Feedback and Oscillator Circuits

Practical Feedback Circuits

Voltage Series Feedback:

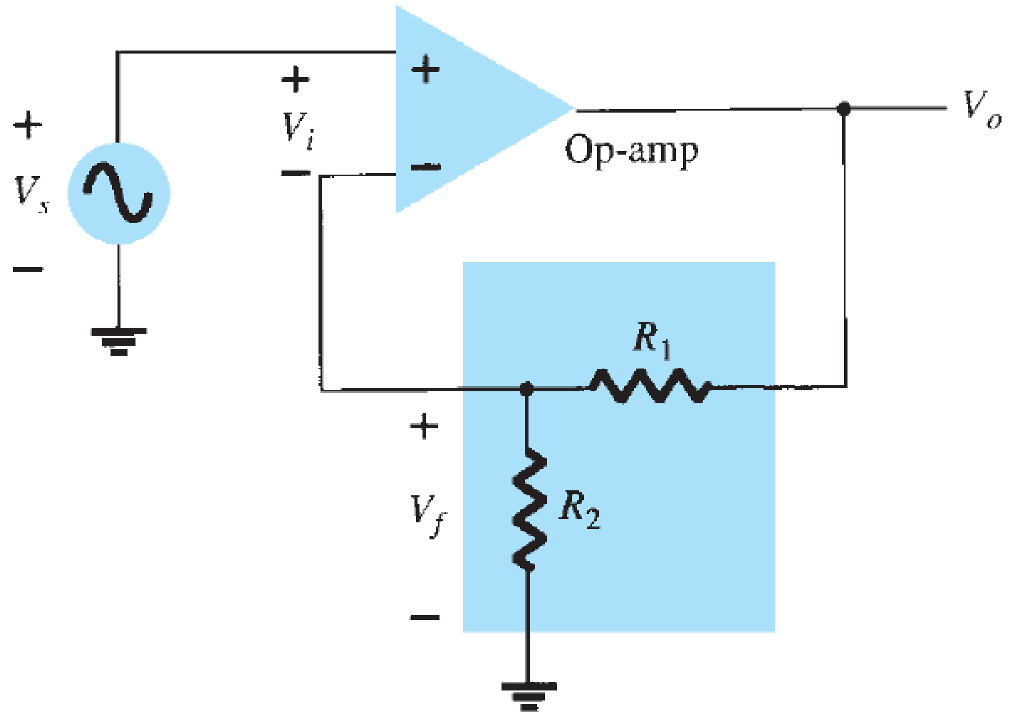
- A part of the output signal (V_o) is obtained using a feedback network of resistors R_1 and R_2
- The feedback voltage V_f is connected in series with the source signal V_s, their difference being the input signal V_i

$$V_f = \frac{R_1}{R_1 + R_2} V_o$$

$$\beta = \frac{V_f}{V_o} = \frac{R_1}{R_1 + R_2}$$

$$A_f = \frac{A}{1 + A\beta} = \frac{\infty}{1 + \frac{R_1}{R_1 + R_2} \cdot \infty} \approx \frac{\infty}{\infty \cdot \frac{R_1}{R_1 + R_2}}$$

$$A_f = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1}$$



Practical Feedback Circuits

Voltage Series Feedback:

Without feedback the amplifier gain is

$$A = \frac{Vo}{Vi} = -g_m R_L, \qquad g_m = \frac{I_D}{V_{GS}}$$

where R_L is the parallel combination of resistors:

$$R_L = R_D // R_o$$

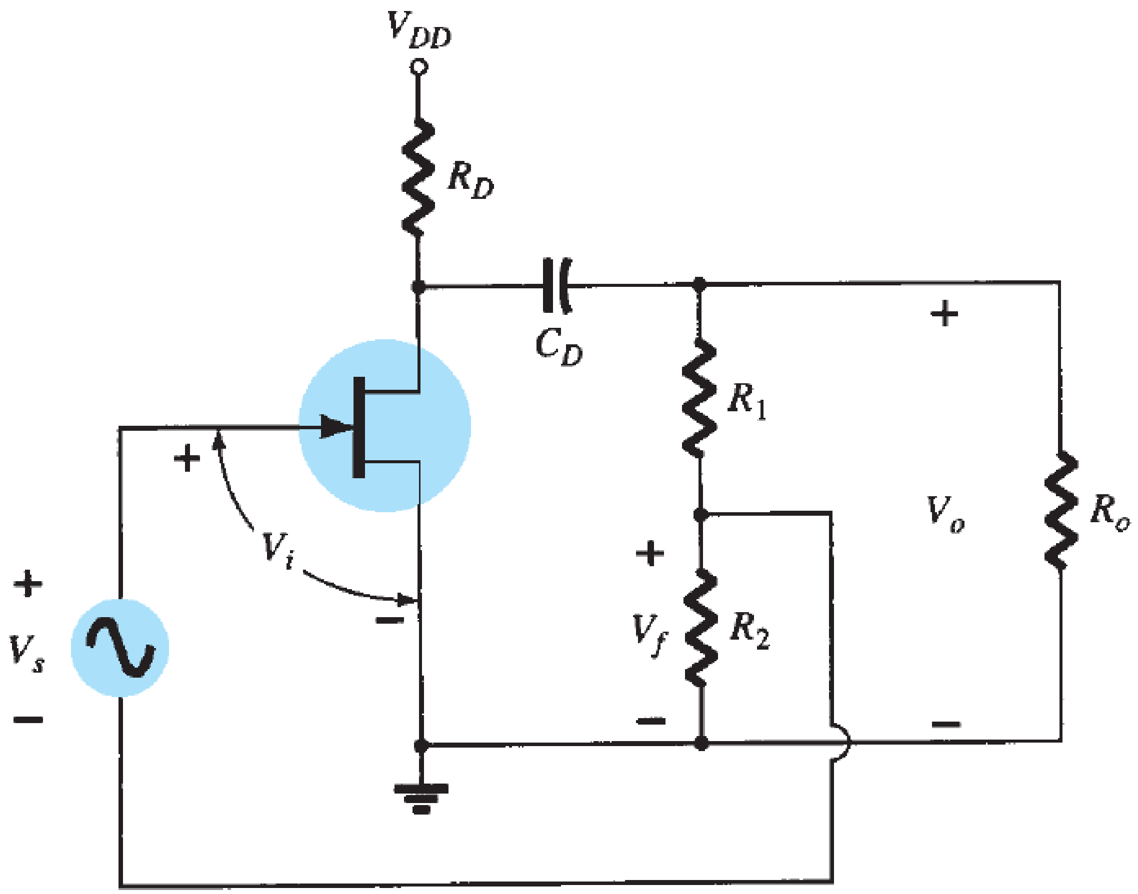
With feedback

$$\beta = \frac{V_f}{V_o} = \frac{-R_2}{R_1 + R_2}$$

$$A_f = \frac{A}{1 + \beta A} = \frac{-g_m R_L}{1 + [R_2 R_L/(R_1 + R_2)]\, g_m}$$

If $\beta A \gg 1$, we have

$$A_f \approx \frac{1}{\beta} = -\frac{R_1 + R_2}{R_2}$$



Practical Feedback Circuits

Voltage Series Feedback:

- The emitter-follower circuit provides voltage-series feedback
- The signal voltage V_s is the input voltage V_i
- The output voltage V_o is also the feedback voltage in series with the input voltage
- The operation of the circuit without feedback provides $V_f = 0$, so that

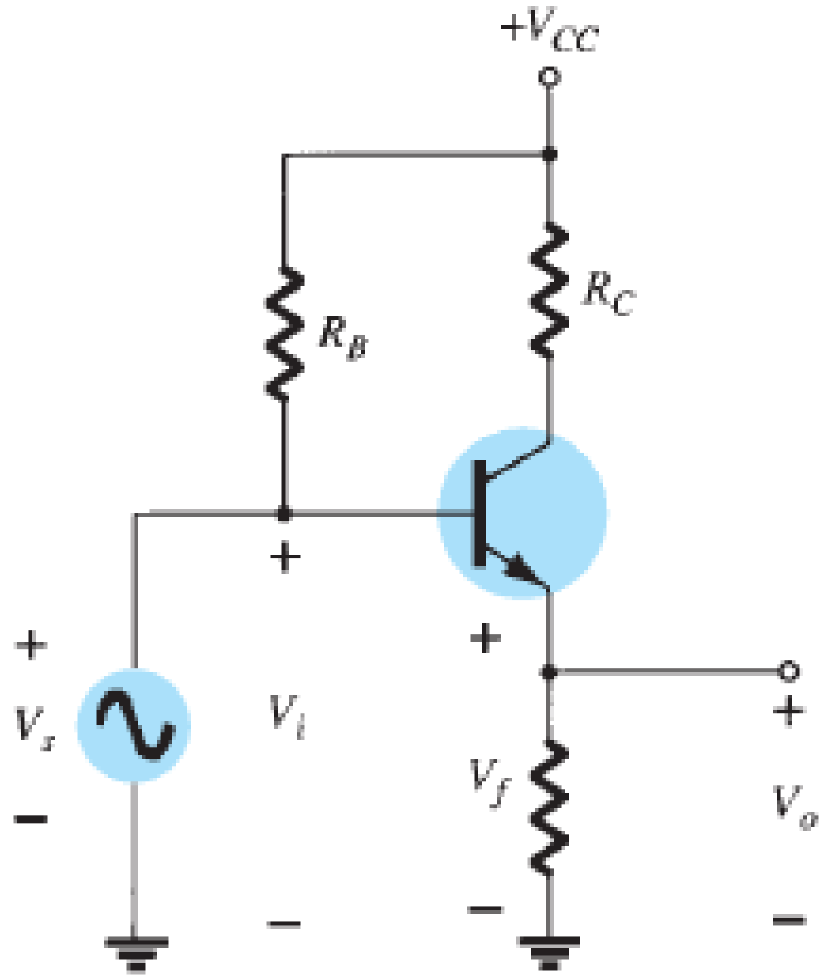
$$A = \frac{V_o}{V_i} = \frac{(\beta_{tr}\ I_b)R_E}{V_i} = \frac{(\beta_{tr} I_b)R_E}{I_b(\beta_{tr} r_e)} = \frac{R_E}{r_e}$$

With feedback

$$\beta = \frac{V_f}{V_o} = 1$$

$$A_f = \frac{V_o}{V_s} = \frac{A}{1 + \beta A} = \frac{R_E / r_e}{1 + (1)(R_E / r_e)}$$

$$= \frac{R_E}{r_e + R_E}$$



Practical Feedback Circuits

Voltage Shunt Feedback:

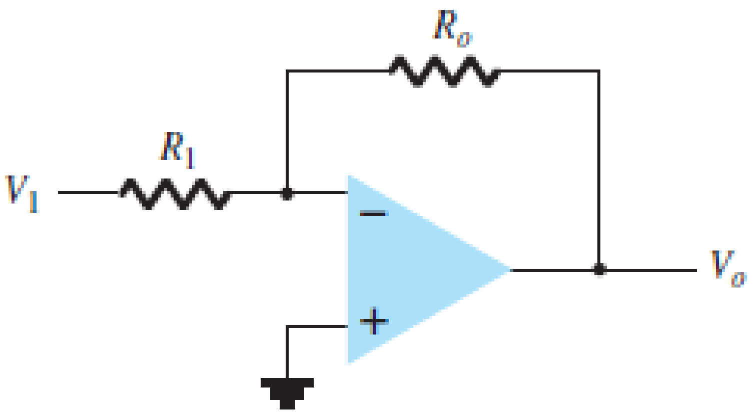
Without feedback

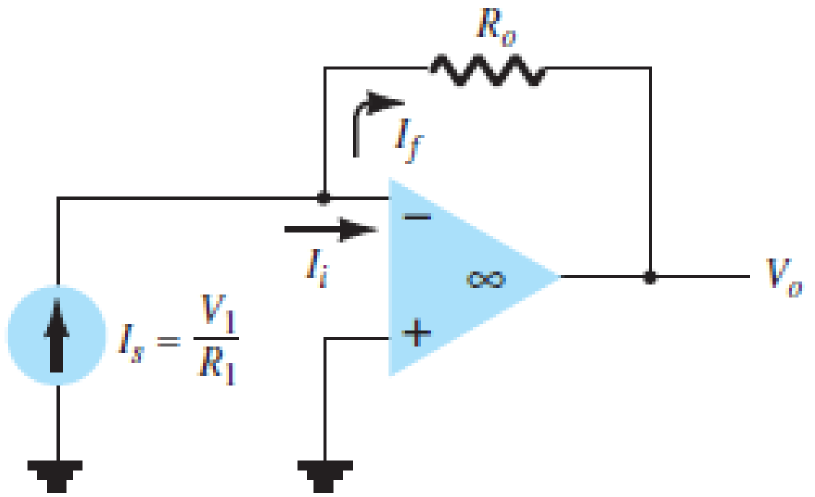
$$A = \frac{V_o}{I_i} = \frac{V_o}{0} = \infty$$

$$\beta = \frac{I_f}{V_o} = \frac{-1}{R_o}$$

With feedback

$$A_f = \frac{V_o}{I_s} = \frac{A}{1 + \beta A} \approx \frac{1}{\beta} = -R_o$$

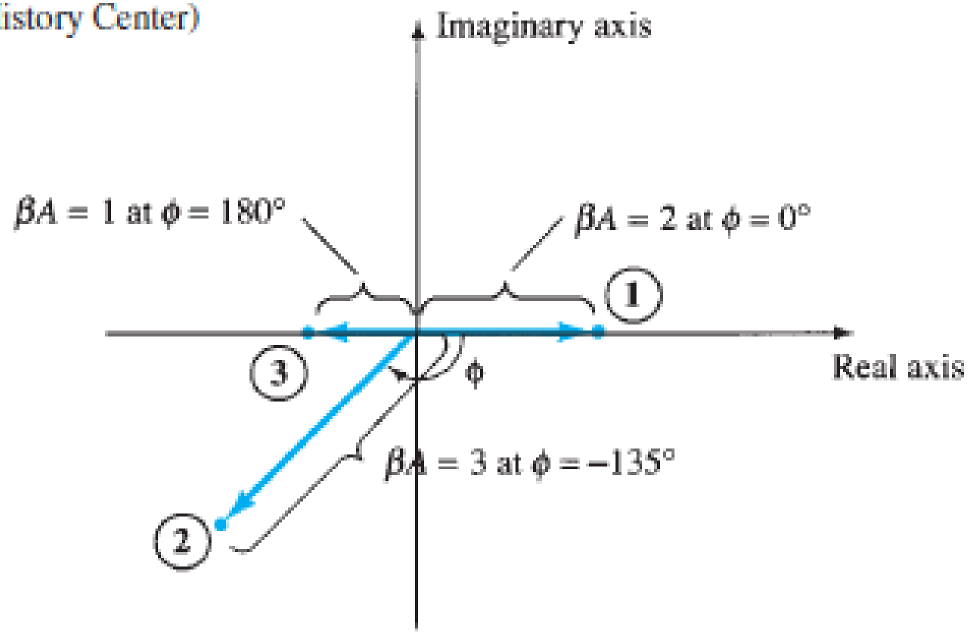




Phase and Frequency Considerations

- Stability of a feedback amplifier is determined by the βA product and the phase shift between input and output
- One of the most popular techniques used to investigate stability is the Nyquist method
- A Nyquist diagram is used to plot gain and phase shift as a function of frequency on a complex plane
- The Nyquist plot, in effect, combines the two Bode plots of gain versus frequency and phase shift versus frequency on a single plot
- A Nyquist plot is used to quickly show whether an amplifier is stable for all frequencies and how stable the amplifier is relative to some gain or phase-shift criteria
- As a start, consider the *complex plane* shown in figure
- A few points of various gain (βA) values are shown at a few different phase-shift angles

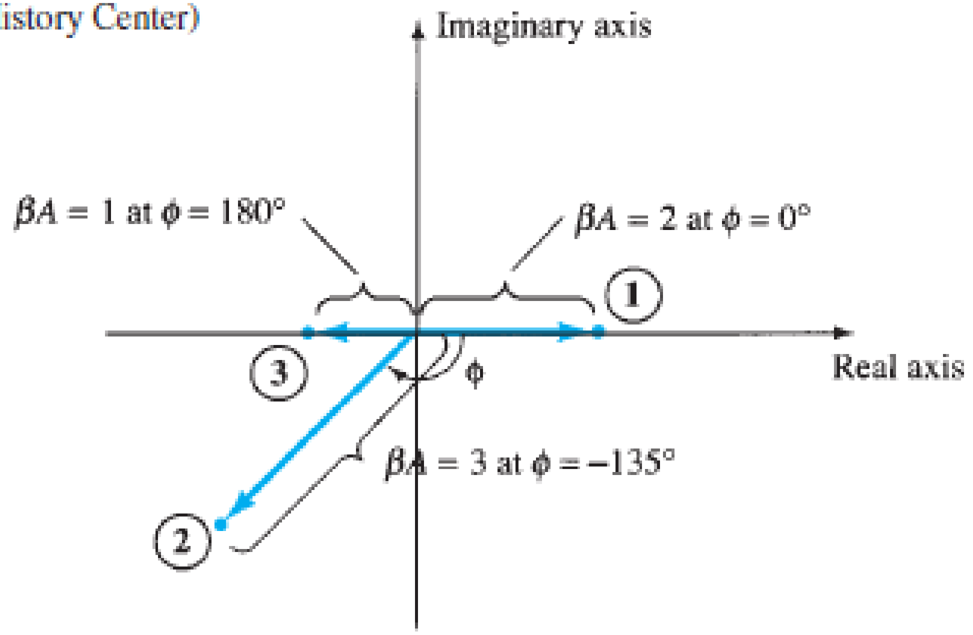
(Courtesy of AT&T Archives and History Center)



Phase and Frequency Considerations

- As a start, consider the *complex plane* shown in figure
- A few points of various gain (βA) values are shown at a few different phase-shift angles
- By using the positive real axis as reference (0°), we see a magnitude of $\beta A = 2$ at a phase shift of 0° at point 1
- Additionally, a magnitude of $\beta A = 3$ at a phase shift of 135° is shown at point 2
- And magnitude/phase of $\beta A = 1$ at 180° is shown at point 3
- Thus points on this plot can represent *both* gain magnitude of βA and phase shift

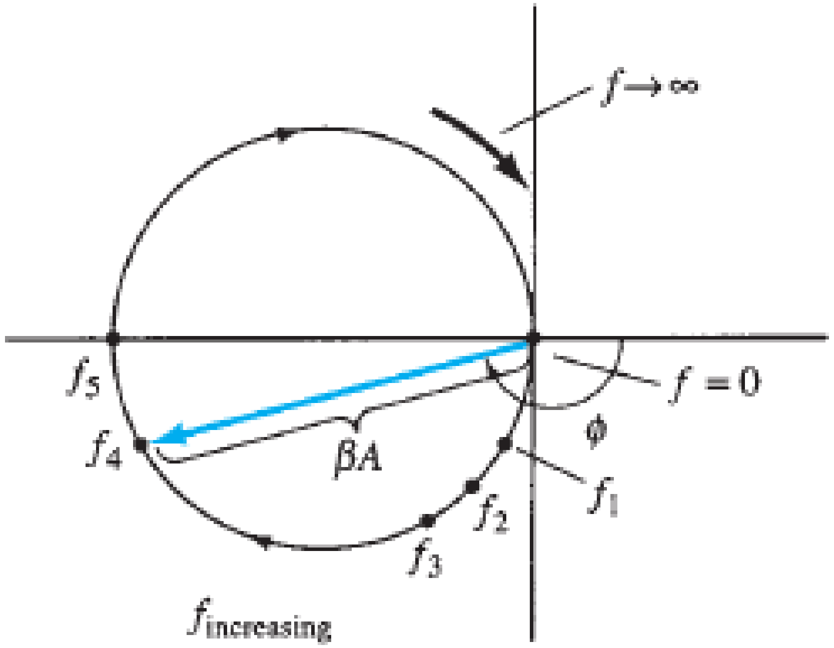
(Courtesy of AT&T Archives and History Center)



Phase and Frequency Considerations

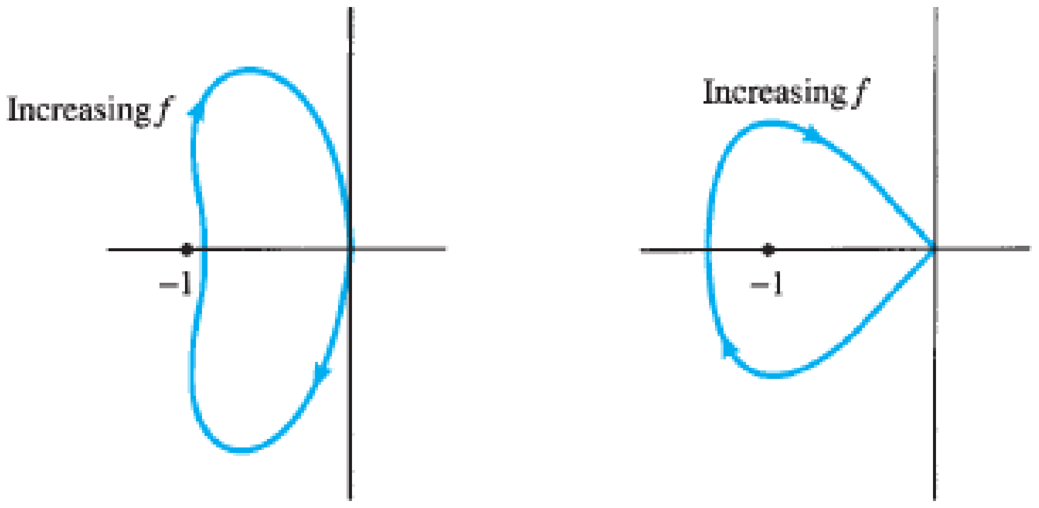
- If the points representing gain and phase shift for an amplifier circuit are plotted at increasing frequency, then a Nyquist plot is obtained as shown by the plot
- At the origin, the gain is 0 at a frequency of 0 (for *RC* –type coupling)
- At increasing frequency, points f_1, f_2, and f_3 and the phase shift increase, as does the magnitude of βA
- At a representative frequency f_4, the value of βA is the vector length from the origin to point f_4 and the phase shift is the angle ϕ
- At a frequency f_5 , the phase shift is 180°
- At higher frequencies, the gain is shown to decrease back to 0
- The Nyquist criterion for stability can be stated as follows:

The amplifier is unstable if the Nyquist curve encloses (encircles) the –1 point, and it is stable otherwise.



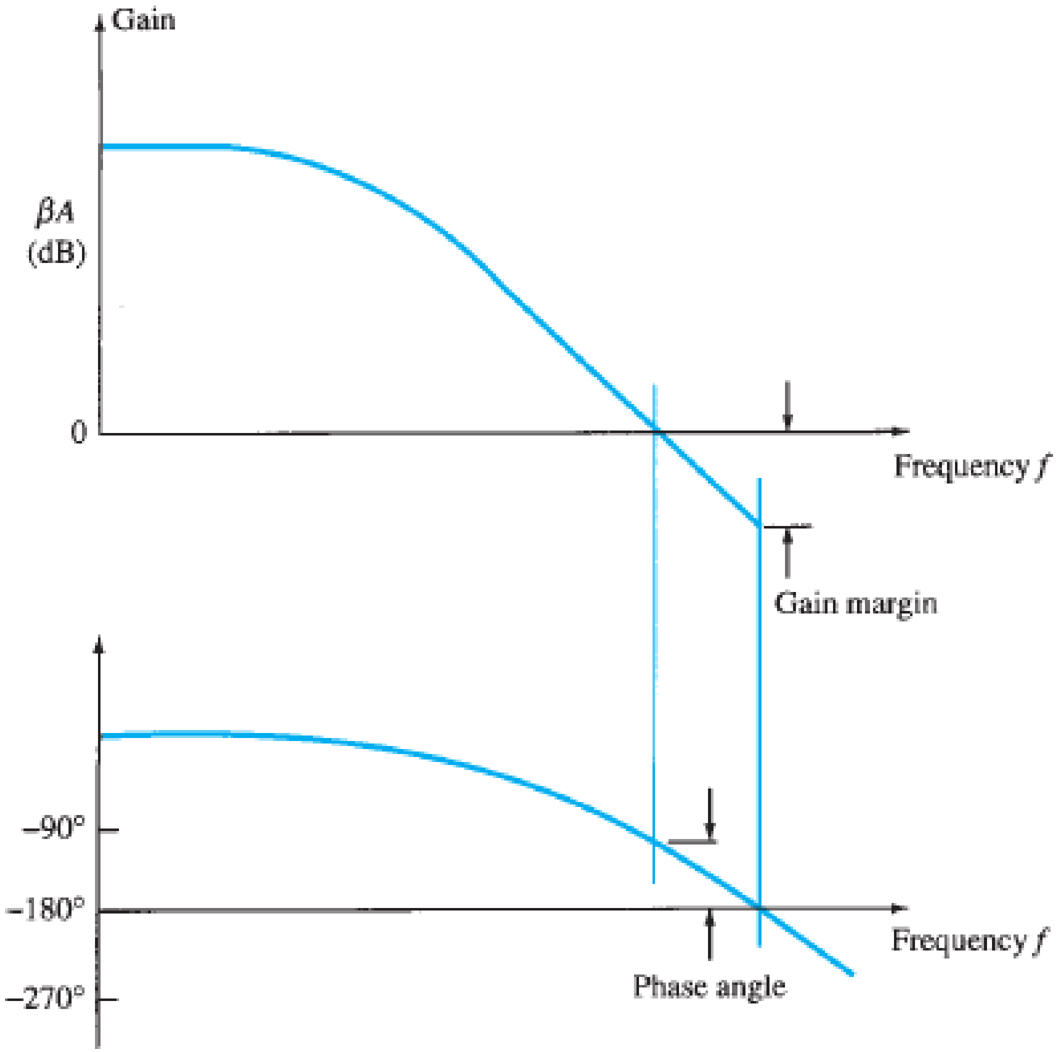
Phase and Frequency Considerations

- An example of the Nyquist criterion is demonstrated by the curves in figures
- The Nyquist plot in figure on the left is stable since it does not encircle the 1 point
- Whereas the plot shown in figure on the right is unstable since the curve does encircle the -1 point
- Keep in mind that encircling the -1 point means that at a phase shift of 180° the loop gain (βA) is greater than 1
- Therefore, the feedback signal is large enough to result in a larger input signal than that applied, with the result that oscillation occurs

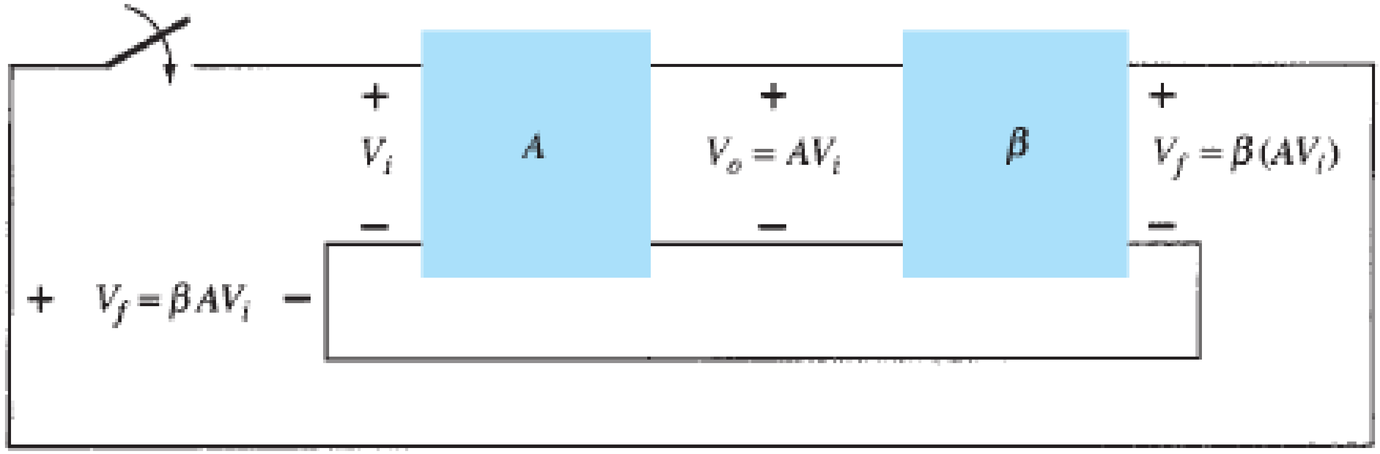


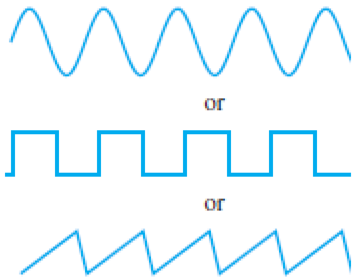
Phase and Frequency Considerations

- From the Nyquist criterion, we know that a feedback amplifier is stable if the loop gain (βA) is less than unity (0 dB) when its phase angle is 180°
- We can additionally determine some margins of stability to indicate how close to instability the amplifier is
- ***Gain margin*** **(GM)** is defined as the value of $|\beta A|$ in decibels at the frequency at which the phase angle is 180°
- Thus, 0 dB, equal to a value of βA*=1*, is on the border of stability and any negative decibel value is stable
- The GM may be evaluated in decibels from the curve of figure on top
- ***Phase margin*** **(PM)** is defined as 180° minus the absolute value of the angle at which the value $|\beta A|$ is unity (0 dB)
- The PM may be evaluated directly from the curve of bottom figure



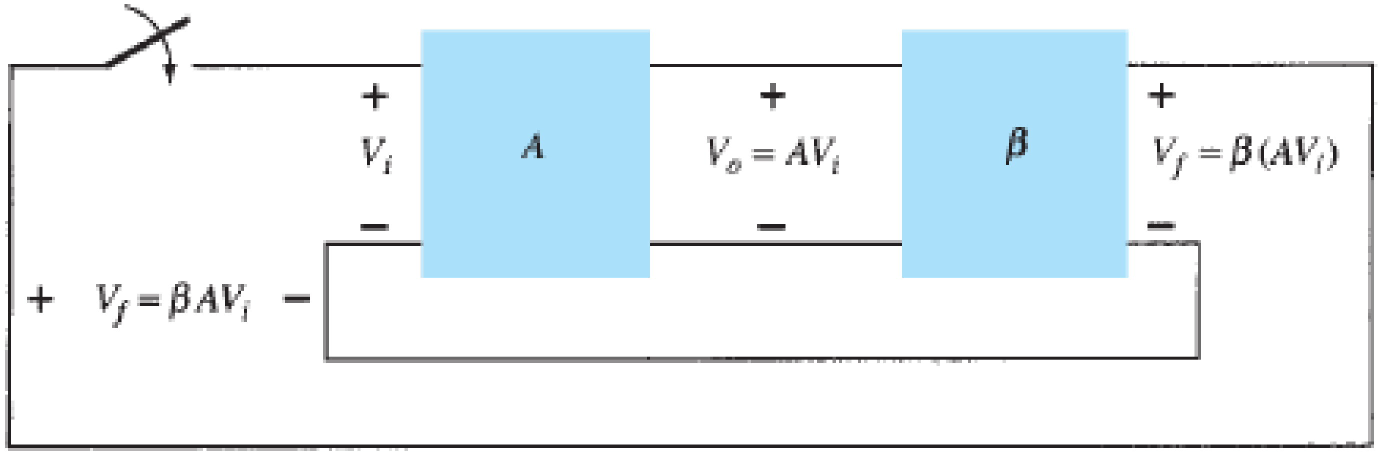
Oscillators





- The use of positive feedback that results in a feedback amplifier having closed-loop gain $|\beta A|$ greater than 1 and satisfies the phase conditions will result in operation as an oscillator circuit
- An oscillator circuit then provides a varying output signal
- Consider the feedback circuit given in the figure
- When the switch at the amplifier input is open, no oscillation occurs

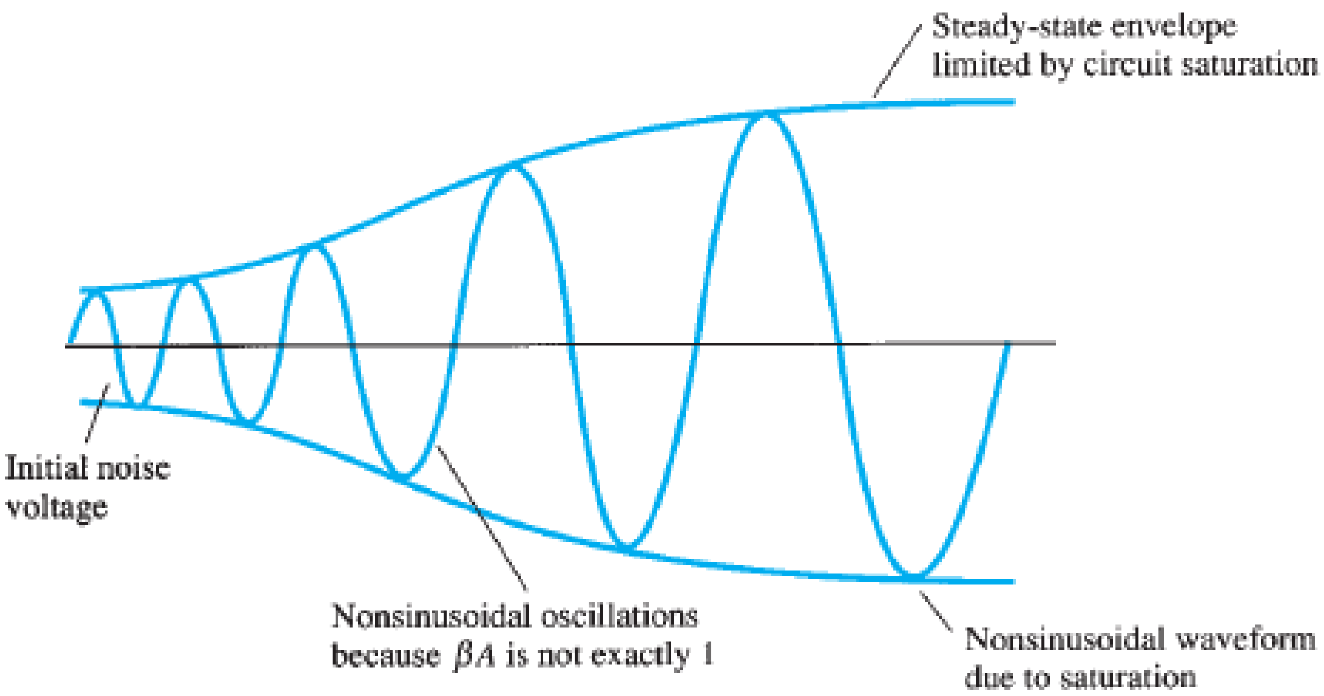
Oscillators



- Consider that we have a *fictitious* voltage at the amplifier input V_i
- Results in output voltage $V_o = AV_i$ and in feedback voltage $V_f = \beta(AV_i)$
- If the circuits of the base amplifier and feedback network provide βA of a correct magnitude and phase, V_f can be made equal to V_i
- Then, when the switch is closed and the fictitious voltage V_i is removed, the circuit will continue operating since the feedback voltage is sufficient to drive the circuit
- The output waveform will still exist after the switch is closed if the condition βA=1 is met
- This is known as the *Barkhausen criterion* for oscillation.

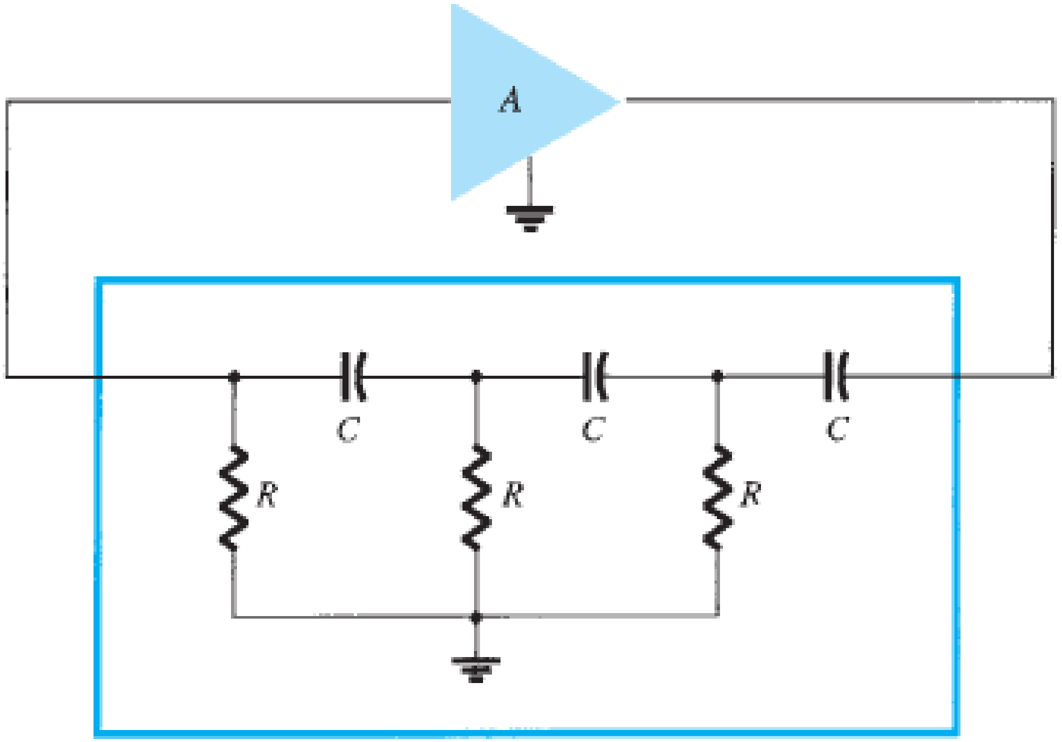
Oscillators

- In reality, no input signal is needed to start the oscillator going
- Only the condition βA=1 must be satisfied for self-sustained oscillations to result
- In practice, βA is made greater than 1, system starts oscillating by amplifying noise voltage, which is always present
- Saturation factors in the practical circuit provide an “average” value of βA of 1
- The resulting waveforms are never exactly sinusoidal
- However, the closer the value βA is to exactly 1, the more nearly sinusoidal is the waveform
- Figure below shows how the noise signal results in a buildup of a steady-state oscillation condition.



Phase-Shift Oscillators

An idealized version of this circuit is shown in the figure.
We consider the feedback network to be driven by a perfect source (zero source impedance)
And the output of the feedback network to be connected into a perfect load (infinite load impedance)



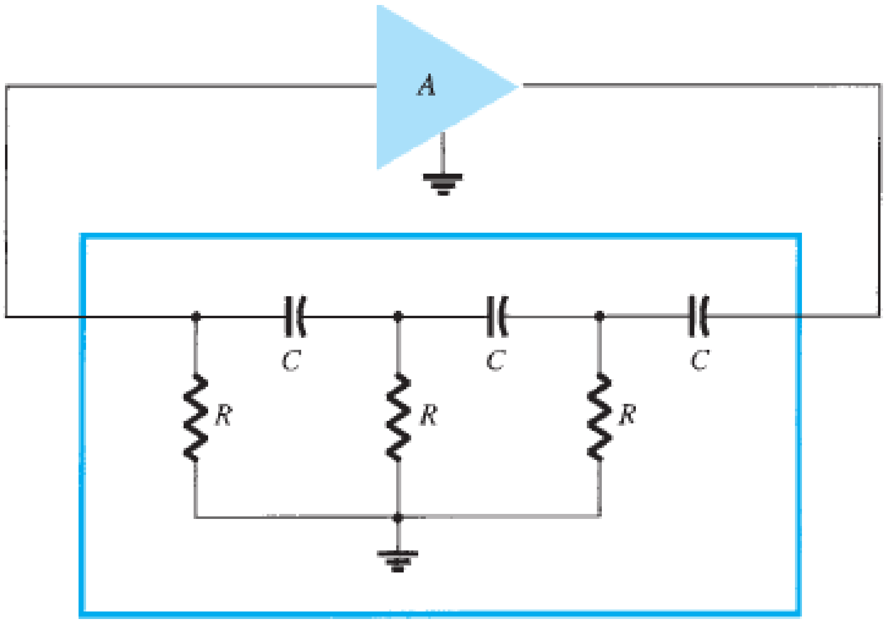
Feedback network

Phase-Shift Oscillators

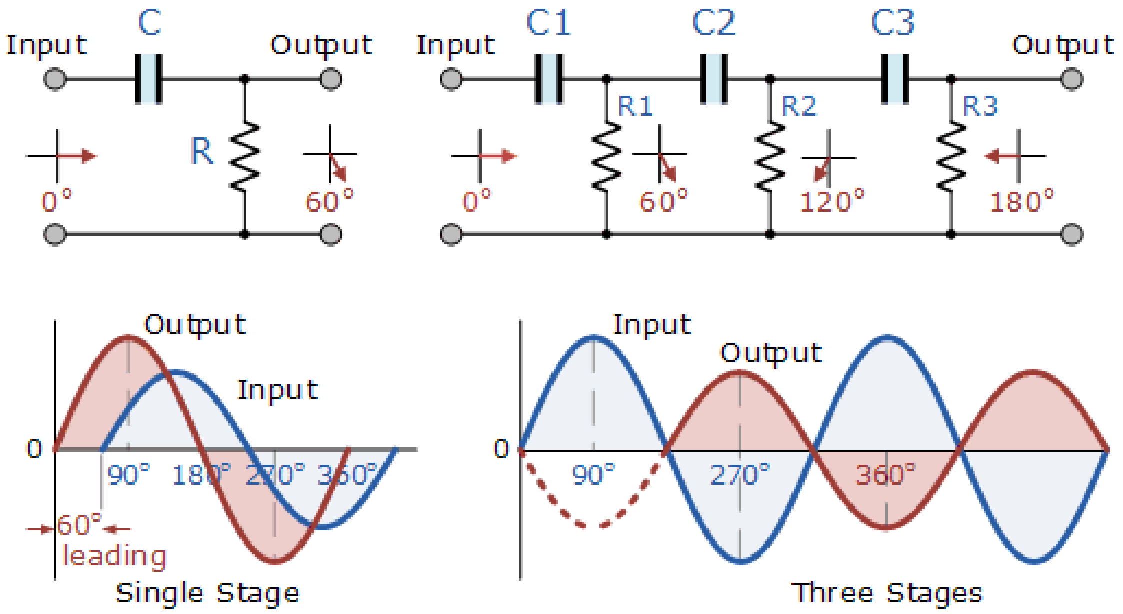
- An ideal single-pole RC circuit would produce a phase shift of exactly 90^0, and because 180^0 of phase shift is required for oscillation, at least two single-poles must be used in an RC oscillator design
- However in reality it is difficult to obtain exactly 90^0 of phase shift so more stages are used
- The amount of actual phase shift is given as:

$$X_C = \frac{1}{2\pi f C} \Rightarrow Z = \sqrt{R^2 + X_C^2} \;\&\; \phi = \tan^{-1}\frac{X_C}{R}$$

$$\text{for } \phi = 60^0,\ \tan^{-1}\frac{1}{2\pi f RC} = 60^0 \Rightarrow \tan(60^0) = \sqrt{3} = \frac{1}{2\pi f RC} \Rightarrow f = \frac{1}{2\pi\sqrt{3}\,RC}$$

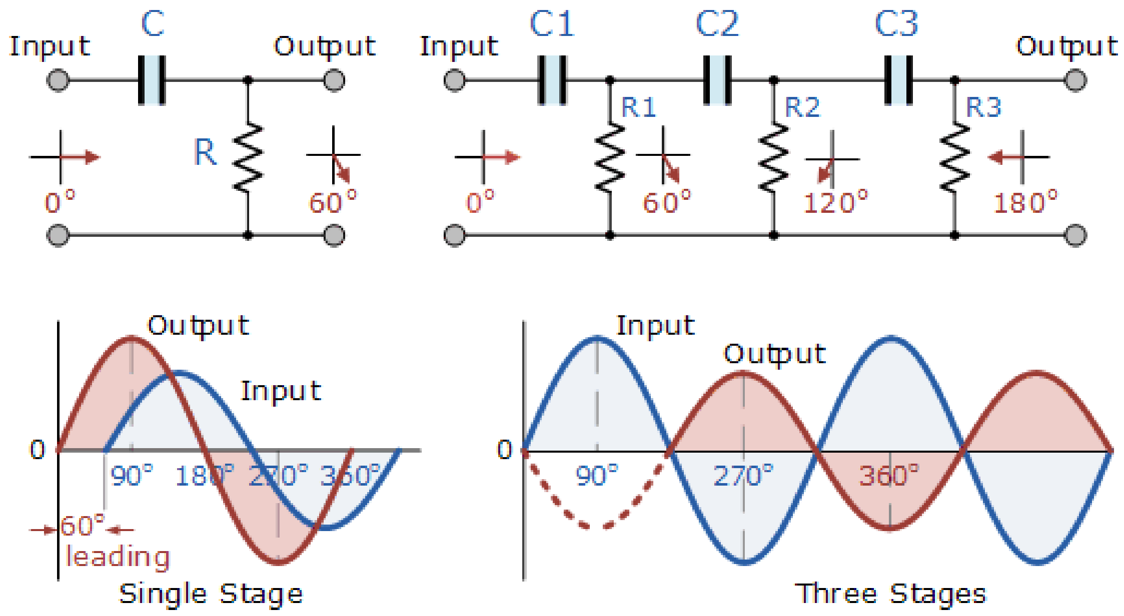


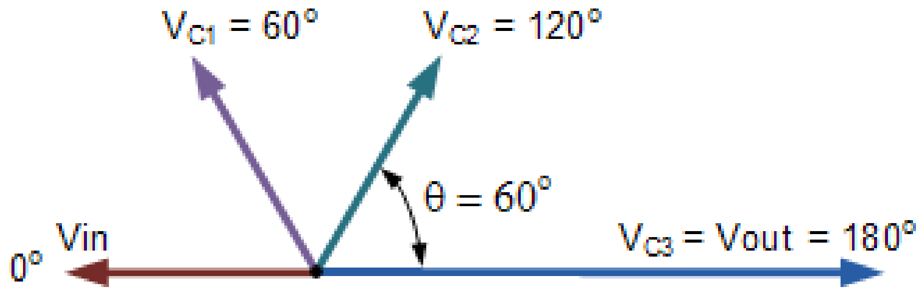
Feedback network



Phase-Shift Oscillators

- Values of R and C have been chosen so that at the required frequency the output voltage leads the input voltage by an angle of about 60°
- Then the phase angle between each successive RC section increases by another 60° giving a phase difference between the input and output of 180° (3 x 60°) as shown by the following vector diagram*
- If all the resistors, R and the capacitors, C in the phase shift network are equal in value, then the frequency of oscillations produced by the RC oscillator is given as: $f = \frac{1}{2\pi RC\sqrt{6}}$ and $\beta = \frac{1}{29}$





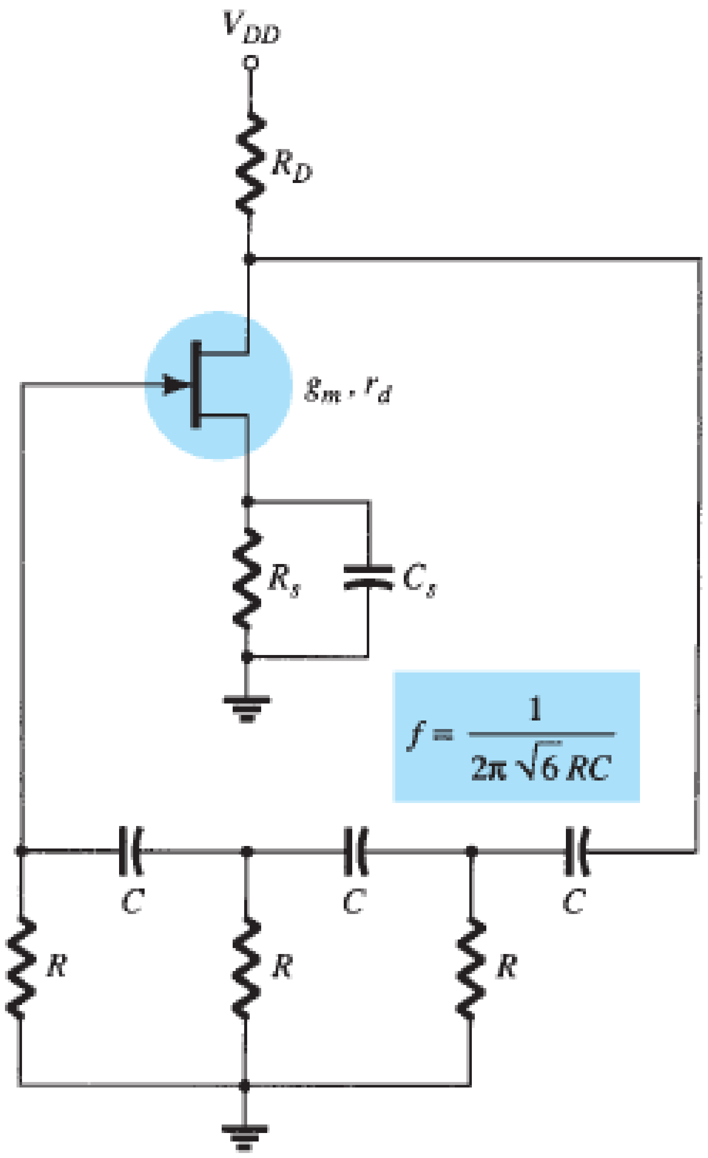
* http://www.electronics-tutorials.ws/oscillator/rc_oscillator.html

FET Phase-Shift Oscillator

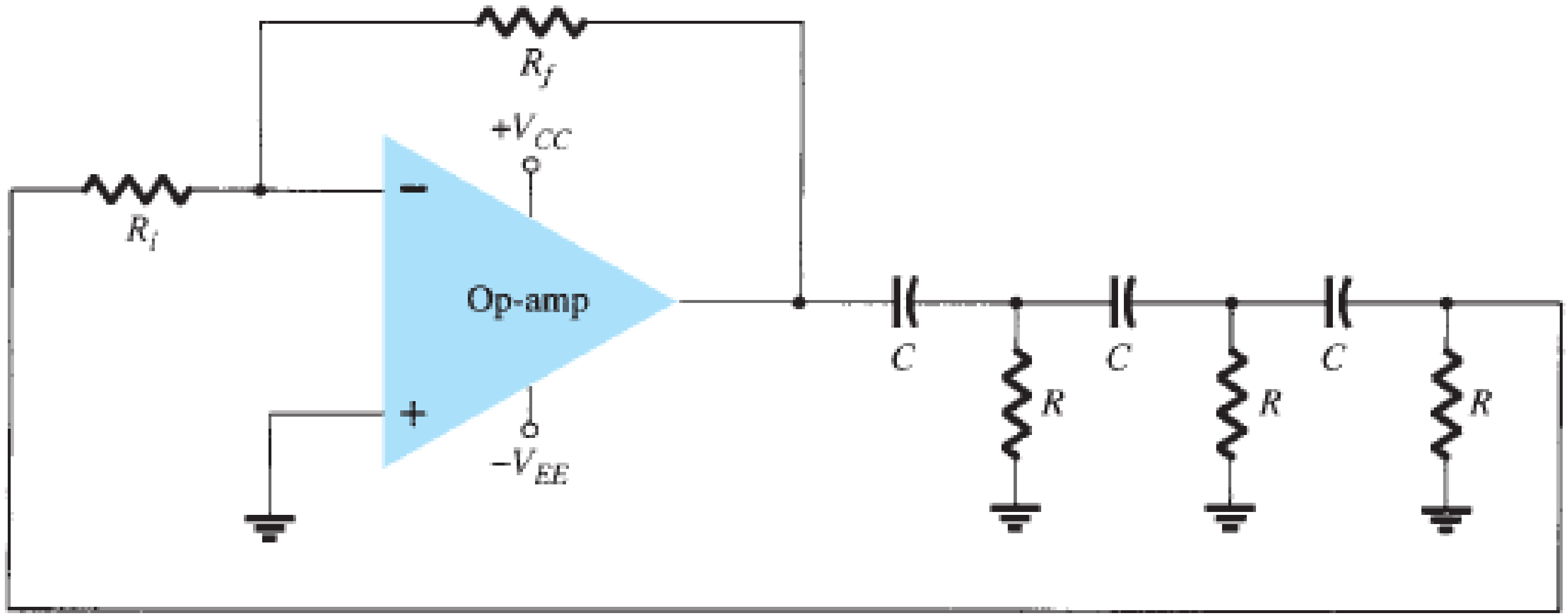
The amplifier stage is self-biased with a capacitor bypassed source resistor R_S and a drain bias resistor R_D

$$A = -g_m R_D$$

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



FET Phase-Shift Oscillator



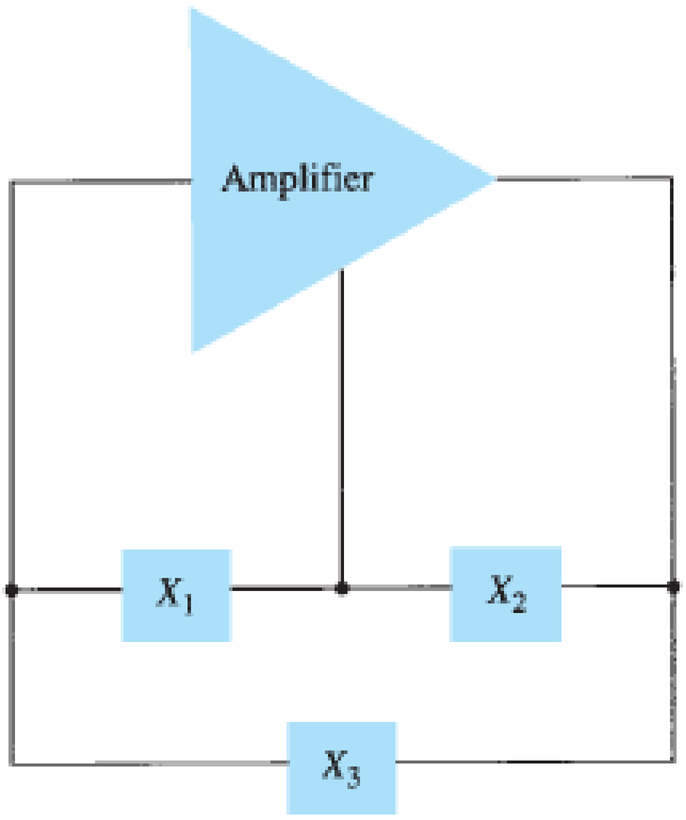
- The output of the op-amp is fed to a three-stage *RC* network, which provides the needed 180° of phase shift (at an attenuation factor of 1/29)
- If the op-amp provides gain (set by resistors R_i and R_f) of greater than 29, a loop gain greater than unity results and the circuit acts as an oscillator with

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

FET Phase-Shift Oscillator

A variety of circuits can be built using that shown in the figure by providing tuning in both the input and output sections of the circuit

Oscillator Type	*Reactance Element*		
	X_1	X_2	X_3
Colpitts oscillator	C	C	L
Hartley oscillator	L	L	C
Tuned input, tuned output	LC	LC	—



FET Phase-Shift Oscillator

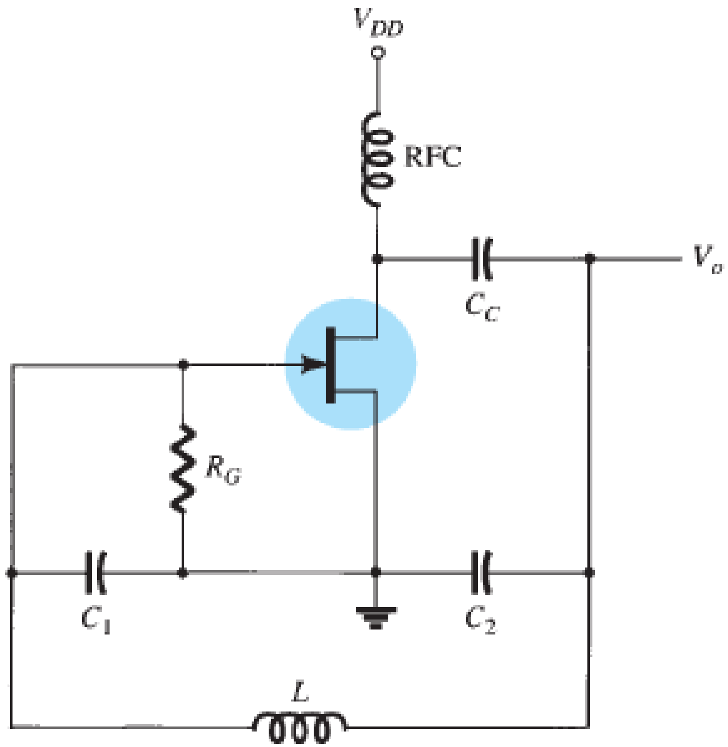
The oscillator frequency can be found to be

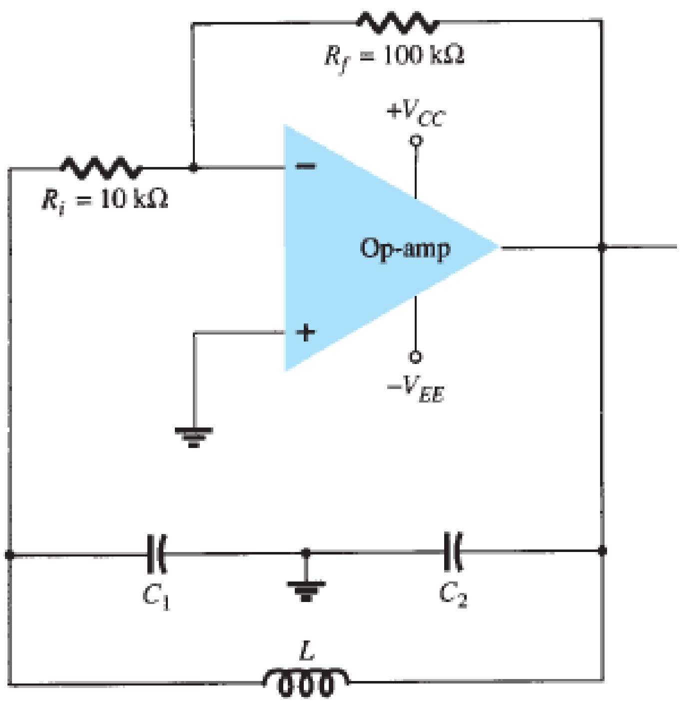
$$f_o = \frac{1}{2\pi \mathrm{LC}_{eq}}$$

Where

$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

Oscillator Type	*Reactance Element* X_1	X_2	X_3
Colpitts oscillator	C	C	L
Hartley oscillator	L	L	C
Tuned input, tuned output	LC	LC	—





FET Phase-Shift Oscillator

Oscillator Type	Reactance Element X_1	X_2	X_3
Colpitts oscillator	C	C	L
Hartley oscillator	L	L	C
Tuned input, tuned output	LC	LC	—

Inductors *L* 1 and *L* 2 have a mutual coupling *M*, which must be taken into account in determining the equivalent inductance for the resonant tank circuit

The circuit frequency of oscillation is then given approximately by

$$f_o = \frac{1}{2\pi\sqrt{L_{eq}C}}$$

with

$$L_{eq} = L_1 + L_2 + 2M$$