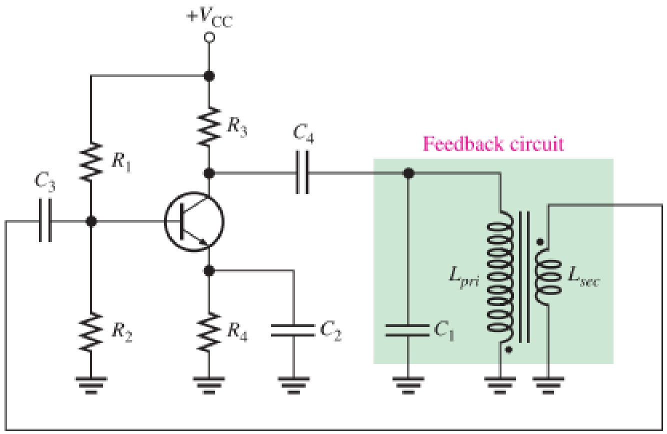


- Loading of the tank circuit has the same effect in the Hartley as in the Colpitts; that is, the Q is decreased and thus f_r decreases.

Armstrong Oscillator

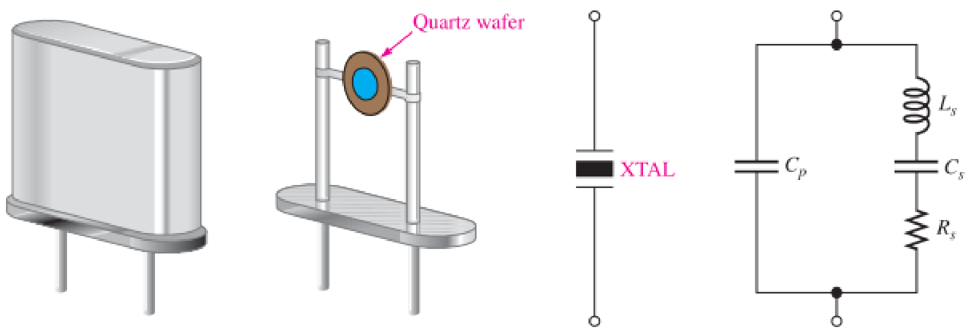
- This type of LC feedback oscillator uses transformer coupling to feed back a portion of the signal voltage.
- It is sometimes called a “tickler” oscillator in reference to the transformer secondary or “tickler coil” that provides the feedback to keep the oscillation going.
- The Armstrong is less common 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

- 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.



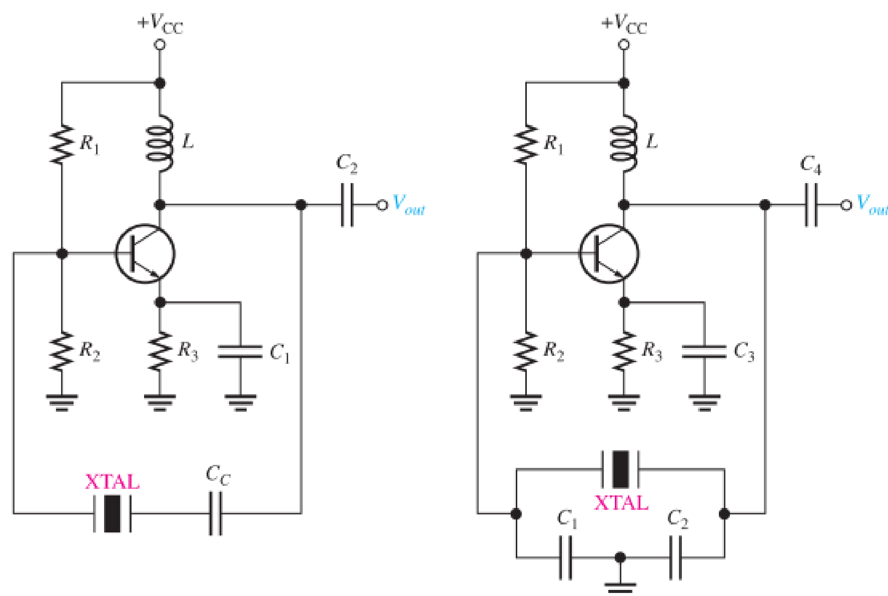
(a) Typical packaged crystal (b) Basic construction (without case) (c) Symbol (d) Electrical equivalent

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.

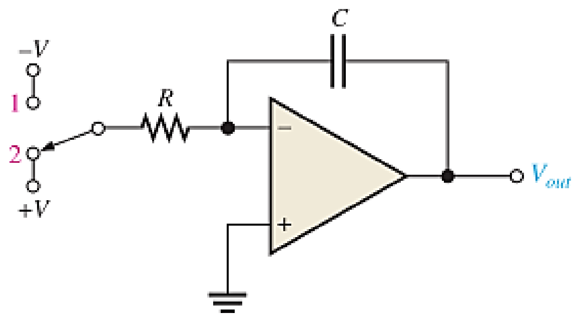


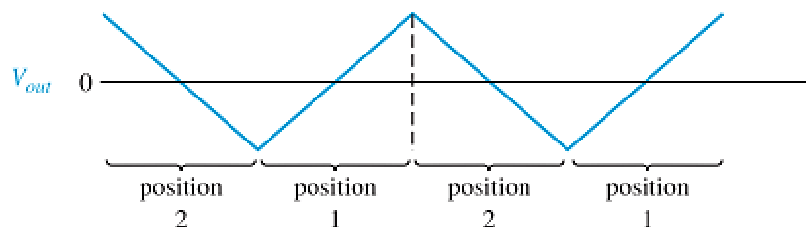
- The **second** major **category** of oscillators is the relaxation oscillator.
- Relaxation oscillators use an **RC timing circuit** and a device typically a **Schmitt trigger** or other device that **changes states** to alternately charge and discharge a capacitor through a resistor to generate a periodic waveform.

RELAXATION OSCILLATORS

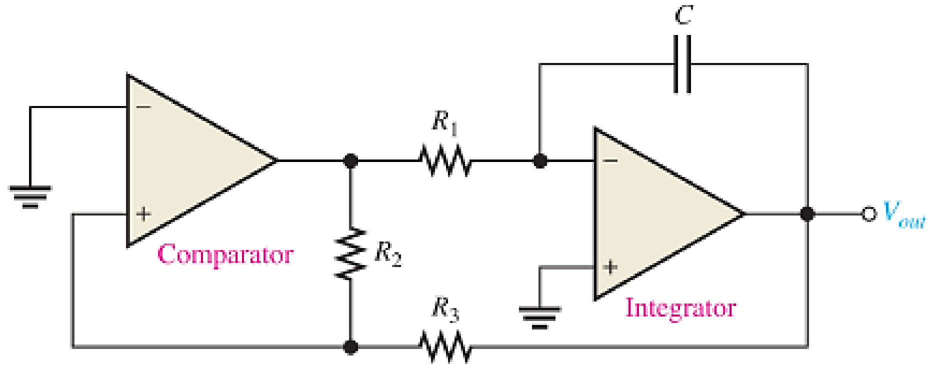
Triangular-Wave Oscillator

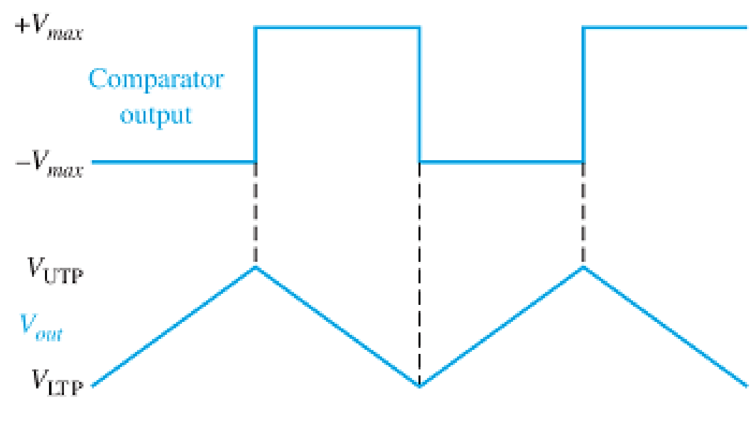
- **Basic triangular-wave oscillator**





- **Practical Triangular-Wave Oscillator**





$$V_{UTP} = +V_{max}\left(\frac{R_3}{R_2}\right)$$

$$V_{LTP} = -V_{max}\left(\frac{R_3}{R_2}\right)$$

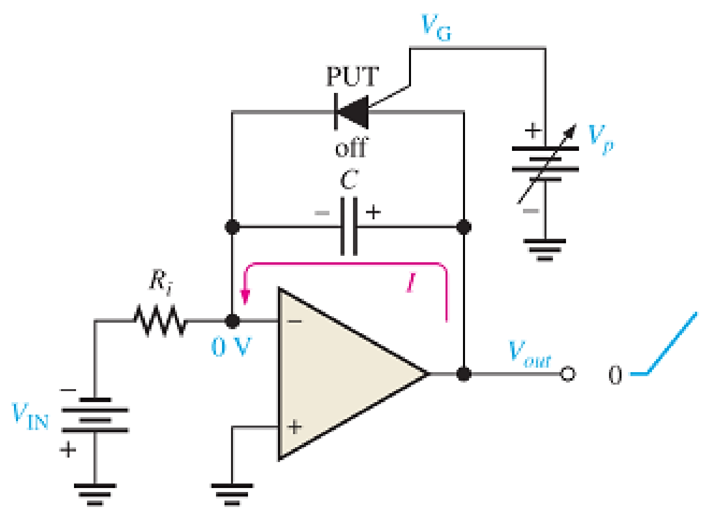
$$f_r = \frac{1}{4R_1C}\left(\frac{R_2}{R_3}\right)$$

Triangular & Square waveforms
→ Function Generator

Sawtooth Voltage-Controlled Oscillator (VCO)

- VCO is a relaxation oscillator whose frequency can be changed by a variable dc control voltage.
- VCOs can be either sinusoidal or nonsinusoidal.
- One way to build a sawtooth VCO is with an op-amp integrator that uses a switching device (PUT) in parallel with the feedback capacitor to terminate each ramp at a prescribed level and effectively “reset” the circuit.
- The PUT is a programmable unijunction transistor with an anode, a cathode, and a gate terminal.

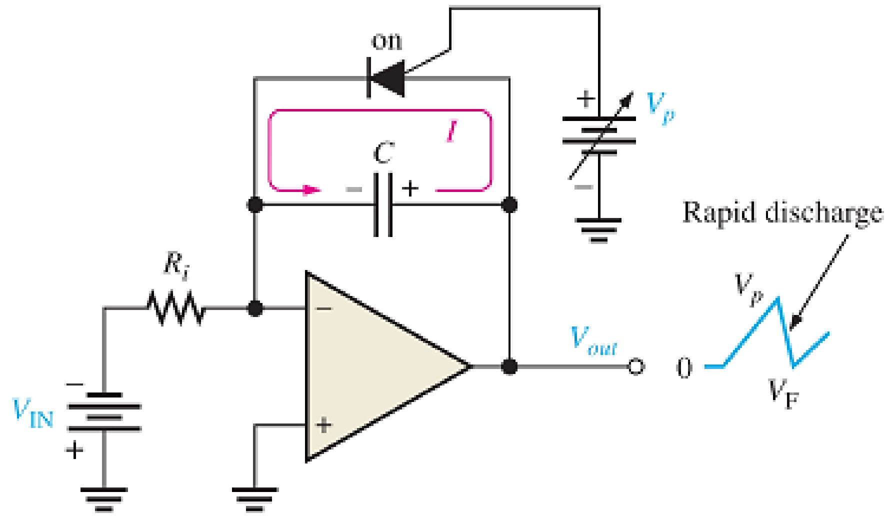
  - Operation:



(a) Initially, the capacitor charges, the output ramp begins, and the PUT is off.

N.B.
For more details regarding PUT, refer to ch. 11

Sawtooth VCO..



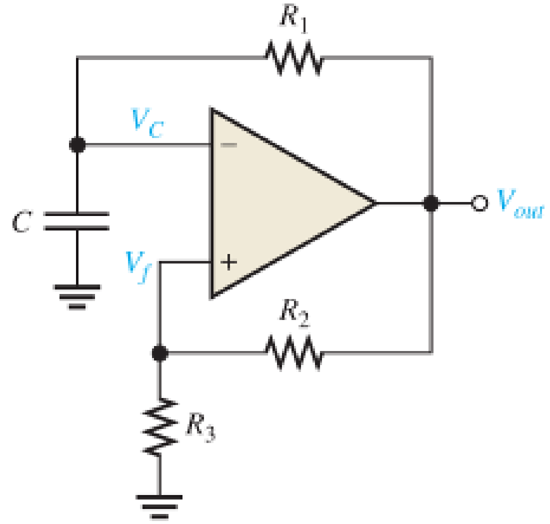
(b) The capacitor rapidly discharges when the PUT momentarily turns on.

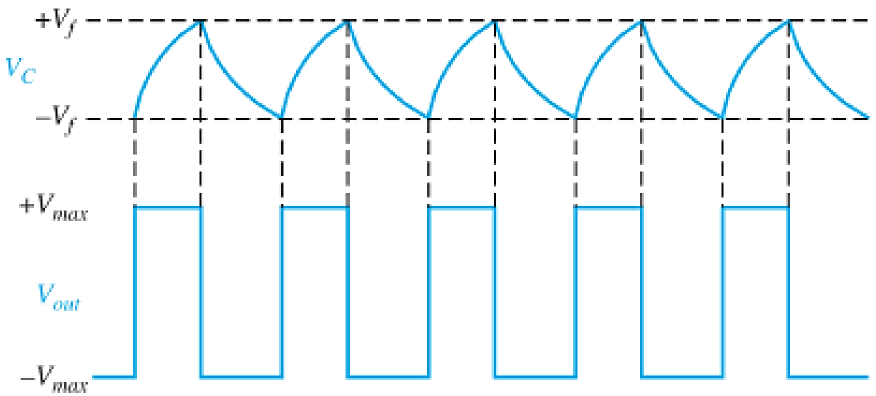
T, of the sawtooth waveform: $$T = \frac{V_p - V_F}{|V_{IN}|/R_iC}$$

f =1/T, gives $$f = \frac{|V_{IN}|}{R_iC}\left(\frac{1}{V_p - V_F}\right)$$

Square-wave Relaxation oscillator

- the op-amp's inverting input is the capacitor voltage and
- the noninverting input is a portion of the output fed back through resistors R_2, R_3 to provide hysteresis.

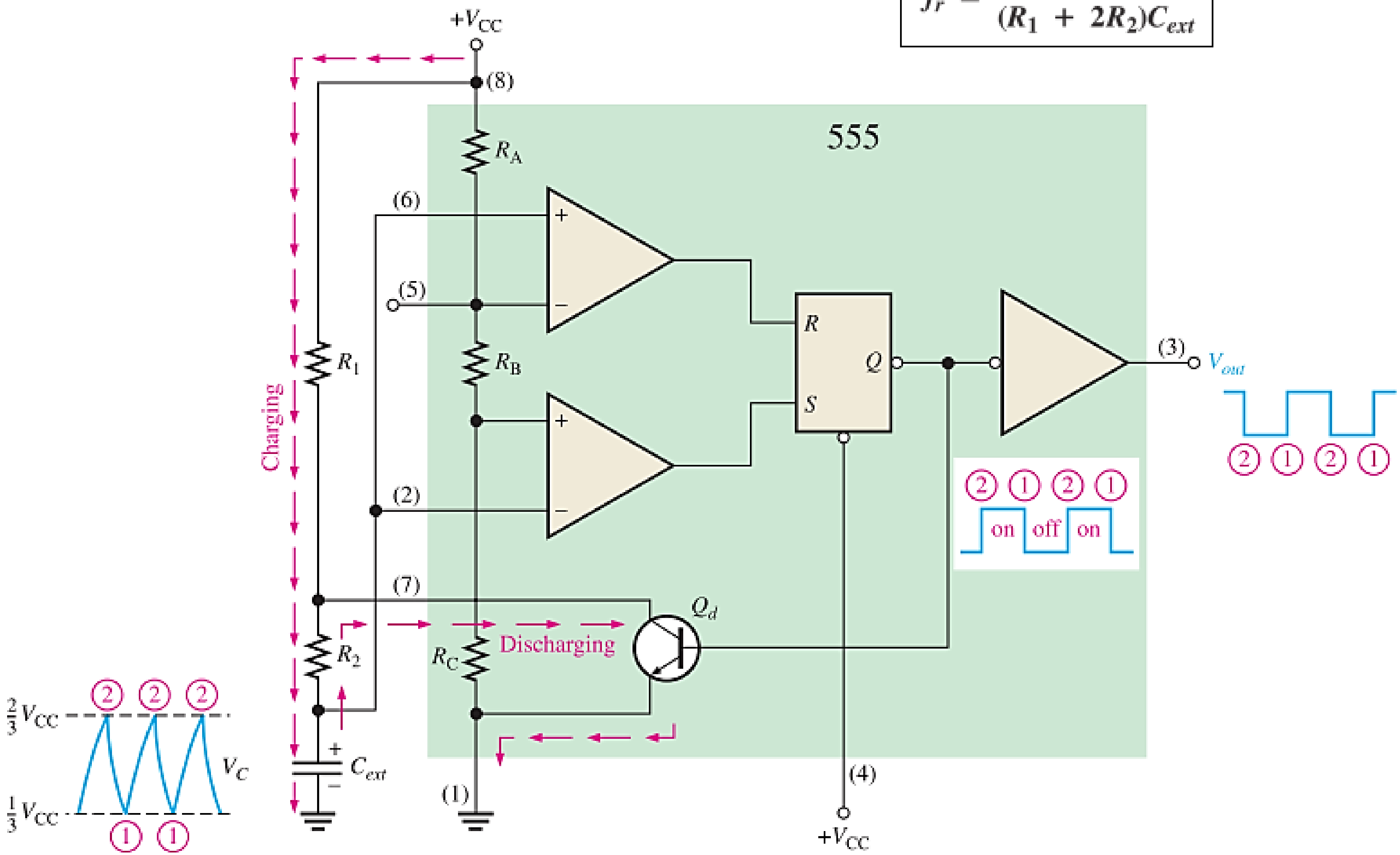




The 555 Timer as an Oscillator

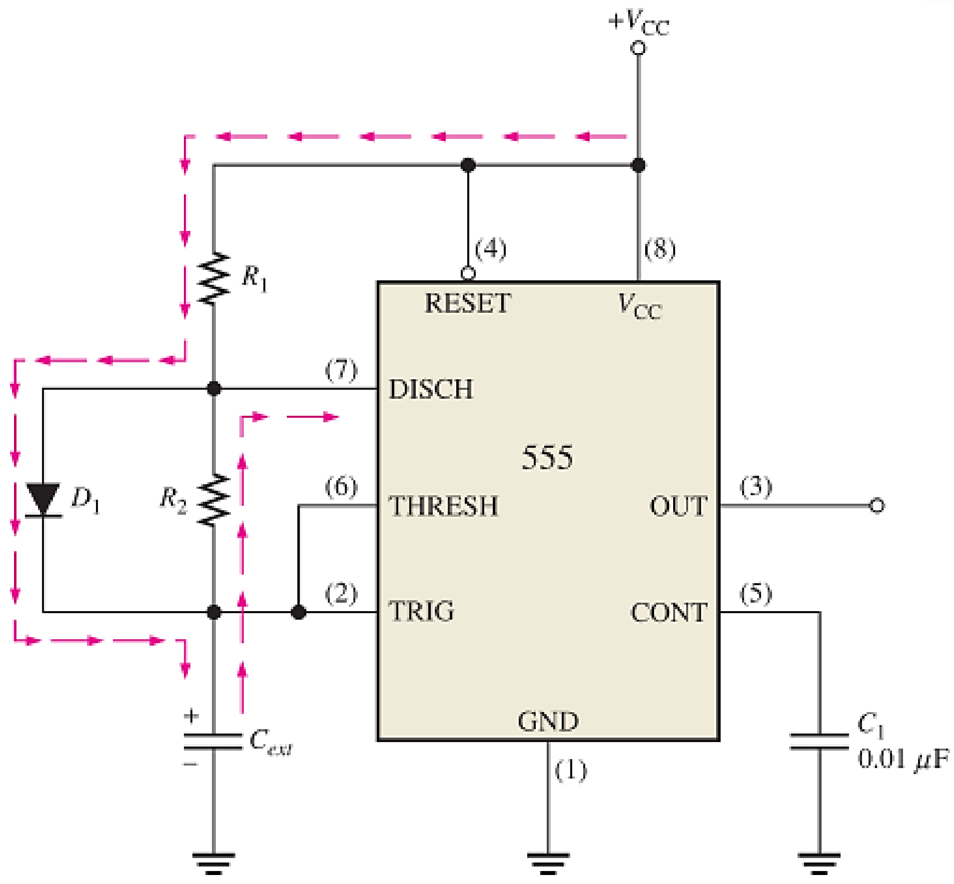
- **Astable Operation**

$$f_r = \frac{1.44}{(R_1 + 2R_2)C_{ext}}$$



555 Timer Oscillator ..

$$\text{Duty cycle} = \left(\frac{R_1 + R_2}{R_1 + 2R_2}\right)100\%$$



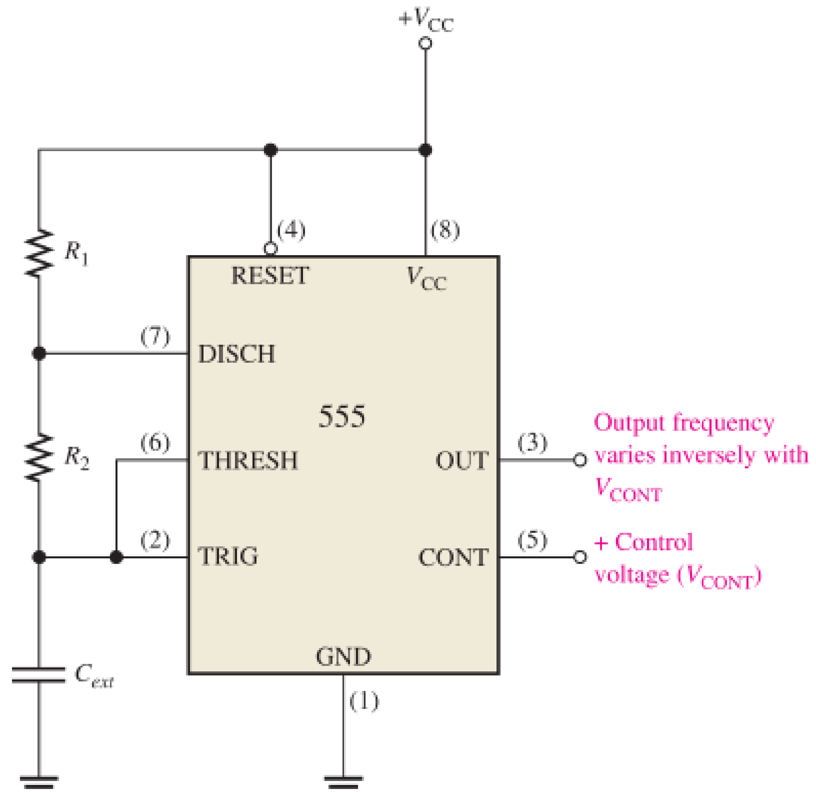
- **Using D1 :**

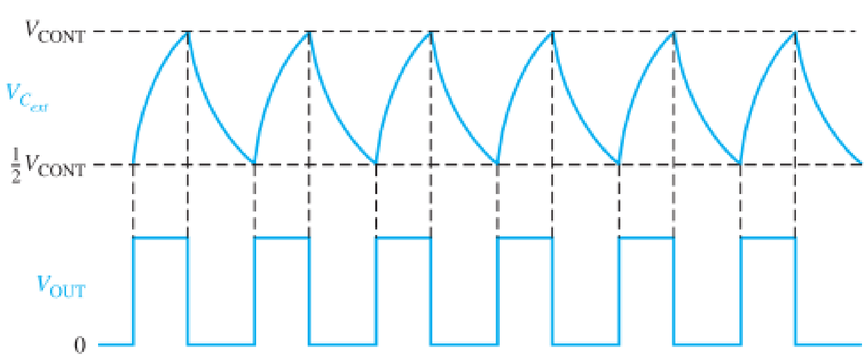
$$f_r \cong \frac{1.44}{(R_1 + R_2)C_{ext}}$$

$$\text{Duty cycle} \cong \left(\frac{R_1}{R_1 + R_2}\right)100\%$$

555 as VCO

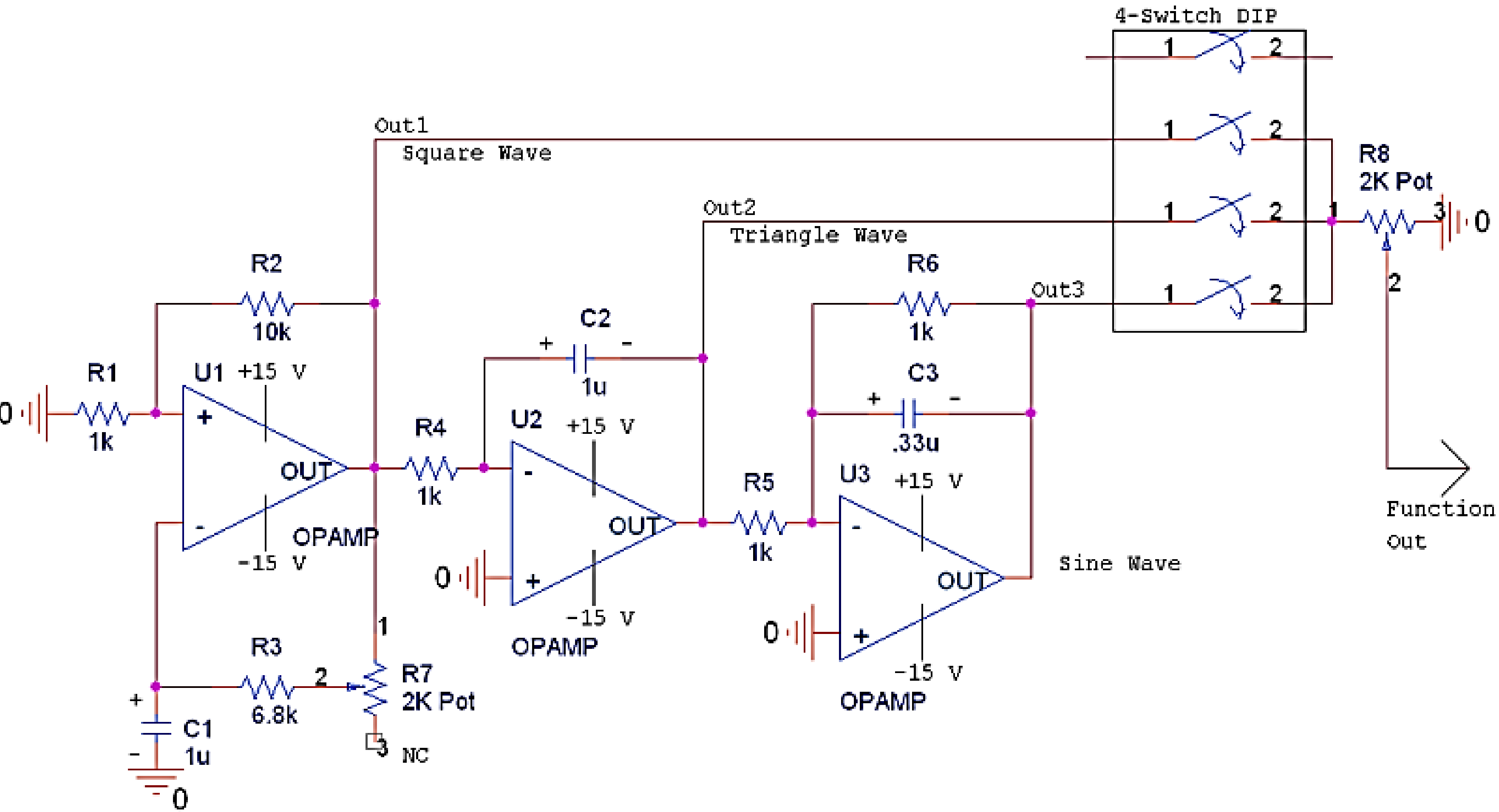
- a variable control voltage is applied to the CONT input (pin 5)





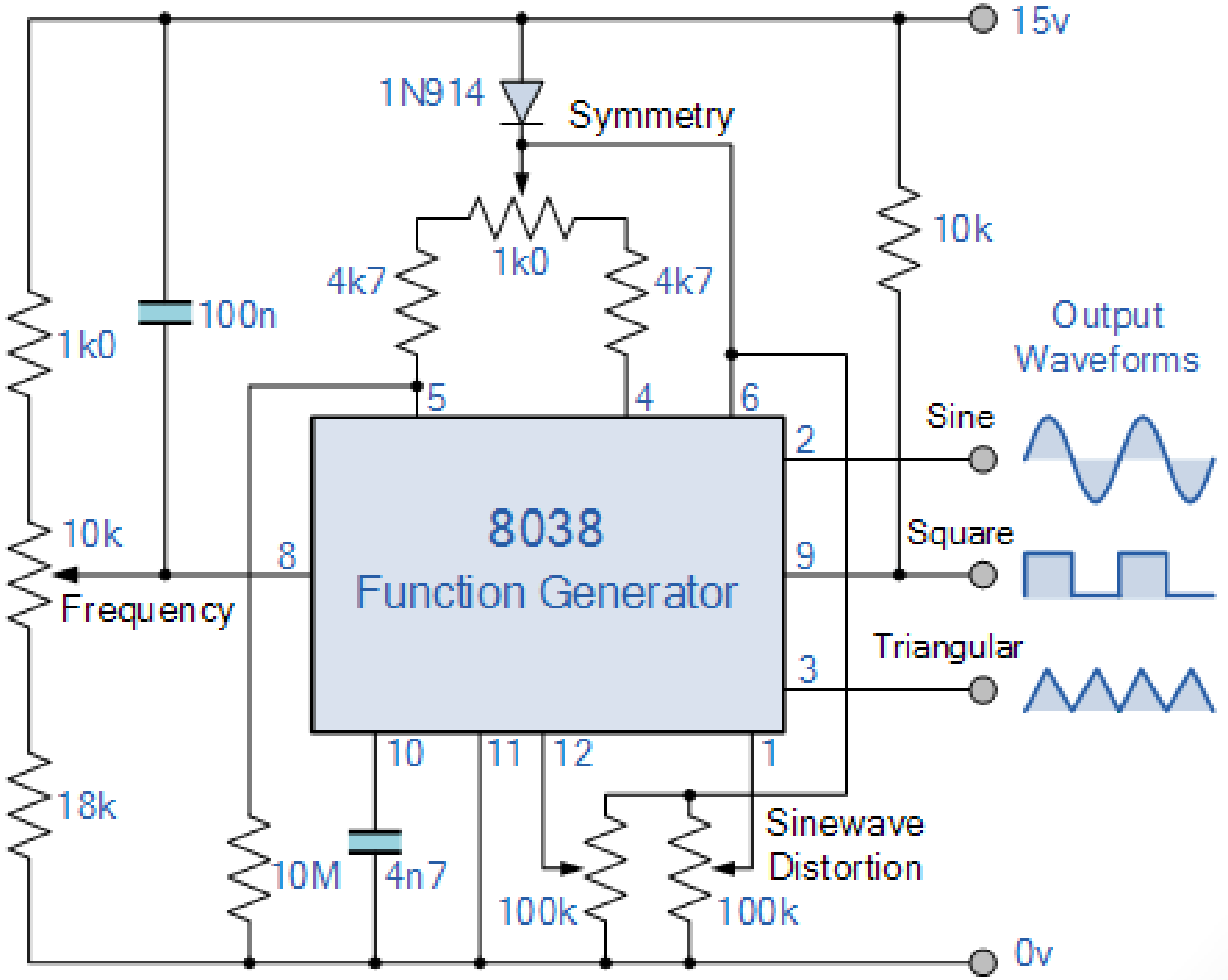
EXAMPLES OF SIMPLE FUNCTION GENERATORS

Waveform Generator, Discrete Circuit



Applied Electronics

Waveform Generator IC

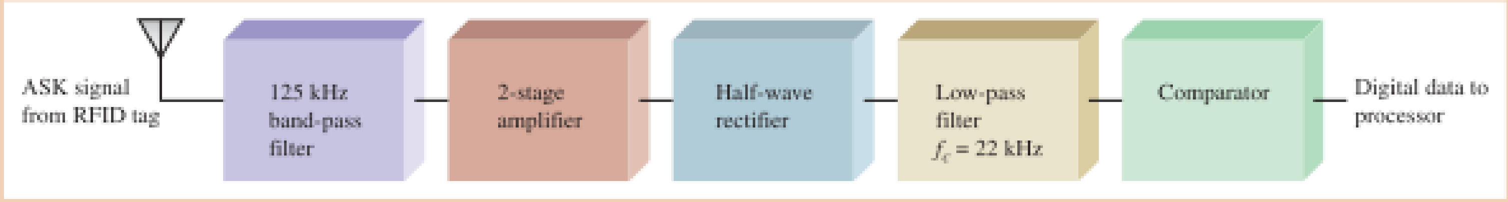


Applied Electronics

Summer 2016

PRACTICAL APPLICATIONS

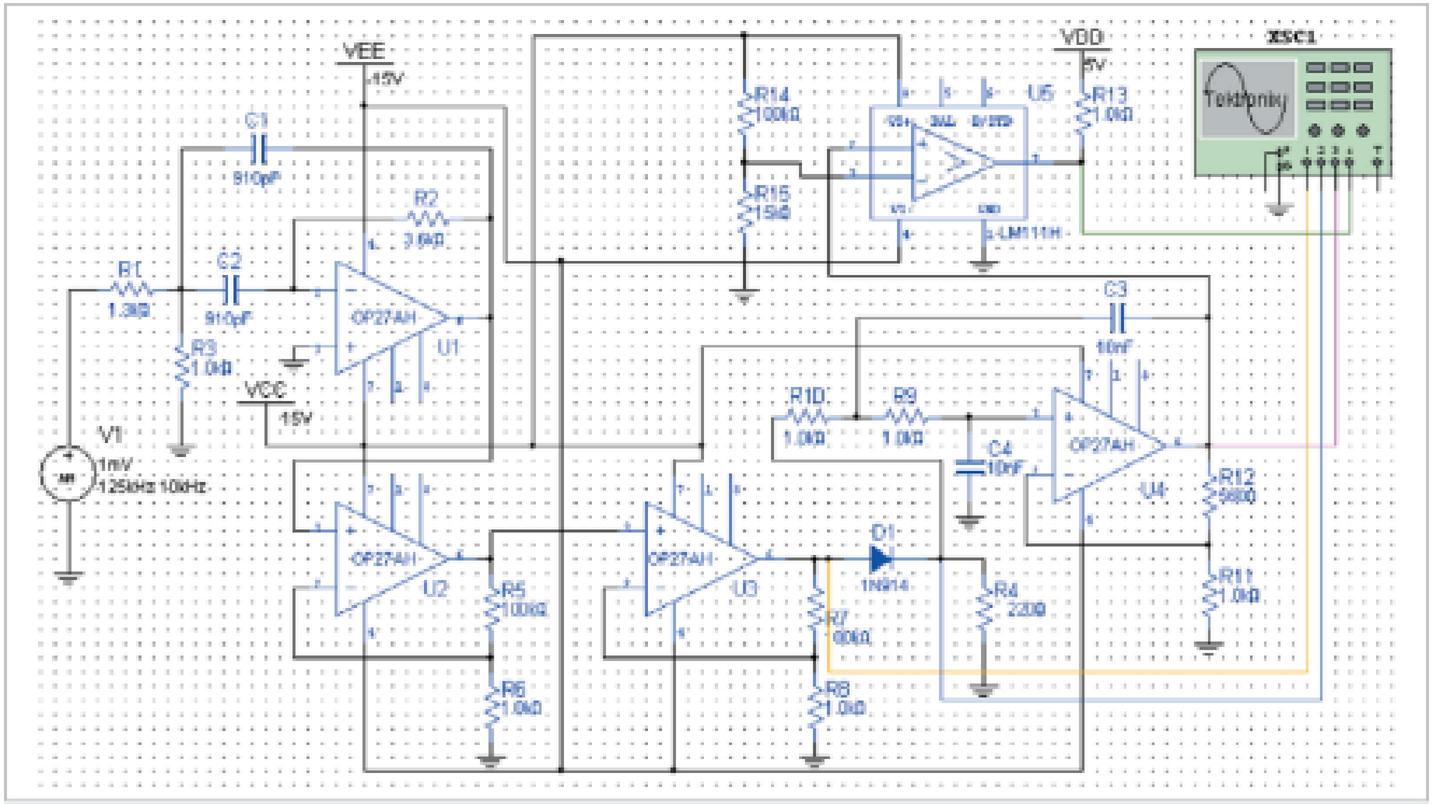
RFID System

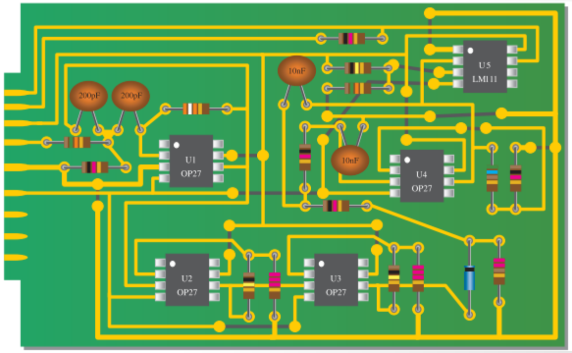


▲ FIGURE 15–31

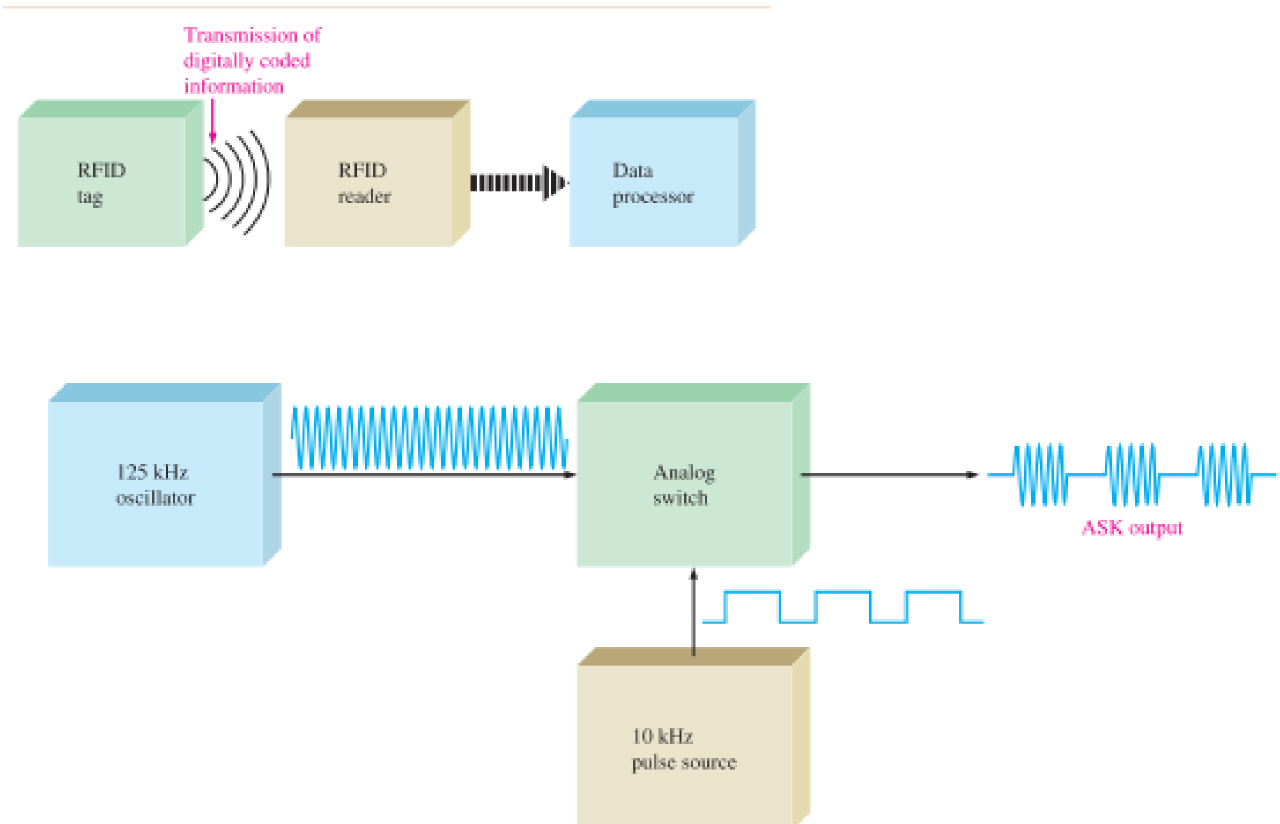
Block diagram of RFID reader.

RFID System..


VEE
-15V
VCC
15V
VDD
5V
XSC1
C1
910pF
C2
910pF
C3
10nF
C4
10nF
R1
1.3kΩ
R2
3.6kΩ
R3
1.0kΩ
R4
220Ω
R5
100kΩ
R6
1.0kΩ
R7
60kΩ
R8
1.0kΩ
R9
1.0kΩ
R10
1.0kΩ
R11
1.0kΩ
R12
560Ω
R13
1.0kΩ
R14
100kΩ
R15
15kΩ
V1
1mV
125kHz 10kHz
U1
U2
U3
U4
U5
OP27AH
LM111H
D1
1N914
Tektronix



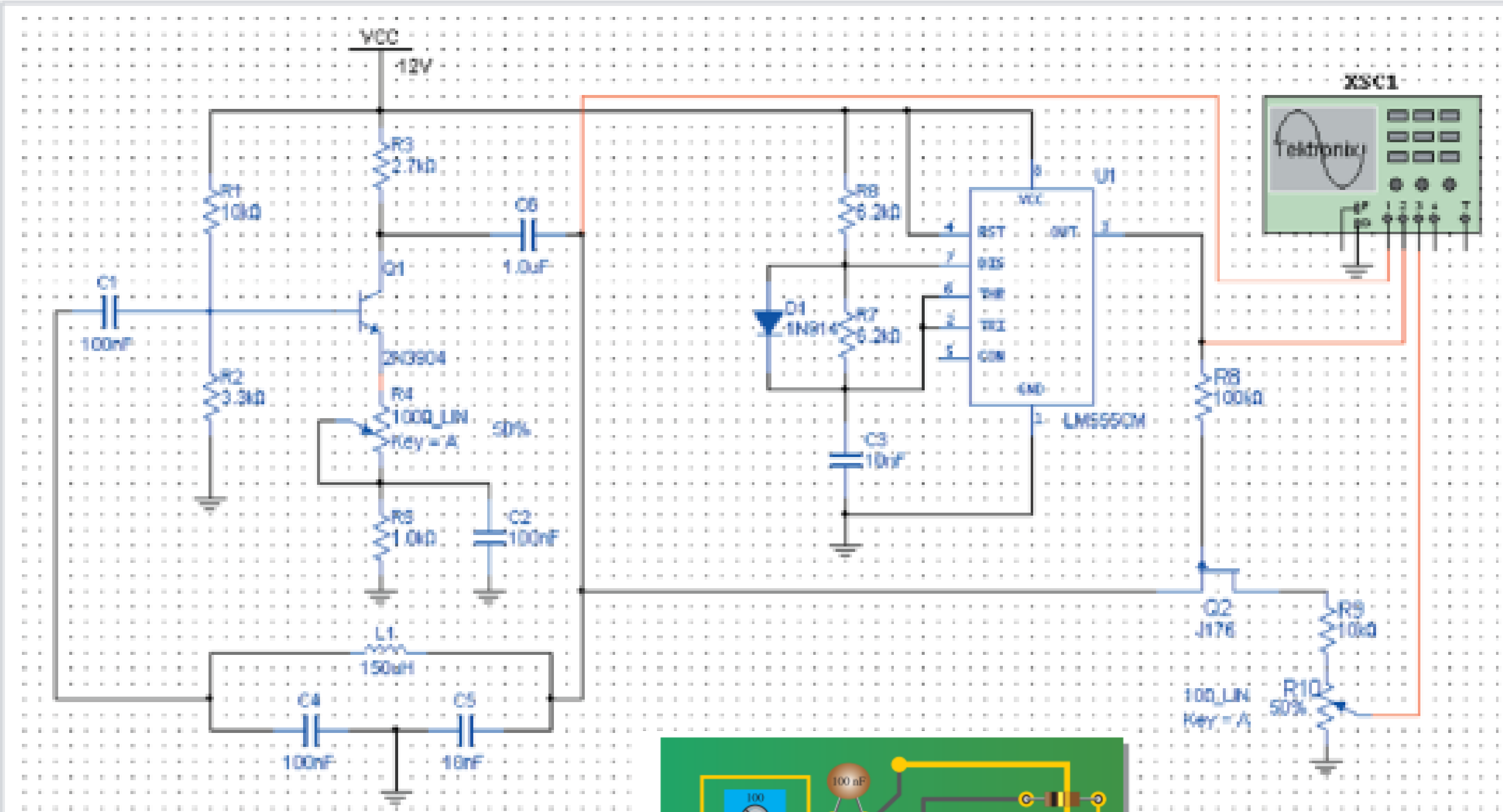
ASK Test Generator

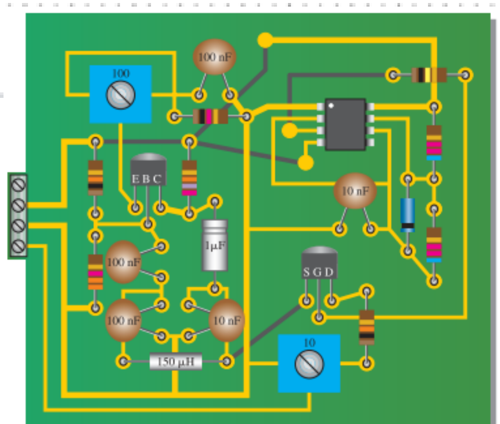


▲ FIGURE 16–45

Basic block diagram of the ASK test generator.

ASK Test Generator..





References

- Floyd, chapters: 15,16
- Boylestad, chapters: 11,14

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