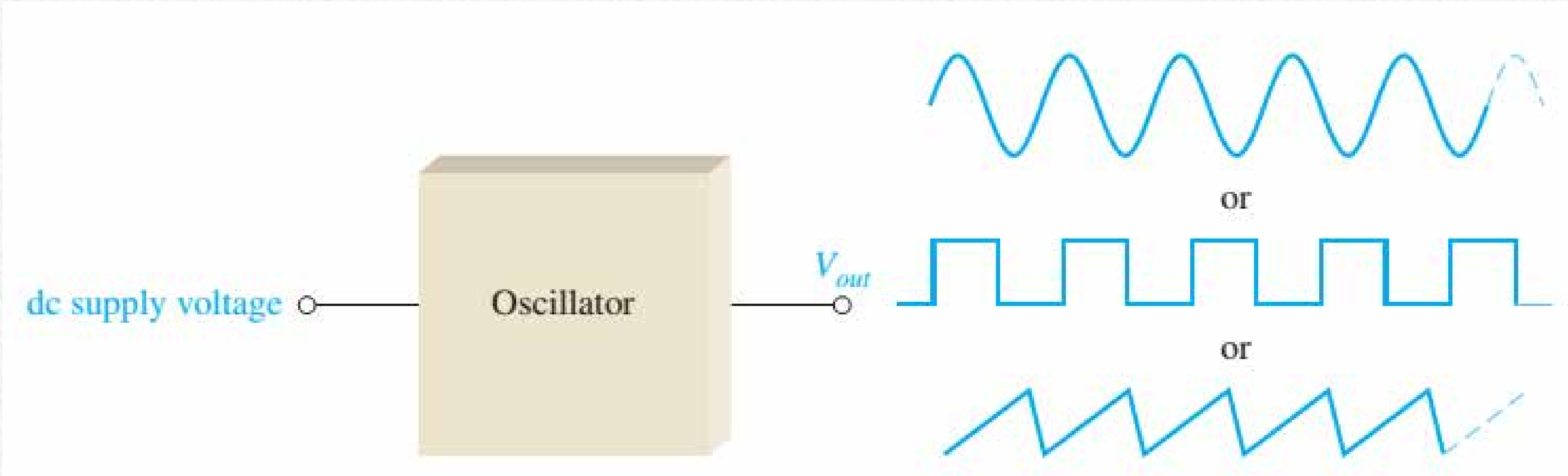
Chapter 4

Oscillators

Oscillators

- Oscillators are electronic circuits that generate an output signal without the necessity of an input signal.
- It produces a periodic waveform on its output with only the DC supply voltage as an input.
- The output voltage can be either sinusoidal or nonsinusoidal, depending on the type of oscillator.
- Different types of oscillators produce various types of outputs including sine waves, square waves, triangular waves, and sawtooth waves.
- A basic oscillator is shown in figure

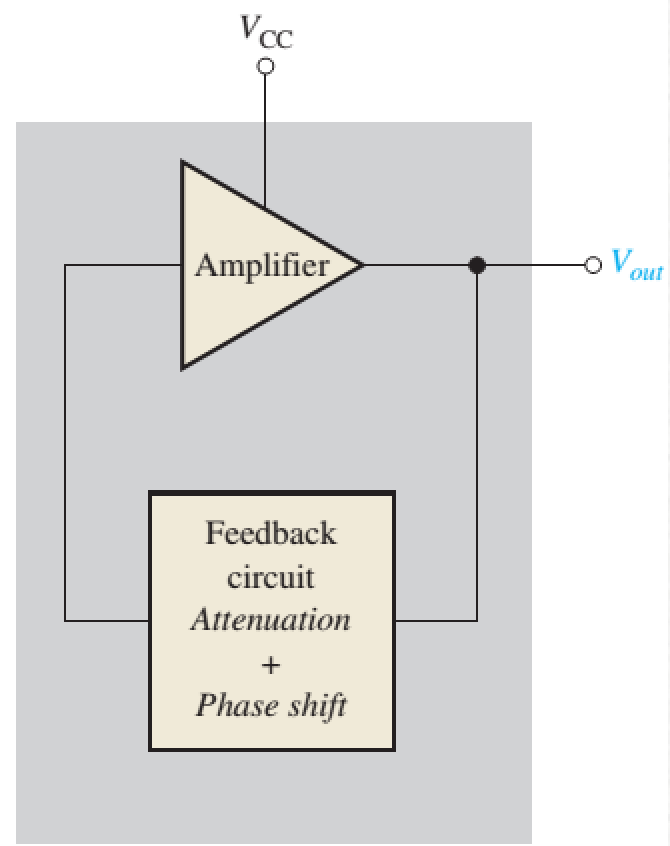
Oscillators



The basic oscillator concept showing three common types of output wave-forms: sine wave, square wave, and sawtooth.

Oscillators

- There are two major classifications for oscillators: **feedback oscillators and relaxation oscillators**.
- **feedback oscillator**: which returns a fraction of the output signal to the input with no net phase shift, resulting in a reinforcement of the output signal.
- A feedback oscillator consists of an amplifier for gain and a positive feedback circuit that produces phase shift and provides attenuation.



Oscillator

Oscillators

Relaxation Oscillators

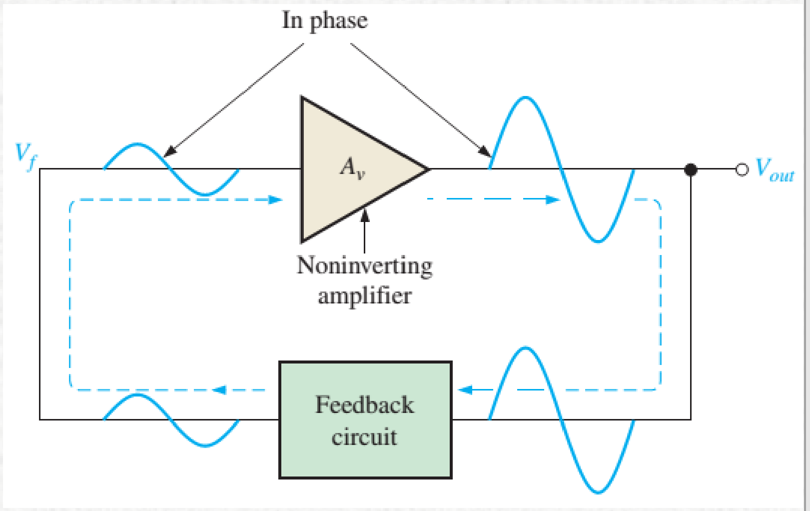
- A second type of oscillator is the relaxation oscillator.
- Instead of feedback, a relaxation oscillator uses an RC timing circuit to generate a waveform that is generally a square wave or other nonsinusoidal waveform.
- Typically, a relaxation oscillator uses a Schmitt trigger or other device that changes states to alternately charge and discharge a capacitor through a resistor.

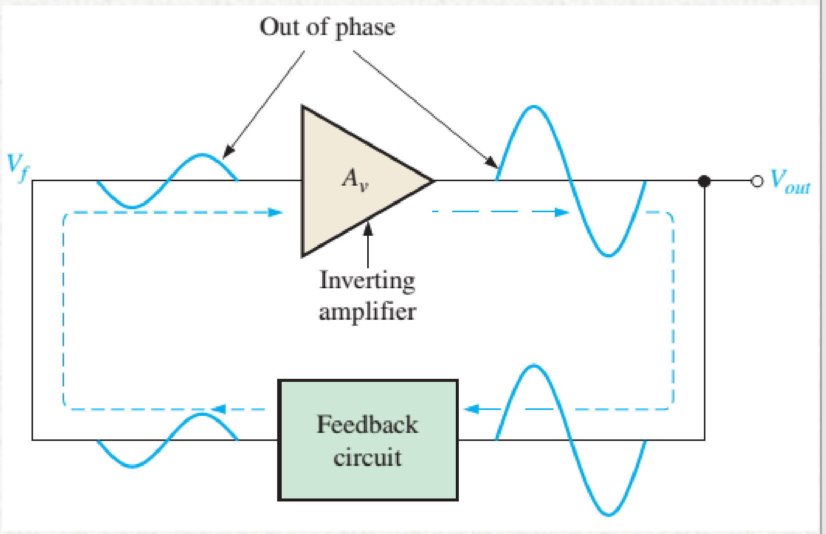
Feedback Oscillators

- Feedback oscillator operation is based on the principle of positive feedback.
- We will look at the general conditions required for oscillation to occur.
- Feedback oscillators are widely used to generate sinusoidal waveforms.
- In **positive feedback**, a portion of the output voltage of an amplifier is fed back to the input with no net phase shift, resulting in a strengthening of the output signal
- This basic idea is illustrated in figure

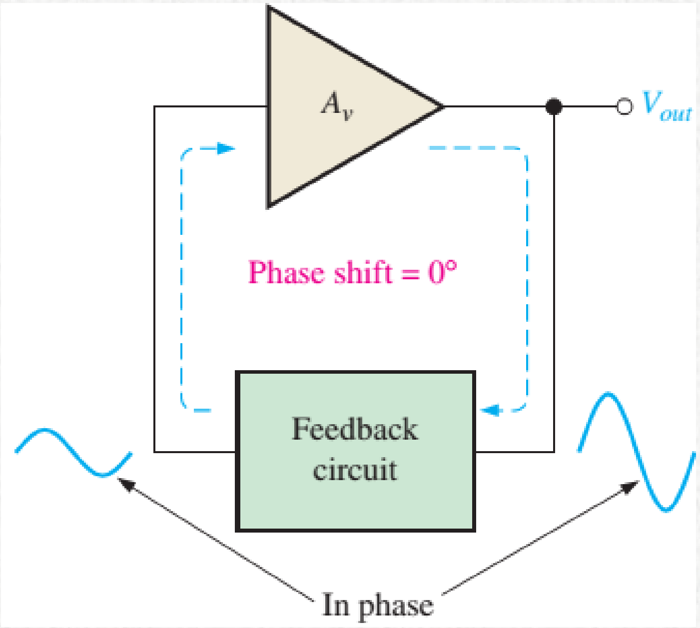
Feedback Oscillators

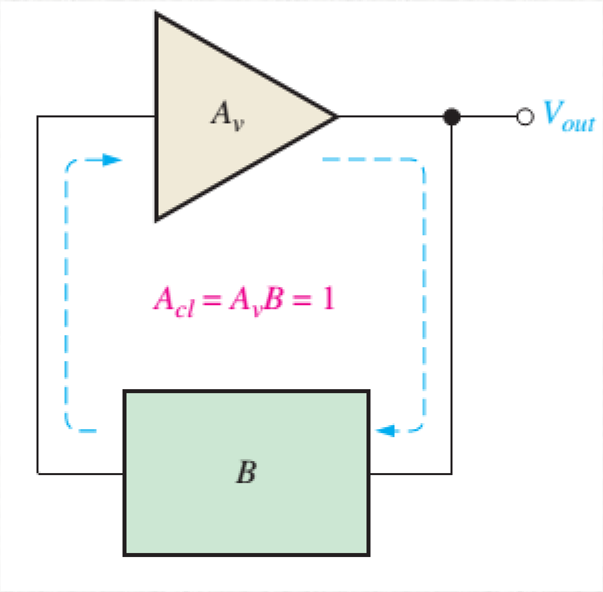
- The in-phase feedback voltage is amplified to produce the output voltage, which in turn produces the feedback voltage.
- A loop is created in which the signal maintains itself and a continuous sinusoidal output is produced.
- This phenomenon is called oscillation





Feedback Oscillators

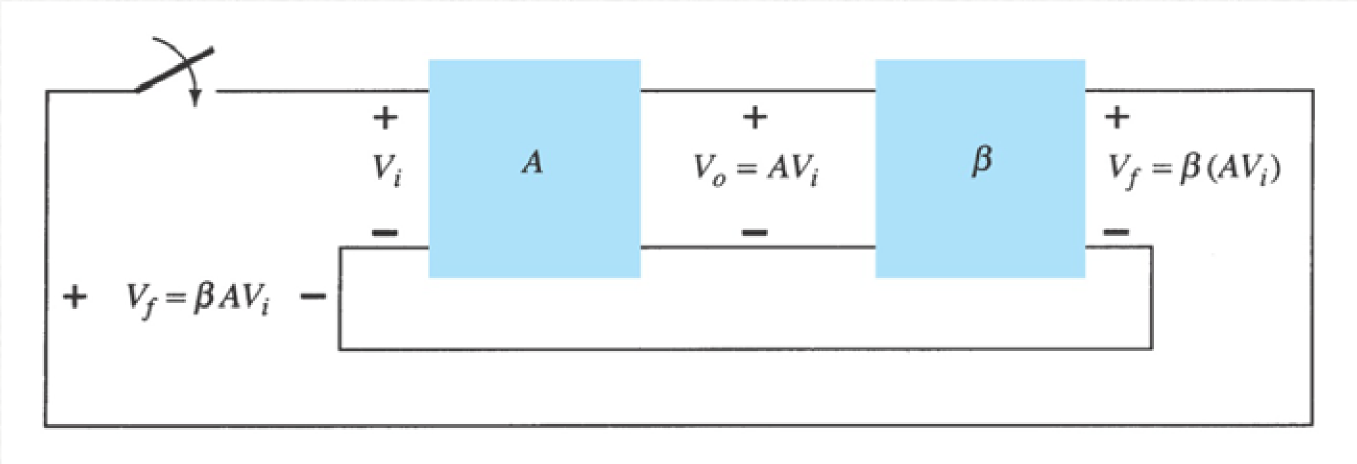




- Two conditions are required for a sustained state of oscillation:

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

Feedback Oscillators



- When switch at the amplifier input is open, no oscillation occurs.
- For input V_i ,the feedback voltage $V_f = (BA)V_i$.
- In order to maintain $V_f = V_i$, BA must be in the correct magnitude and phase.
- When the switch is closed and V_i is removed, the circuit will continue operating since the feedback voltage is sufficient to drive the amplifier and feedback circuit, resulting in proper input voltage to sustain the loop operation.

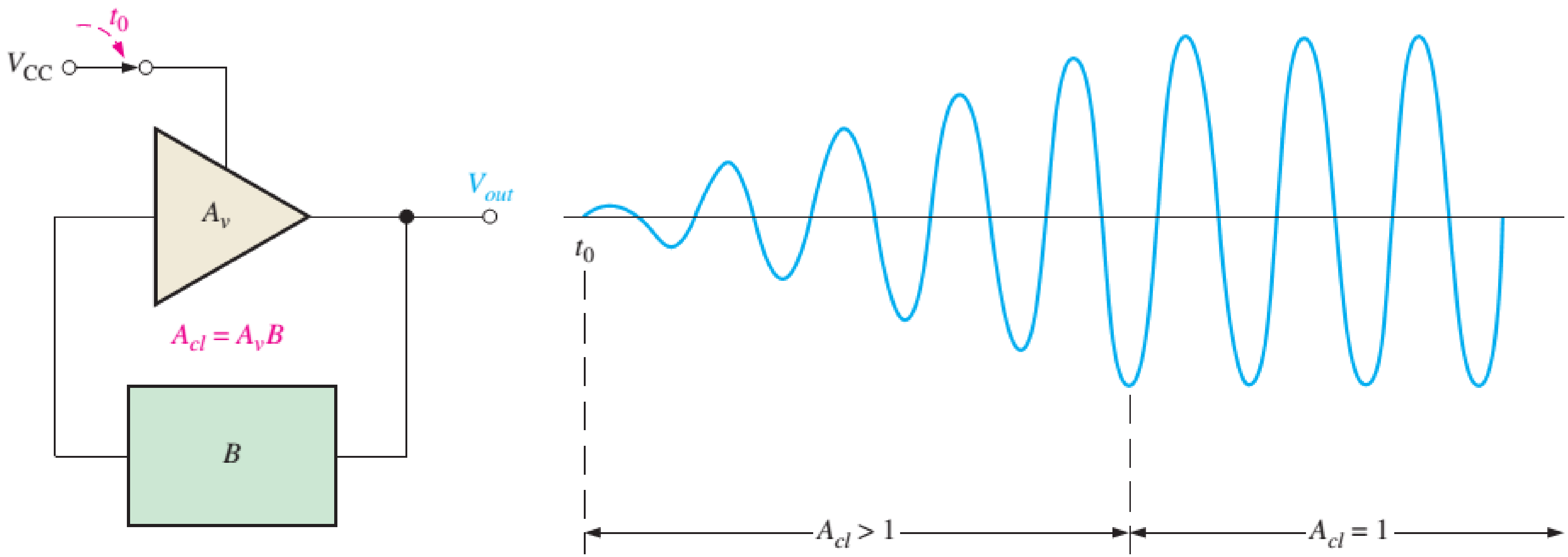
Feedback Oscillators

- The voltage gain around the closed feedback loop, A_{cl}, is the product of the amplifier gain, A_v, and the attenuation, B, of the feedback circuit $A_{cl} = A_v B$
- If a sinusoidal wave is the desired output, a loop gain greater than 1 will rapidly cause the output to saturate at both peaks of the waveform, producing unacceptable distortion
- To avoid this, some form of gain control must be used to keep the loop gain at exactly 1 once oscillations have started.

Start-up Conditions

- We have seen what it takes for an oscillator to produce a continuous sinusoidal output.
- What are the requirements for the oscillation to start when the dc supply voltage is first turned on?
- The unity-gain condition must be met for oscillation to be maintained.
- 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.

Start-up Conditions



▲ **FIGURE 16–5**

When oscillation starts at t_0, the condition $A_{cl} > 1$ causes the sinusoidal output voltage amplitude to build up to a desired level. Then A_{cl} decreases to 1 and maintains the desired amplitude.

RC Feedback Circuits

- Three types of feedback oscillators that use RC circuits to produce sinusoidal outputs are the

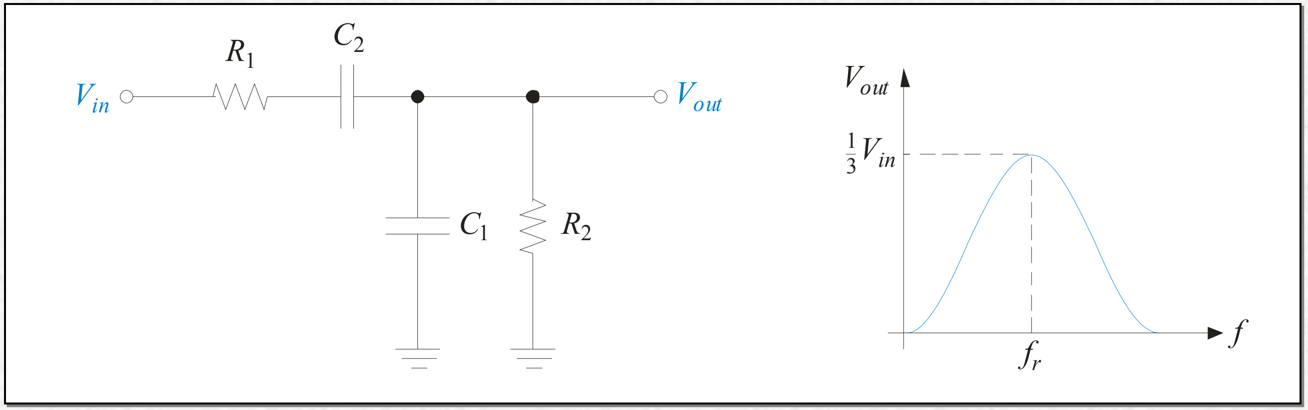
1. Wien-bridge oscillator
2. Phase-shift oscillator
3. Twin-T oscillator

- 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.

The Wien-Bridge Oscillator

RC feedback is used in various lower frequency sine-wave oscillators. The text covers three: the Wien-bridge oscillator, the phase-shift oscillator, and the twin-T oscillator.

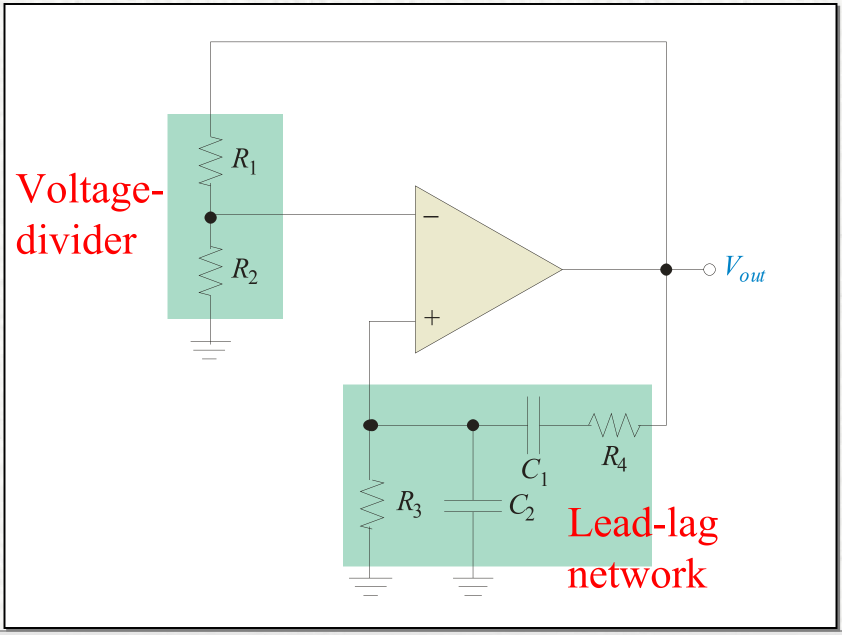
The feedback circuit in a Wien-bridge uses a lead-lag circuit. When the *R*'s and *C*'s have equal values, the output will be ⅓ of the input at only one frequency and the phase shift at this frequency will be 0°.



The Wien-Bridge Oscillator

The basic Wien-bridge uses the lead-lag network to select a specific frequency that is amplified. The voltage-divider sets the gain to make up for the attenuation of the feedback network.

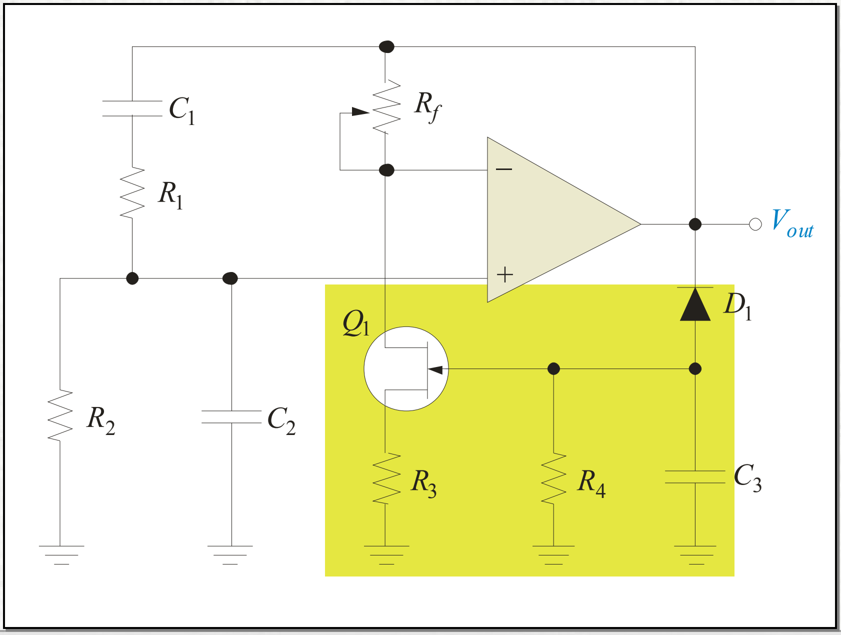
The noninverting amplifier must have a gain of exactly 3.0 as set by R_1 and R_2 to make up for the attenuation. If it is too little, oscillations will not occur; if it is too much the sine wave will be clipped.



The Wien-Bridge Oscillator

To produce the precise gain required, the Wien bridge needs some form of automatic gain control (AGC). One popular method is shown here and uses a JFET transistor.

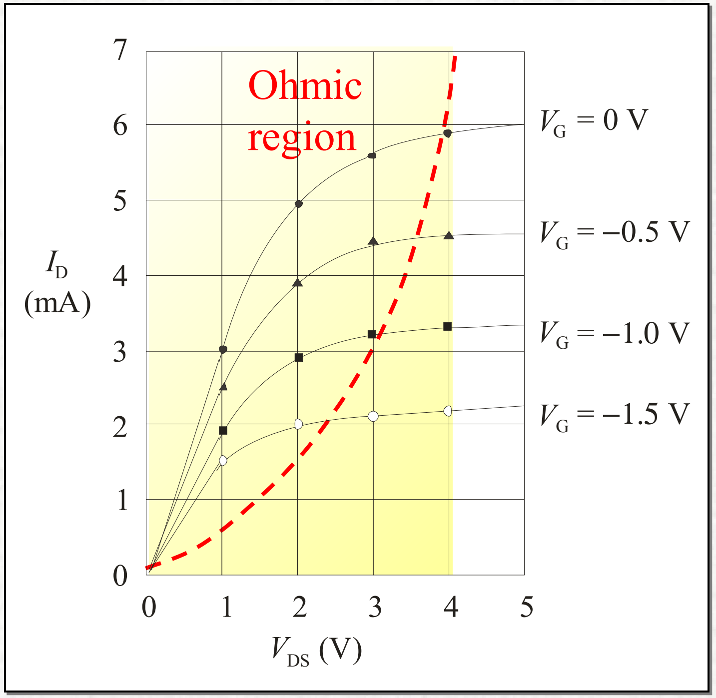
The key elements of the AGC circuit are highlighted in yellow. The diode charges C_3 to the negative peak of the signal. This develops the gate bias voltage for the JFET that is related to the output level.



The Wien-Bridge Oscillator

The JFET is operated in the ohmic region and can change its resistance rapidly if conditions change.

Recall from Chapter 8 that a JFET acts as a variable resistor in the ohmic region. If the output increases, the bias tends to be larger, and the drain-source resistance increases (and vice-versa). In the Wien-bridge, the JFET drain-source resistance controls the gain of the op-amp and will compensate for any change to the output.

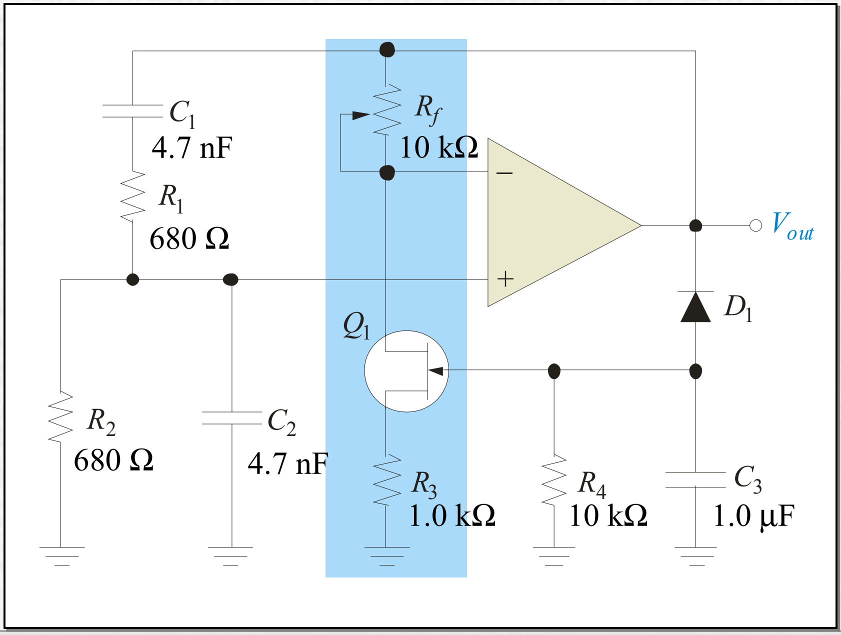


The Wien-Bridge Oscillator

When the R's and C's in the feedback circuit are equal, the frequency of the bridge is given by $f_r = \dfrac{1}{2\pi RC}$

Example:

What is f_r for the Wien bridge?



Solution:

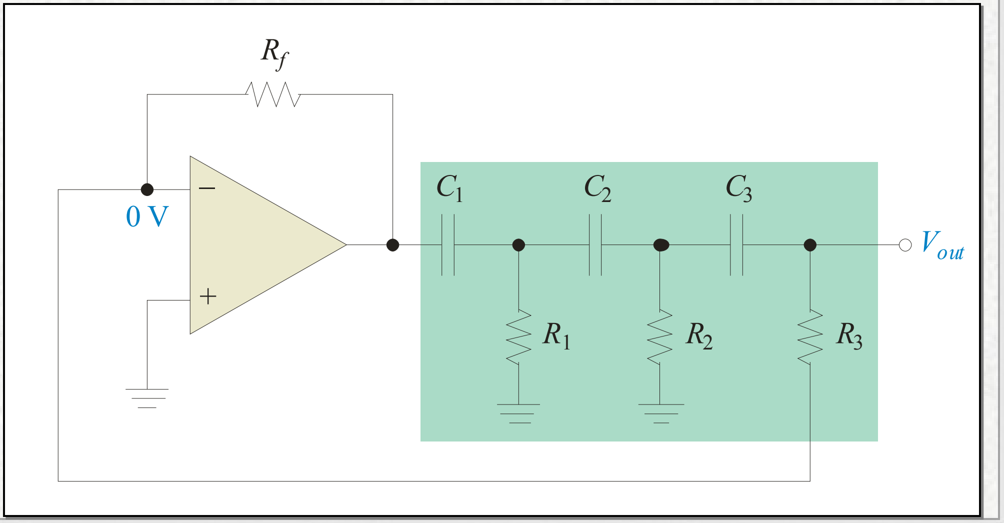
$$f_r = \frac{1}{2\pi RC}$$

$$= \frac{1}{2\pi(680\ \Omega)(4.7\ \text{nF})} = 48.9\ \text{kHz}$$

The Phase-Shift Oscillator

The phase-shift oscillator uses three *RC* circuits in the feedback path that have a total phase shift of 180° at one frequency – for this reason an inverting amplifier is required for this circuit.

Even with identical *R*'s and *C*'s, the phase shift in each *RC* circuit is slightly different because of loading effects. When all *R*'s and *C*'s are equal, the feedback attenuates the signal by a factor of 29.

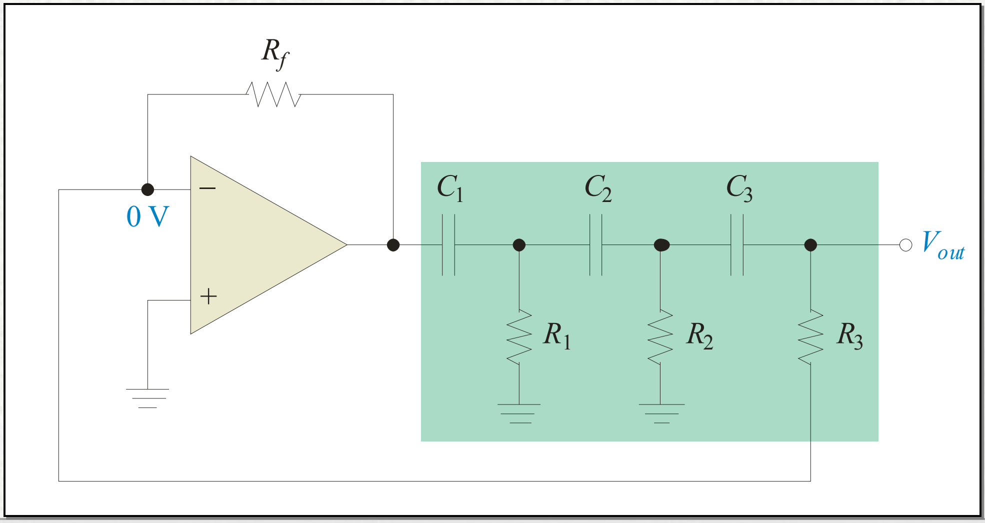


The Phase-Shift Oscillator

Conditions for oscillation with the phase-shift oscillator is that if all *R*'s and *C*'s are equal, the amplifier must have a gain of at least 29 to make up for the attenuation of the feedback circuit. This means that $R_f/R_3 \geq 29$.

Under these conditions, the frequency of oscillation is given by

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



The Phase-Shift Oscillator

Example: Design a phase-shift oscillator for a frequency of 800 Hz. The capacitors are to be 10 nF.

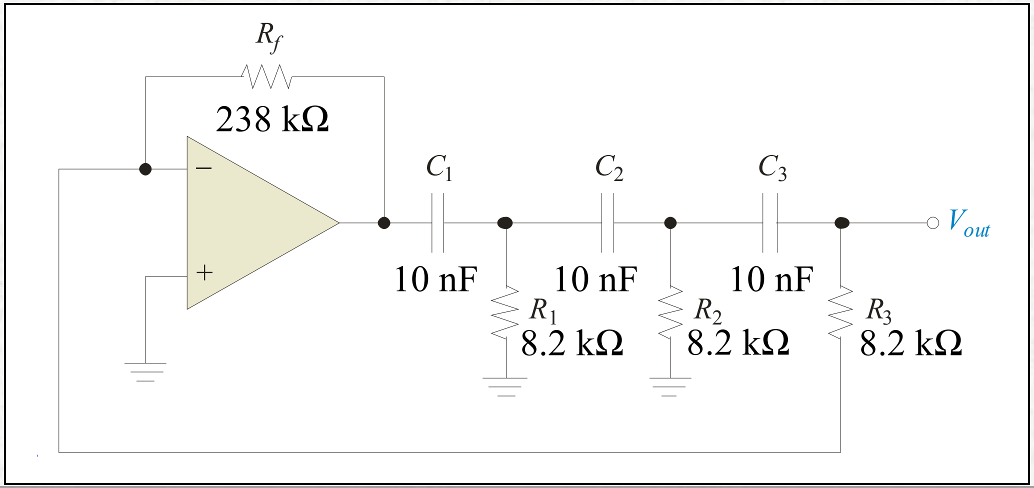
Solution:

Start by solving for the resistors needed in the feedback circuit:

$$R = \frac{1}{2\pi\sqrt{6}f_rC} = \frac{1}{2\pi\sqrt{6}(800\text{ Hz})(10\text{ nF})} = 8.12\text{ k}\Omega \quad \text{(Use 8.2 k}\Omega\text{.)}$$

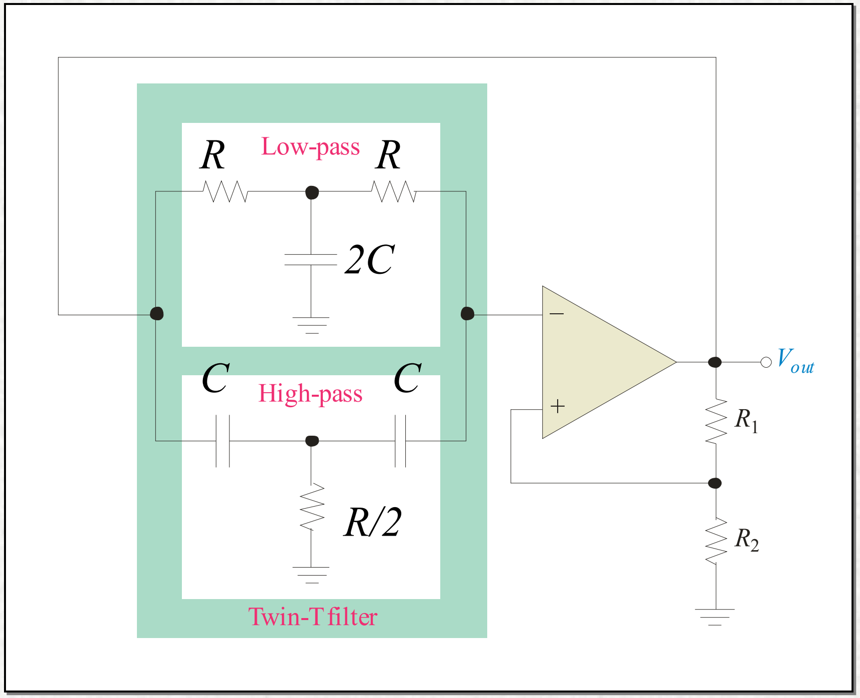
Calculate the feedback resistor needed:

$R_f = 29R = 238\text{ k}\Omega$.



The Twin-T Oscillator

The basic twin-T oscillator combines a low-pass and high-pass filter to form a notch filter at the oscillation frequency.



An excellent notch filter can be formed by using *R*'s and *C*'s related by a factor of 2 as shown here.

With this relationship, the oscillation frequency is approximately

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

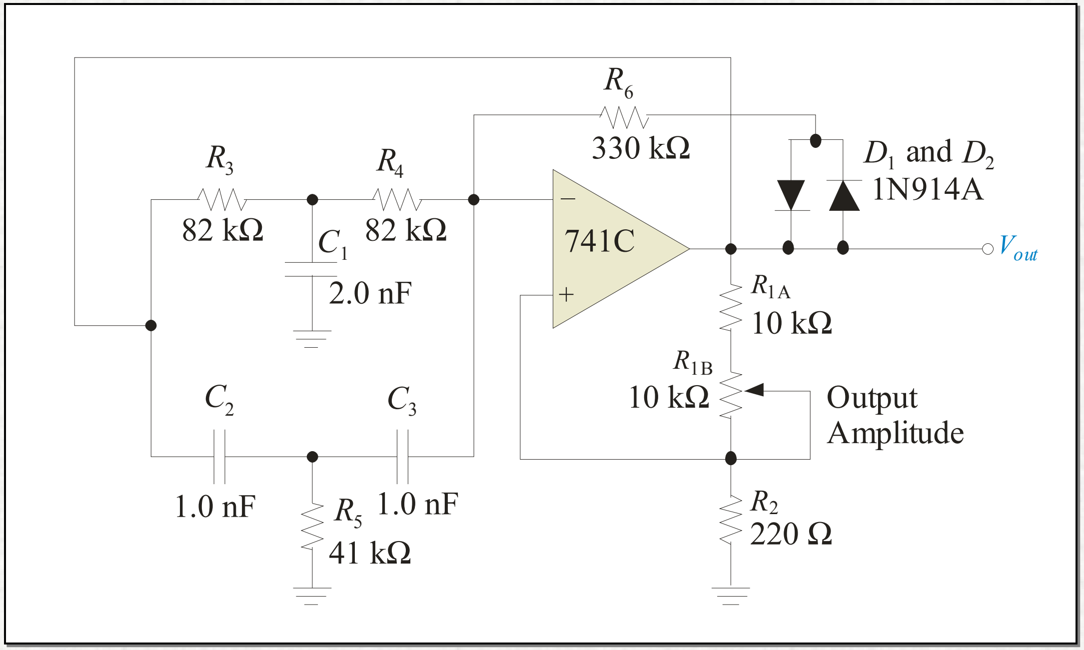
The Twin-T Oscillator

Two improvements to the basic circuit are shown here – adding the parallel diodes and R_6 significantly reduces distortion by attenuating harmonics. The potentiometer adds output amplitude adjustment.

The frequency is a little higher than the predicted value of 1.94 kHz. With ±15 V power supplies, the measured values are:

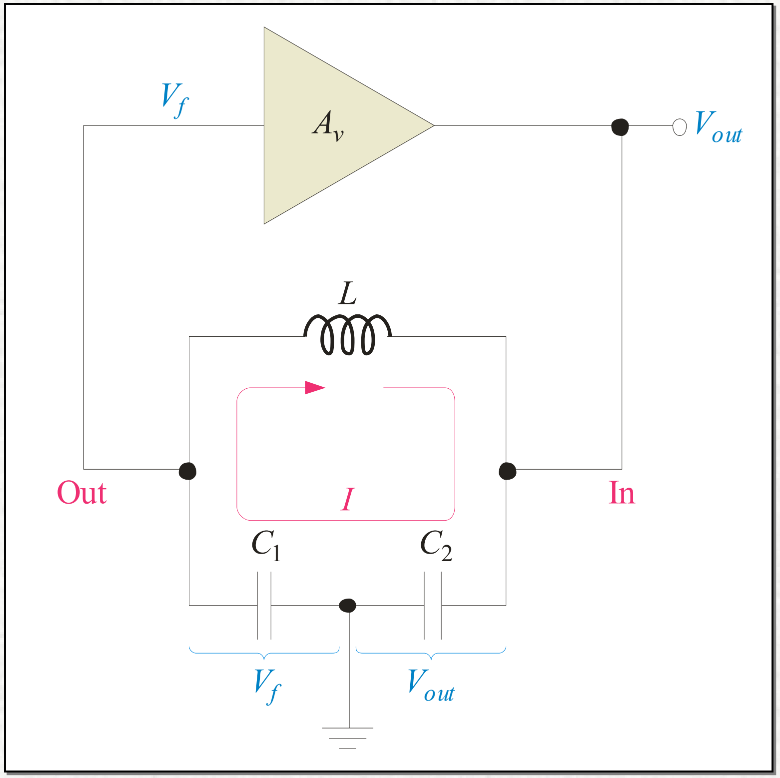
f = 2.28 kHz @2.0 V_{pp}

Amplitude = 0 to 27 V_{pp}



The Colpitts Oscillator

LC feedback oscillators use resonant circuits in the feedback path. A popular *LC* oscillator is the **Colpitts oscillator**. It uses two series capacitors in the resonant circuit. The feedback voltage is developed across C_1.



The effect is that the tank circuit is "tapped". Usually C_1 is the larger capacitor because it develops the smaller voltage.

The Colpitts Oscillator

The resonant frequency is found by $f_r = \dfrac{1}{2\pi\sqrt{LC_T}}$

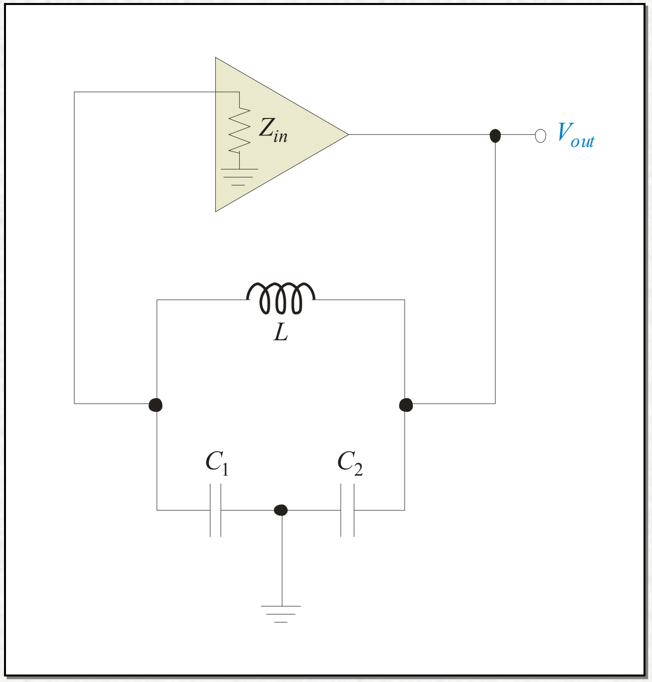
If $Q > 10$, this formula gives good results.

Recall that the total capacitance of two series capacitors is the product-over-sum of the individual capacitors. Therefore,

$$f_r = \frac{1}{2\pi\sqrt{L\left(\dfrac{C_1C_2}{C_1+C_2}\right)}}$$

For $Q < 10$, a correction for Q is

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

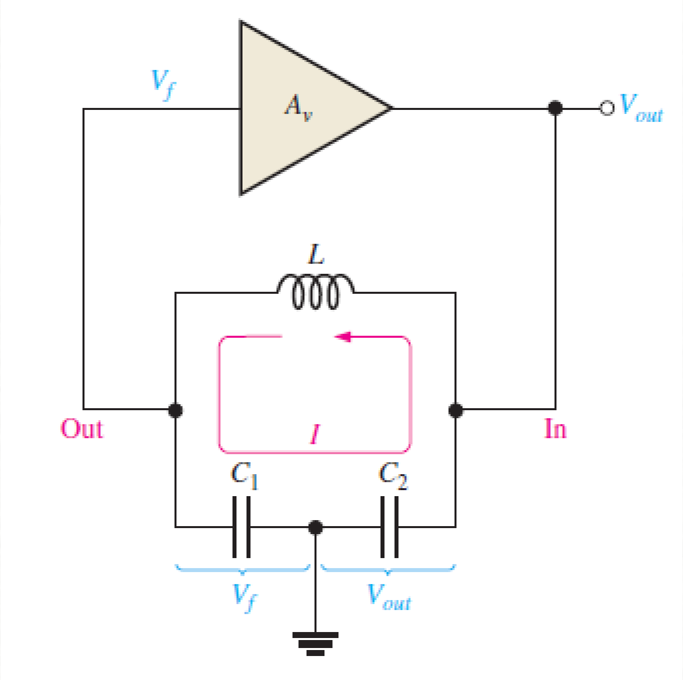


Conditions for Oscillation and Start-Up

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

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

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



Example:

(a) Determine the frequency for the oscillator in the figure below. Assume there is negligible loading on the feedback circuit and that its Q is greater than 10.

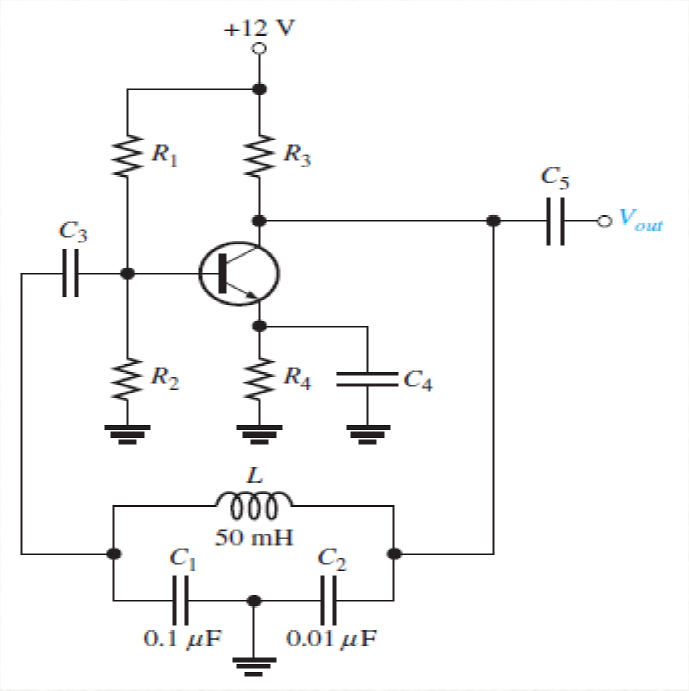
(b) Find the frequency if the oscillator is loaded to a point where the Q drops to 8.

Solution

(a) $$C_T = \frac{C_1 C_2}{C_1 + C_2} = \frac{(0.1\ \mu F)(0.01\ \mu F)}{0.11\ \mu F} = 0.0091\ \mu F$$

$$f_r \cong \frac{1}{2\pi\sqrt{LC_T}} = \frac{1}{2\pi\sqrt{(50\ mH)(0.0091\ \mu F)}} = \mathbf{7.46\ kHz}$$

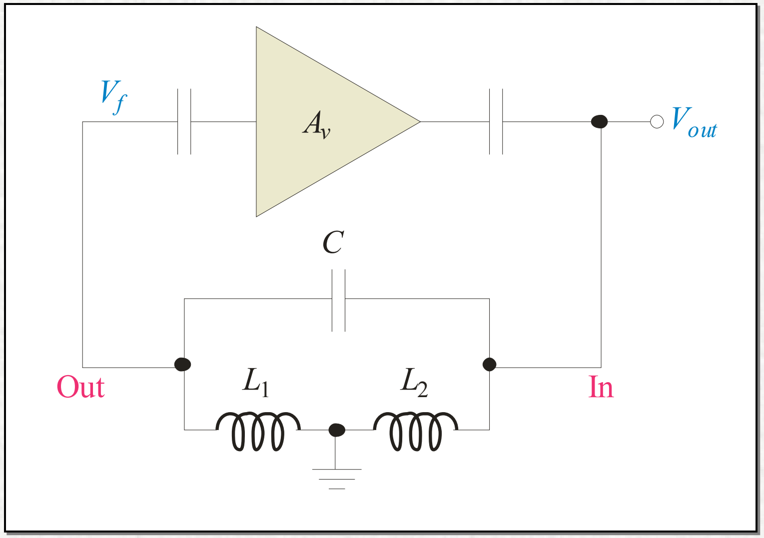
(b) $$f_r = \frac{1}{2\pi\sqrt{LC_T}}\sqrt{\frac{Q^2}{Q^2+1}} = (7.46\ kHz)(0.9923) = \mathbf{7.40\ kHz}$$



The Hartley Oscillator

The Hartley oscillator is similar to the Colpitts oscillator, except the resonant circuit consists of two series inductors (or a single tapped inductor) and a parallel capacitor. The frequency for $Q > 10$ is

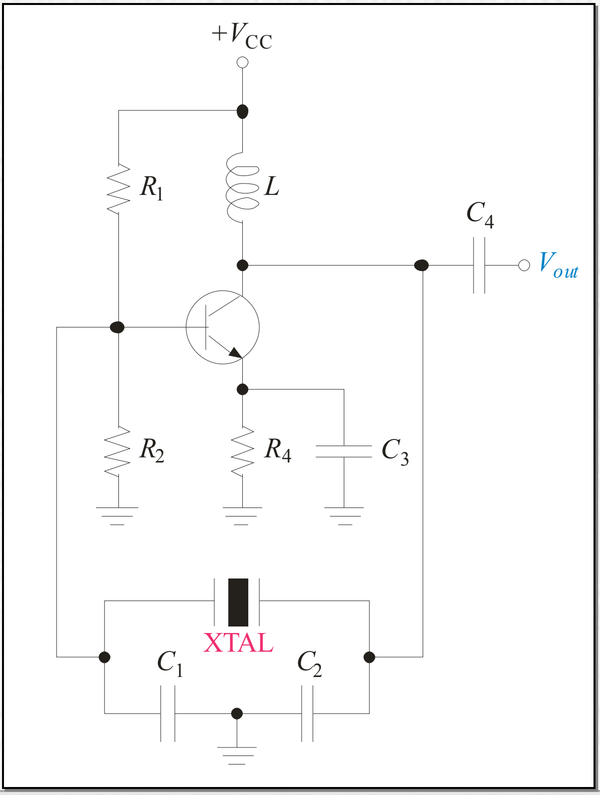
$$f_r = \frac{1}{2\pi\sqrt{L_T C}} = \frac{1}{2\pi\sqrt{(L_1 + L_2)\,C}}$$



One advantage of a Hartley oscillator is that it can be tuned by using a variable capacitor in the resonant circuit.

The Crystal Oscillator

Crystal oscillators are highly stable oscillators for demanding circuits such a radio transmitters. Crystals have very high *Q*.



Manufacturers prepare natural crystals (usually quartz) by mounting a very thin slab between metal electrodes. When a small ac voltage is applied, the crystal oscillates at its own resonant frequency.

The crystal acts as the resonant circuit for the modified Colpitts oscillator and stabilizes the oscillations. The capacitors still tap off a feedback signal to the CE amplifier.

Relaxation Oscillators

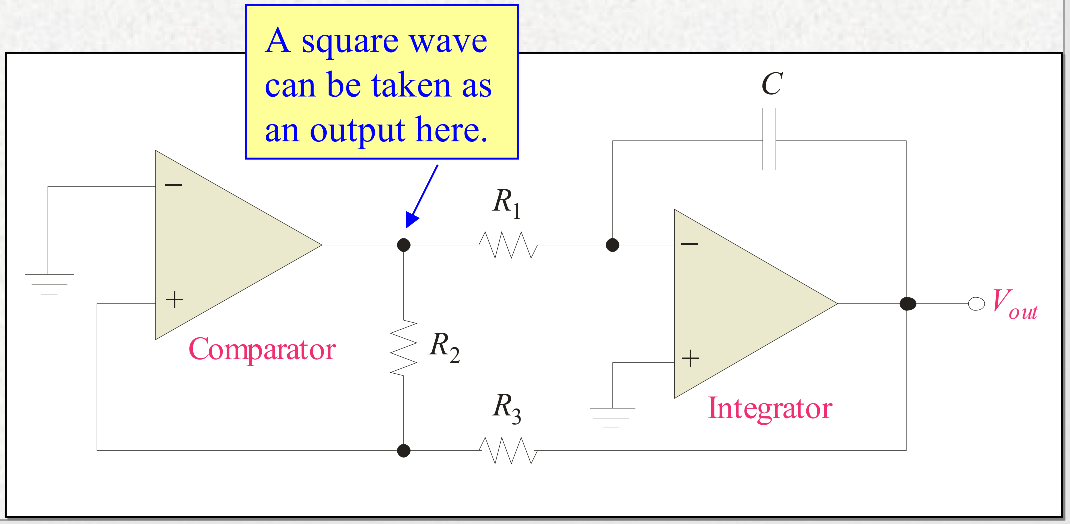
Relaxation oscillators are characterized by an *RC* timing circuit and a device that periodically changes state.

The triangular wave oscillator is an example. For this circuit, the device that changes states is a comparator with hysteresis (Schmitt trigger). The *RC* timing device is an integrator. The comparator output can be used as a square wave output.

The trigger points set the triangle's peak-to-peak voltage:

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

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



Relaxation Oscillators

For the triangular wave generator, the frequency is found from:

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

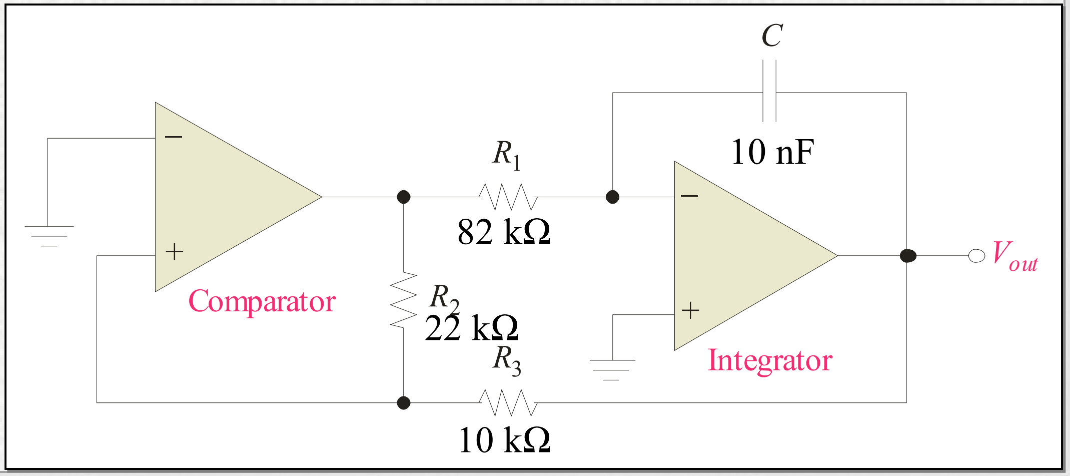
Example: What is the frequency of the circuit shown here?

Solution:

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

$$= \frac{1}{4(82\ \text{k}\Omega)(10\ \text{nF})}\left(\frac{22\ \text{k}\Omega}{10\ \text{k}\Omega}\right)$$

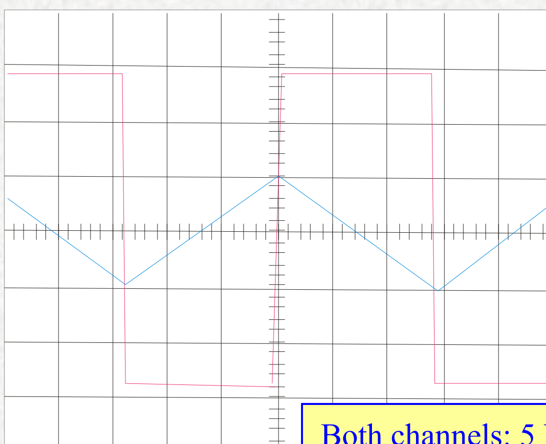
$$= 671\ \text{Hz}$$



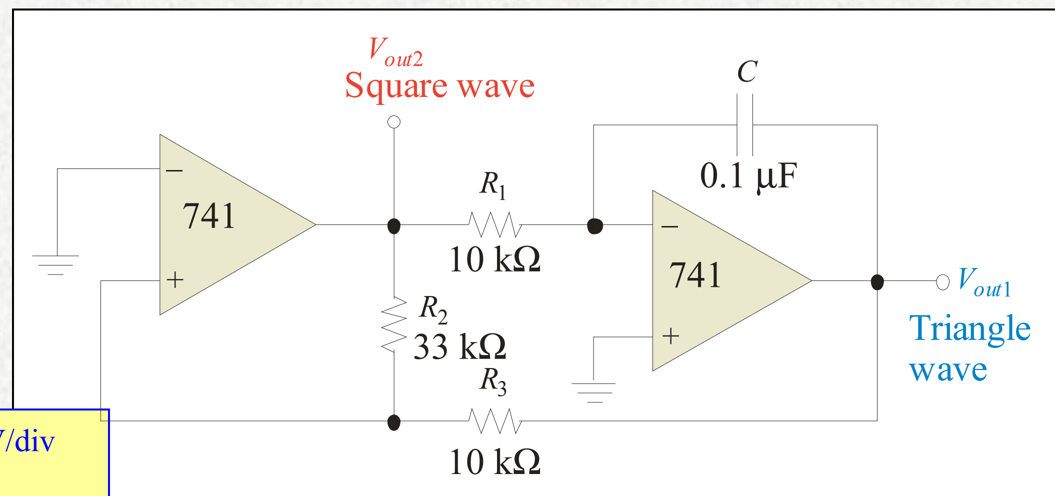
Relaxation Oscillators

Normally, the triangle wave generator uses fast comparators to avoid slew rate problems. For non-critical applications, a 741 will work nicely for low frequencies (<2 kHz). The circuit here is one you can construct easily in lab.

The waveforms are:



Both channels: 5 V/div
250 µs/div

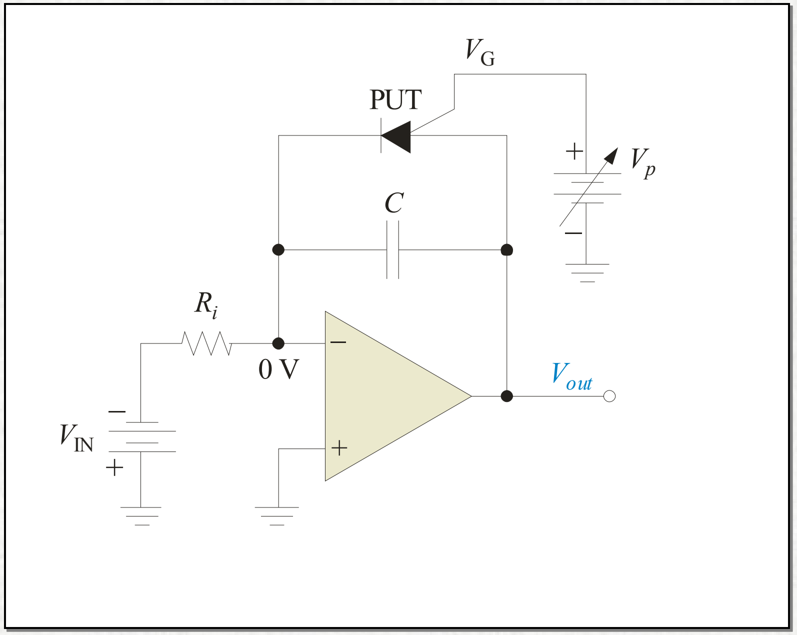


Relaxation Oscillators

A sawtooth VCO also uses an integrator to create the ramp portion of the waveform. In this case, when $V_C > V_G + 0.7$ V, the PUT fires and the capacitor discharges rapidly.

In this circuit, the device that changes state is a PUT and the *RC* timing circuit is an integrator. PUT is a programmable unijunction transistor with an anode, a cathode, and a gate terminal.
The frequency is found by:

$$f = \frac{V_{IN}}{4R_iC}\left(\frac{1}{V_p - V_F}\right)$$



Relaxation Oscillators

Another relaxation oscillator that uses a Schmitt trigger is the basic square-wave oscillator. The trigger points are set by R_2 and R_3. The capacitor charges and discharges between these levels:

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

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

The period of the waveform is given by:

$$T = 2R_1C\ln\left(1 + \frac{2R_3}{R_2}\right)$$