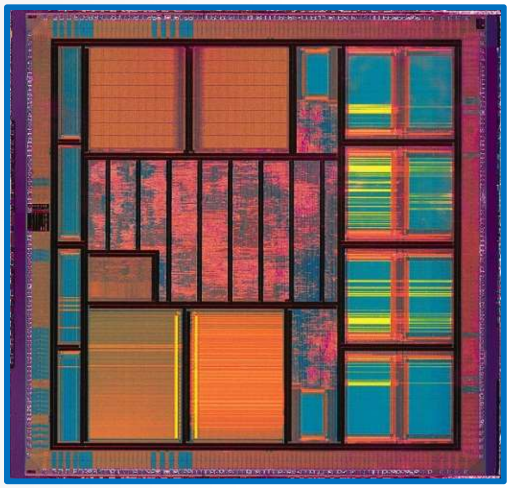
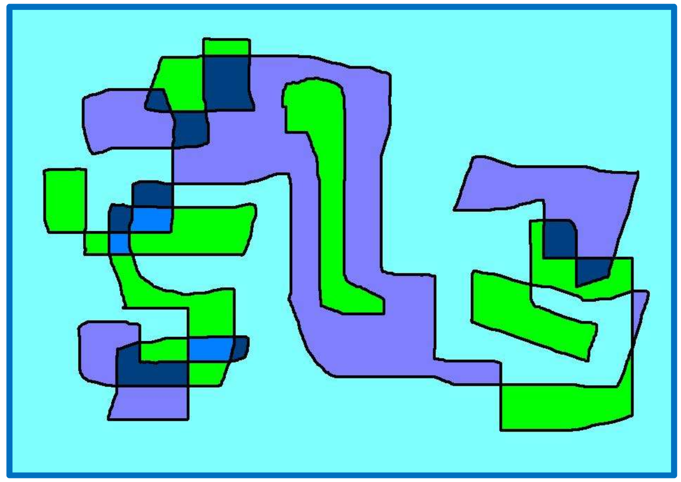
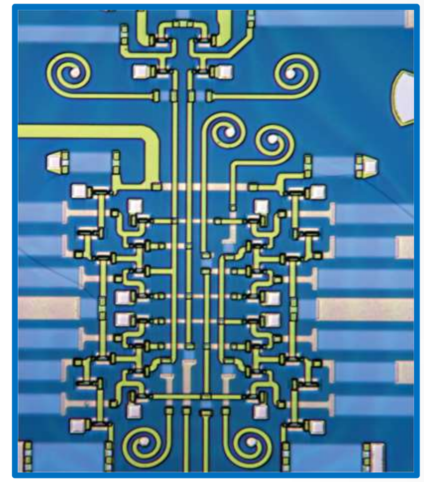


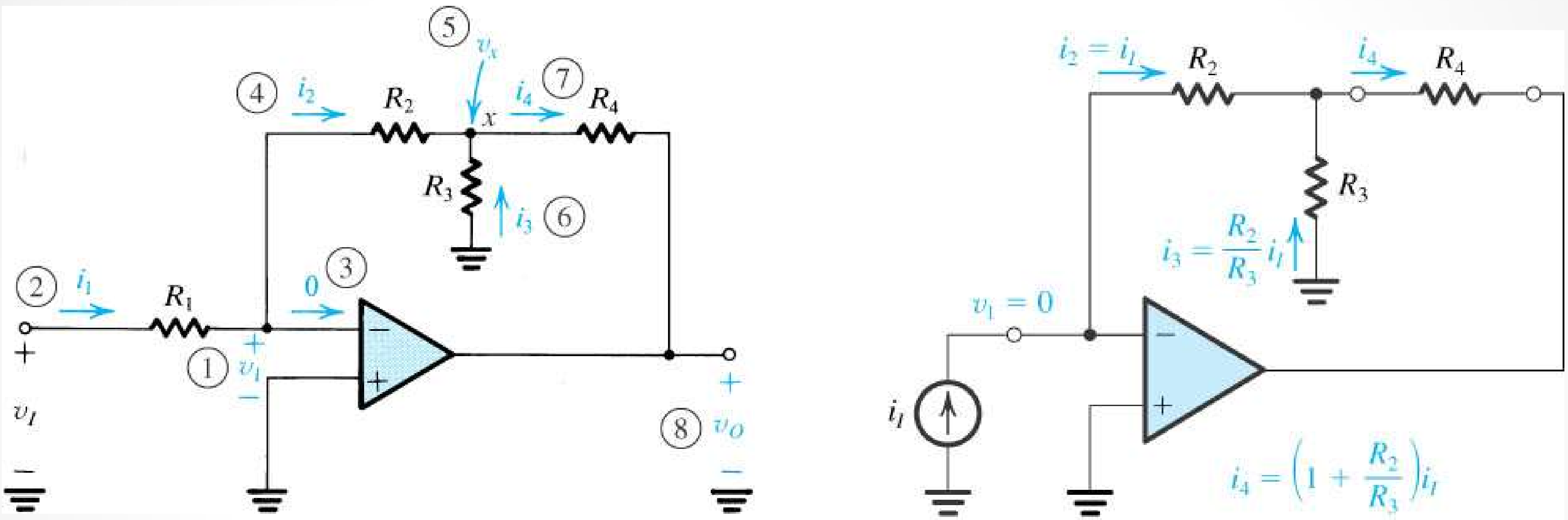




ENE/EIE 211 : Electronic Devices and Circuit Design II

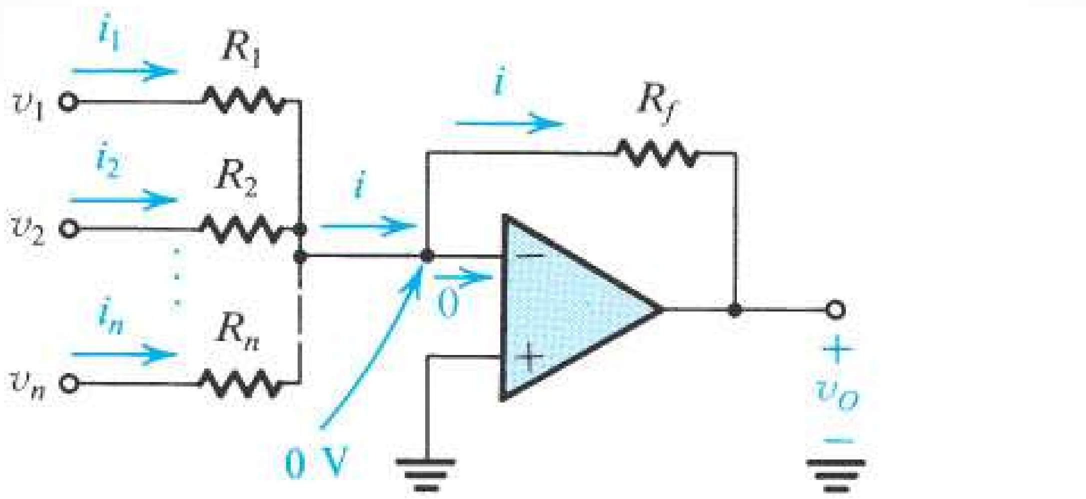
Lecture 2

Inverting Amp with a T-network as the feedback



It is the current multiplication by the factor of 1 + R_2/R_3 that enables a large voltage drop to develop across R_4 and hence a large v_O without using a large value for R_4.

The Weighted Summer



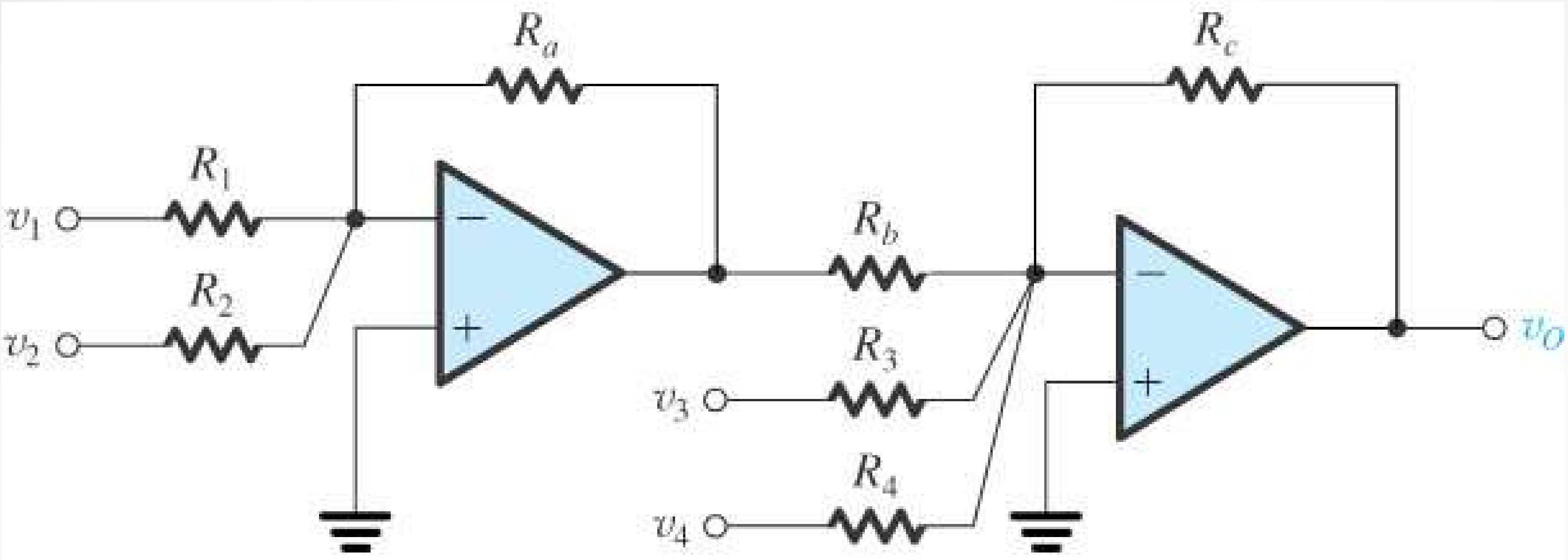
$$v_O = -\left(\frac{R_f}{R_1}v_1 + \frac{R_f}{R_2}v_2 + \cdots + \frac{R_f}{R_n}v_n\right)$$

From Ohm's Law: $i_1 = v_1/R_1$, $i_2 = v_2/R_2$, ….

$i = i_1 + i_2 + \ldots.. + i_n$

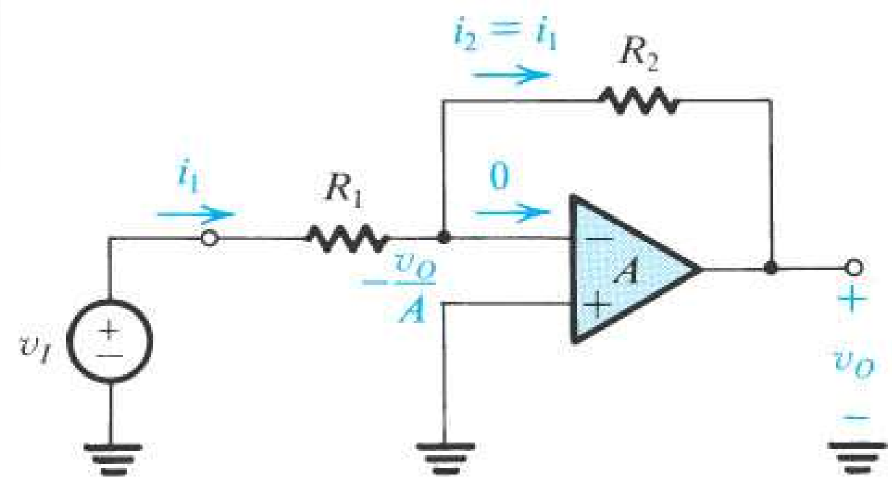
$v_O = 0 - iR_f = -iR_f$

$$v_O = -\left(\frac{R_f}{R_1}v_1 + \frac{R_f}{R_2}v_2 + \ldots + \frac{R_f}{R_n}v_n\right)$$



$$v_O = v_1\left(\frac{R_a}{R_1}\right)\left(\frac{R_c}{R_b}\right) + v_2\left(\frac{R_a}{R_2}\right)\left(\frac{R_c}{R_b}\right) - v_3\left(\frac{R_c}{R_3}\right) - v_4\left(\frac{R_c}{R_4}\right)$$

Effect of finite open-loop gain

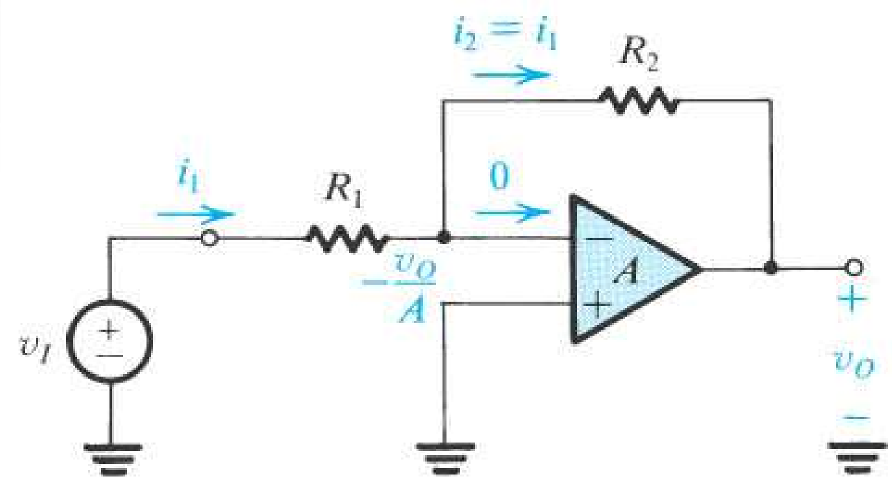


- Assume, open-loop gain A is finite. If the output voltage is v_O, the voltage between two input terminals will be v_O/A. Since the positive input terminal is grounded, the voltage at the negative terminal must be $-v_O/A$.
- The current i_1 through R_1 is

$$i_1 = \frac{v_I - (-v_O / A)}{R_1} = \frac{v_I + v_O / A}{R_1}$$

$$v_O = -\frac{v_O}{A} - i_1 R_2 = -\frac{v_O}{A} - \left(\frac{v_I + v_O / A}{R_1} \right) R_2$$

Effect of finite open-loop gain

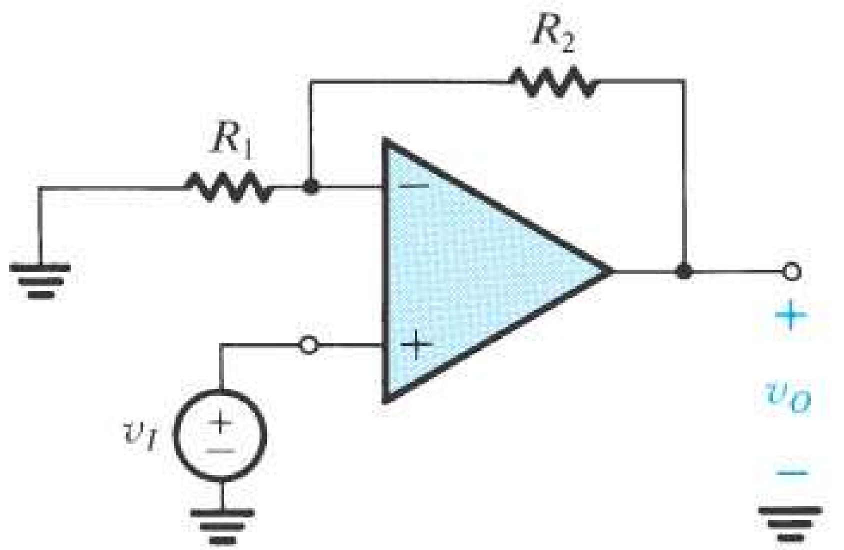


The closed-loop gain G is found as $G \equiv \dfrac{v_O}{v_I} = \dfrac{-R_2/R_1}{1+\left(1+R_2/R_1\right)/A}$

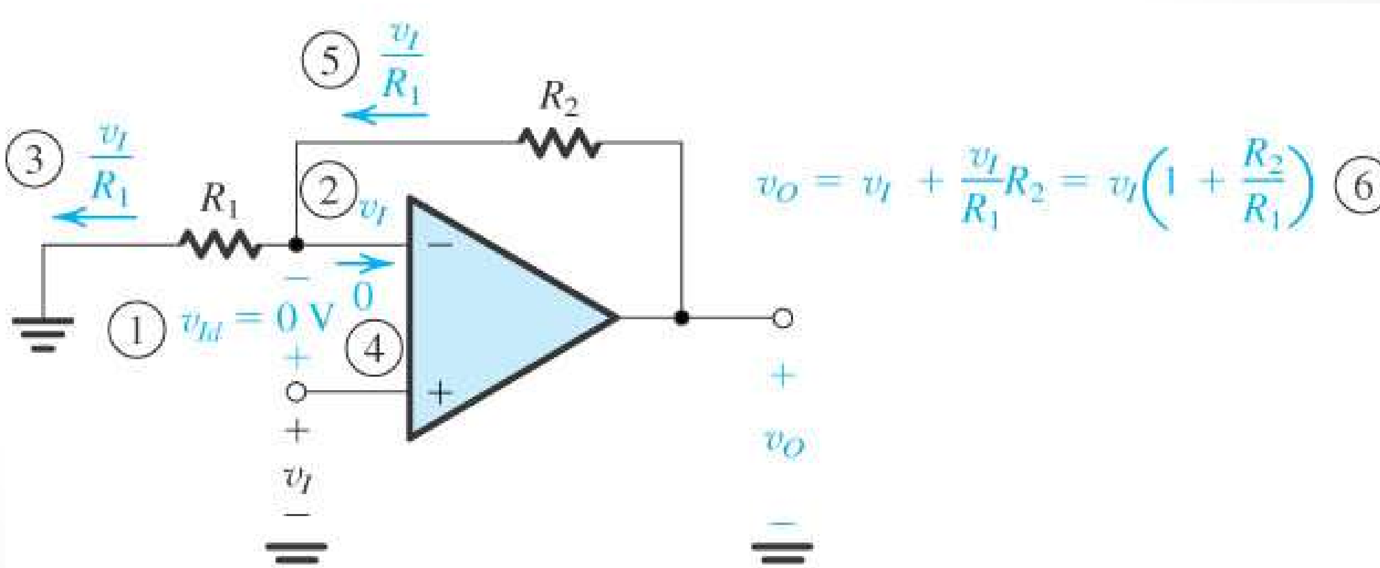
To minimize the dependence of the closed-loop gain G on the value of the open-loop gain A, we should make

$$1+\frac{R_2}{R_1} << A$$

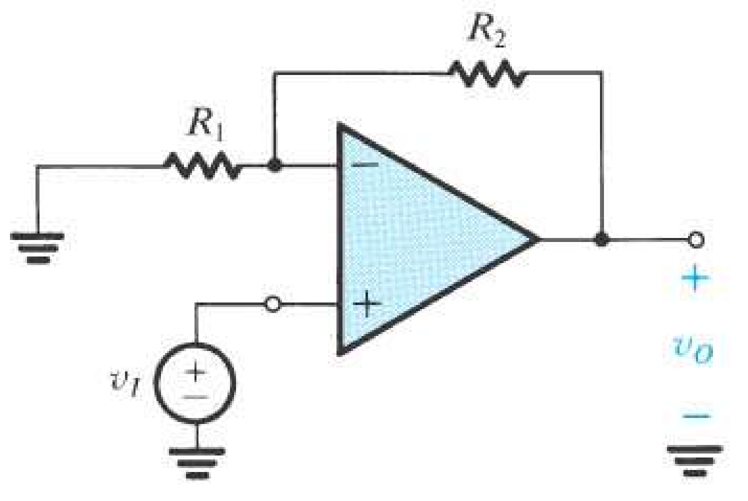
The noninverting configuration



The closed-loop gain



$$\frac{v_O}{v_I} = 1 + \frac{R_2}{R_1}$$

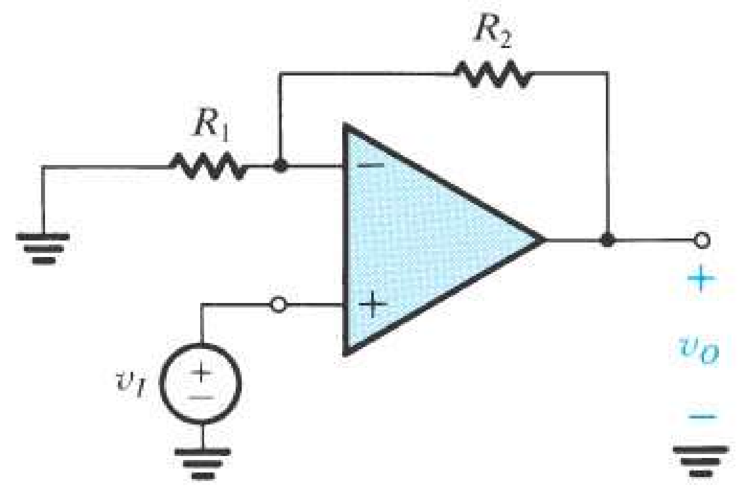


Since the current into the op amp inverting input is zero, the circuit composed of R1 and R2 acts in effect as a voltage divider feeding a fraction of the v_O back to the inverting terminal of the op-amp.

$$v_I = v_O\left(\frac{R_1}{R_1 + R_2}\right)$$

Negative feedback (or degenerative feedback) will act to counteract any changes in v_I

Characteristics of the noninverting configuration



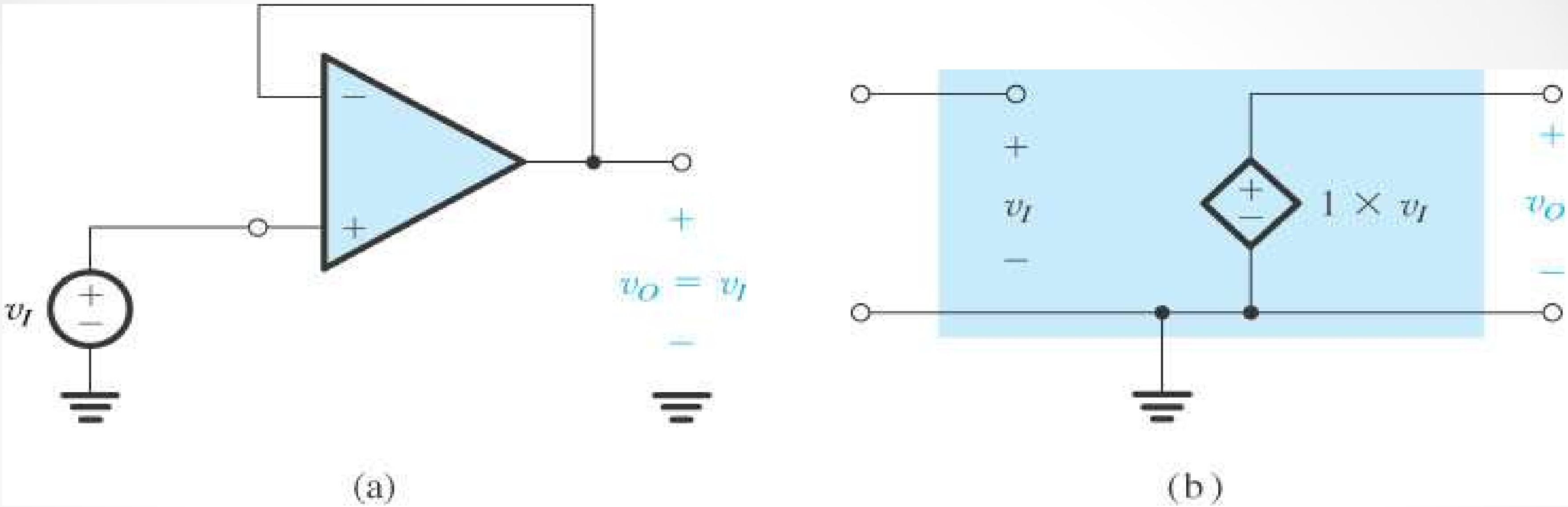
- The gain is positive.
- The closed-loop input impedance is infinite.
- The closed-loop output impedance is zero.

Effect of finite loop gain: when the open-loop gain, A, is finite.

The closed-loop gain:
$$G \equiv \frac{v_O}{v_I} = \frac{1 + (R_2/R_1)}{1 + \left(1 + R_2/R_1\right)/A}$$

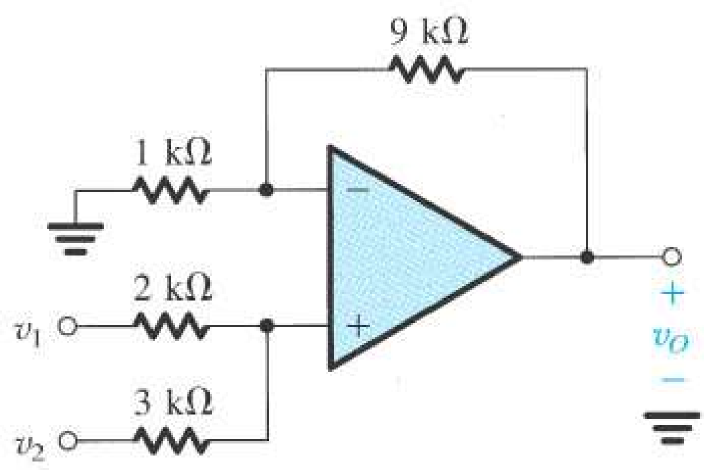
The ideal situation occurs when
$$1 + \frac{R_2}{R_1} << A$$

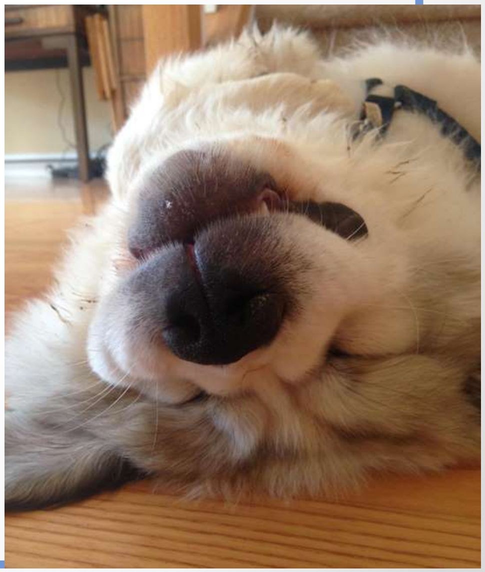
The Voltage Follower



- Used as a buffer amplifier of a unity gain.
- Used to connect a source with a high impedance to a low-impedance load.
- Called "voltage follower" since the output "follows" the input.
- In the ideal case, $v_O = v_I$, $R_{in} = \infty$, $R_{out} = 0$.

Ex1: Use the superposition principle to find the output voltage of the ckt shown





Difference Amplifier

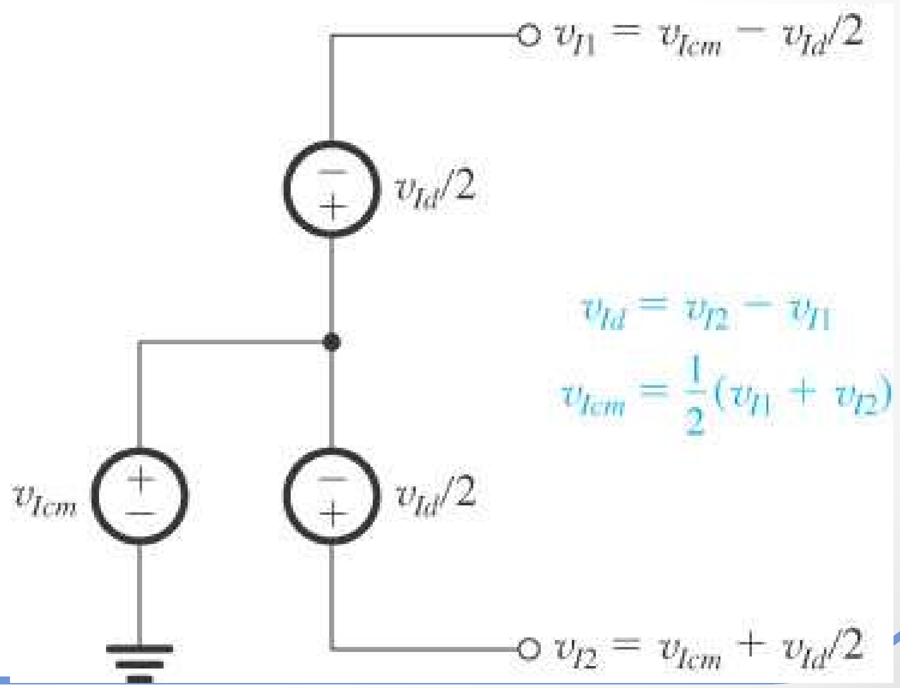
A difference amp is one that responds to the difference between the two signals applied at its input and ideally rejects signals that are common to the two inputs.

$$v_O = A_d v_{Id} + A_{cm} v_{Icm}$$

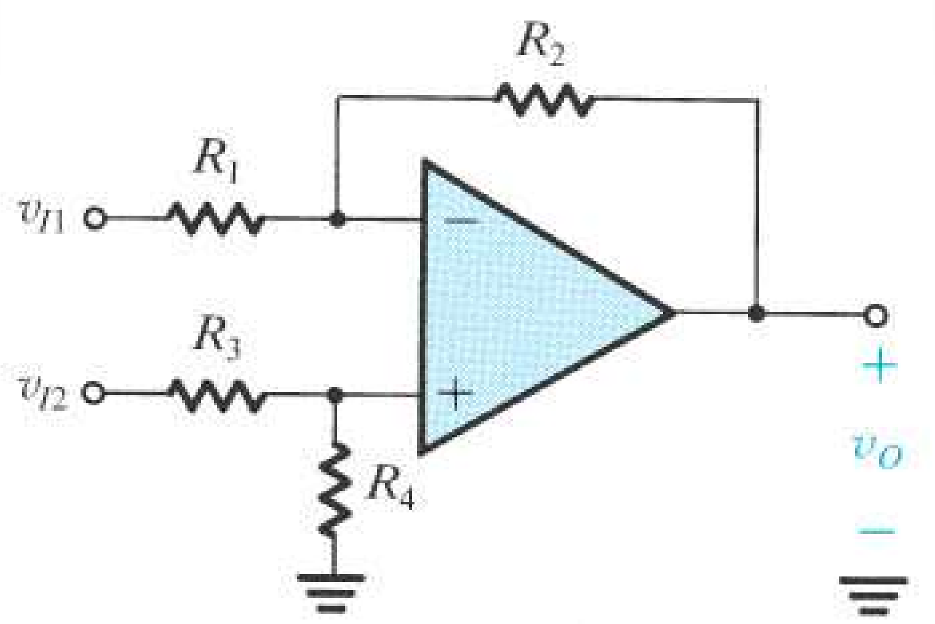
where A_d = differential gain,
A_{cm} = common-mode gain (ideally zero)

The efficacy of a differential amp is measured by the degree of its rejection of common-mode signals in preference to differential signals. The common-mode rejection ratio (CMRR) is defined as

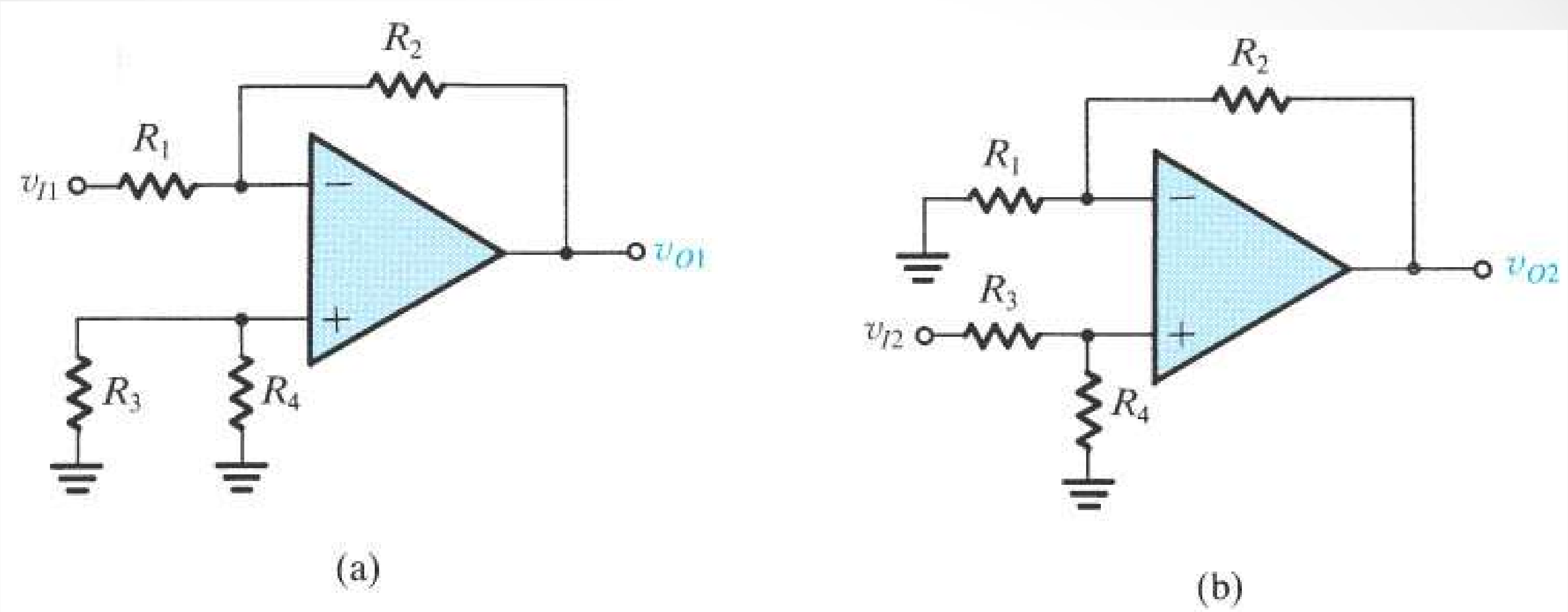
$$CMRR = 20\log\frac{|A_d|}{|A_{cm}|}$$



A Single Op-Amp Difference Amplifier



To analyze this ckt, we use the superposition principle. We look at one input voltage source at a time while turning off the other sources (ground them).



$$v_{O1} = -\frac{R_2}{R_1} v_{I1} \qquad v_{O2} = v_{I2} \frac{R_4}{R_4 + R_3}\left(1 + \frac{R_2}{R_1}\right)$$

We have to make two gain magnitudes equal in order to reject common-mode signals. Therefore,

$$\frac{R_4}{R_4 + R_3}\left(1 + \frac{R_2}{R_1}\right) = \frac{R_2}{R_1}$$

To make $$\frac{R_4}{R_4+R_3}\left(1+\frac{R_2}{R_1}\right)=\frac{R_2}{R_1}$$

which can be put in the form: $$\frac{R_4}{R_4+R_3}=\frac{R_2}{R_2+R_1}$$

The condition is satisfied by selecting $$\frac{R_4}{R_3}=\frac{R_2}{R_1}$$

Therefore $v_{O1}=-\dfrac{R_2}{R_1}v_{I1}$ and $v_{O2}=v_{I2}\dfrac{R_4}{R_4+R_3}\left(1+\dfrac{R_2}{R_1}\right)=v_{I2}\dfrac{R_2}{R_1}$

The superposition tells us that the output voltage v_O is equal to the sum of v_{O1} and v_{O2}. Thus we have

$$v_O=\frac{R_2}{R_1}(v_{I2}-v_{I1})=\frac{R_2}{R_1}v_{Id}$$

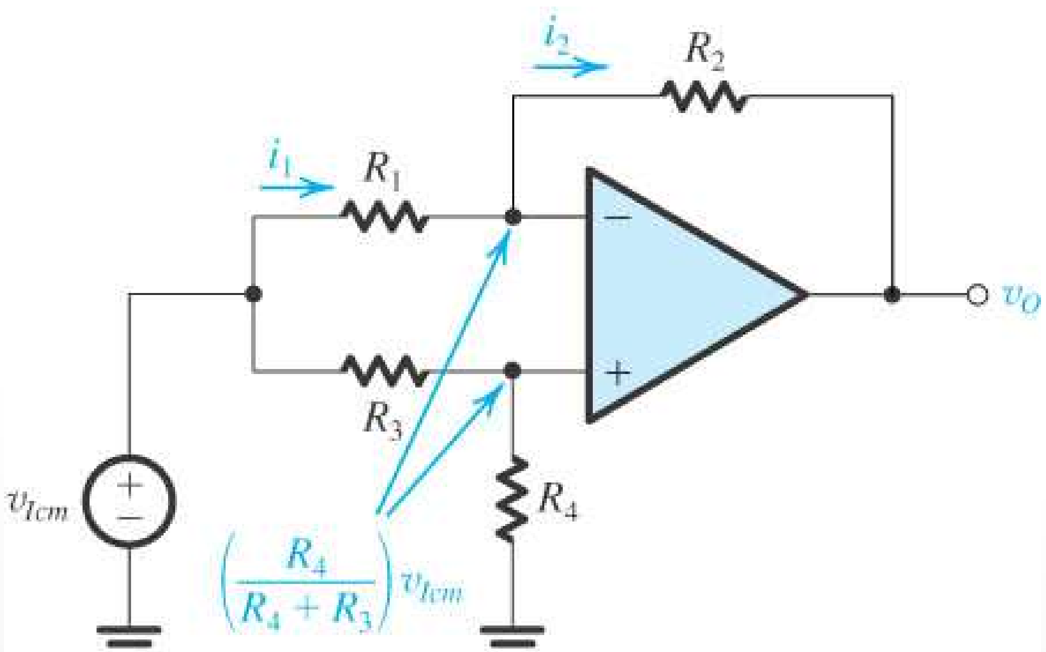
The ckt acts as a difference amp with a differential gain Ad of

$$A_d=\frac{R_2}{R_1}$$

Next, we look at the ckt with only a common-mode signal applied at the input.

$$i_1 = \frac{1}{R_1}\left[v_{Icm} - \frac{R_4}{R_4 + R_3} v_{Icm}\right] = v_{Icm} \frac{R_3}{R_4 + R_3} \frac{1}{R_1}$$

$$v_O = \frac{R_4}{R_4 + R_3} v_{Icm} - i_2 R_2$$

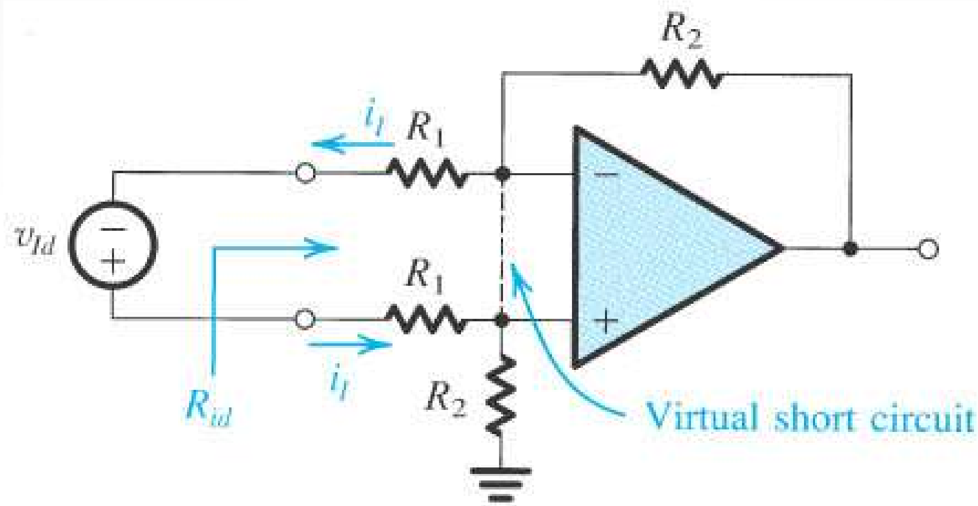


Substituting $i_2 = i_1$,

$$v_O = \frac{R_4}{R_4 + R_3} v_{Icm} - \frac{R_2}{R_1} \frac{R_3}{R_4 + R_3} v_{Icm} = \frac{R_4}{R_4 + R_3} \left(1 - \frac{R_2}{R_1} \frac{R_3}{R_4} \right) v_{Icm}$$

$$A_{cm} \equiv \frac{v_O}{v_{Icm}} = \left(\frac{R_4}{R_4 + R_3} \right) \left(1 - \frac{R_2}{R_1} \frac{R_3}{R_4} \right)$$

For the design with $\frac{R_4}{R_3} = \frac{R_2}{R_1}$, we'll get Acm = 0



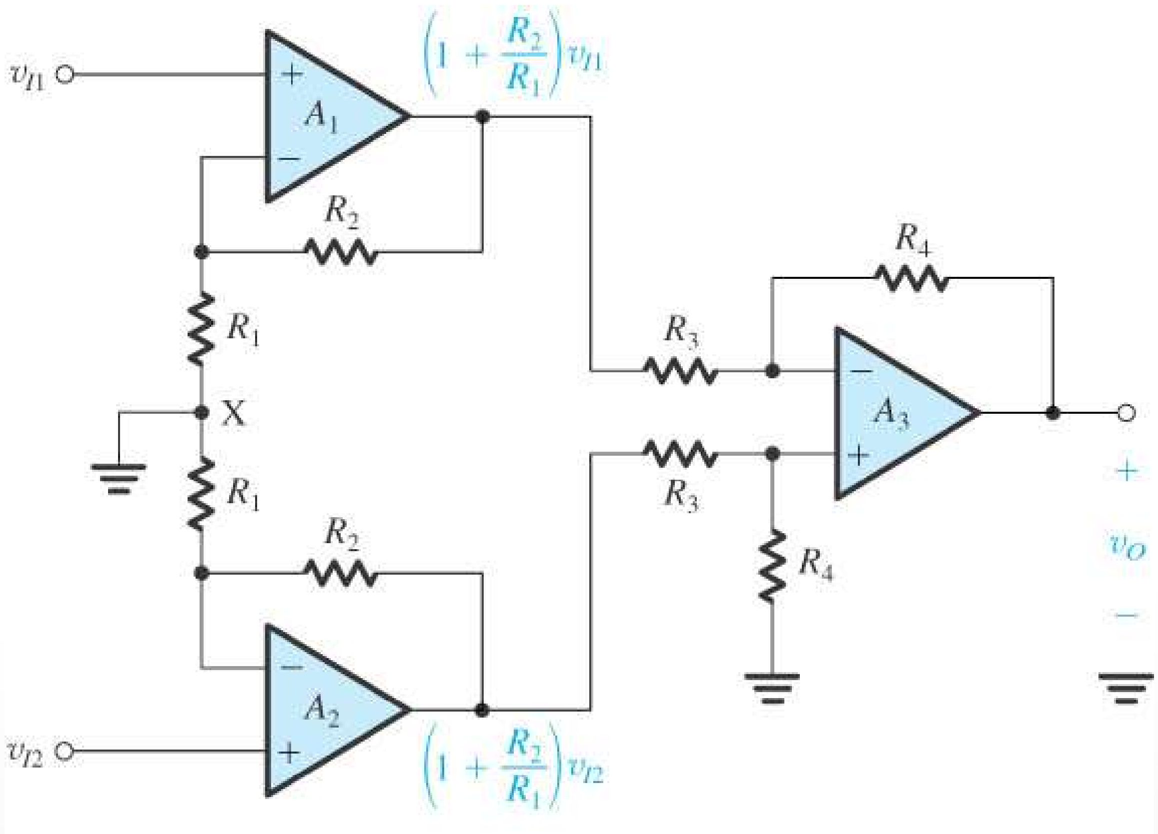
To find the differential input resistance, Rid, we assume $R_3 = R_1$ and $R_4 = R_2$, so

$$R_{id} = \frac{v_{Id}}{i_I} = \frac{R_1 i_I + 0 + R_1 i_I}{i_I} = 2R_1$$

To have large differential gain (R_2/R_1), then R_1 should be small. This will make the input resistance be correspondingly small. A drawback for this config.

An instrumentation amplifier

A better design to solve low-input resistance problem is to use the buffers at the two input terminals. The first stage is noninverting amp with gain of 1 + R2/R1, and the second stage is the difference amp with gain of R4/R3.



(a)

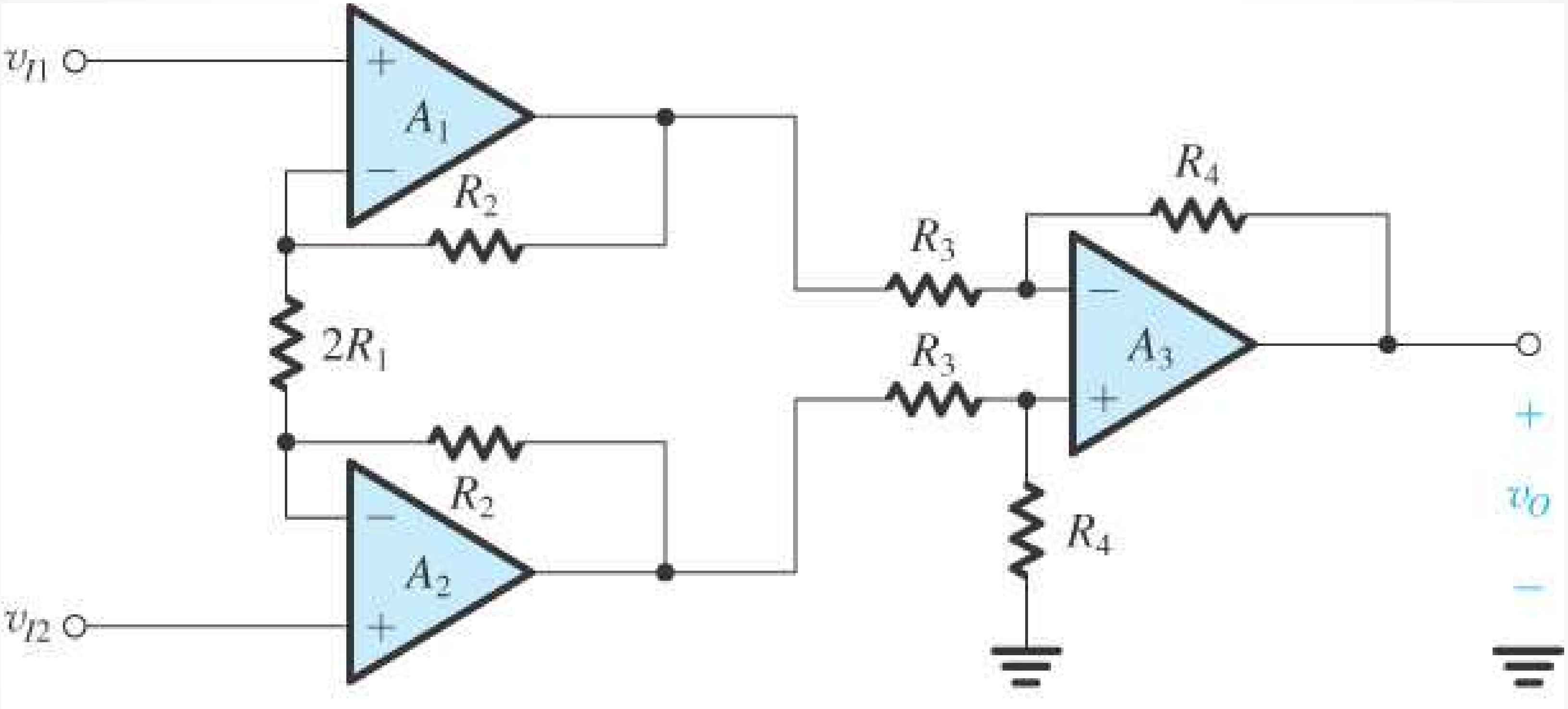
Therefore, $$v_O = \frac{R_4}{R_3}\left(1+\frac{R_2}{R_1}\right)v_{Id}$$

The differential gain is $$A_d = \frac{R_4}{R_3}\left(1+\frac{R_2}{R_1}\right)$$

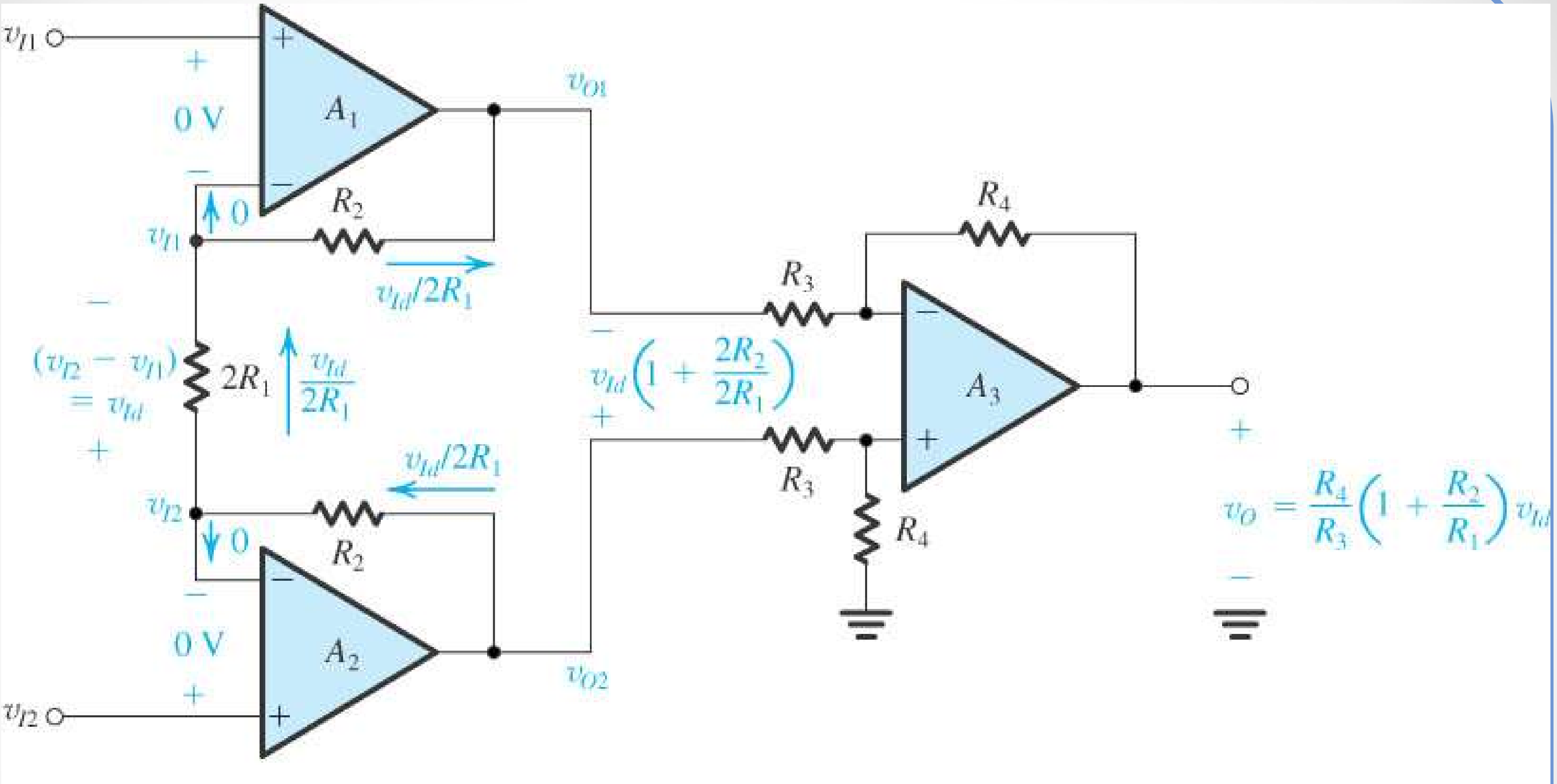
Problems with this design:

- The input common-mode signal is amplified in the first stage and can result in signals with large magnitude at the outputs of A1 and A2. This can saturate the op amps.
- The two amp channels in the 1st stage have to be perfectly matched, otherwise a spurious (or fake) signal may appear between their two outputs.
- To vary the differential gain Ad, the two R1 resistors needed to be varied simultaneously. At each gain setting, the resistors have to be perfectly matched.

A better design:



(b)

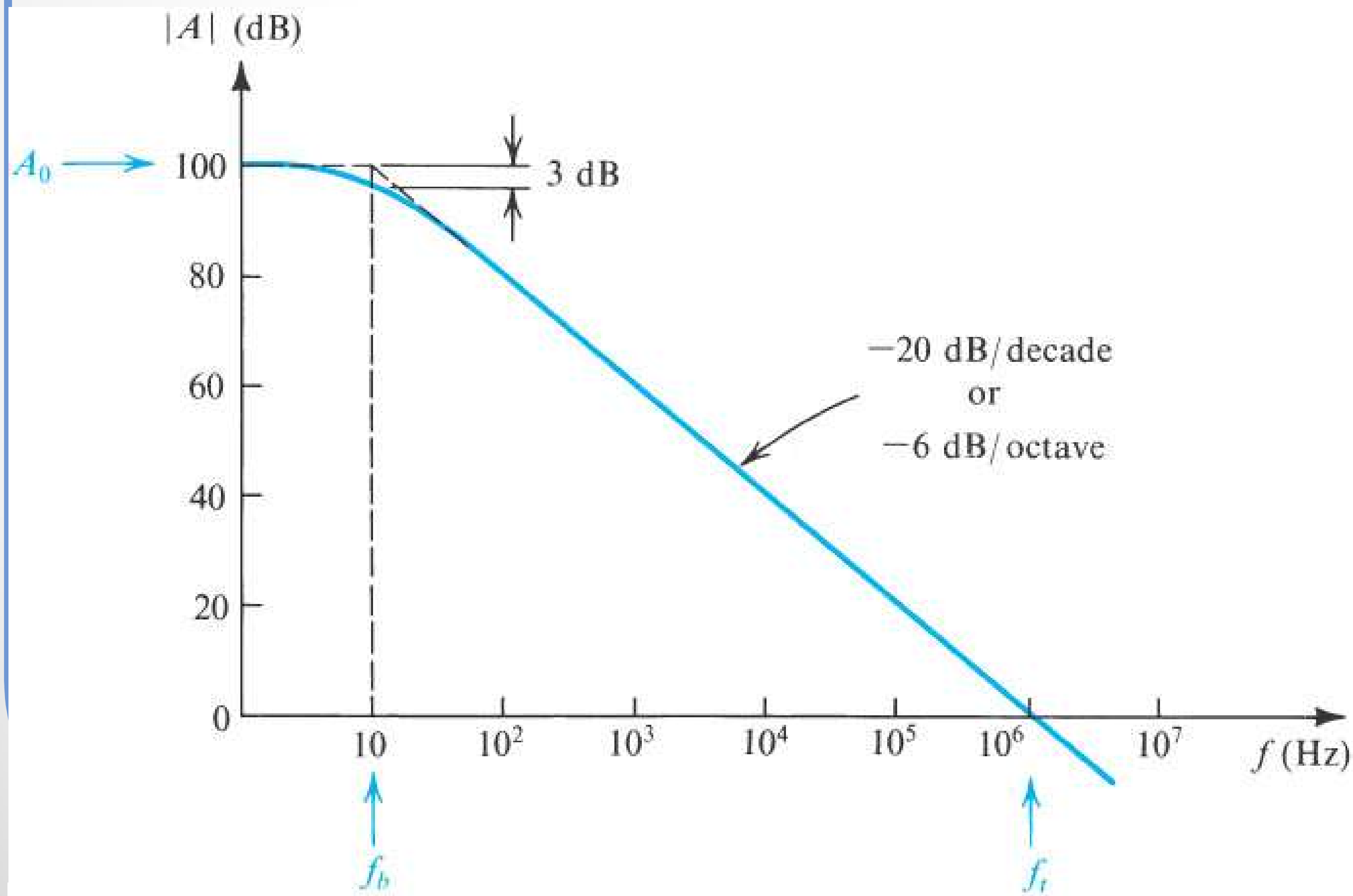


(c)

A_d remains the same as the previous case! It does not depend on the matching of the two resistors R_2.

Effect of finite open-loop gain and bandwidth on ckt performance

1. Freq dependence of the open-loop gain: high gain at dc, then drops off at -20 dB/decade due to an internal compensation whose function is cause to opamp to have the single-time constant (STC) low-pass response.



The process of modifying open-loop gain is called "freq compensation".
This will ensure the circuit will be stable (as opposed to oscillatory).
By analogy to the response of low-pass STC ckts, the gain A(s) of an internally compensated op amp may be expressed as

$$A(s) = \frac{A_O}{1 + s/\omega_b} \qquad A(j\omega) = \frac{A_O}{1 + j\omega/\omega_b}$$

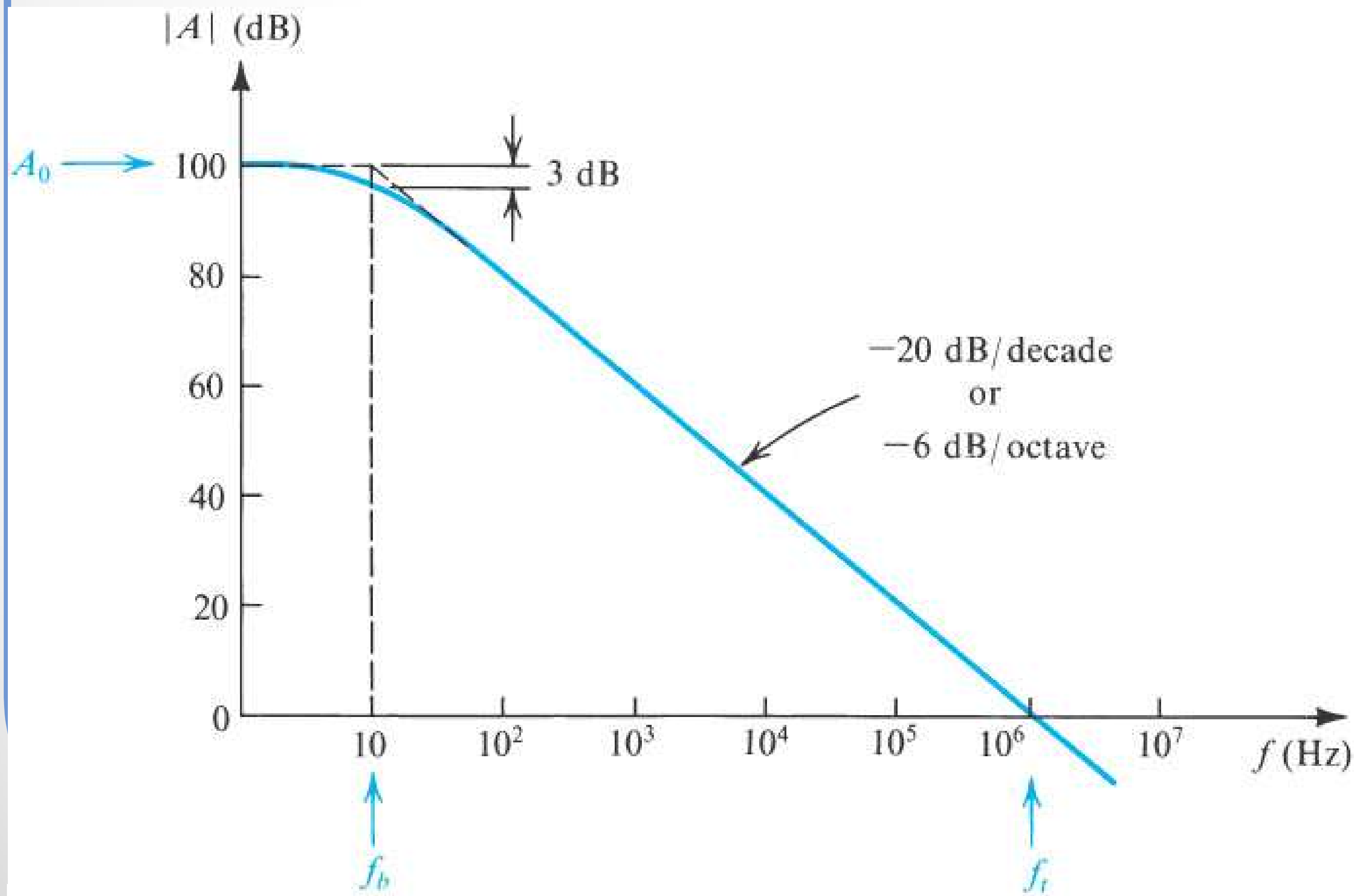
where A_O denotes the dc gain and ω_b is the 3-dB freq (corner freq or break freq).
For frequencies $\omega >> \omega_b$, A(j ω) can be approximated as

$$A(j\omega) \approx \frac{A_O \omega_b}{j\omega} = \frac{\omega_t}{j\omega}$$

The freq $f_t = \omega_t/2\pi = A_o f_b$ is known as the unit-gain bandwidth, and is often specified on the data sheets. Therefore, for frequencies $\omega >> \omega_b$

$$|A(j\omega)| \approx \frac{\omega_t}{\omega} = \frac{f_t}{f}$$

For frequencies $\omega >> \omega_b$, increasing f by a factor of 10 (a decade increase) results in reducing |A| by a factor of 10 (20 dB). Or doubling f (an octave increase) results in halving the gain (a 6-dB reduction).
This “single-pole” model shows a roll-off response resulted from the dominant pole.



2. Freq response of closed-loop amplifiers.

The closed-loop gain of the inverting amp, assuming a finite op-amp open-loop gain A, is given by

$$G \equiv \frac{v_O}{v_I} = \frac{-R_2/R_1}{1+(1+R_2/R_1)/A}$$

It can be shown that

$$\frac{v_O(s)}{v_I(s)} = \frac{-R_2/R_1}{1+\frac{1}{A_O}\left(1+\frac{R_2}{R_1}\right)+\frac{s}{\omega_t/(1+R_2/R_1)}}$$

For Ao >> 1 +R2/R1,

$$\frac{v_O(s)}{v_I(s)} = \frac{-R_2/R_1}{1+\frac{s}{\omega_t/(1+R_2/R_1)}}$$

which is the same form as that of the STC network. The inverting amp has an STC low-pass response with a dc gain of magnitude equal to R2/R1, and corner freq

$$\omega_{3dB} = \frac{\omega_t}{1+R_2/R_1}$$

Similarly, for the noninverting amp, assuming a finite open-loop gain A,

$$G \equiv \frac{v_O}{v_I} = \frac{1 + R_2/R_1}{1 + (1 + R_2/R_1)/A}$$

Substituting A(s) for A, and approx. Ao >> 1+ R2/R1, results in

$$\frac{v_O(s)}{v_I(s)} = \frac{1 + R_2/R_1}{1 + \dfrac{s}{\omega_t/(1 + R_2/R_1)}}$$

Thus, it has an STC low-pass response with a dc gain of 1+R2/R1 and the same corner freq as the inverting amp case.

Ex2 Consider an op amp with f_t = 1 MHz. Find the 3-dB freq of closed-loop amp With nominal gain of 1000, 100, 10, 1, -1, -10, -100, and -1000.

Closed-loop gain	R_2/R_1	$f_{3\text{-dB}} = f_t/(1+R_2/R_1)$
1000	999	1 kHz
100	99	10 kHz
10	9	100 kHz
1	0	1 MHz
-1	1	0.5 MHz
-10	10	90.9 kHz
-100	100	9.9 kHz
-1000	1000	1 kHz

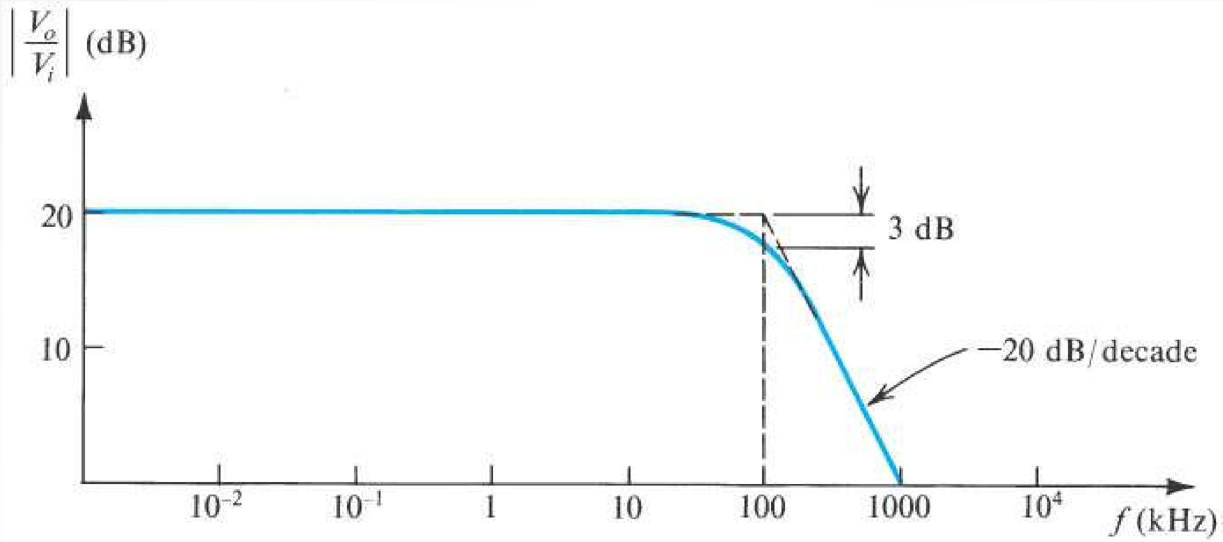


Figure 2.23 Frequency response of an amplifier with a nominal gain of +10 V/V.

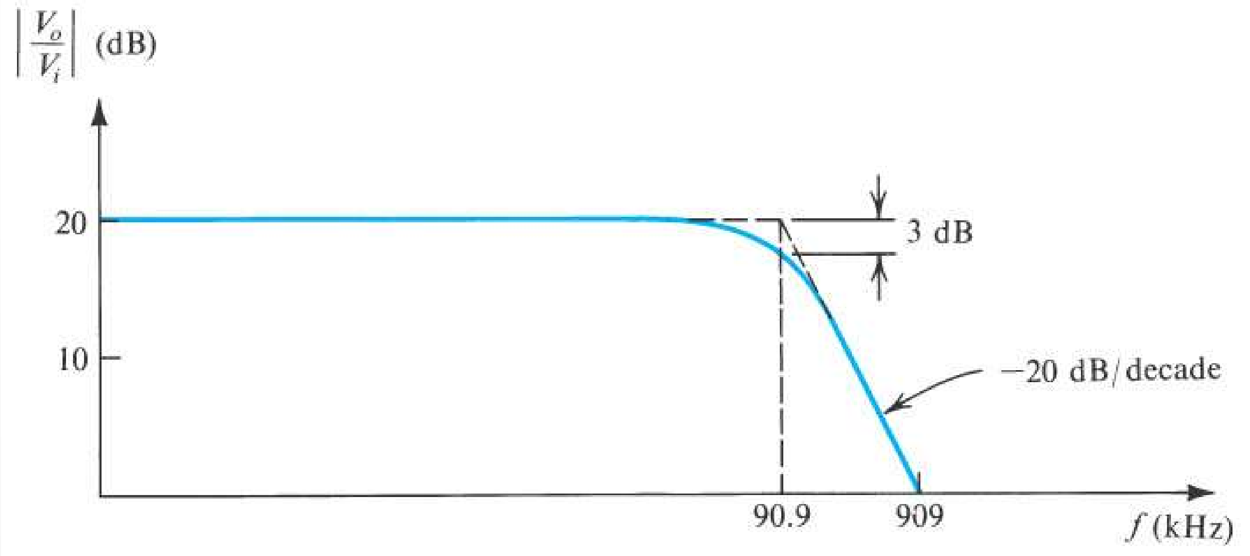


Figure 2.24 Frequency response of an amplifier with a nominal gain of –10 V/V.

Reference

Microelectronic Circuits by Adel S. Sedra & Kenneth C. Smith. Saunders College Publishing


I CORRECT AUTOCORRECT
MORE THAN AUTOCORRECT
CORRECTS ME.