OPERATIONAL AMPLIFIERS

OR OP AMPS FOR SHORT

OBJECTIVE OF LECTURE

Describe how an ideal operational amplifier (op amp) behaves.

Define voltage gain, current gain, transresistance gain, and transconductance gain.

Explain the operation of an ideal op amp in a voltage comparator and inverting amplifier circuit.

- Show the effect of using a real op amp.
  - Chapters 5.1-5.3 Fundamentals of Electric Circuits

OP AMPS APPLICATIONS

Audio amplifiers

- Speakers and microphone circuits in cell phones, computers, mpg players, boom boxes, etc.

Instrumentation amplifiers

- Biomedical systems including heart monitors and oxygen sensors.

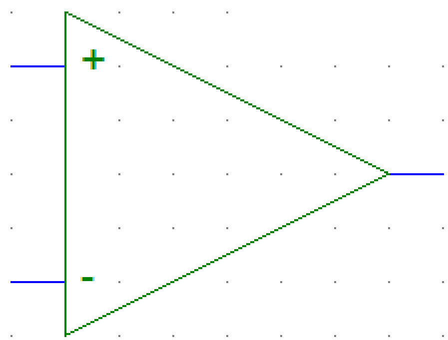
Power amplifiers

Analog computers

- Combination of integrators, differentiators, summing amplifiers, and multipliers

SYMBOLS FOR IDEAL AND REAL OP AMPS

OpAmp



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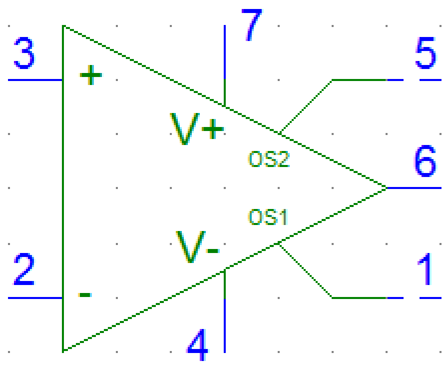
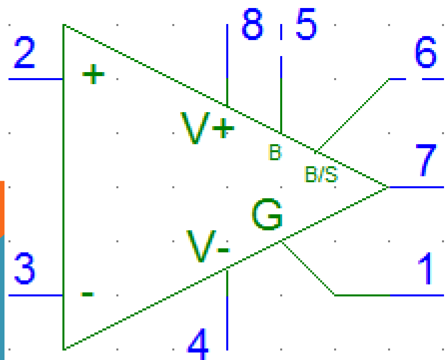
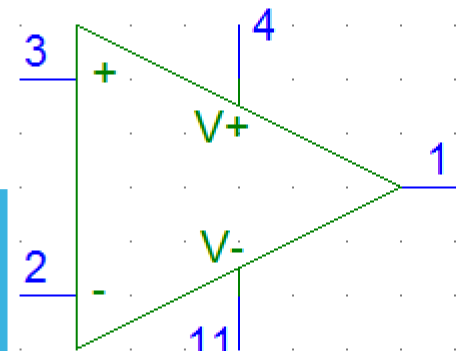


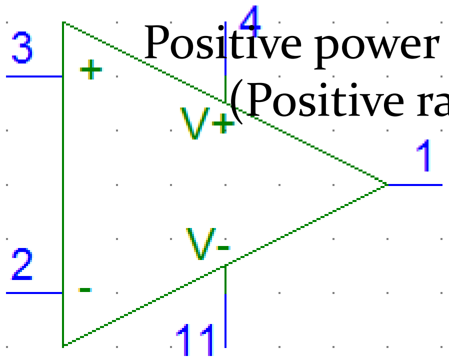
LM111



LM324



TERMINALS ON AN OP AMP



Positive power supply
(Positive rail)

Non-inverting
Input terminal

Output terminal

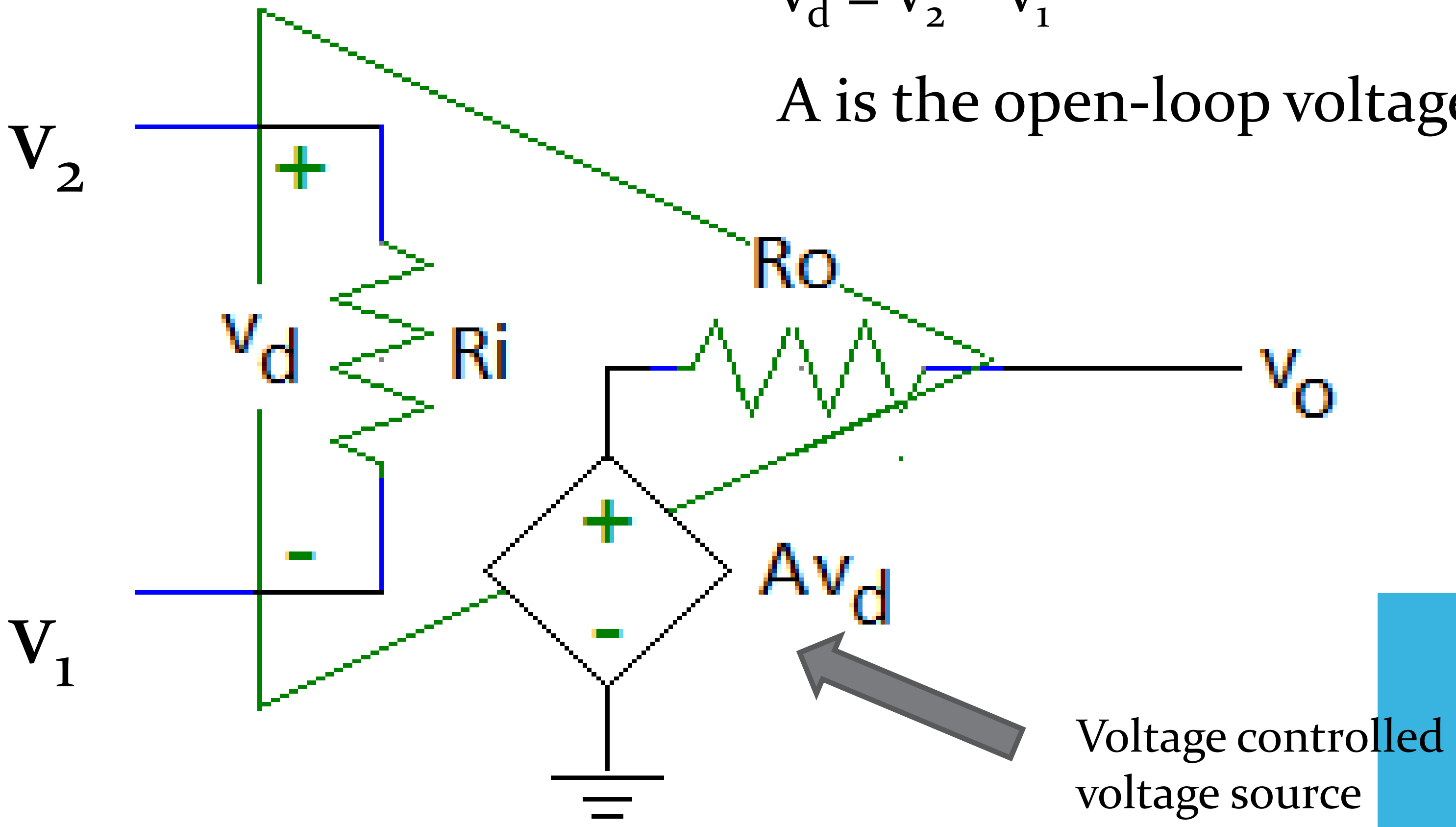
Inverting input
terminal

Negative power supply
(Negative rail)

OP AMP EQUIVALENT CIRCUIT

$v_d = v_2 - v_1$

A is the open-loop voltage gain



TYPICAL OP AMP PARAMETERS

Parameter	Variable	Typical Ranges	Ideal Values
Open-Loop Voltage Gain	A	10^5 to 10^8	∞
Input Resistance	Ri	10^5 to 10^{13} Ω	∞ Ω
Output Resistance	Ro	10 to 100 Ω	0 Ω
Supply Voltage	Vcc/V^+ $-Vcc/V^-$	5 to 30 V -30V to 0V	N/A N/A

HOW TO FIND THESE VALUES

Component Datasheets

- Many manufacturers have made these freely available on the internet
  - Example: LM 324 Operational Amplifier

National Semiconductor

August 2000

LM124/LM224/LM324/LM2902
Low Power Quad Operational Amplifiers

General Description

The LM124 series consists of four independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage.

Application areas include transducer amplifiers, DC gain blocks and all the conventional op amp circuits which now can be more easily implemented in single power supply systems. For example, the LM124 series can be directly operated off of the standard +5V power supply voltage which is used in digital systems and will easily provide the required interface electronics without requiring the additional ±15V power supplies.

Unique Characteristics

- In the linear mode the input common-mode voltage range includes ground and the output voltage can also

Advantages

- Eliminates need for dual supplies
- Four internally compensated op amps in a single package
- Allows directly sensing near GND and V_{OUT} also goes to GND
- Compatible with all forms of logic
- Power drain suitable for battery operation

Features

- Internally frequency compensated for unity gain
- Large DC voltage gain 100 dB
- Wide bandwidth (unity gain) 1 MHz (temperature compensated)
- Wide power supply range:
  Single supply 3V to 32V
  or dual supplies ±1.5V to ±16V
- Very low supply current drain (700 µA)—essentially independent of supply voltage
- Low input biasing current 45 nA

DB

Decibels

Since $P = V^2/R$

$10 \log (P/P_{ref})$ or $20 \log (V/V_{ref})$

In this case:

$$20 \log (V_o/V_{in}) = 20 \log (A) = 100$$

$$A = 10^5 = 100{,}000$$

Electrical Characteristics

$V^+ = +5.0V$, (Note 7), unless otherwise stated

Parameter	Conditions	LM124A			LM224A			LM324A			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	(Note 8) $T_A = 25^\circ C$		1	2		1	3		2	3	mV
Input Bias Current (Note 9)	$I_{IN(+)}$ or $I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25^\circ C$		20	50		40	80		45	100	nA
Input Offset Current	$I_{IN(+)}$ or $I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25^\circ C$		2	10		2	15		5	30	nA
Input Common-Mode Voltage Range (Note 10)	$V^+ = 30V$, (LM2902, $V^+ = 26V$), $T_A = 25^\circ C$	0		$V^+-1.5$	0		$V^+-1.5$	0		$V^+-1.5$	V
Supply Current	Over Full Temperature Range $R_L = \infty$ On All Op Amps										mA
	$V^+ = 30V$ (LM2902 $V^+ = 26V$)		1.5	3		1.5	3		1.5	3	
	$V^+ = 5V$		0.7	1.2		0.7	1.2		0.7	1.2	
Large Signal Voltage Gain	$V^+ = 15V$, $R_L \geq 2k\Omega$, ($V_O = 1V$ to $11V$), $T_A = 25^\circ C$	50	100		50	100		25	100		V/mV
Common-Mode	DC, $V_{CM} = 0V$ to $V^+ - 1.5V$,	70	85		70	85		65	85		dB

LARGE SIGNAL VOLTAGE GAIN = A

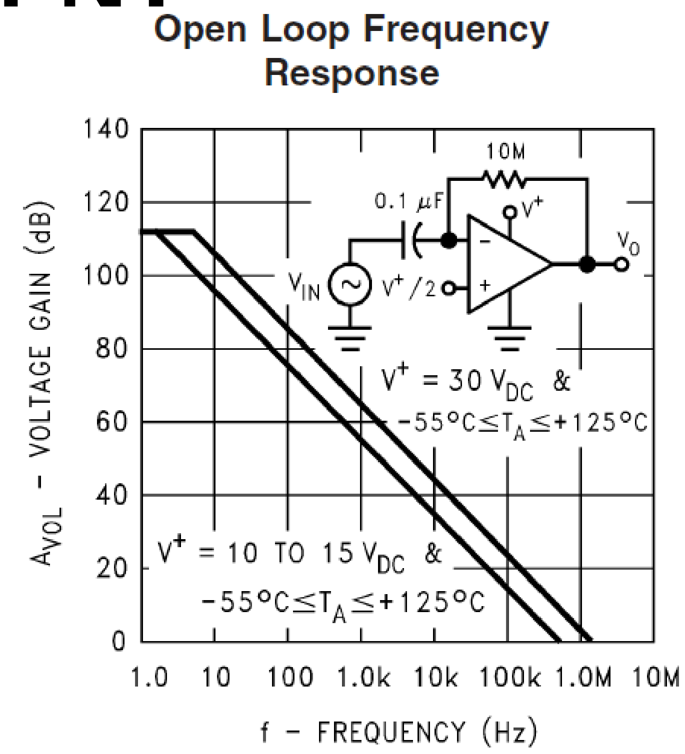
Typical

- A = 100 V/mV = 100V/0.001V = 100,000

Minimum

- A = 25 V/mV = 25 V/0.001V = 25,000

CAUTION – A IS FREQUENCY DEPENDENT



http://www.national.com/ds/LM/LM124.pdf

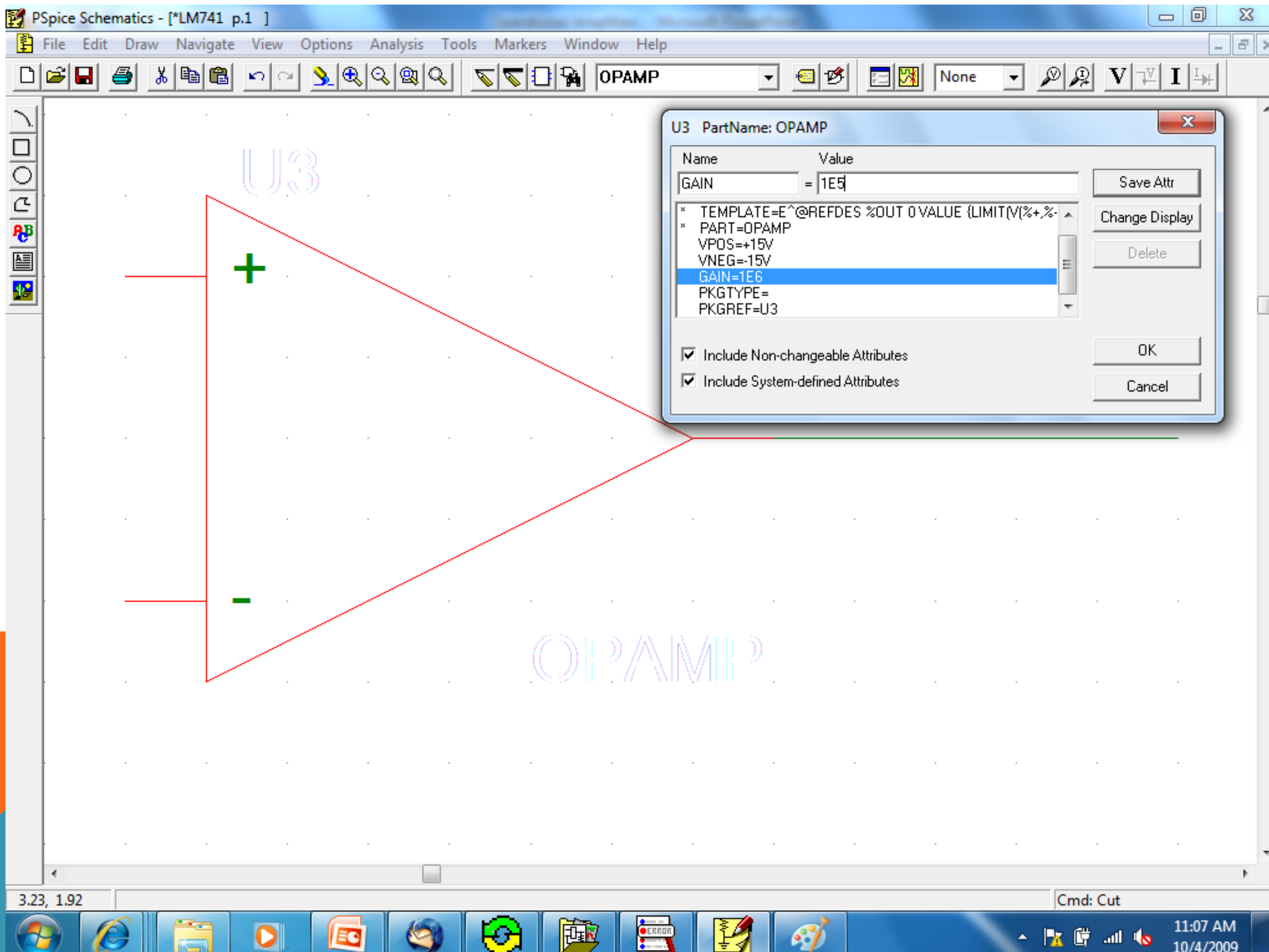
MODIFYING GAIN IN PSPICE OPAMP

Place part in a circuit

Double click on component

Enter a new value for the part attribute called GAIN

ORCAD SCHEMATICS



OPEN CIRCUIT OUTPUT VOLTAGE

$$v_o = A\, v_d$$

- **Ideal Op Amp**

$$v_o = \infty\, (v_d)$$

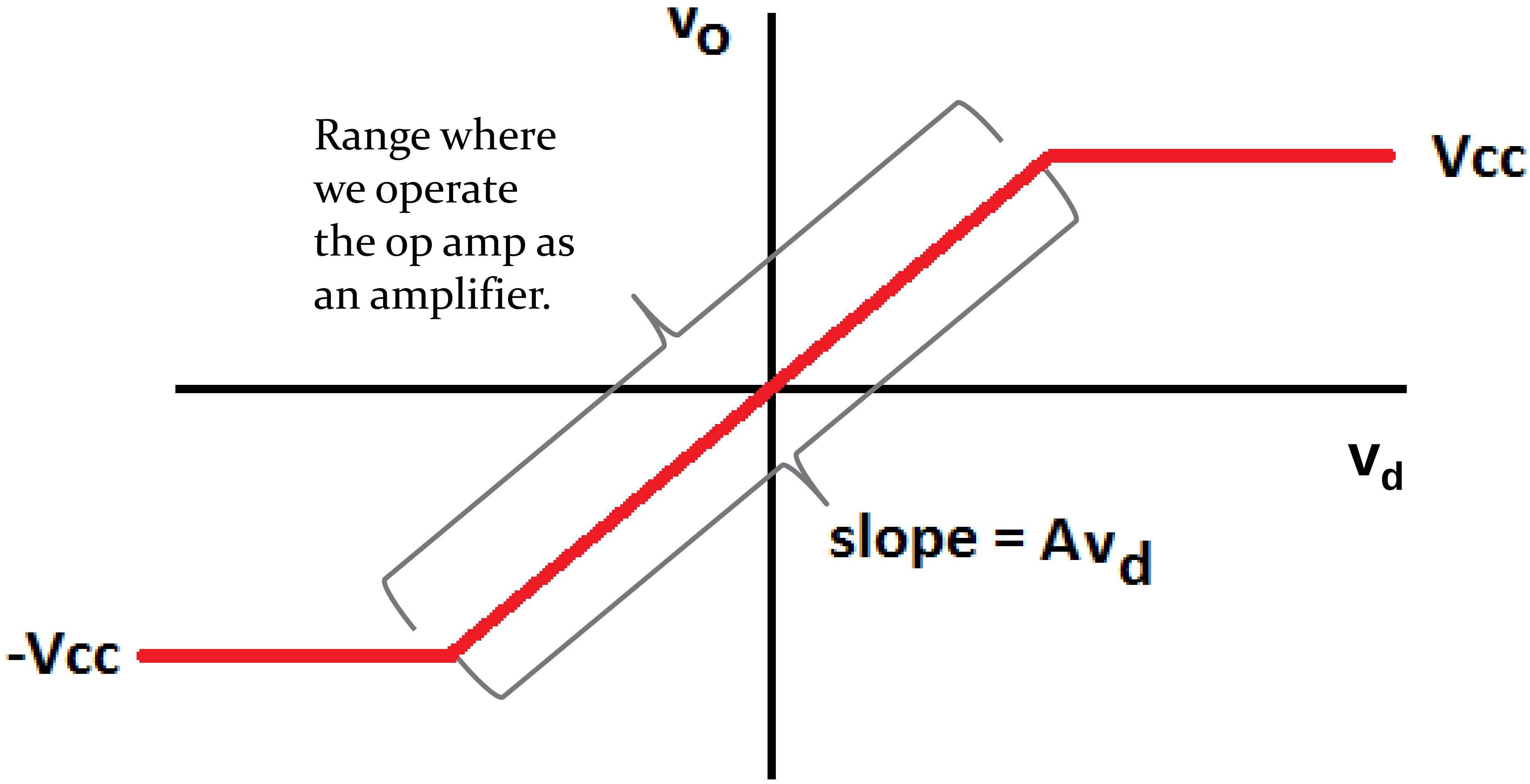
OPEN CIRCUIT OUTPUT VOLTAGE

Real Op Amp

	Voltage Range	Output Voltage
Positive Saturation	$A\,v_d > V^+$	$v_o \sim V^+$
Linear Region	$V^- < A\,v_d < V^+$	$v_o = A\,v_d$
Negative Saturation	$A\,v_d < V^-$	$v_o \sim V^-$

The voltage produced by the dependent voltage source inside the op amp is limited by the voltage applied to the positive and negative rails.

VOLTAGE TRANSFER CHARACTERISTIC

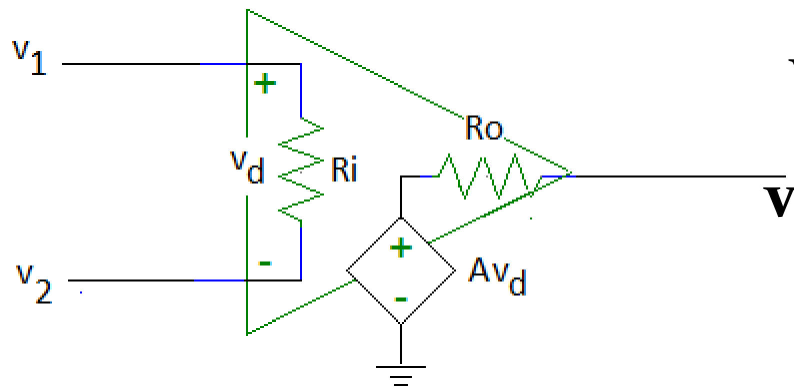


IDEAL OP AMP

Because Ri is equal to ∞Ω, the voltage across Ri is 0V.

V_2

$i_2 = 0$



$v_1 = v_2$

$v_d = 0$ V

$i_1 = 0$

V_1

ALMOST IDEAL OP AMP

Ri = ∞ Ω

- Therefore, $i_1 = i_2 = 0A$

Ro = 0 Ω

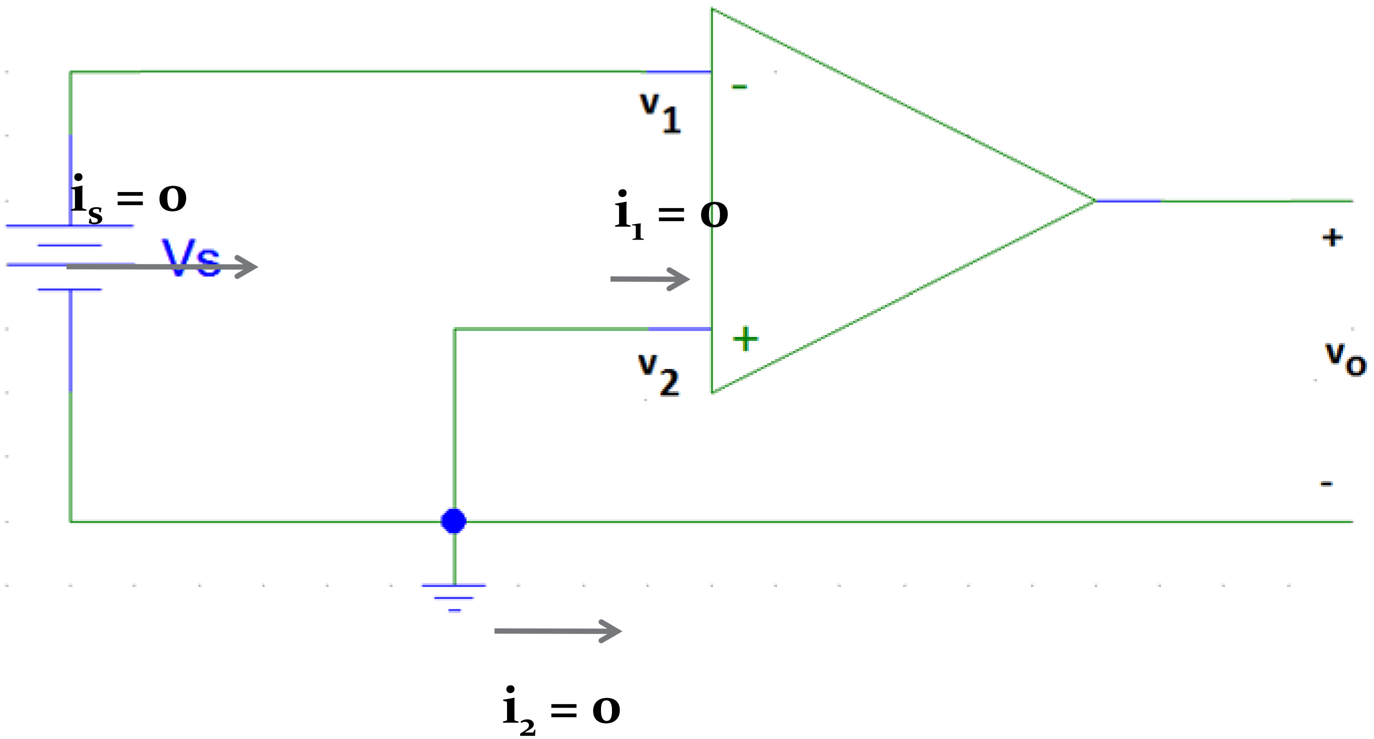
Usually, $v_d = 0V$ so $v_1 = v_2$

- The op amp forces the voltage at the inverting input terminal to be equal to the voltage at the noninverting input terminal if there is some component connecting the output terminal to the inverting input terminal.

Rarely is the op amp limited to $V^- < v_o < V^+$.

- The output voltage is allowed to be as positive or as negative as needed to force $v_d = 0V$.

EXAMPLE #1: VOLTAGE COMPARATOR



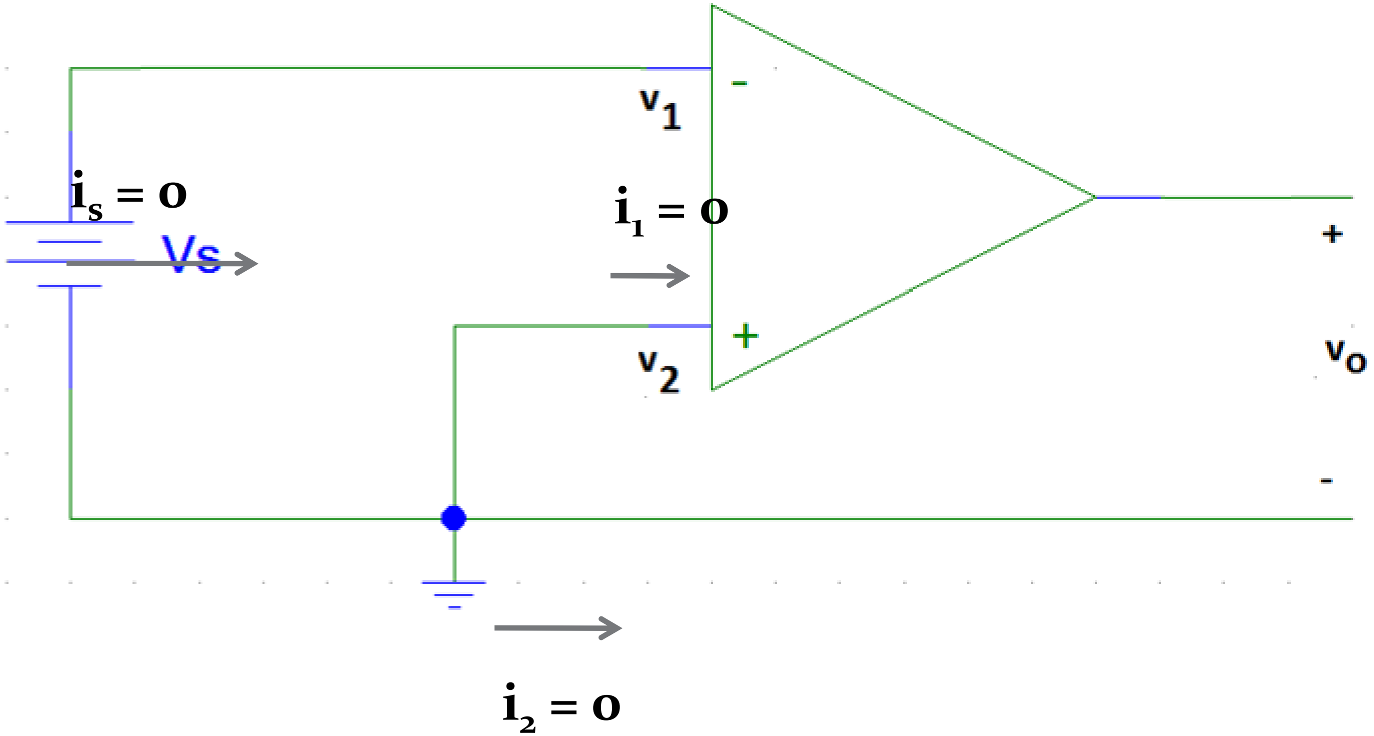
Note that the inverting input and non-inverting input terminals have rotated in this schematic.

EXAMPLE #1 (CON'T)

The internal circuitry in the op amp tries to force the voltage at the inverting input to be equal to the non-inverting input.

- As we will see shortly, a number of op amp circuits have a resistor between the output terminal and the inverting input terminals to allow the output voltage to influence the value of the voltage at the inverting input terminal.

EXAMPLE #1: VOLTAGE COMPARATOR

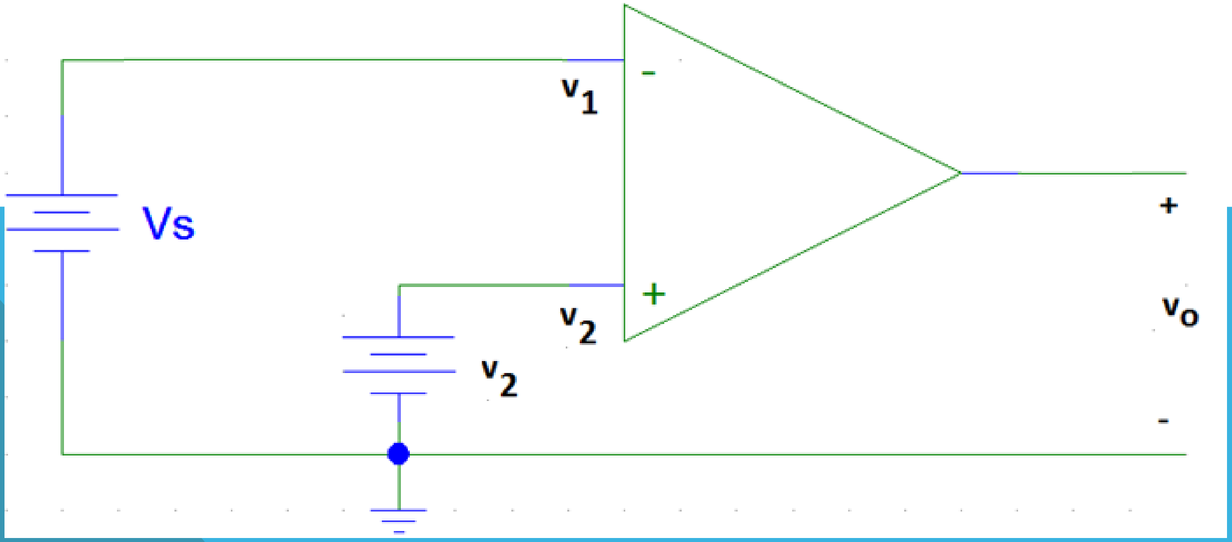


When Vs is equal to 0V, Vo = 0V.
When Vs is smaller than 0V, Vo = V^{+}.
When Vs is larger than 0V, Vo = V^{-}.

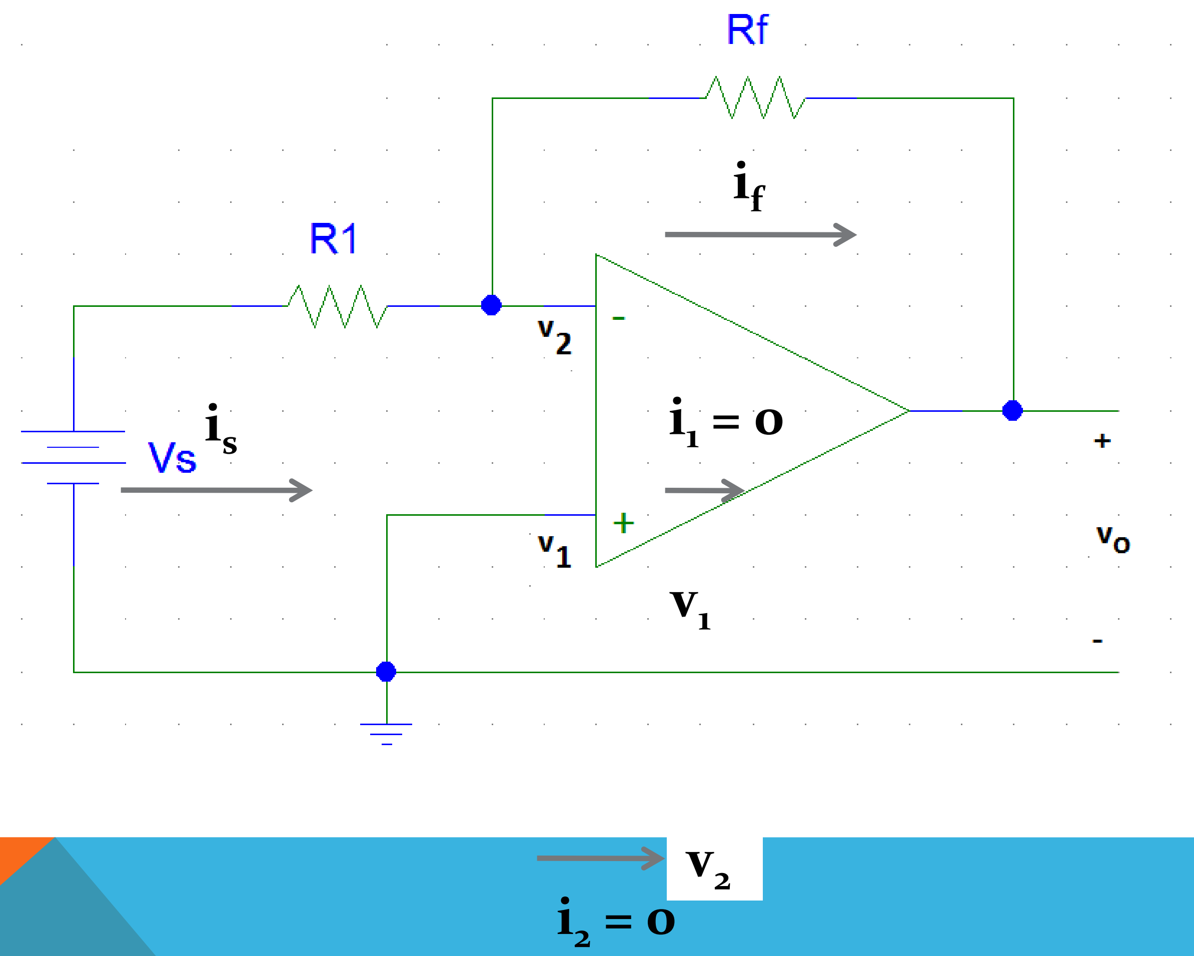
ELECTRONIC RESPONSE

Given how an op amp functions, what do you expect Vo to be if v2 = 5V when:

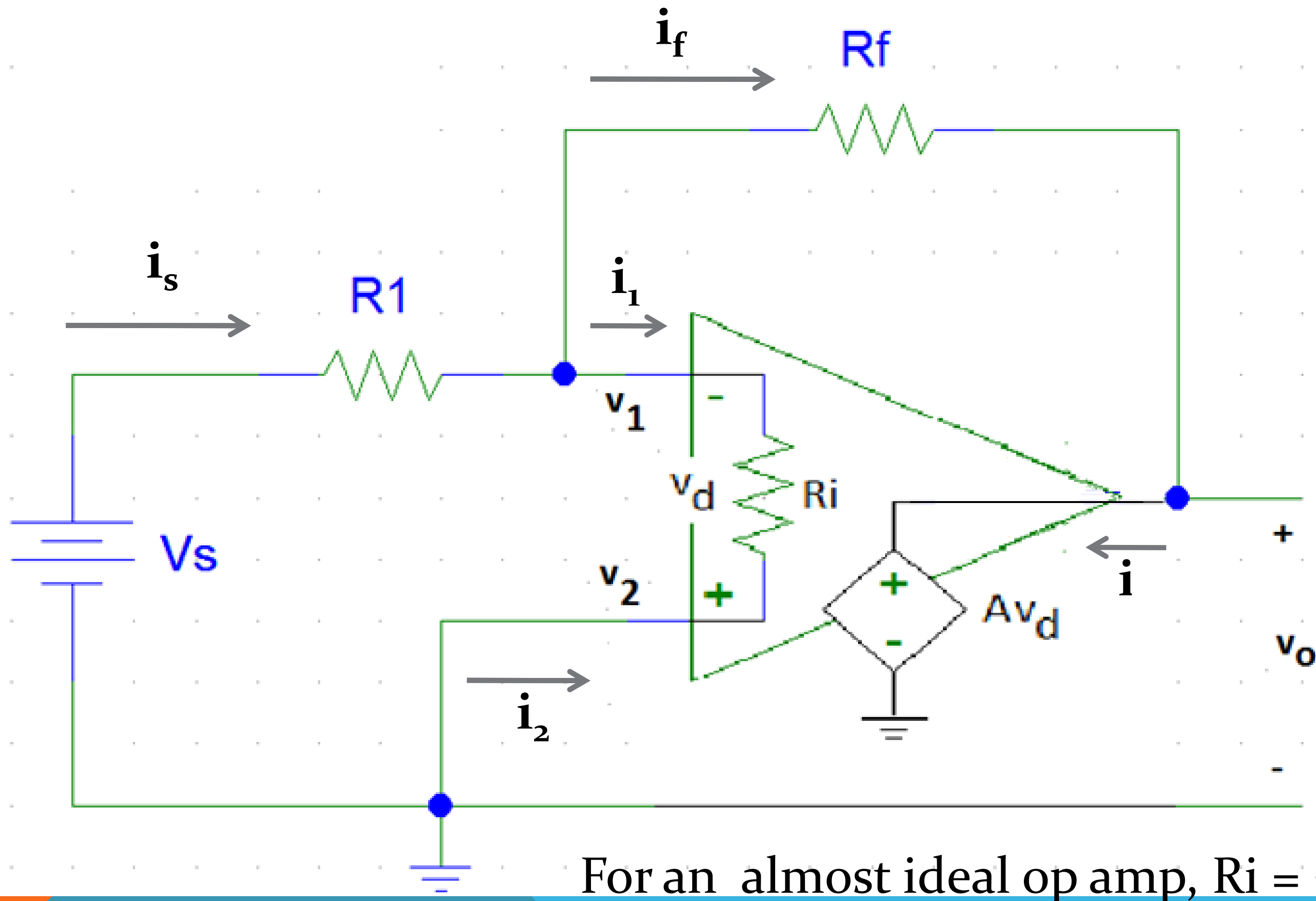
1. Vs = 0V?
2. Vs = 5V?
3. Vs = 6V?



EXAMPLE #2: CLOSED LOOP GAIN



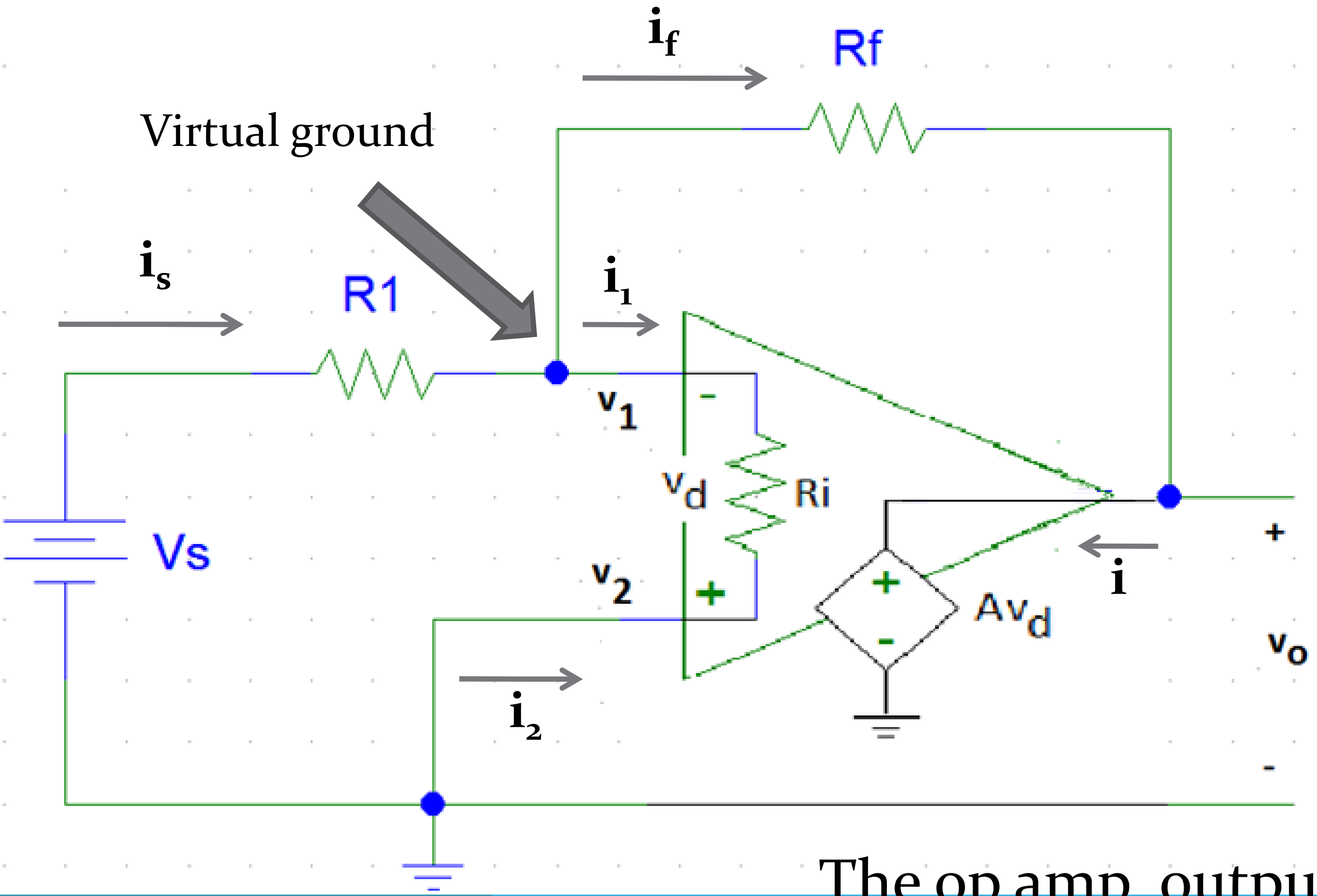
EXAMPLE #2 (CON'T)



For an almost ideal op amp, Ri = ∞ Ω and Ro = 0 Ω.

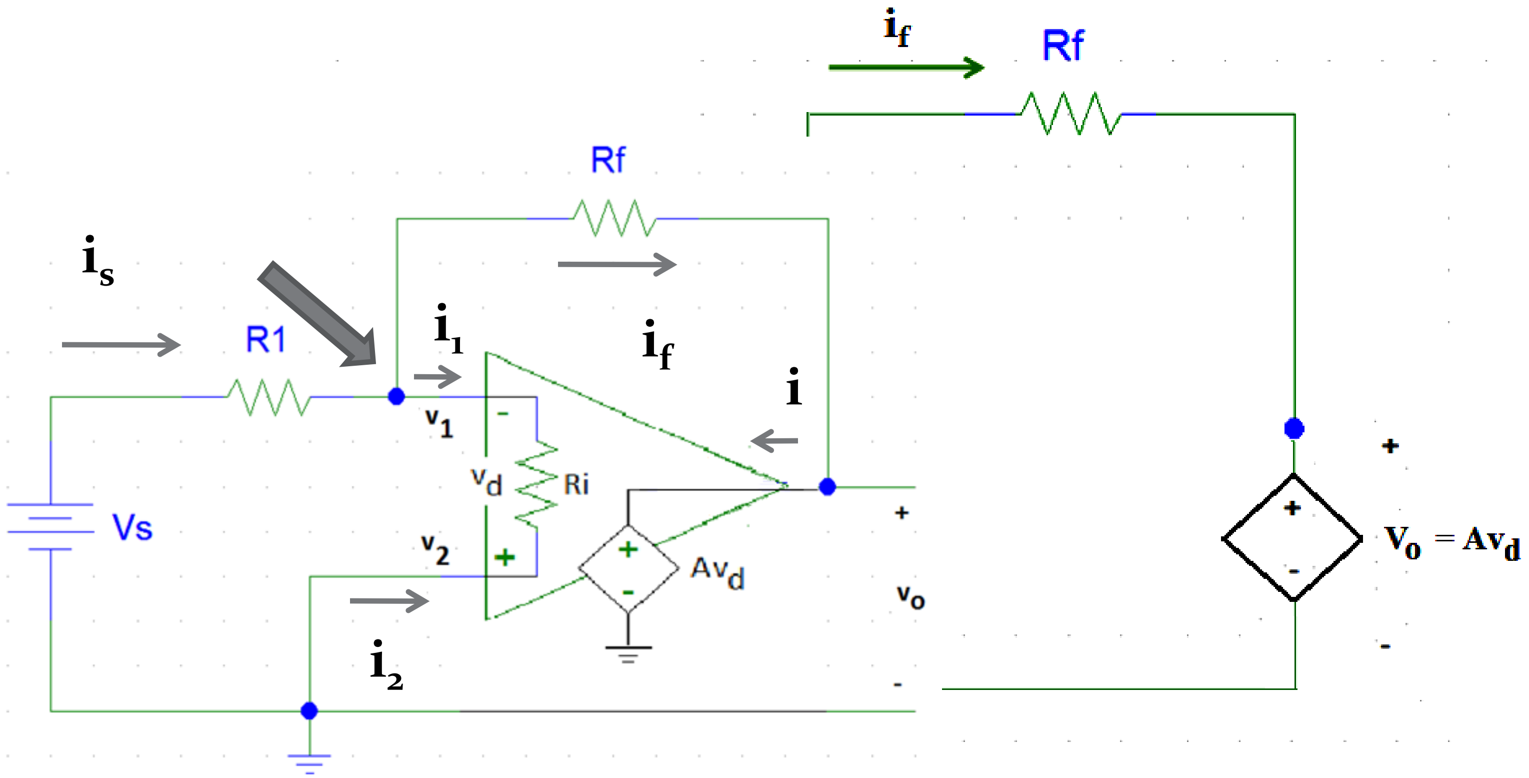
The output voltage will never reach V^+ or V^-.

EXAMPLE #2 (CON'T)

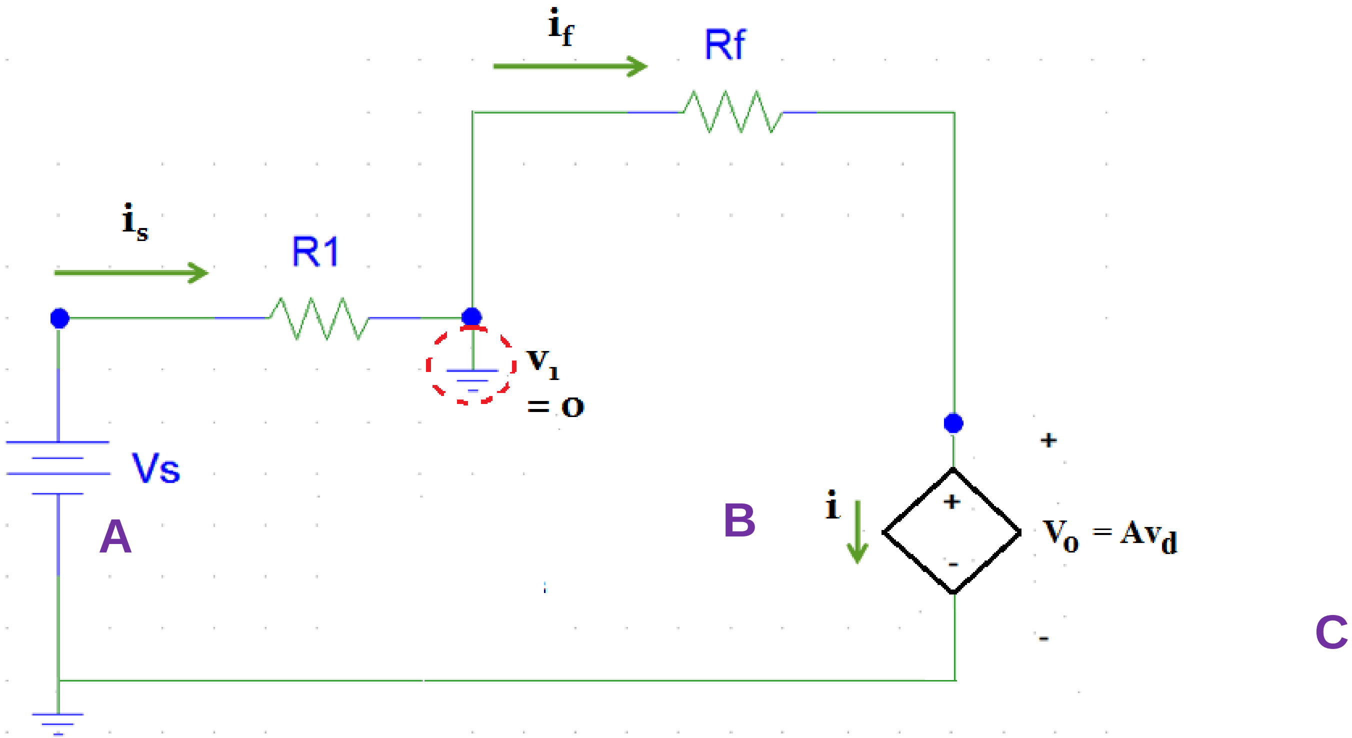


The op amp outputs a voltage Vo such that V1 = V2.

EXAMPLE #2 (CON'T)



EXAMPLE #2: CLOSED LOOP GAIN



$$v_1 = 0V$$

$$V_S = R_1 i_s$$

$$v_o = -R_f i_f$$

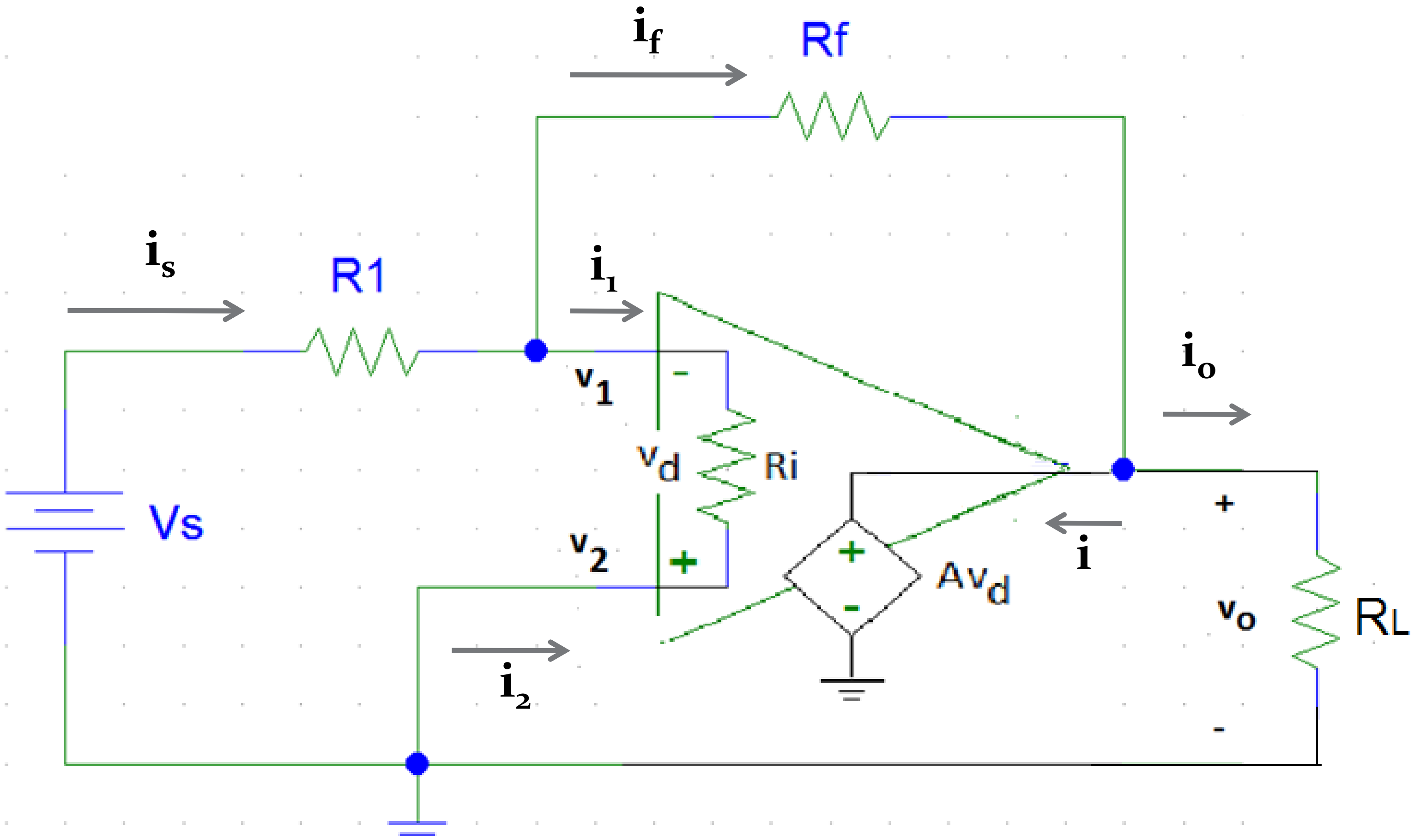
$$i_s = i_f = i$$

$$v_o / V_s = -R_f / R_1$$

$$A_V = -R_f / R_1$$

This circuit is known as an inverting amplifier.

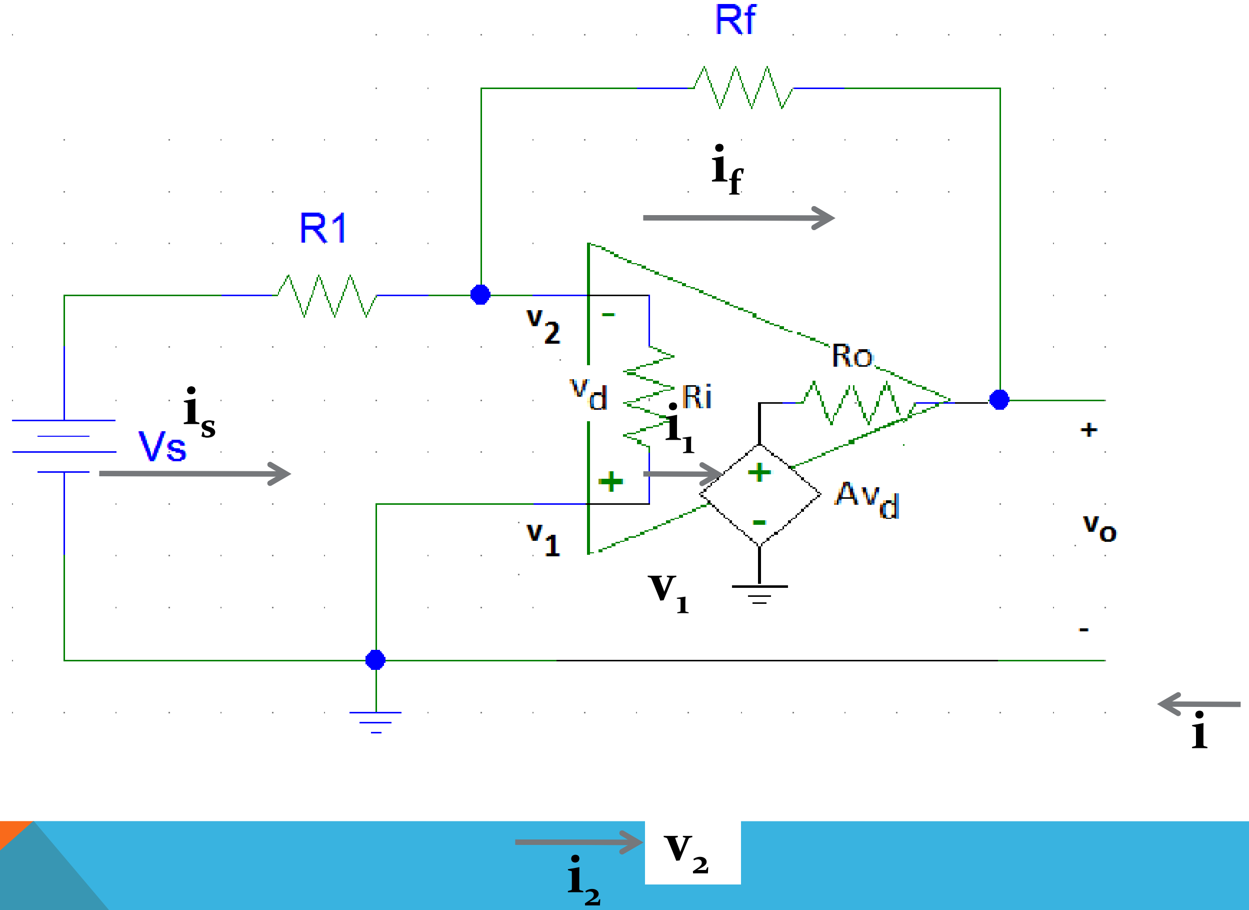
TYPES OF GAIN



TYPES OF CLOSED LOOP GAIN

Gain	Variable Name	Equation	Units
Voltage Gain	A_V	v_o/v_s	None or V/V
Current Gain	A_I	i_o/i_s	None or A/A
Transresistance Gain	A_R	v_o/i_s	V/A or Ω
Transconductance Gain	A_G	i_o/v_s	A/V or Ω^{-1}

EXAMPLE #3: CLOSED LOOP GAIN WITH REAL OP AMP



EXAMPLE #3 (CON'T)

$$i_s = i_1 + i_f$$

$$i = i_f$$

$$- i_1 = i_2$$

$$v_d = v_2 – v_1 = Ri\ (- i_1) = Ri\ (i_2)$$

$$V_o = Av_d - Ro(- i)$$

$$V_s = R1(i_s) – v_d$$

$$V_s = R1(i_s) + Rf(i_f) + V_o$$

$$V_o / V_s = (-R_f/R1)\{A\beta/[1 + A\beta]\}, \text{ where } \beta = R1/(R1+R_f)$$

SUMMARY

The output of an ideal op amp is a voltage from a dependent voltage source that attempts to force the voltage at the inverting input terminal to equal the voltage at the non-inverting input terminal.

- Almost ideal op amp: Output voltage limited to the range between V^+ and V^-.

Ideal op amp is assumed to have Ri = ∞ Ω and Ro = 0 Ω.

- Almost ideal op amp: v_d = **0** V and the current flowing into the output terminal of the op amp is as much as required to force $v_1 = v_2$ when $V^+ < v_o < V^-$.

Operation of an op amp was used in the analysis of voltage comparator and inverting amplifier circuits.

- Effect of Ri < ∞ Ω and Ro > **0** Ω was shown.