FACULTY OF ENGINEERING
DEPARTMENT OF ELECTRONICS AND COMMUNICATIONS

GEE336
Electronic Circuits II

Lecture #2
Feedback Effects on Op-Amp

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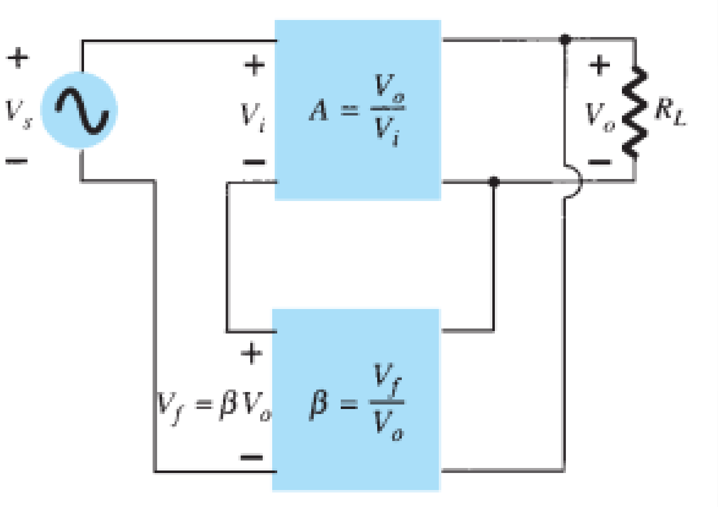
Agenda

- Gain With Feedback
- Effect of Feedback on Gain and Bandwidth
- Op-Amps with Negative Feedback
- Open & Closed Loop Frequency Responses

GAIN WITH FEEDBACK

Voltage-Series Feedback

$$A = \frac{V_o}{V_s} = \frac{V_o}{V_i}$$

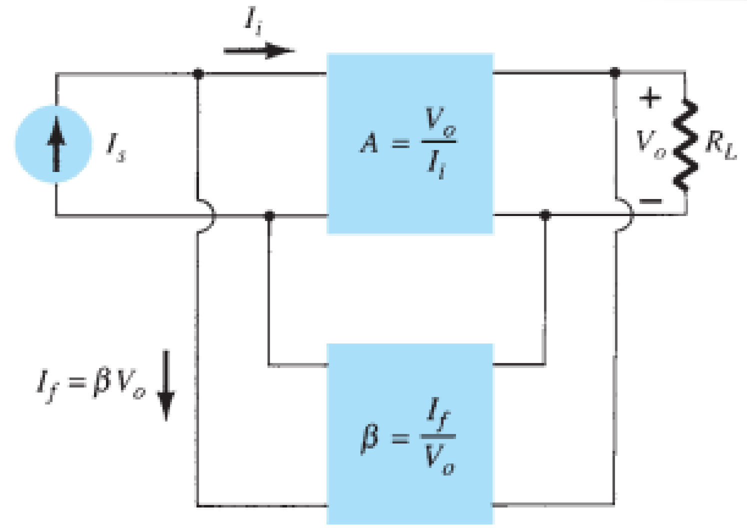


$$V_i = V_s - V_f$$
$$V_o = AV_i = A(V_s - V_f) = AV_s - AV_f = AV_s - A(\beta V_o)$$
$$(1 + \beta A)V_o = AV_s$$

overall voltage gain with feedback:

$$A_f = \frac{V_o}{V_s} = \frac{A}{1 + \beta A}$$

Voltage-Shunt Feedback



$$A_f = \frac{V_o}{I_s} = \frac{A\,I_i}{I_i + I_f} = \frac{A\,I_i}{I_i + \beta V_o} = \frac{A\,I_i}{I_i + \beta A\,I_i}$$

$$A_f = \frac{A}{1 + \beta A}$$

EFFECT OF FEEDBACK ON GAIN AND BANDWIDTH

Effect of Feedback on Gain and Bandwidth

the overall gain with negative feedback is shown to be

$$A_f = \frac{A}{1 + \beta A} \cong \frac{A}{\beta A} = \frac{1}{\beta} \qquad \text{for } \beta A \gg 1$$

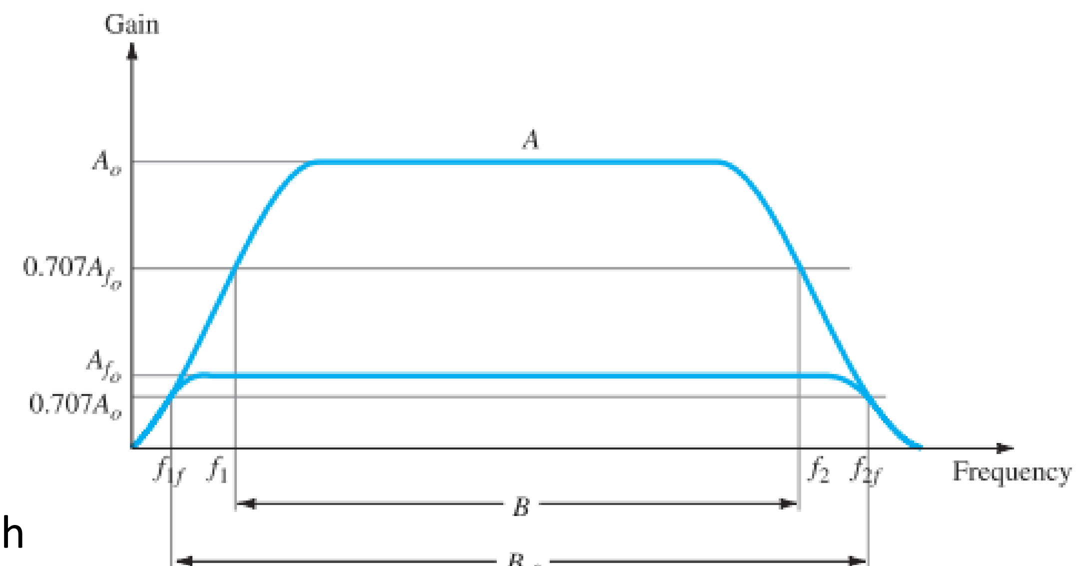


FIG. 14.6

Effect of negative feedback on gain and bandwidth.

The amplifier with negative feedback has more bandwidth (B_f) than the amplifier without feedback (B).

Gain Stability with feedback

$$\left|\frac{dA_f}{A_f}\right| = \frac{1}{|1 + \beta A|}\left|\frac{dA}{A}\right|$$

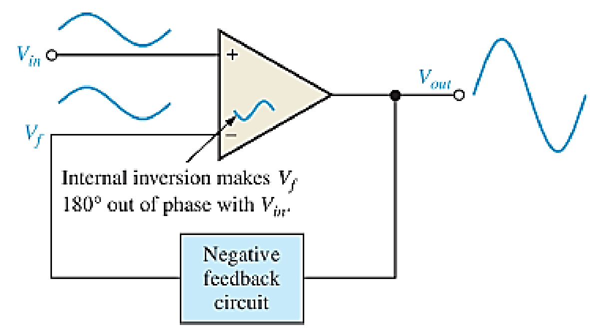
$$\left|\frac{dA_f}{A_f}\right| \cong \left|\frac{1}{\beta A}\right|\left|\frac{dA}{A}\right| \qquad \text{for } \beta A \gg 1$$

This shows that magnitude of the relative change in gain $\left|\frac{dA_f}{A_f}\right|$ is reduced by the factor $|\beta A|$ compared to that without feedback $\left(\left|\frac{dA}{A}\right|\right)$.

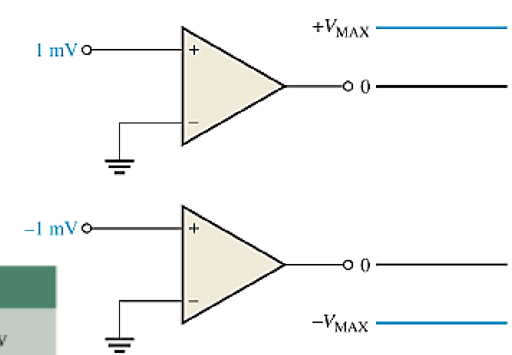
OP-AMPS WITH NEGATIVE FEEDBACK

Why Use Negative Feedback?

- **Negative feedback** is the process whereby a portion of the output voltage of an amplifier is returned to the input with a phase angle that opposes (or subtracts from) the input signal.



- Open-loop voltage gain of a typical op-amp is very high.
- Therefore, an extremely small input voltage drives the op-amp into its saturated output states.
- In fact, even the input offset voltage of the op-amp can drive it into saturation.



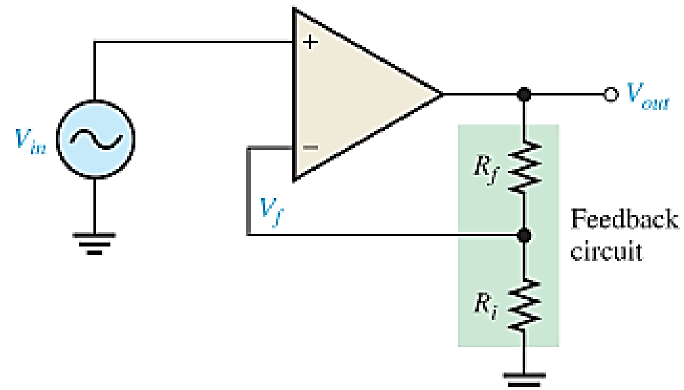
	VOLTAGE GAIN	INPUT Z	OUTPUT Z	BANDWIDTH
Without negative feedback	A_{ol} is too high for linear amplifier applications	Relatively high (see Table 12–1)	Relatively low	Relatively narrow (because the gain is so high)
With negative feedback	A_{cl} is set to desired value by the feedback circuit	Can be increased or reduced to a desired value depending on type of circuit	Can be reduced to a desired value	Significantly wider

OP-AMPS WITH NEGATIVE FEEDBACK

- An op-amp can be connected using negative feedback to stabilize the gain and increase frequency response.
- The closed-loop voltage gain is the voltage gain of an op-amp with external feedback.
- The closed-loop voltage gain is determined by the external component values and can be precisely controlled by them.

- **Non-inverting Amplifier**

$$A_{cl(NI)} = 1 + \frac{R_f}{R_i}$$



OP-AMPS WITH NEGATIVE FEEDBACK
Non-inverting Amplifier

$$V_f = \left(\frac{R_i}{R_i + R_f}\right)V_{out}$$

$$V_{out} = A_{ol}(V_{in} - V_f)$$

$$B = \frac{R_i}{R_i + R_f}$$

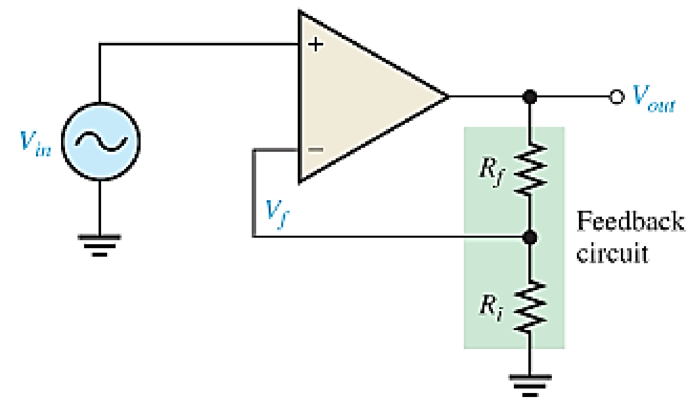
$$V_{out} = A_{ol}(V_{in} - BV_{out})$$

$$V_{out} = A_{ol}V_{in} - A_{ol}BV_{out}$$

$$V_{out} + A_{ol}BV_{out} = A_{ol}V_{in}$$

$$V_{out}(1 + A_{ol}B) = A_{ol}V_{in}$$

$$\frac{V_{out}}{V_{in}} = \frac{A_{ol}}{1 + A_{ol}B}$$



$$\frac{V_{out}}{V_{in}} \cong \frac{A_{ol}}{A_{ol}B} = \frac{1}{B}$$

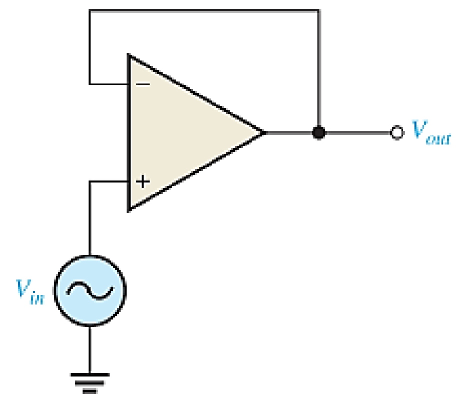
$$A_{cl(NI)} = \frac{V_{out}}{V_{in}} \cong \frac{1}{B} = \frac{R_i + R_f}{R_i}$$

$$\mathbf{A_{cl(NI)} = 1 + \frac{R_f}{R_i}}$$

OP-AMPS WITH NEGATIVE FEEDBACK..

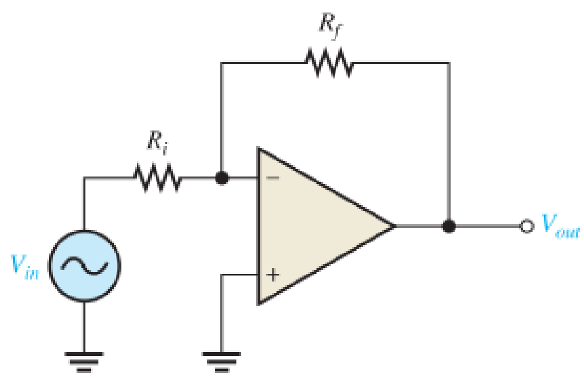
- **Voltage-Follower**

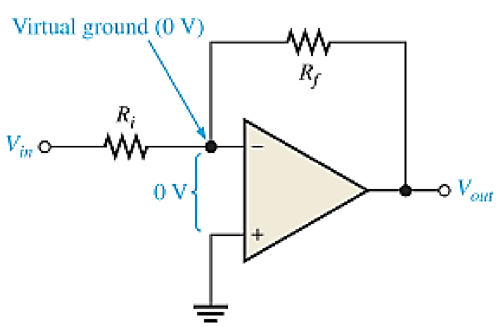
$$A_{cl(VF)} = 1$$



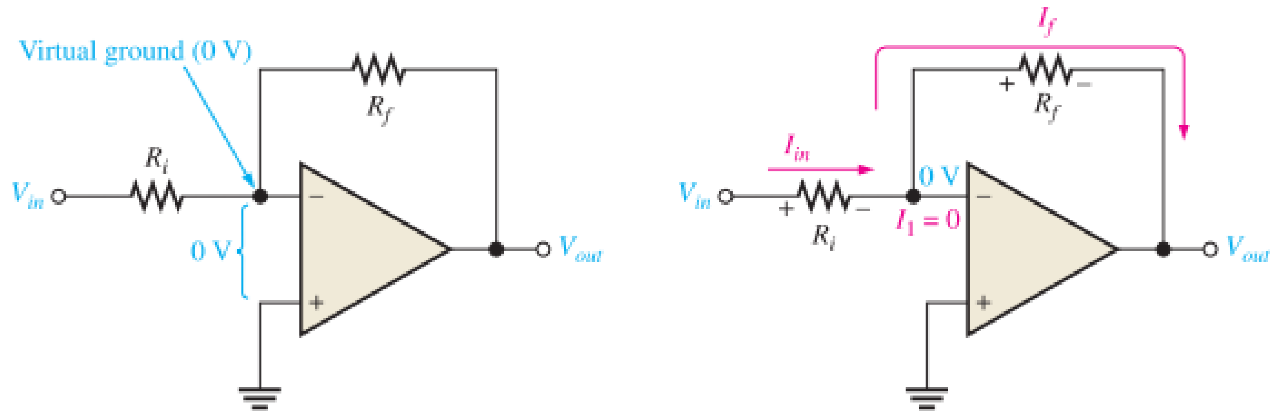
- **Inverting Amplifier**

$$A_{cl(I)} = -\frac{R_f}{R_i}$$





OP-AMPS WITH NEGATIVE FEEDBACK..
Inverting Amplifier



(a) Virtual ground

(b) $I_{in} = I_f$ and current at the inverting input (I_1) is 0.

$$I_{in} = I_f$$

$$I_f = \frac{-V_{out}}{R_f}$$

$$I_{in} = \frac{V_{in}}{R_i}$$

$$\frac{-V_{out}}{R_f} = \frac{V_{in}}{R_i}$$

$$\mathbf{A_{cl(I)} = -\frac{R_f}{R_i}}$$

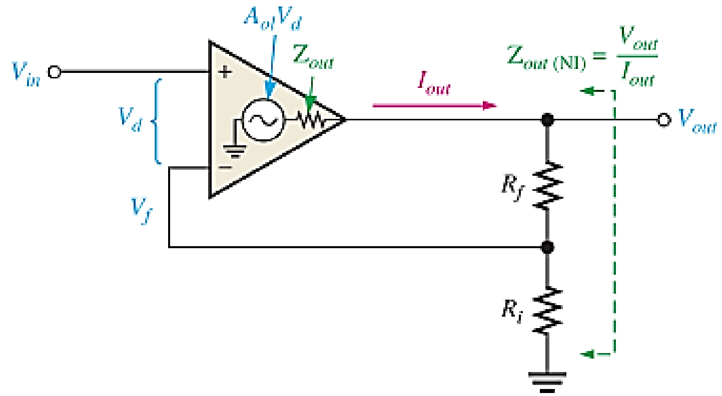
$$\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_i}$$

EFFECTS OF NEGATIVE FEEDBACK ON OP-AMP IMPEDANCES

- **Non-inverting Amplifier**

$$Z_{in(NI)} = (1 + A_{ol}B)Z_{in}$$

$$Z_{out(NI)} = \frac{Z_{out}}{1 + A_{ol}B}$$



- **Voltage Follower**

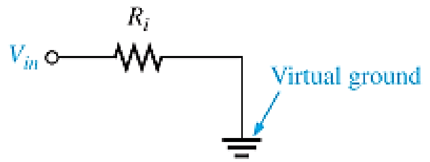
$$Z_{in(VF)} = (1 + A_{ol})Z_{in}$$

$$Z_{out(VF)} = \frac{Z_{out}}{1 + A_{ol}}$$

- **Inverting Amplifier**

$$Z_{in(I)} \cong R_i$$

$$Z_{out(I)} = \frac{Z_{out}}{1 + A_{ol}B}$$



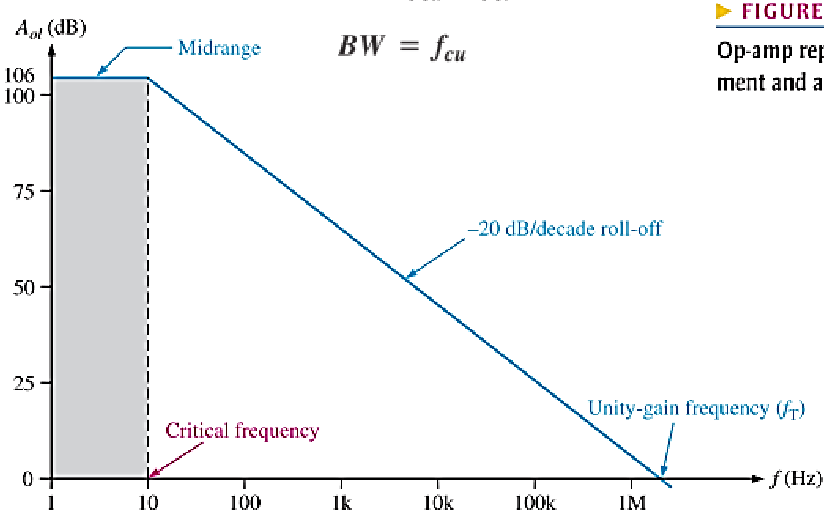
Assignment: Derive the impedance equations for Non-inverting and Inverting Amplifiers

OPEN & CLOSED LOOP FREQUENCY RESPONSES

Open-Loop Frequency & Phase Responses

$$BW = f_{cu} - f_{cl}$$

$$BW = f_{cu}$$

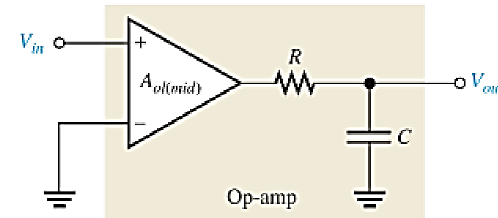


▲ **FIGURE 12–36**

Ideal plot of open-loop voltage gain versus frequency for a typical op-amp. The frequency scale is logarithmic.

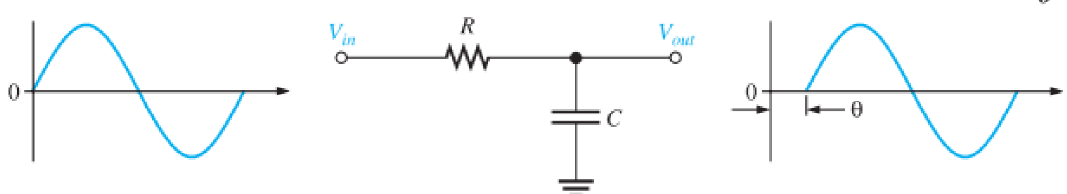
▶ **FIGURE 12–38**

Op-amp represented by a gain element and an internal *RC* circuit.

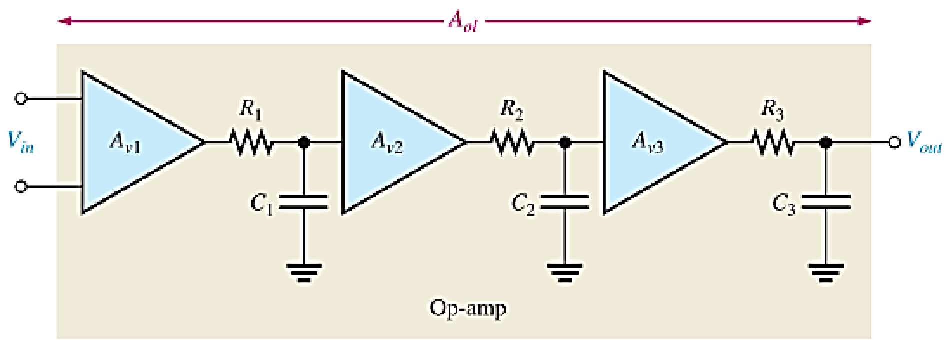


$$A_{ol} = \frac{A_{ol(mid)}}{\sqrt{1 + f^2/f_c^2}}$$

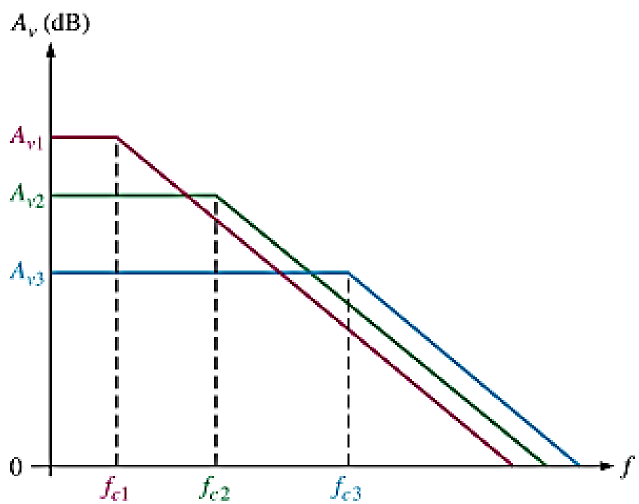
$$\theta = -\tan^{-1}\left(\frac{f}{f_c}\right)$$



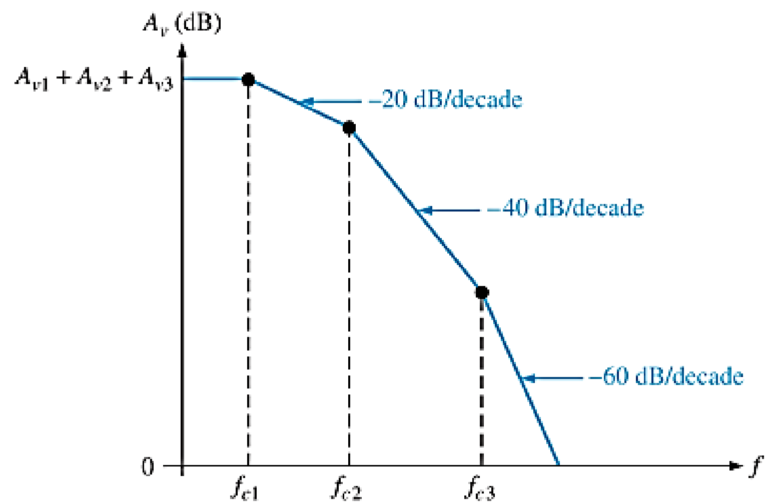
Overall Frequency & Phase Responses (Open-Loop)



(a) Representation of an op-amp with three internal stages



(b) Individual responses



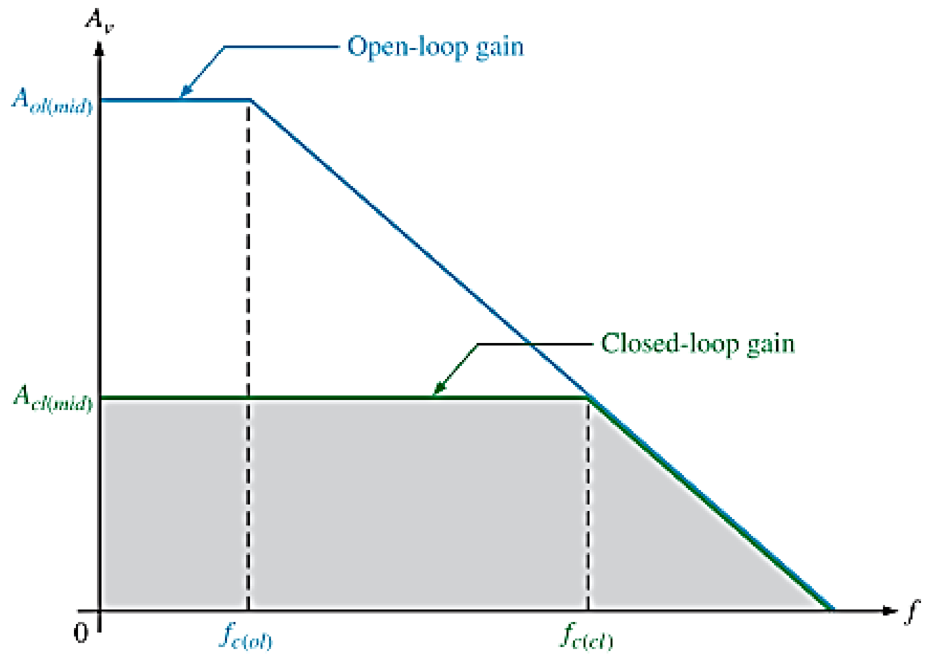
(c) Composite response

$$\theta_{tot} = -\tan^{-1}\left(\frac{f}{f_{c1}}\right) - \tan^{-1}\left(\frac{f}{f_{c2}}\right) - \tan^{-1}\left(\frac{f}{f_{c3}}\right)$$

CLOSED-LOOP FREQUENCY RESPONSE

▶ FIGURE 12–42

Closed-loop gain compared to open-loop gain.



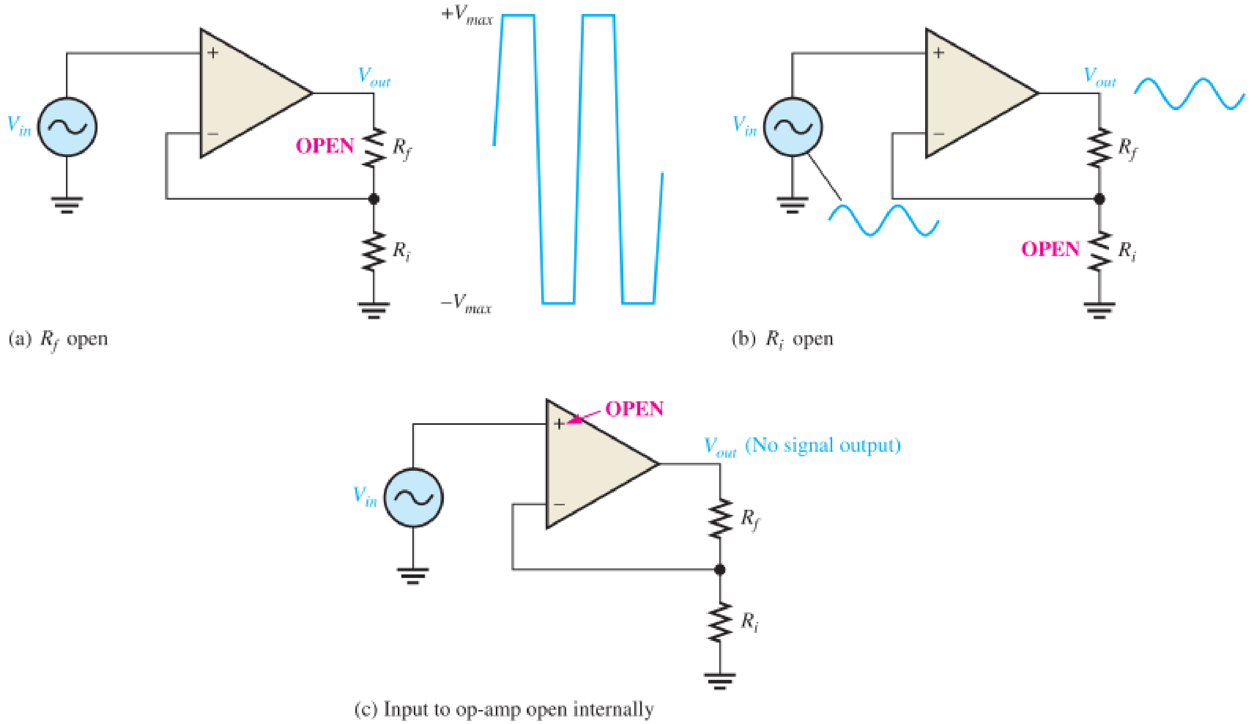
$$f_{c(cl)} = f_{c(ol)}(1 + BA_{ol(mid)})$$

$$BW_{cl} = BW_{ol}(1 + BA_{ol(mid)})$$

- The **gain-bandwidth product** is always equal to the frequency at which the op-amp's open-loop gain is unity or 0 dB (unity-gain bandwidth, f_T).

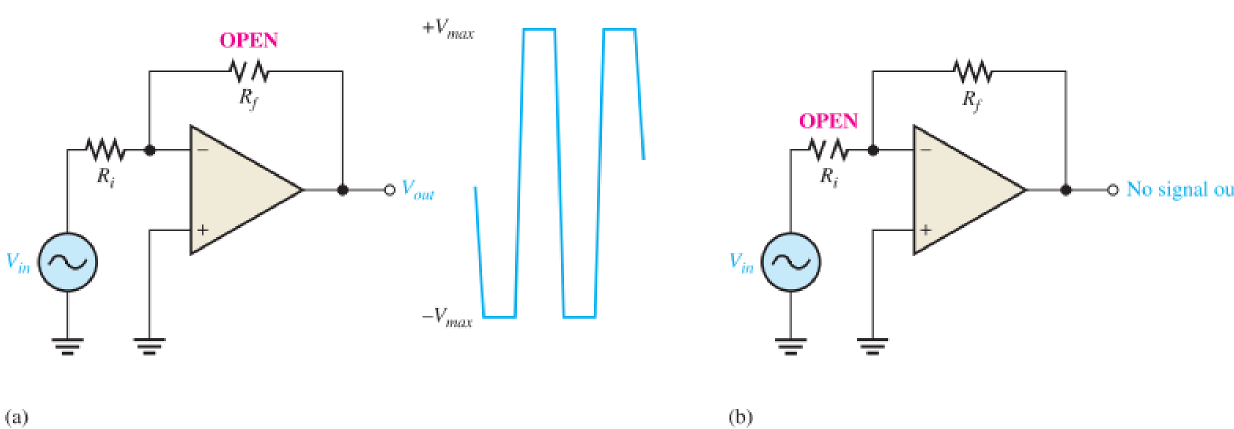
$$f_T = A_{cl}f_{c(cl)}$$

Troubleshooting



▲ FIGURE 12–44

Faults in the noninverting amplifier.



▲ FIGURE 12–45

Faults in the inverting amplifier.

- For more details, refer to:
  - Chapter 14, Boylestad, **Electronic Devices and Circuit theory**, 11th edition
  - Chapter 12, T. Floyd, **Electronic Devices**, 9th edition.
- The lecture is available online at:
  - http://bu.edu.eg/staff/ahmad.elbanna-courses/12884
- For inquires, send to:
  - ahmad.elbanna@feng.bu.edu.eg