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Circuit Theory (SKEE 1023)

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Operational Amplifiers

Topics

- ❖ Operational Amplifiers, Ideal Op Amp, Inverting Amplifier, Noninverting Amplifier, Summing Amplifier, Difference Amplifier, Cascaded Op Amp Circuits.

Operational Amplifiers

Introduction

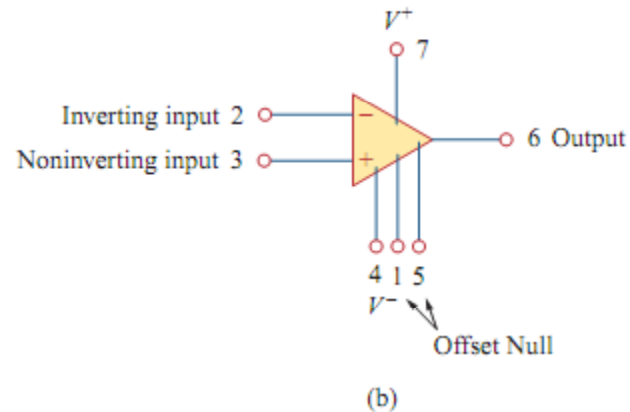
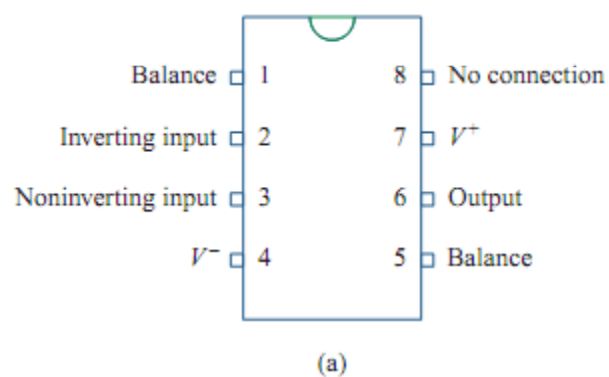
- The operational amplifier (**op amp**) is an electronic unit that behaves like a voltage-controlled voltage source.
- An op amp can sum signals, amplify a signal, integrate it or differentiate it.
- An op amp is **an active circuit element** designed to perform mathematical operations of addition, subtraction, multiplication, division, differentiation and integration.
- The op amp is an electronic device consisting of a complex arrangement of resistors, transistors, capacitors, and diodes.



Operational Amplifiers

Introduction

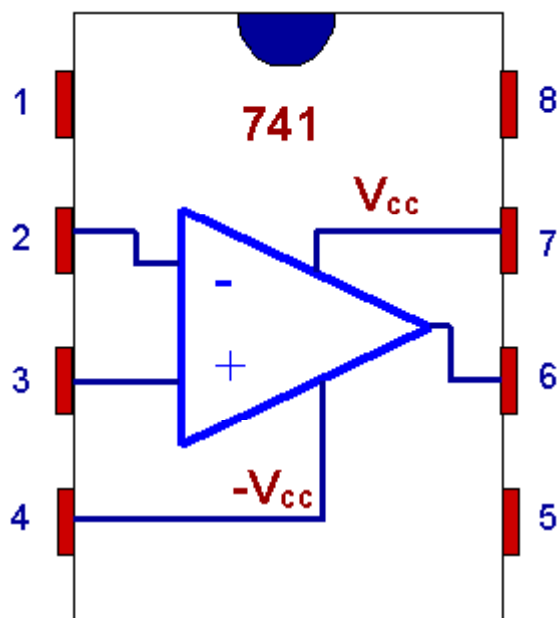
- ✓ A typical op amp: (a) pin configuration, (b) circuit symbol.



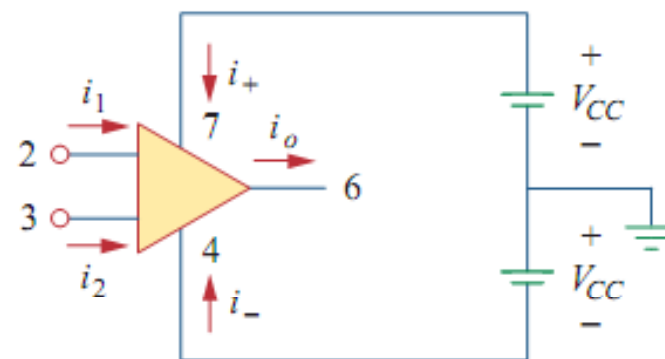


Operational Amplifiers

Introduction



✓ Powering the op amp

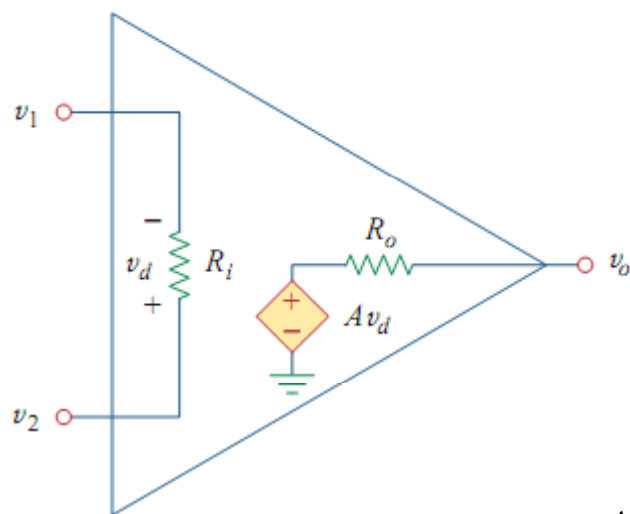


$$i_o = i_1 + i_2 + i_+ + i_-$$

Operational Amplifiers

Introduction

- ✓ Equivalent circuit of the non-ideal op amp



The differential input voltage, v_d ;

$$v_d = v_2 - v_1$$

- ✓ Op amp senses the difference between the two inputs, multiplies it by the gain A , and causes the resulting output.

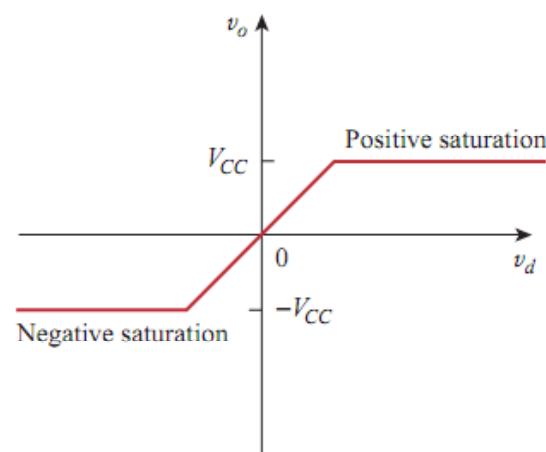
$$v_o = Av_d = A(v_2 - v_1)$$

A : open - loop voltage gain

Operational Amplifiers

Introduction

- The concept of feedback is crucial to understanding of op amp circuits.
- **Negative feedback** is achieved when the output is fed back to the inverting terminal of the op amp.
- The ratio of the output voltage to the input voltage is called the **closed-loop gain**, $\Rightarrow (v_o / v_s)$
- A practical limitation of the op amp is that the magnitude of its output voltage cannot exceed $|V_{CC}|$.



Operational Amplifiers

✓ Some applications of op amp

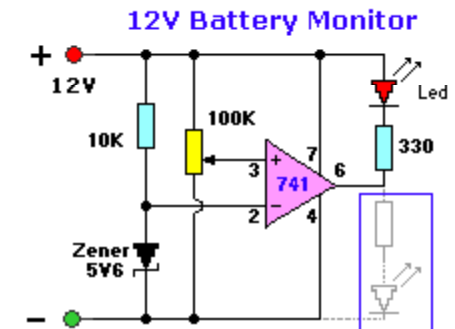
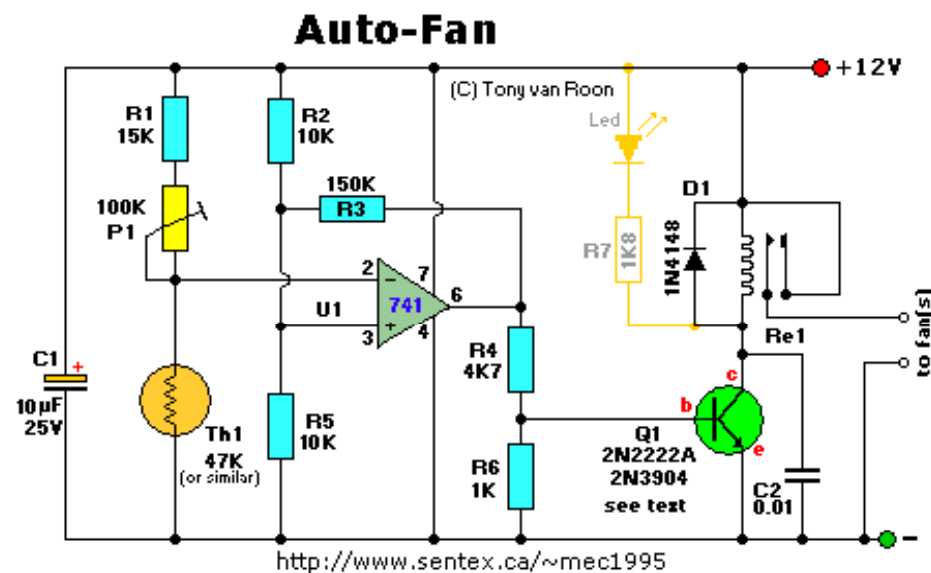
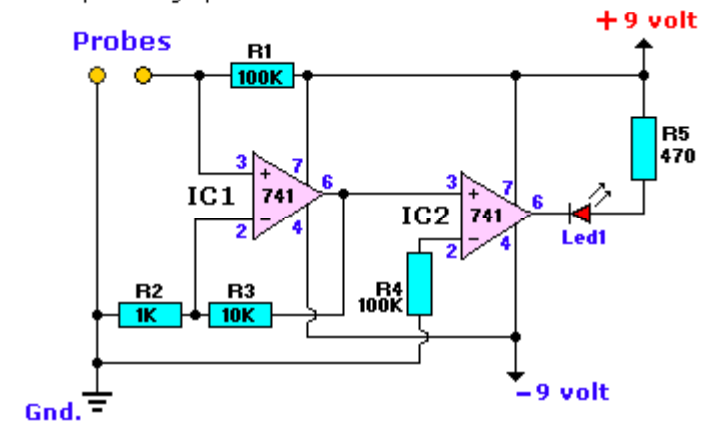


Fig. 14

Smart Continuity Tester

<http://www.uoguelph.ca/~antoon>

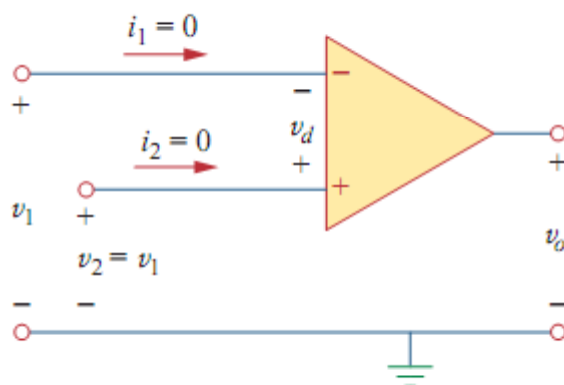


Gnd., +9V, and -9V NEEDS to be connected or the circuit will **NOT** work!

Operational Amplifiers

Ideal Op Amp

- An **ideal op amp** is an amplifier with infinite open-loop gain, infinite input resistance, and zero output resistance.
- Two important characteristics of the ideal op amp are:
 - The currents into both input terminals are zero.
 - The voltage across the input terminals is equal to zero



$$i_1 = 0; \quad i_2 = 0$$

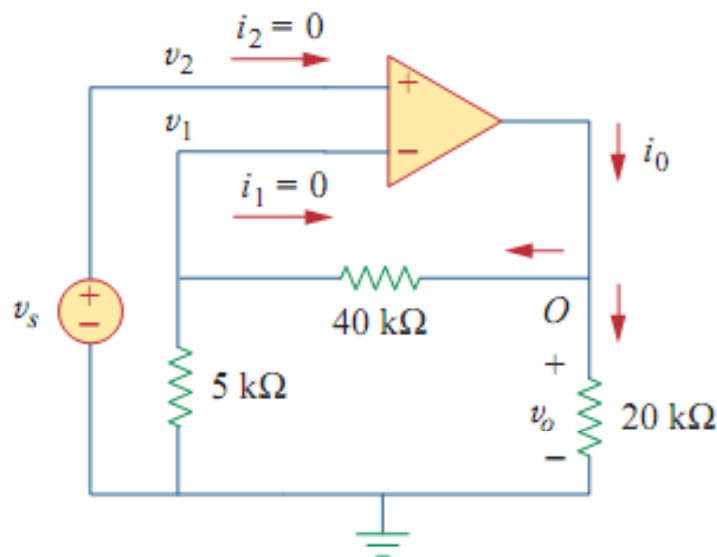
$$v_d = v_2 - v_1 = 0$$

$$v_1 = v_2$$

Operational Amplifiers

Example 1

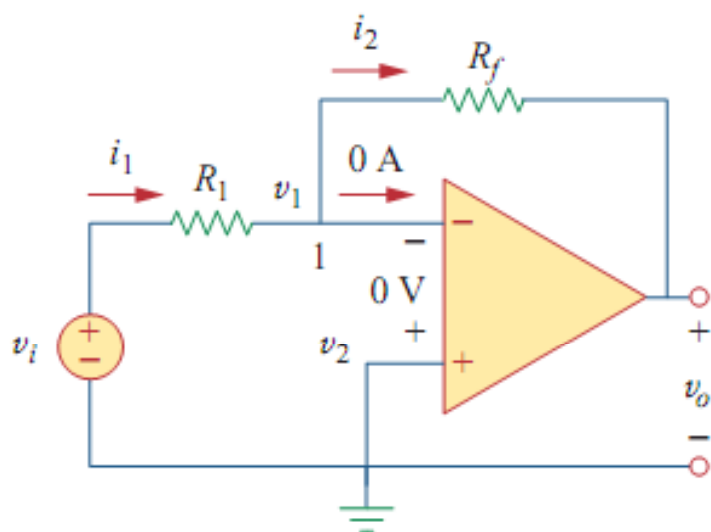
Calculate the closed-loop gain (v_o / v_s). Find i_o when $v_s = 1V$.



Operational Amplifiers

Inverting Op Amp

- ✓ v_i is connected to the inverting input through R_1 , and the feedback resistor R_f is connected between the inverting input and output



$$i_1 = i_2 \Rightarrow \frac{v_i - v_1}{R_1} = \frac{v_1 - v_o}{R_f}$$

$v_1 = v_2 = 0$ for an ideal op amp.

Noninverting terminal is grounded, hence

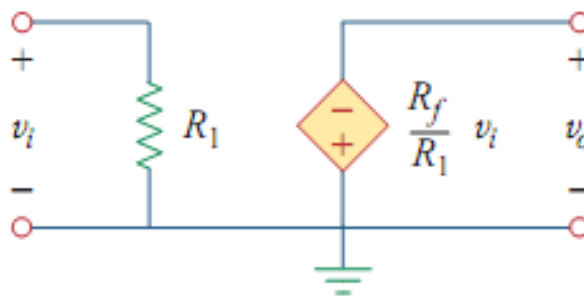
$$\frac{v_i}{R_1} = -\frac{v_o}{R_f}$$

Operational Amplifiers

Inverting Op Amp

$$\text{Voltage gain, } A_v = \frac{v_o}{v_i} = -\frac{R_f}{R_1}$$

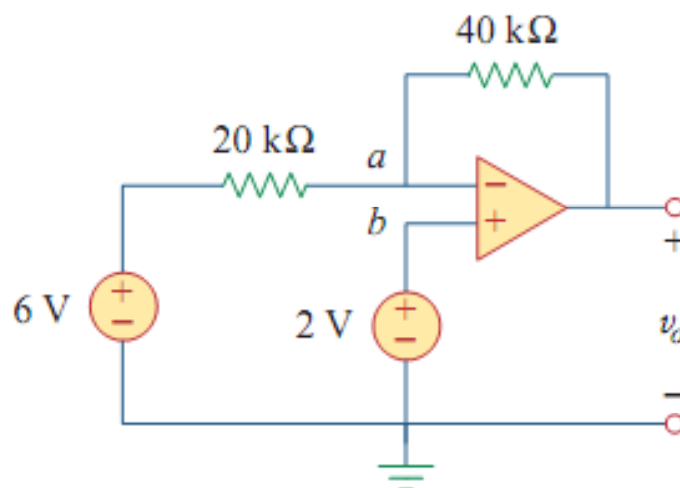
- An inverting amplifier reverses the polarity of the input signal while amplifying it.
- The gain depends only on the external elements connected to the op amp.
- Equivalent circuit for the inverting amplifier;



Operational Amplifiers

Example 2

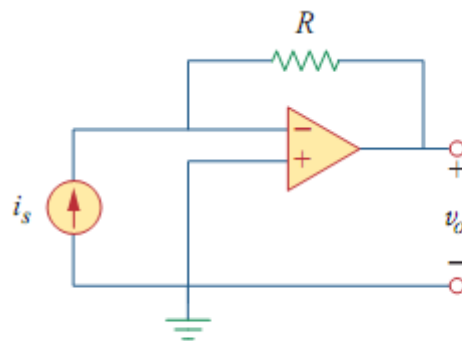
Determine v_o in the op amp circuit below.



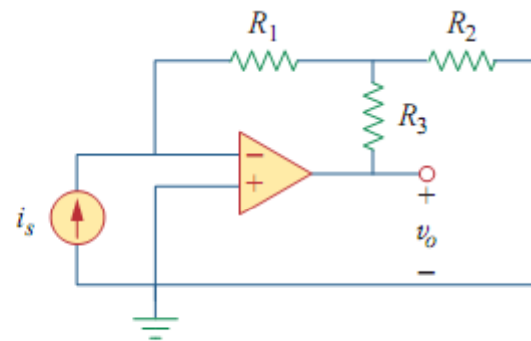
Operational Amplifiers

Practice Problem 1

Find v_o / i_s for the current-to-voltage converter circuits as shown below.



(a)



(b)

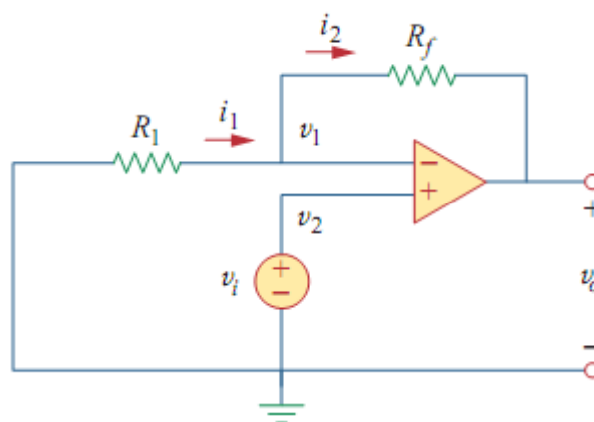
Answers:

$$(a) \frac{v_o}{i_s} = -R; \quad (b) \frac{v_o}{i_s} = -R_1 \left(1 + \frac{R_3}{R_1} + \frac{R_3}{R_2} \right)$$

Operational Amplifiers

Noninverting Op Amp

- Input voltage v_i is applied directly at the noninverting input terminal, and R_1 is connected between the ground and the inverting terminal.



$$\text{Voltage gain, } A_v = \frac{v_o}{v_i} = \left(1 + \frac{R_f}{R_1} \right)$$



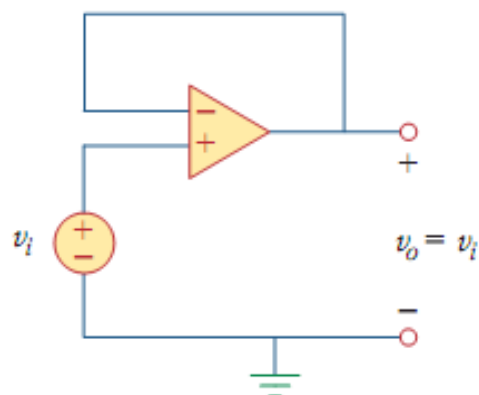
Operational Amplifiers

Noninverting Op Amp

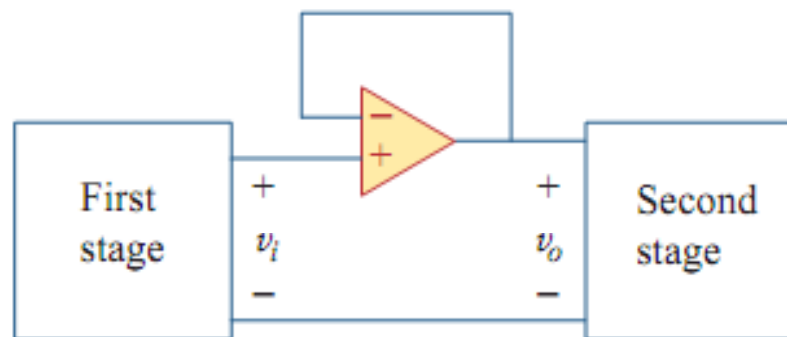
- A noninverting amplifier is an op amp circuit designed to provide a positive voltage gain.
- Gain depends only on the external resistors.
- If $R_f = 0$ (short-circuit) or $R_1 = \infty$ (open-circuit) or both, the gain becomes 1; \Rightarrow called a **voltage follower** (or unity gain amplifier).
- This voltage follower circuit has a very high input impedance and is therefore useful as an **intermediate-stage (or buffer) amplifier** to isolate one circuit from another.

Operational Amplifiers

Noninverting Op Amp



The voltage follower



A voltage follower used to isolate two cascaded stages of a circuit

Operational Amplifiers

Example 3

For the op amp circuit in Fig E3, calculate the output voltage v_o .

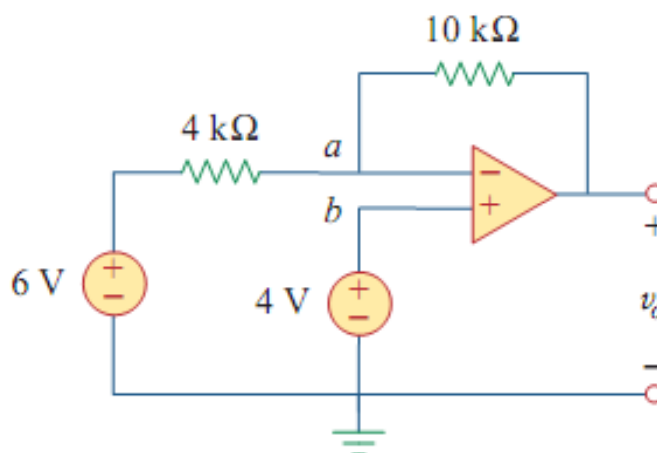
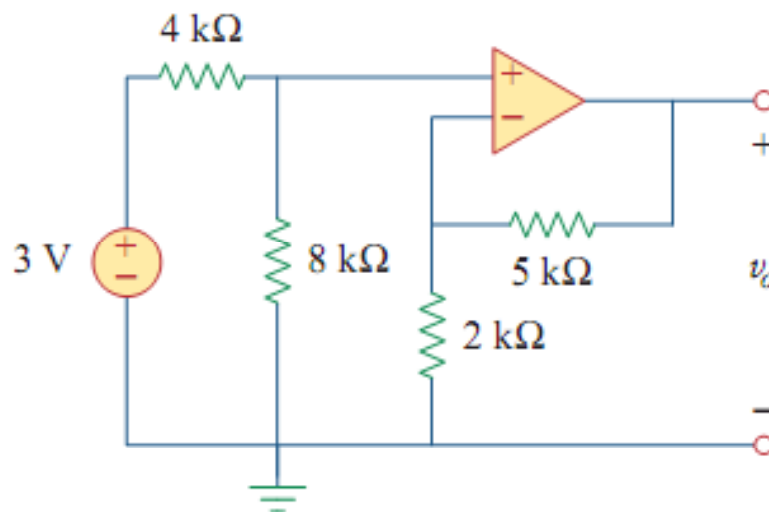


Fig E3

Operational Amplifiers

Practice Problem 2

Calculate v_o in the circuit of Fig. P2.



Answers: 7V