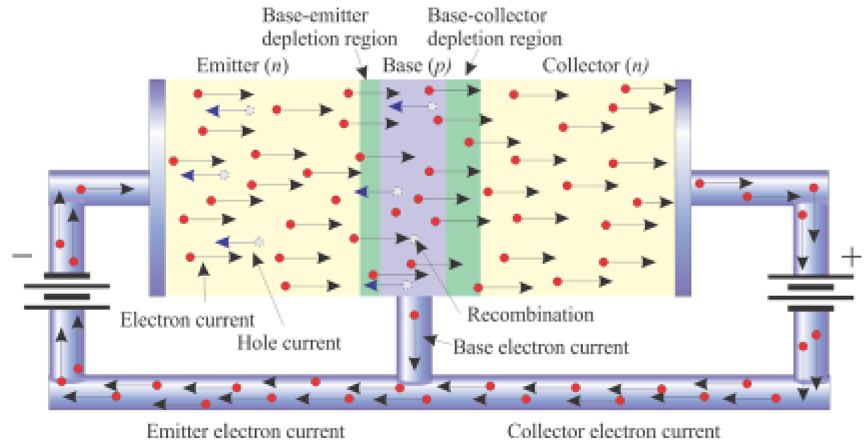
Electronic Devices

Ninth Edition

Floyd

Chapter 12

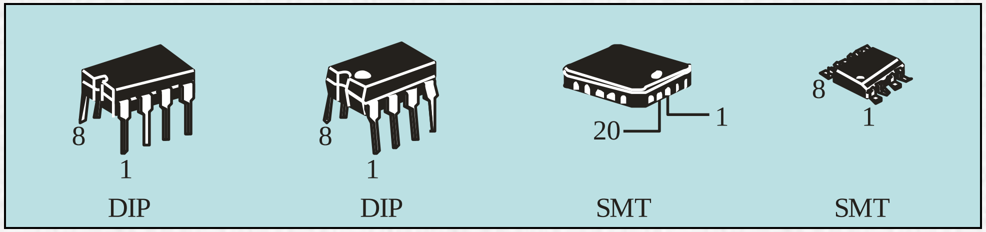


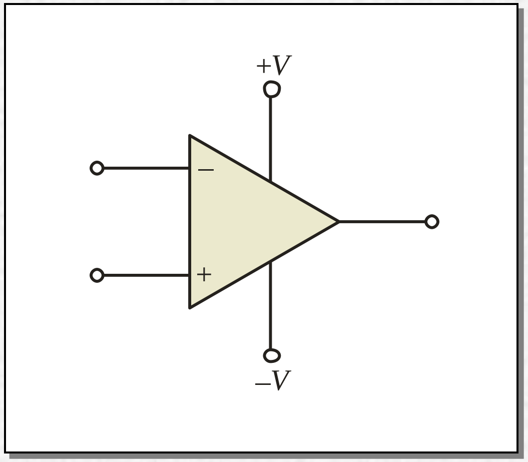
Summary

Operational Amplifers

Operational amplifiers (op-amps) are very high gain dc coupled amplifiers with differential inputs. One of the inputs is called the inverting input (–); the other is called the noninverting input. Usually there is a single output.

Most op-amps operate from plus and minus supply voltages, which may or may not be shown on the schematic symbol.

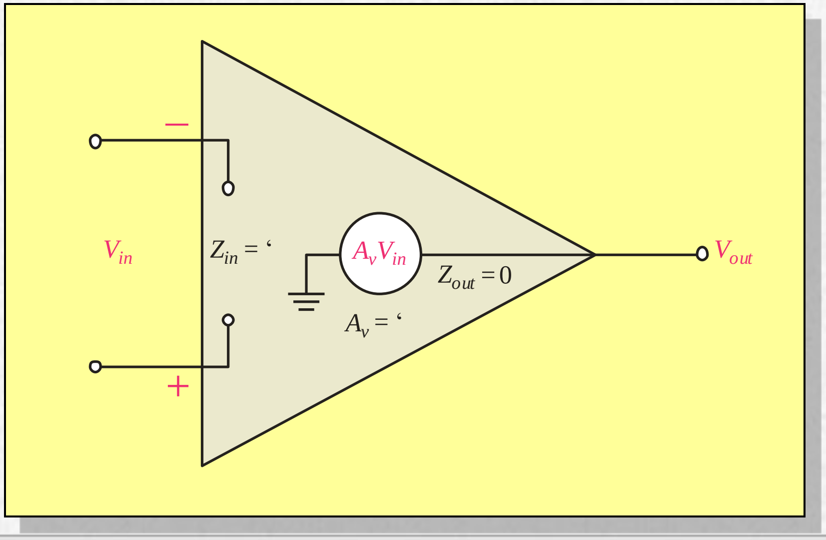




Summary

The Ideal Op-Amp

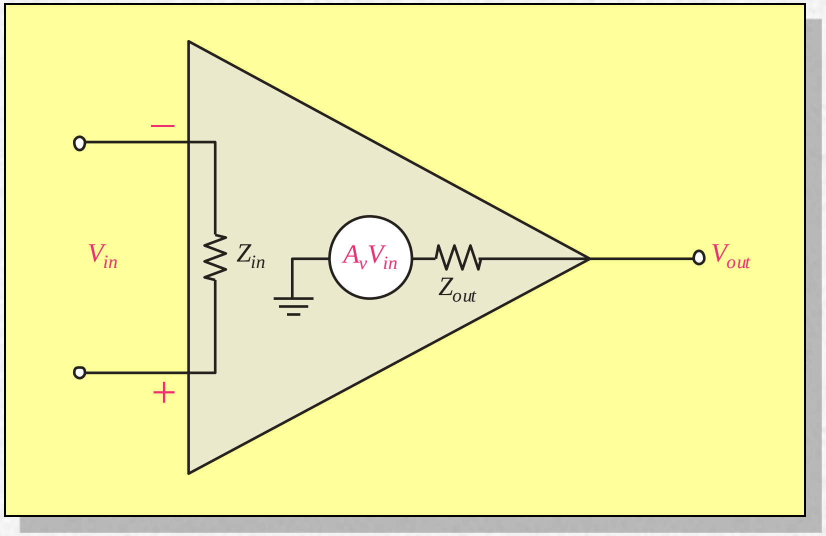
The ideal op-amp has characteristics that simplify analysis of op-amp circuits. Ideally, op-amps have *infinite voltage gain*, *infinite bandwidth*, and *infinite input impedance*. In addition, the ideal op-amp has *zero output impedance*.



Summary

The Practical Op-Amp

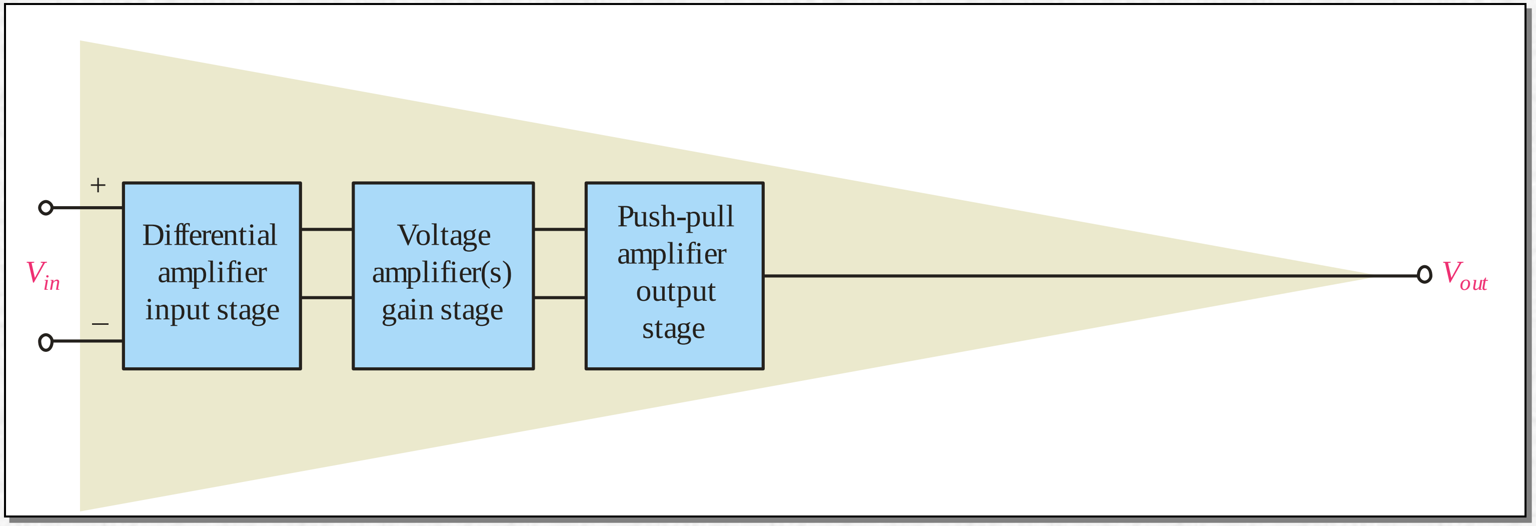
Practical op-amps have characteristics that often can be treated as ideal for certain situations, but can never actually attain ideal characteristics. In addition to finite gain, bandwidth, and input impedance, they have other limitations.



Summary

Block Diagram

Internally, the typical op-amp has a differential input, a voltage amplifier, and a push-pull output. Recall from the discussion in Section 6-7 of the text that the differential amplifier amplifies the *difference* in the two inputs.

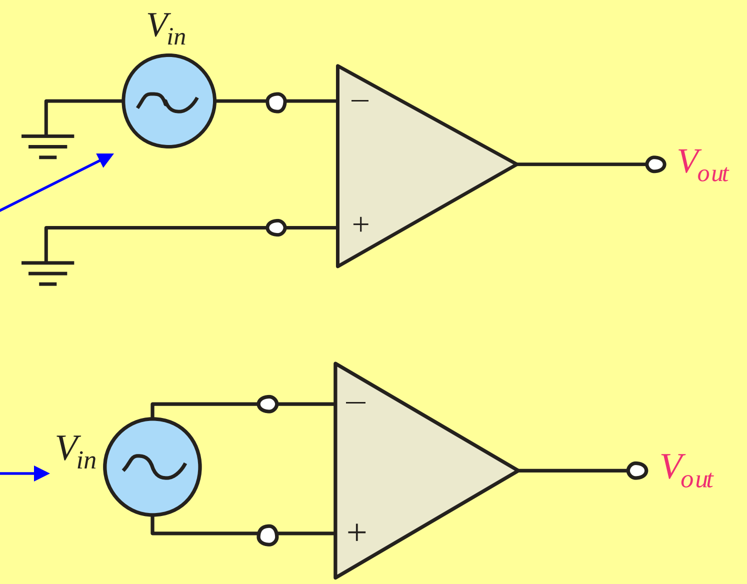


Summary

Signal modes

The input signal can be applied to an op-amp in differential-mode or in common-mode.

Differential-mode signals are applied either as single-ended (one side on ground) or double-ended (opposite phases on the inputs).



Differential signals

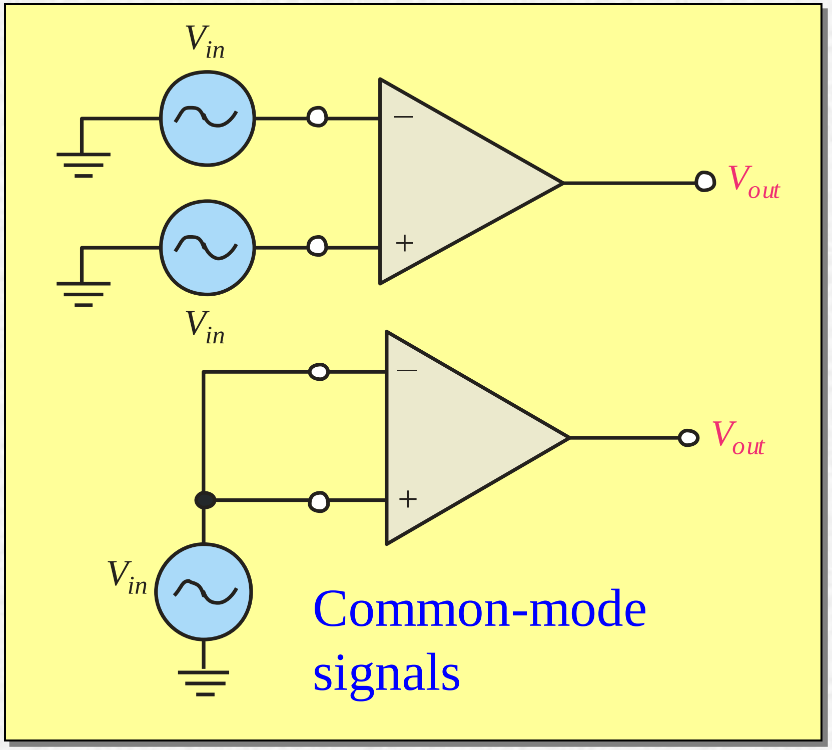
Summary

Signal modes

The input signal can be applied to an op-amp in differential-mode or in common-mode.

Common-mode signals are applied to both sides with the same phase on both.

Usually, common-mode signals are from unwanted sources, and affect both inputs in the same way. The result is that they are essentially cancelled at the output.



Summary

Common-Mode Rejection Ratio

The ability of an amplifier to amplify differential signals and reject common-mode signals is called the **common-mode rejection ratio (CMRR)**.

CMRR is defined as $\mathbf{CMRR} = \frac{A_{ol}}{A_{cm}}$

where A_{ol} is the open-loop differential-gain and A_{cm} is the common-mode gain.

CMRR can also be expressed in decibels as $\mathbf{CMRR} = 20\log\left(\frac{A_{ol}}{A_{cm}}\right)$

Summary

Common-Mode Rejection Ratio

Example:

What is CMRR in decibels for a typical 741C op-amp?

The typical open-loop differential gain for the 741C is 200,000 and the typical common-mode gain is 6.3.

Solution:

$$\textbf{CMRR} = 20\log\left(\frac{A_{ol}}{A_{cm}}\right)$$

$$= 20\log\frac{200{,}000}{6.3} = 90\text{ dB}$$

(The minimum specified CMRR is 70 dB.)

Summary

Voltage and Current Parameters

$V_{O(p\text{-}p)}$: The **maximum output voltage swing** is determined by the op-amp and the power supply voltages

V_{OS}: The **input offset voltage** is the differential dc voltage required between the inputs to force the output to zero volts

I_{BIAS}: The **input bias current** is the average of the two dc currents required to bias the differential amplifier

$$I_{BIAS} = \frac{I_1 + I_2}{2}$$

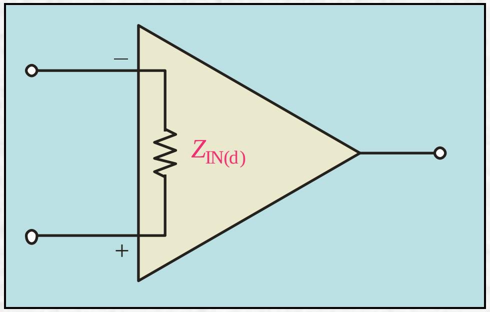
I_{OS}: The **input offset current** is the difference between the two dc bias currents

$$I_{OS} = \left| I_1 - I_2 \right|$$

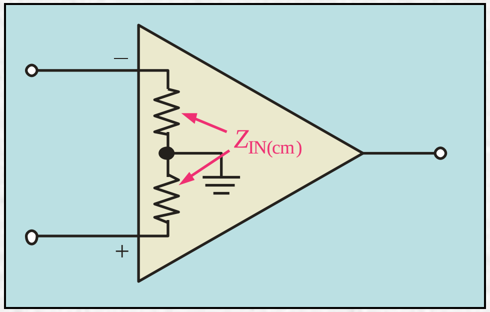
Summary

Impedance Parameters

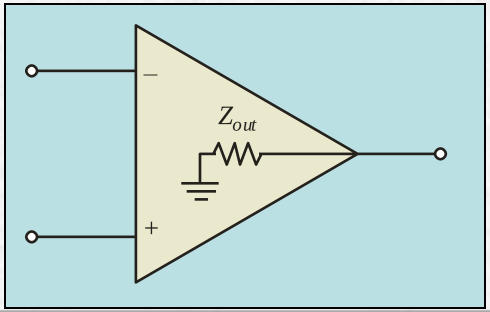
$Z_{IN(d)}$: The **differential input impedance** is the total resistance between the inputs



$Z_{IN(cm)}$: The **common-mode input impedance** is the resistance between each input and ground



Z_{out}: The **output impedance** is the resistance viewed from the output of the circuit.



Summary

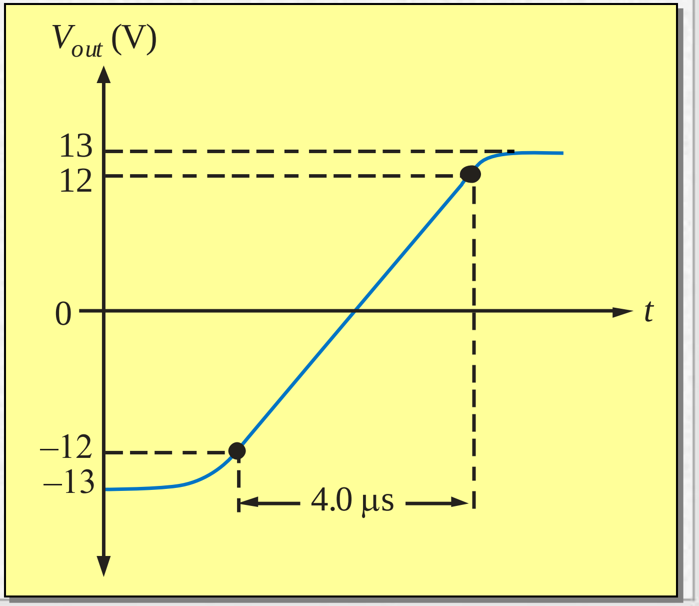
Other Parameters

Slew rate: The **slew rate** is the maximum rate of change of the output voltage in response to a step input voltage

$$\text{Slew Rate} = \frac{\Delta V_{out}}{\Delta t}$$

Example:

Determine the slew rate for the output response to a step input.



Solution:

$$\text{Slew Rate} = \frac{\Delta V_{out}}{\Delta t} = \frac{(+12\text{ V}) - (-12\text{ V})}{4.0\ \mu\text{s}}$$

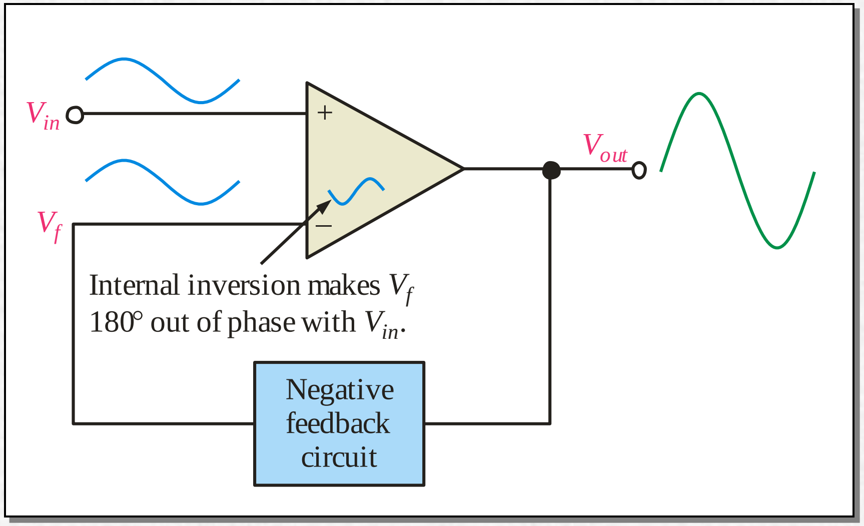
$$= 6\text{ V}/\mu\text{s}$$

Summary

Negative Feedback

Negative feedback is the process of returning a portion of the output signal to the input with a phase angle that opposes the input signal.

The advantage of negative feedback is that precise values of amplifier gain can be set. In addition, bandwidth and input and output impedances can be controlled.



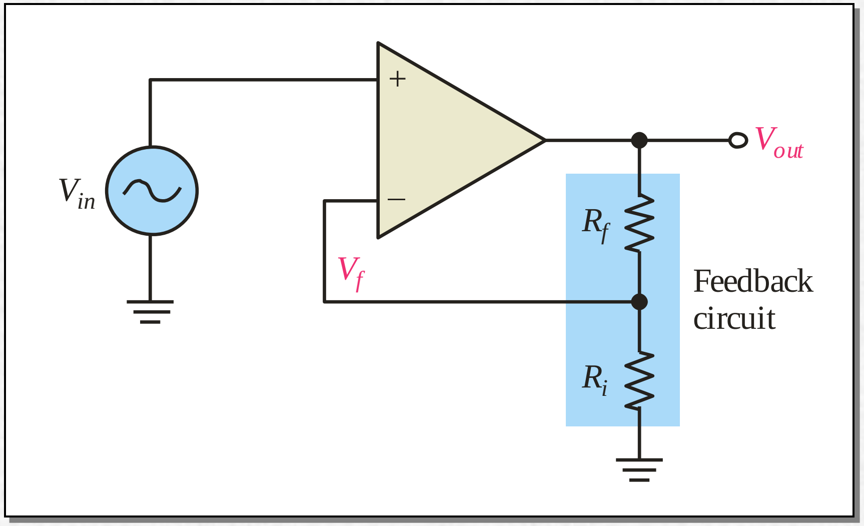
Summary

Noninverting Amplifier

A **noninverting amplifier** is a configuration in which the signal is on the noninverting input and a portion of the output is returned to the inverting input.

Feedback forces V_f to be equal to V_{in}, hence V_{in} is across R_i. With basic algebra, you can show that the closed-loop gain of the noninverting amplifier is

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



Summary

Noninverting Amplifier

Example:

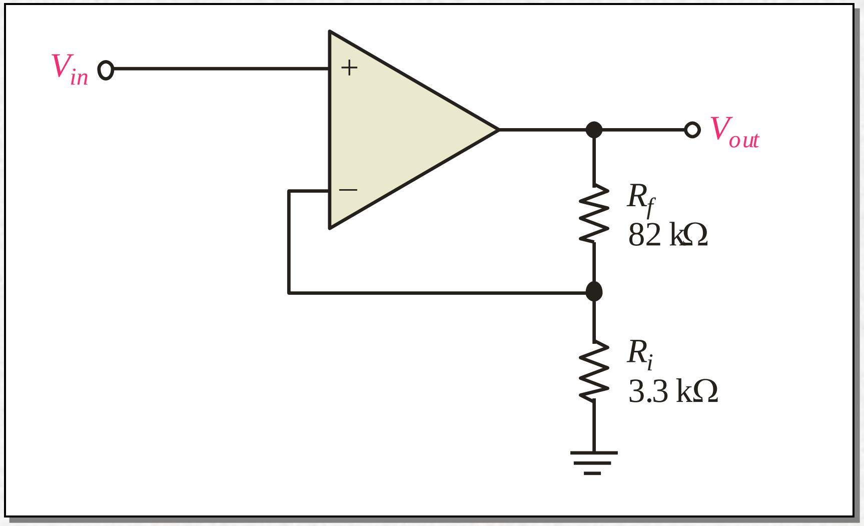
Determine the gain of the noninverting amplifier shown.

Solution:

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

$$= 1 + \frac{82\ \mathrm{k\Omega}}{3.3\ \mathrm{k\Omega}}$$

$$= 25.8$$

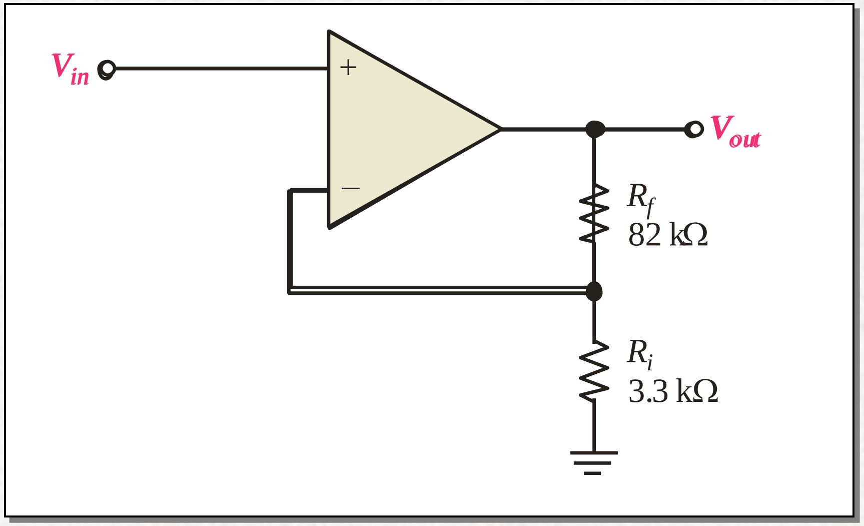


Summary

Noninverting Amplifier

A special case of the inverting amplifier is when R_f =0 and $R_i = \infty$. This forms a voltage follower or unity gain buffer with a gain of 1.

The input impedance of the voltage follower is very high, producing an excellent circuit for isolating one circuit from another, which avoids "loading" effects.



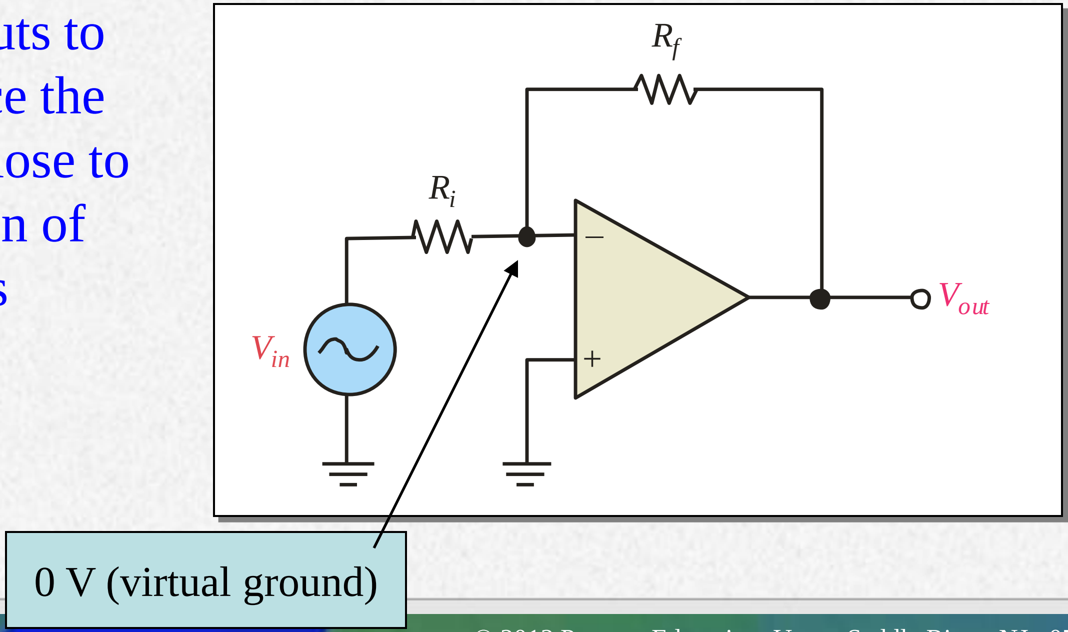
Summary

Inverting Amplifier

An **inverting amplifier** is a configuration in which the noninverting input is grounded and the signal is applied through a resistor to the inverting input.

Feedback forces the inputs to be nearly identical; hence the inverting input is very close to 0 V. The closed-loop gain of the inverting amplifier is

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



Summary

Inverting Amplifier

Example:

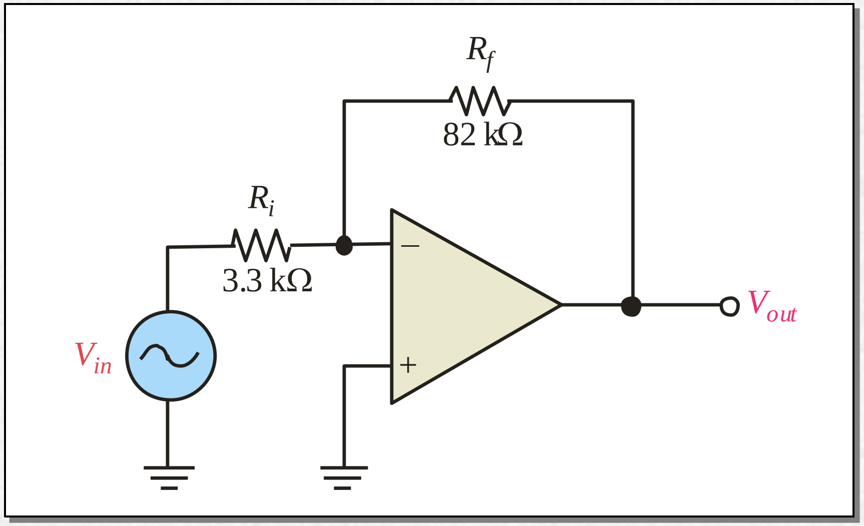
Determine the gain of the inverting amplifier shown.

Solution:

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

$$= -\frac{82\ \mathrm{k\Omega}}{3.3\ \mathrm{k\Omega}}$$

$$= -24.8$$



The minus sign indicates inversion.

Summary

Impedances

Noninverting amplifier:

$$Z_{in(\mathrm{NI})} = (1 + A_{ol}B)Z_{in}$$ Generally, assumed to be ∞

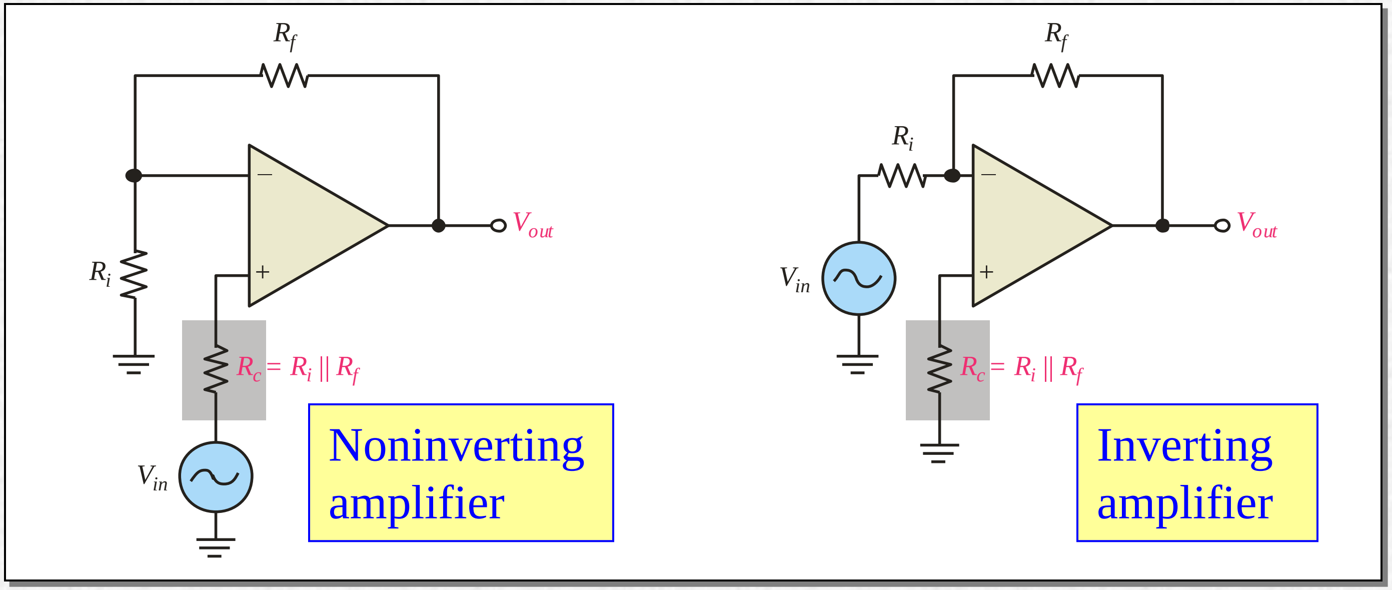
$$Z_{out(\mathrm{NI})} = \frac{Z_{out}}{(1 + A_{ol}B)}$$ Generally, assumed to be 0

Note that the output impedance has the same form for both amplifiers.

Summary

Bias Current Compensation

For op-amps with a BJT input stage, bias current can create a small output error voltage. To compensate for this, a resistor equal to $R_i || R_f$ is added to one of the inputs.

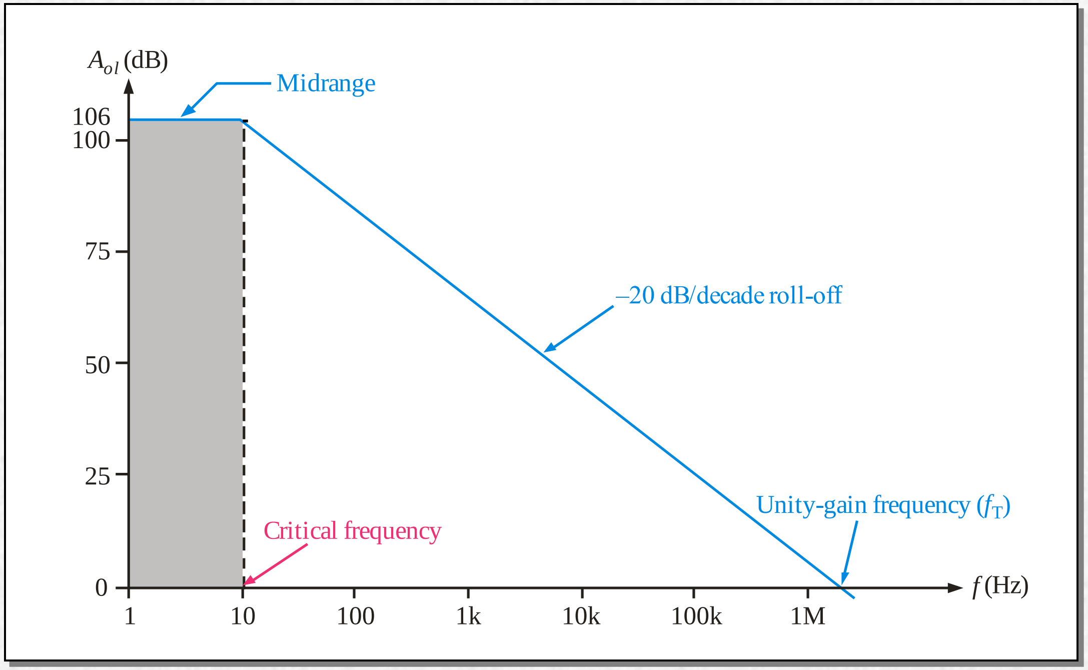


Summary

Bandwidth Limitations

Many op-amps have a roll off rate determined by a single low-pass *RC* circuit, giving a constant –20 dB/decade down to unity gain.

Op-amps with this characteristic are called *compensated* op-amps. The blue line represents the open-loop frequency characteristic (Bode plot) for the op-amp.

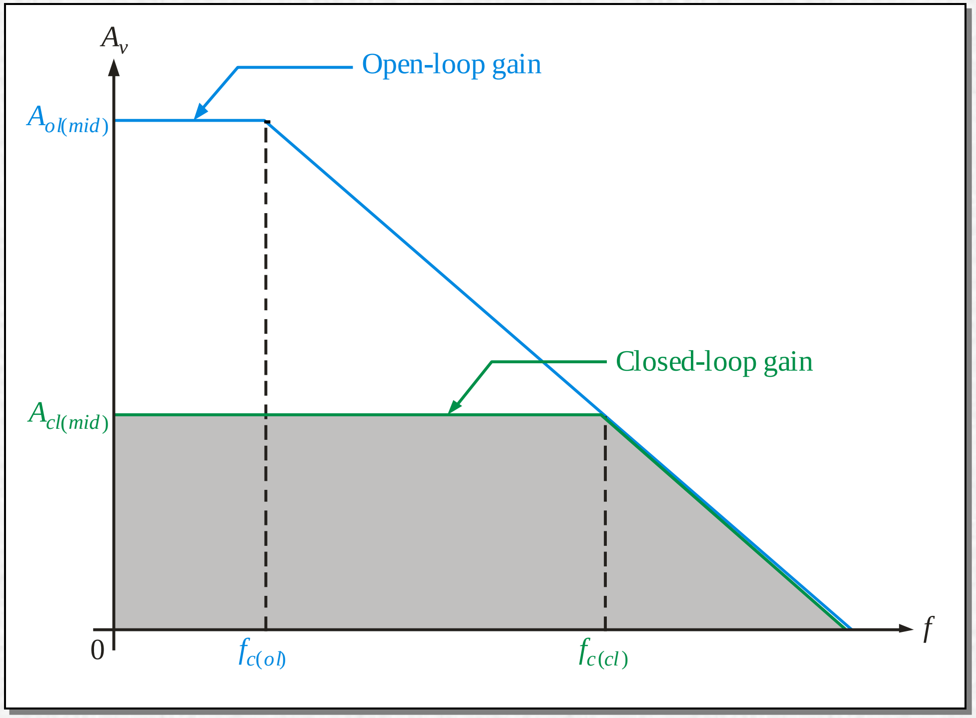


Summary

Bandwidth Limitations

For op-amps with a –20 dB/decade open-loop gain, the closed-loop critical frequency is given by $f_{c(cl)} = f_{c(ol)}(1 + BA_{ol(mid)})$

The closed-loop critical frequency is higher than the open-loop critical frequency by the factor $(1 + BA_{ol(mid)})$. This means that you can achieve a higher *BW* by accepting less gain. For a compensated op-amp, $A_{cl}\, f_{(cl)} = A_{ol}\, f_{c(ol)}$.



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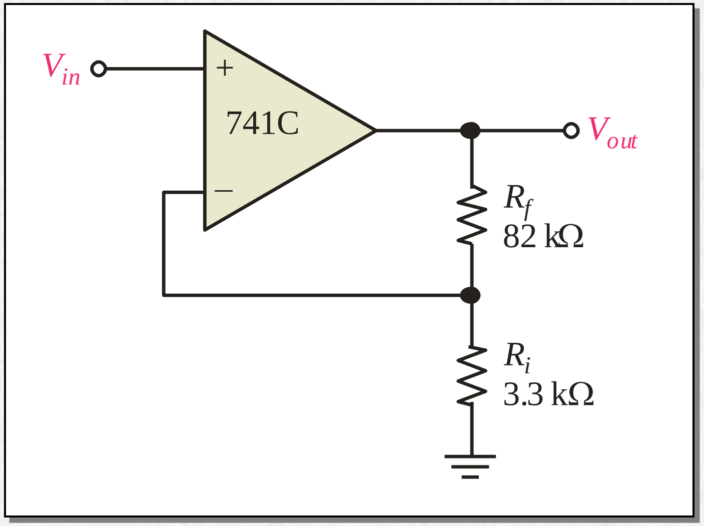
Summary

Bandwidth Limitations

The equation, $A_{cl}\, f_{(cl)} = A_{ol}\, f_{c(ol)}$ shows that the product of the gain and bandwidth are constant. The gain-bandwidth product is also equal to the unity gain frequency. That is $f_T = A_{cl}\, f_{c(cl)}$, where f_T is the unity-gain bandwidth.

Example:

The f_T for a 741C op amp is 1 MHz. What is the BW_{cl} for the amplifier?



Solution:

$$A_{cl(\mathrm{NI})} = 1 + \frac{R_f}{R_i} = 1 + \frac{82\ \mathrm{k\Omega}}{3.3\ \mathrm{k\Omega}} = 25.8$$

$$BW_{cl} = \frac{f_T}{A_{cl}} = \frac{1\ \mathrm{MHz}}{25.8} = 38.8\ \mathrm{kHz}$$

Selected Key Terms

Operational amplifier	A type of amplifier that has very high voltage gain, very high input impedance, very low output impedance and good rejection of common-mode signals.
Differential mode	A mode of op-amp operation in which two opposite-polarity signals voltages are applied to the two inputs (double-ended) or in which a signal is applied to one input and ground to the other input (single-ended).
Common mode	A condition characterized by the presence of the same signal on both inputs

Selected Key Terms

Open-loop voltage gain	The voltage gain of an op-amp without external feedback.
Negative feedback	The process of returning a portion of the output signal to the input of an amplifier such that it is out of phase with the input.
Closed-loop voltage gain	The voltage gain of an op-amp with external feedback.
Gain-bandwidth product	A constant parameter which is always equal to the frequency at which the op-amp’s open-loop gain is unity (1).