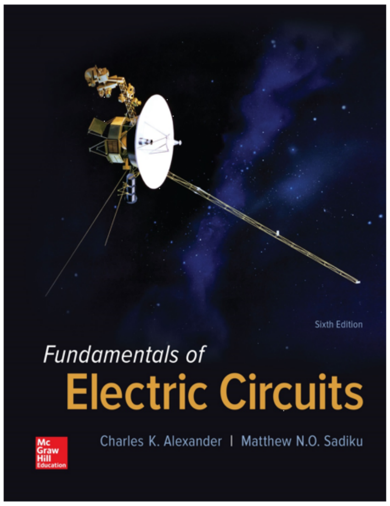

Chapter 5 - Operational Amplifiers

- **In this chapter, the operation amplifier will be introduced.**
- **The basic function of this useful device will be discussed.**
- **Examples of amplifier circuits that may be constructed from the operation amplifier will be covered.**
- ~~**Instrumentation amplifiers will also be discussed.**~~

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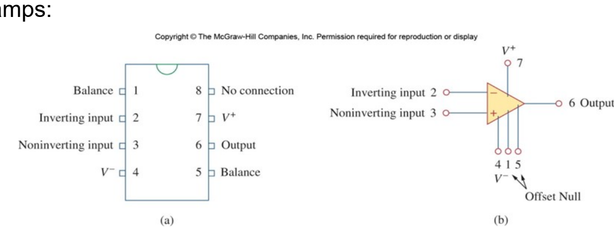
5.1 Introduction

An operational amplifier (Op-Amp) is an electronic circuit that behaves like a voltage-controlled voltage source. The reason it is called "operational" is because it can perform basic mathematical operations to analog signals - e.g. sum, amplify, integrate, differentiate, etc. Generally, in circuit analysis we start by focusing on ideal op-amps.

5.2 Operational Amplifiers

An operational amplifier (Op-Amp) is an active circuit element - i.e. it requires power to be supplied to it fo rit to function - it contains a complex arrangement of resistors, transistors, capacitors, and diodes, but we will only study the behavior of ideal op-amps as one device and what occurs at its terminals.

There are five terminals found on all op-amps:
- the inverting input
- the non-inverting input
- the output
- the (+) and (-) power supplies



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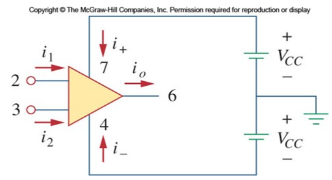
Usually on circuit diagrams, the power supply terminals are obscured and it is taken for granted that they are there. In addition, they usually use two voltage sources with a ground reference between them - this gives a positive and negative supply voltage.



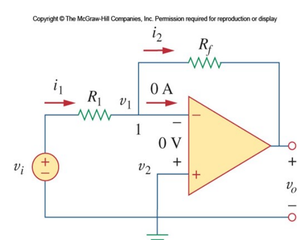
The voltage output of an op-amp is proportional to the difference between the non-inverting and inverting inputs.

$$v_0 = Av_d = A(v_2 - v_1)$$

A is called the "open loop gain."

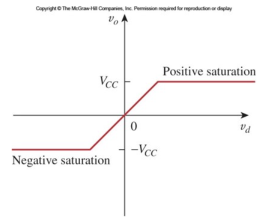
Parameter	Typical range	Ideal values
Open-loop gain, A	10^5 to 10^8	∞
Input resistance,R_i	10^5 to 10^13 ohms	∞ ohms
Output resistance, R_0	10 to 100 ohms	0 ohms
Supply voltage,V_cc	5 to 24 V	

A is called the **"open loop gain"** because it is the gain of the op-amp without any external feedback from the output to the input.



This configuration has the feedback used with the inverting terminal. The ratio of the output voltage to the input voltage is called the **"closed-loop gain."** Due to the negative feedback, the closed-loop gain is insensitive to the open-loop gain. Therefore op-amps are used in circuits with feedback pathways.

A practical limitation of the op-amp is that the magnitude of its output voltage cannot exceed the power supplies. The practical implication of this is that the op-amp can operate in 3 "modes" as shown in the plot below.



Attempting to increase the output beyond the linear range, the op-amp becomes "saturated.

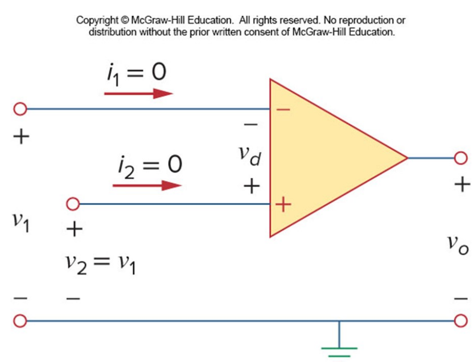
5.3 Ideal Op-Amps

When analyzing op-amps, we generally start by assuming they are "ideal" and unless otherwise stated, we assume it to be the case. An ideal op-amp has the following properties:

- Infinite open-loop gain
- Infinite input resistance
- Zero output resistance

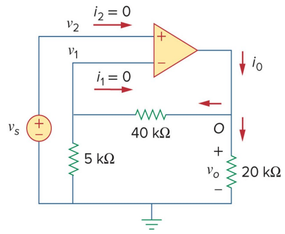
What this means in practical terms is the following:

$i_1 = 0$
$i_2 = 0$
$v_1 = v_2$



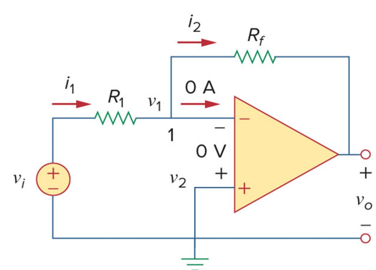
These characteristics make analyzing op-amps in circuits not as hard as it may seem!!

Find i_o when v_s = 1 V.



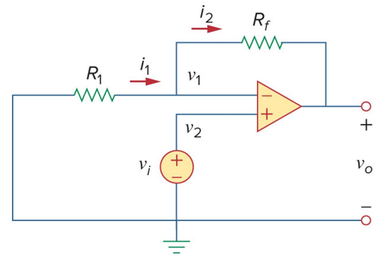
5.4 Inverting Amplifier

Find relationship between v_o and v_i.



5.5 Noninverting Amplifier

Find relationship between v_o and v_i.



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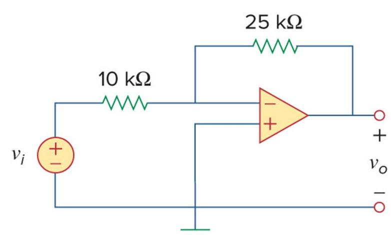
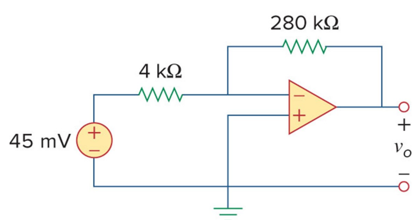
Example and Practice Problems

E5.3 Find v_0 when vi is 0.5 V.
Find the current in the 10k-ohm resistor.



P5.3 Find the current through the feedback resistor and the output voltage.



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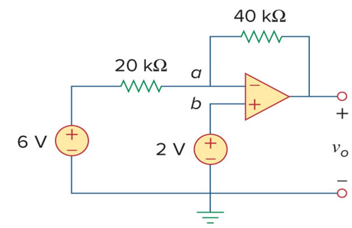
Example and Practice Problems

E5.4 Find v_0.



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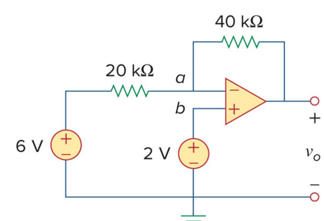
Example and Practice Problems

E5.3 Find v_0. (Try using multiple methods.)



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