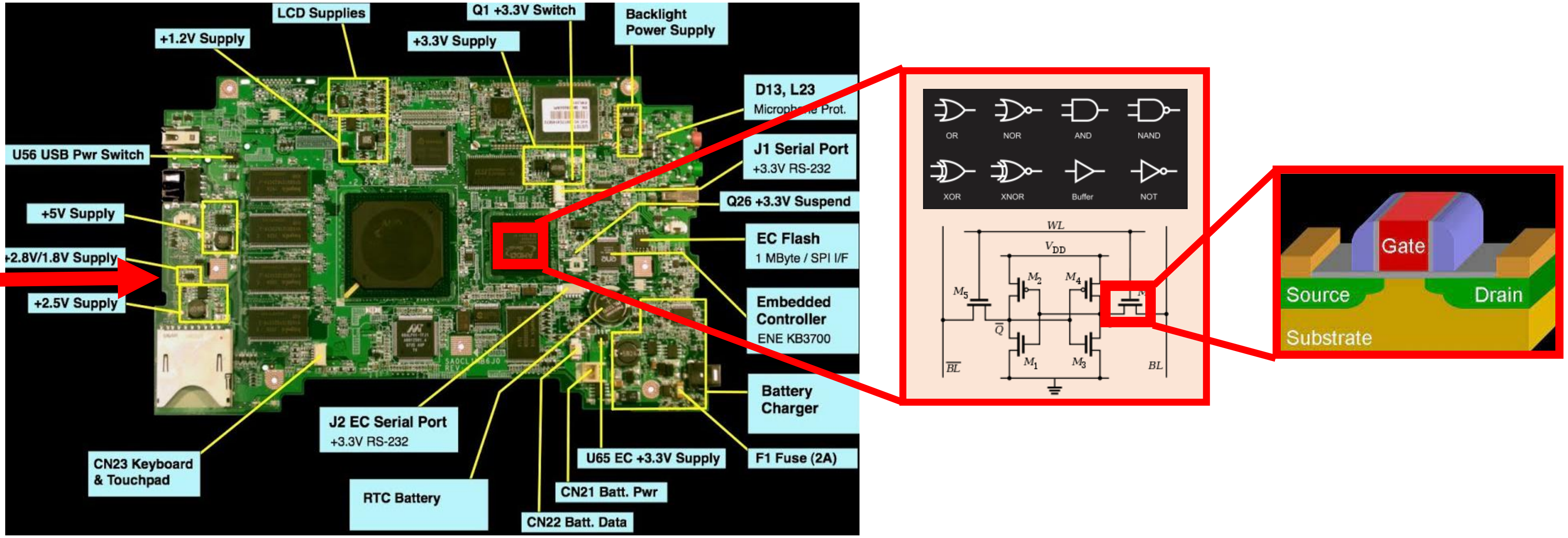

ESC201: Introduction to Electronics

Module 5: Amplifiers

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Assistant Professor,
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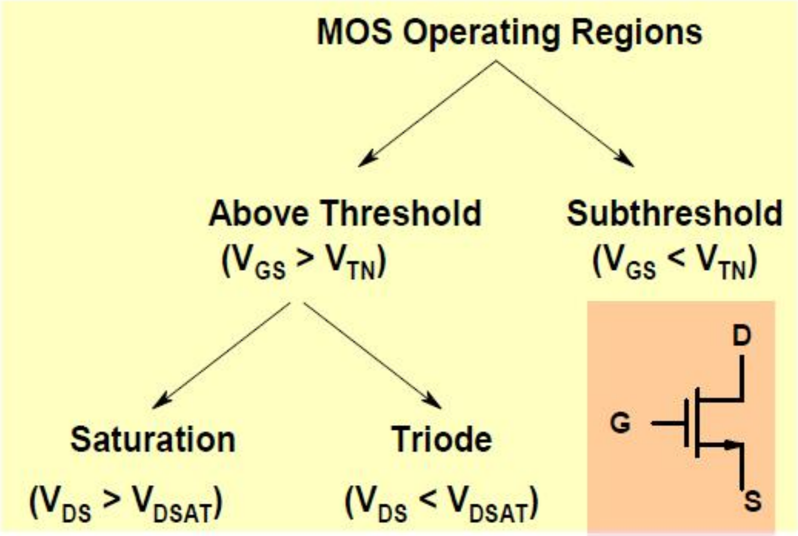
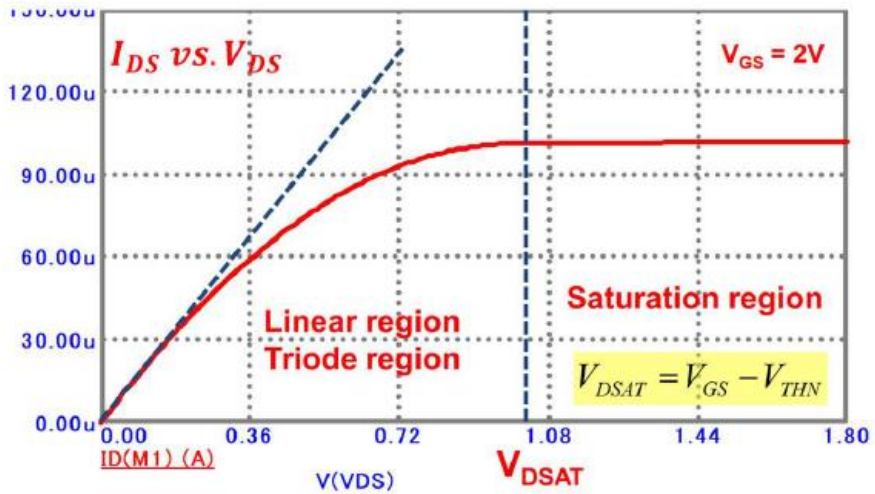
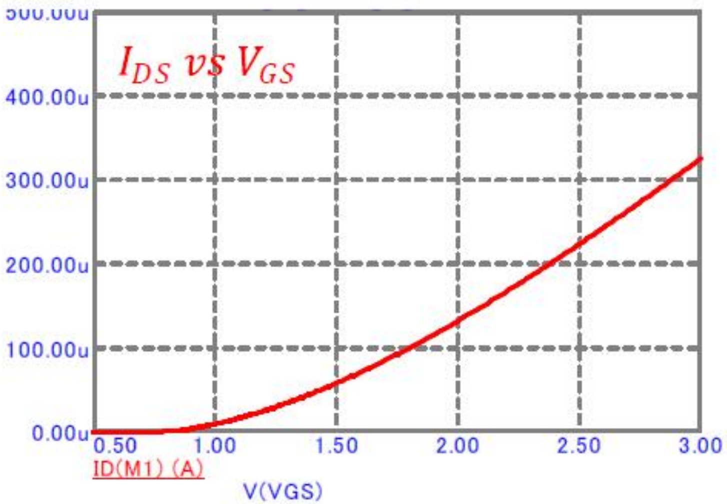
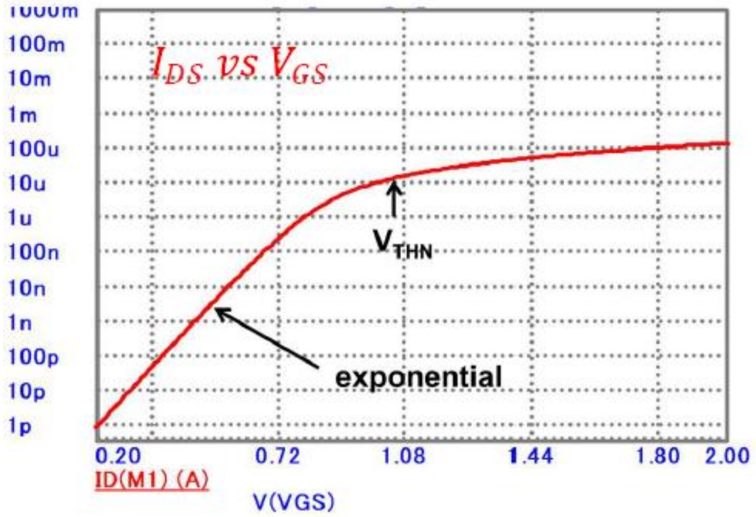
IIT Kanpur

Factors Determining Current

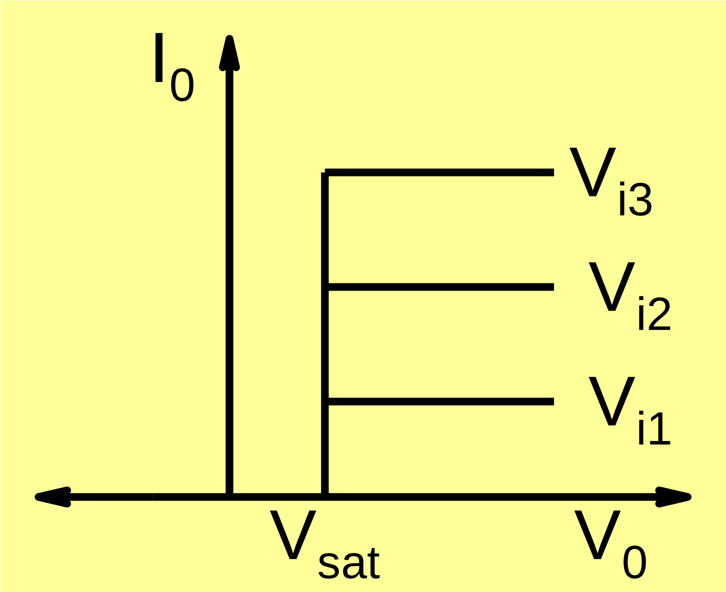


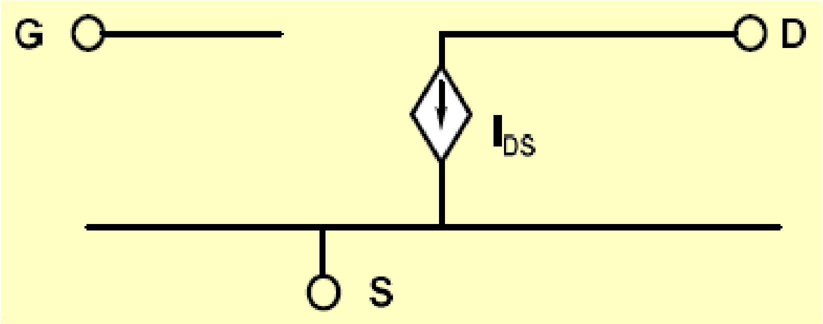






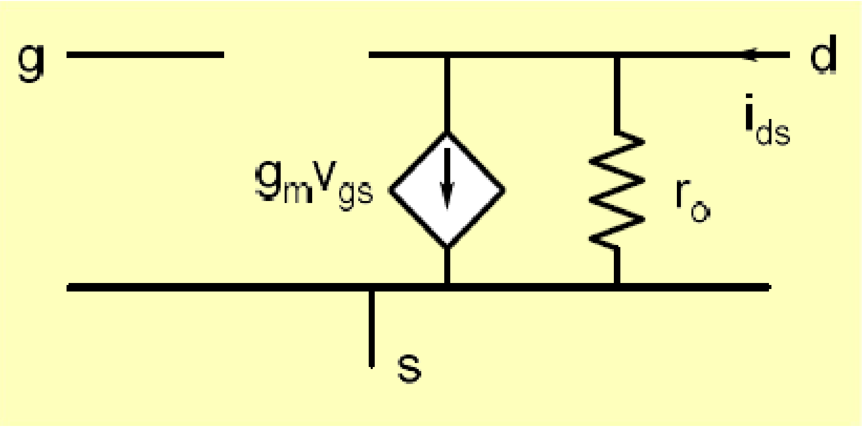
DC and AC model of a MOSFET





$$I_{DS} = \frac{\beta_N}{2}(V_{GS} - V_{THN})^2 \quad ; \ \beta_N = KP_N \times \frac{W}{L}$$

$$kP_N: Transconductance\ parameter\ \frac{\mu A}{V^2}$$

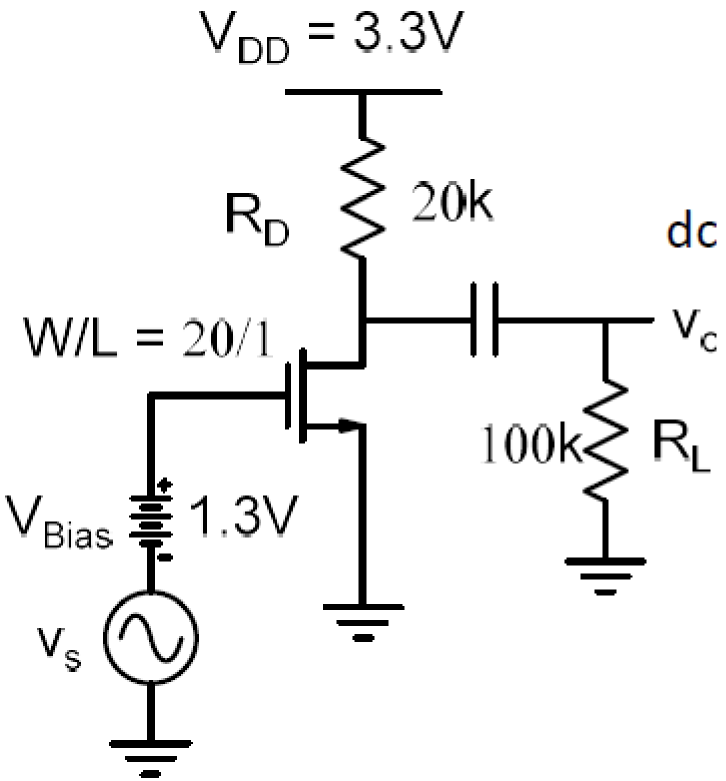


$$g_m = \frac{2I_{DSQ}}{V_{GSQ} - V_{THN}} = \sqrt{2I_{DSQ}\beta}$$

$$r_o = \frac{1}{\lambda_n I_{DSQ}}$$

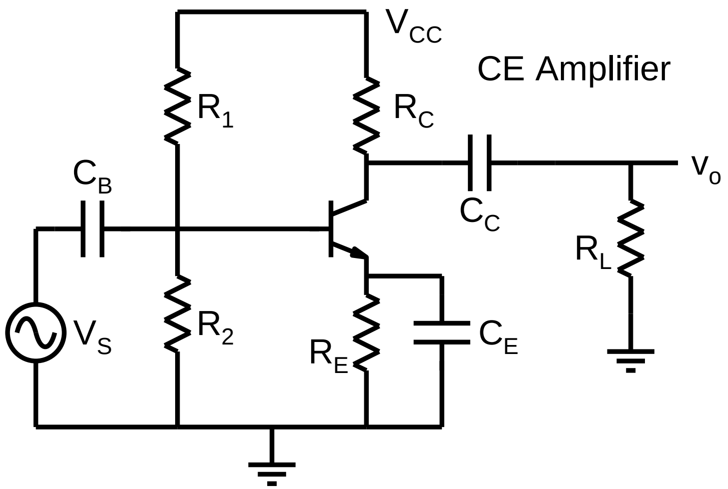
λ_N *is the channel length modulation parameter*

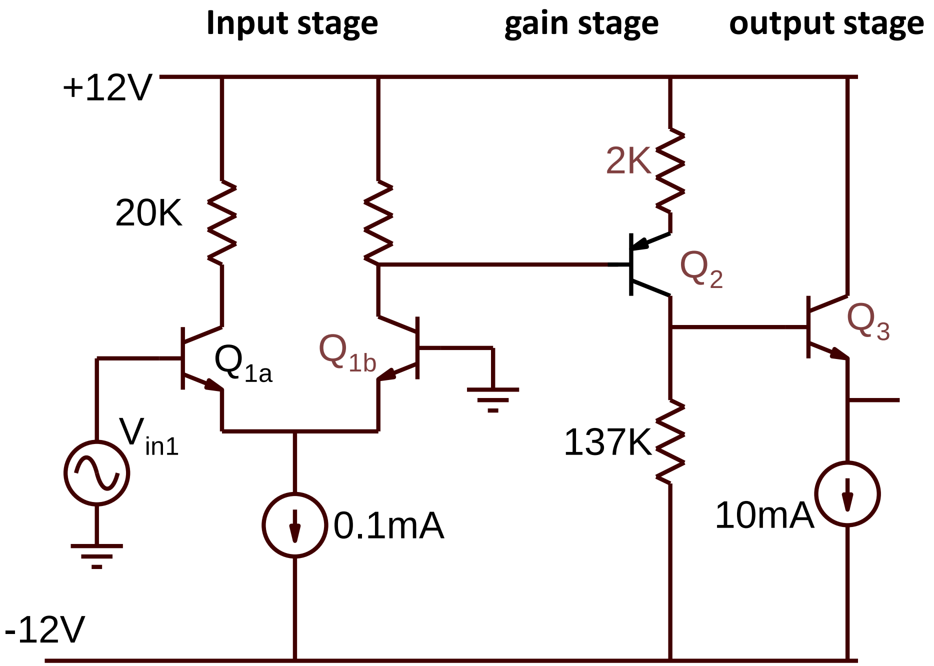
Example 3



Amplifier Design

Requires specialized knowledge





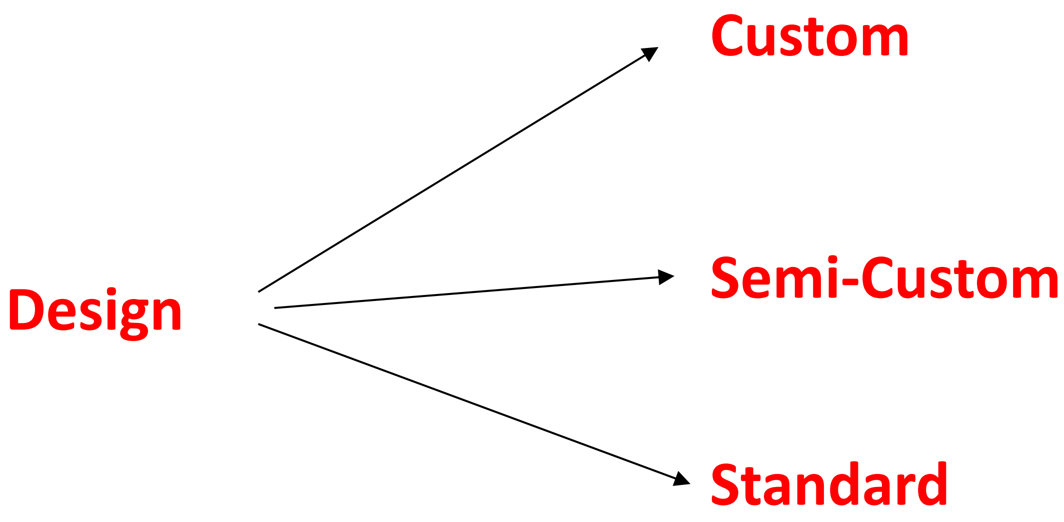
It is not possible for every user to design his/her own amplifier !

Handling Amplifier Design Complexity

Let experts have fun designing and implementing amplifiers!

They can make it available to everybody else as a commodity product

Although this is done, it does not satisfy all the users due to diverse requirements



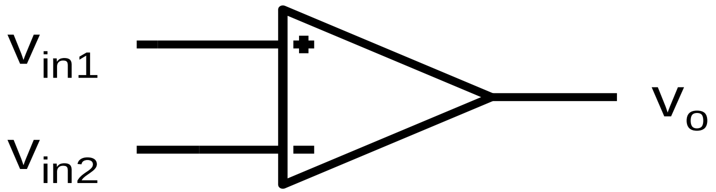
Semi-custom: partially competed design which is customized by the user

Op-amp is a good illustration of the advantages of semi-custom approach

Difference Amplifier

An amplifier that is:

- sensitive to difference in input voltages; and
- insensitive to what is common.



$$v_{id} = v_{in1} - v_{in2}$$

$$v_{ic} = \frac{v_{in1} + v_{in2}}{2}$$

$$v_o = A_d v_{id} + A_{cm} v_{ic}$$

A_d : Differential mode gain

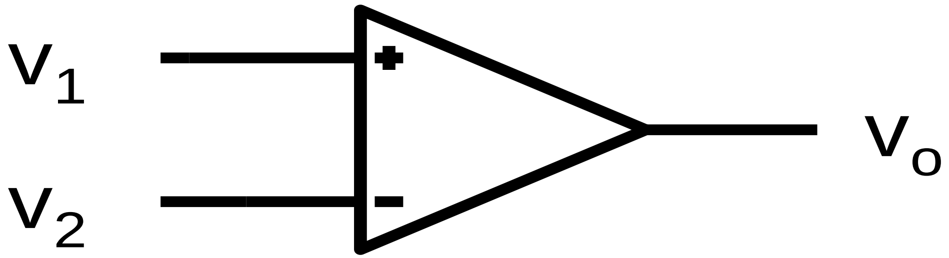
A_{cm} : Common mode gain

$$A_d \gg A_{cm}$$

$$\text{Common Mode Rejection Ratio}: CMRR = \frac{A_d}{A_{cm}}$$

Popularly called **op-amp**

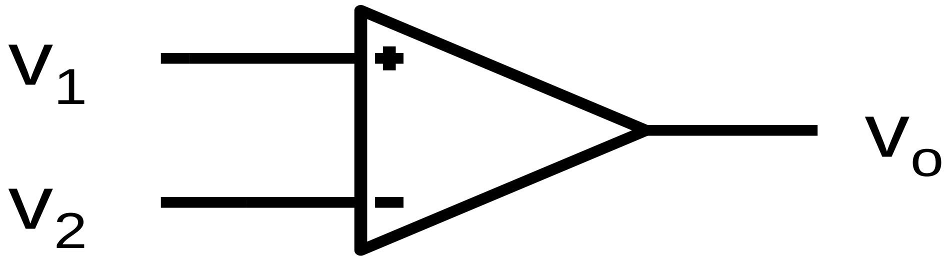
Operational Amplifier



A special kind of difference amplifier

1. Very High Differential-mode voltage gain
2. Very High Common mode Rejection ratio
3. Very High Input Resistance
4. Very Low output Resistance
5. ….

Ideal Operational Amplifier



1. Infinite Differential-mode voltage gain
2. Infinite Common mode Rejection ratio
3. Infinite Input Resistance
4. Zero output Resistance
5. ….

A Commercially Available Op-amp

LM741
Operational Amplifier

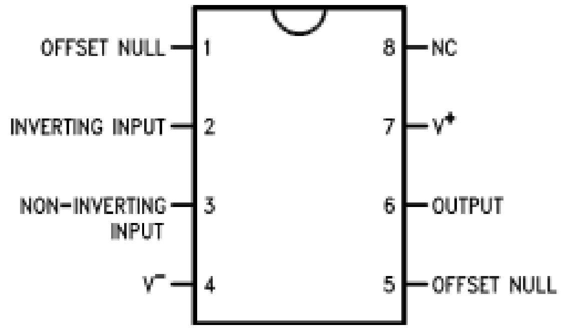
General Description

The LM741 series are general purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439 and 748 in most applications.

The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common mode range is exceeded, as well as freedom from oscillations.

The LM741C is identical to the LM741/LM741A except that the LM741C has their performance guaranteed over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

Dual-In-Line or S.O. Package



Electrical Characteristics

(V_{CC} = 15V, V_{EE} = -15V, T_A = 25°C, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Input Resistance (Note1)	R_I	$V_{CC} = \pm 20V$		0.3	2.0	-	MΩ
Large Signal Voltage Gain	G_V	$R_L \geq 2k\Omega$	$V_{CC} = \pm 20V$, $V_{O(P-P)} = \pm 15V$	-	-	-	V/mV
			$V_{CC} = \pm 15V$, $V_{O(P-P)} = \pm 10V$	20	200	-	
Common Mode Rejection Ratio	CMRR	$R_S \leq 10k\Omega$, $V_{CM} = \pm 12V$		70	90	-	dB
		$R_S \leq 50\Omega$, $V_{CM} = \pm 12V$		-	-	-	

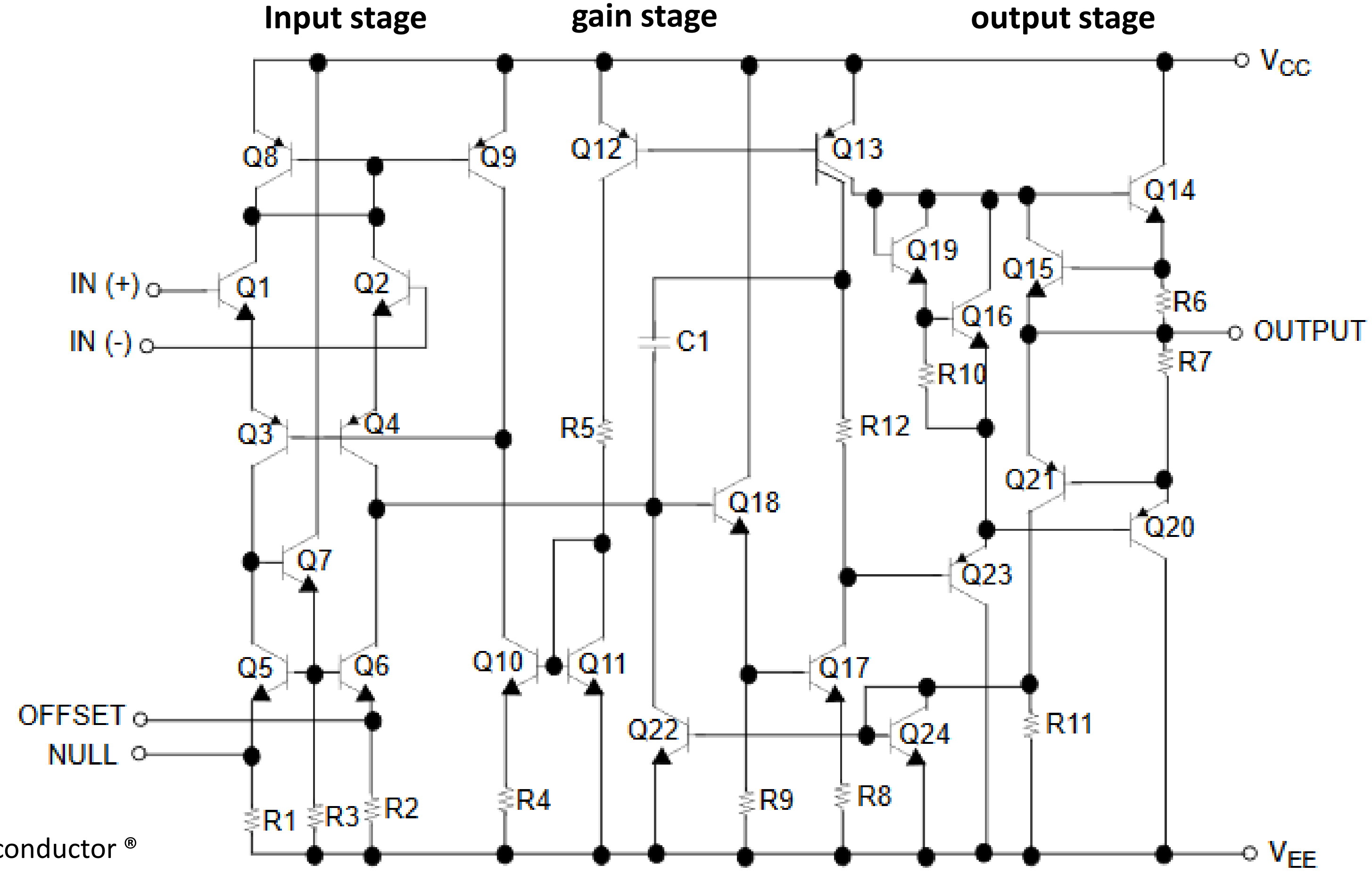
Note:
1. Guaranteed by design.

Fairchild Semiconductor ®

Op-amp Circuit

- The circuit is appears to be complicated
- Circuit contains several transistors and resistors.

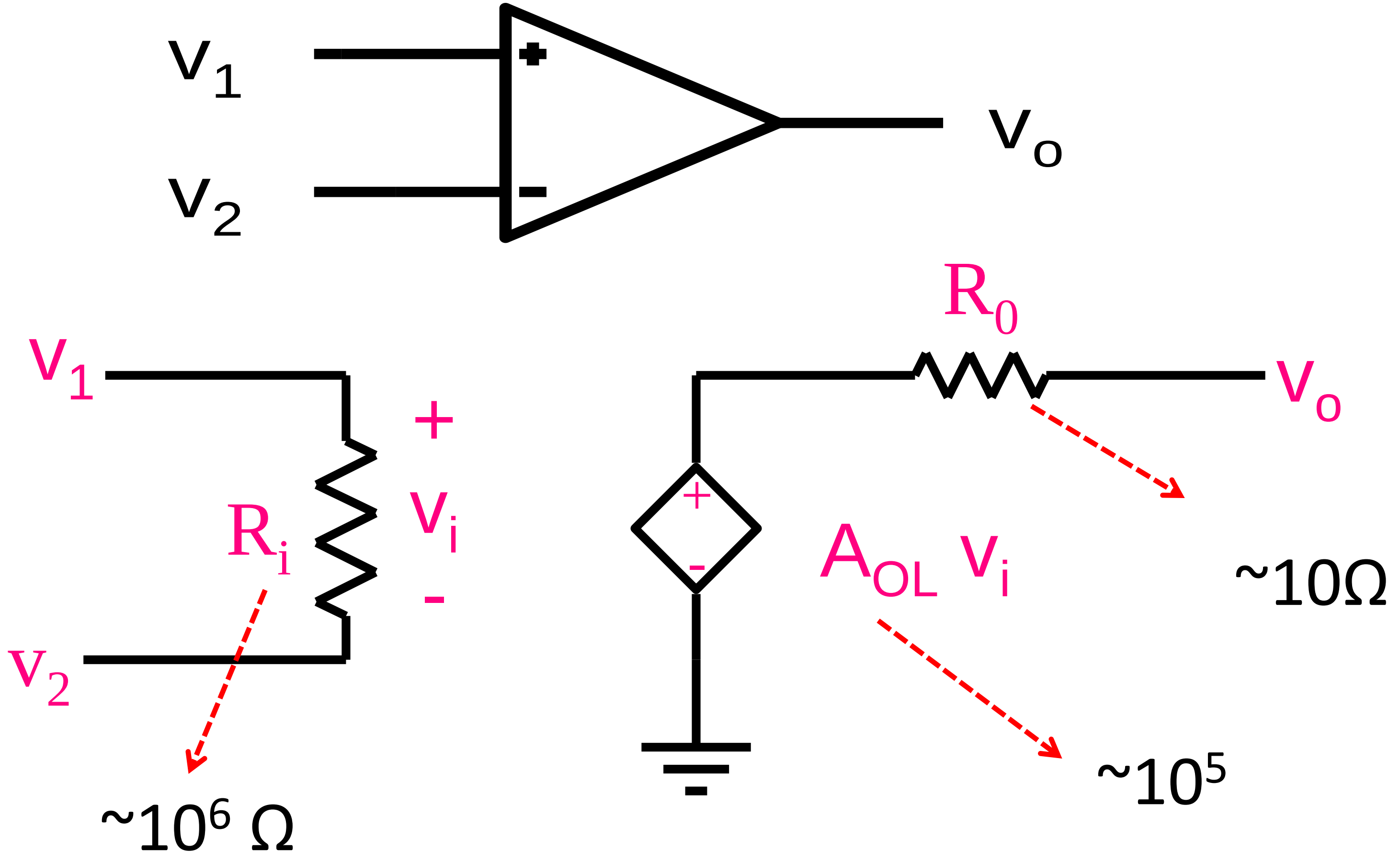
Schematic Diagram



Fairchild Semiconductor ®

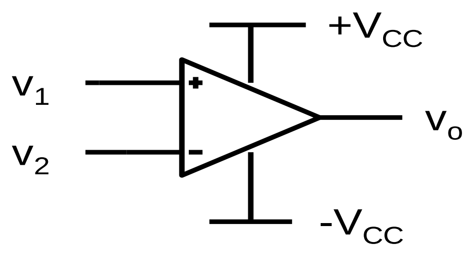
Equivalent Circuit Model

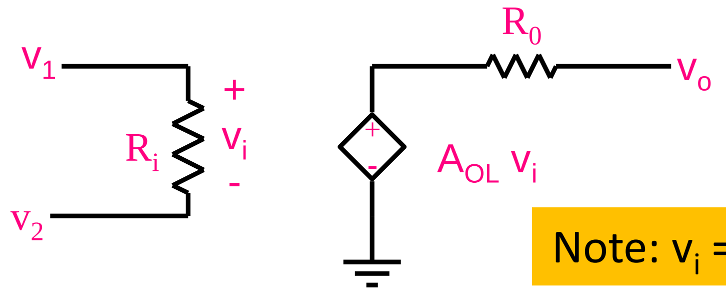
A simple equivalent circuit model of an op-amp



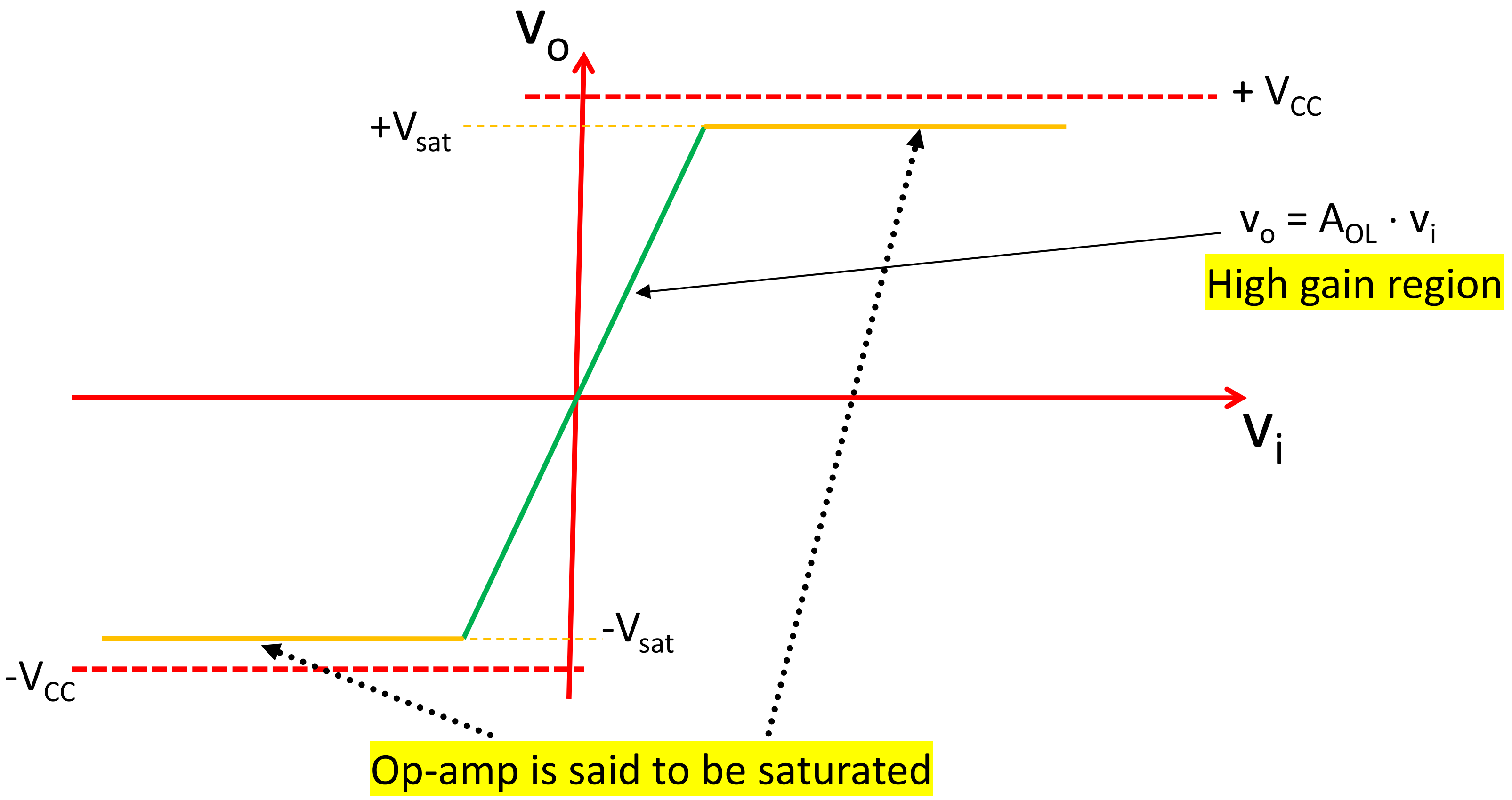
This assumes very high CMRR

Regions of Operation of Op-amp

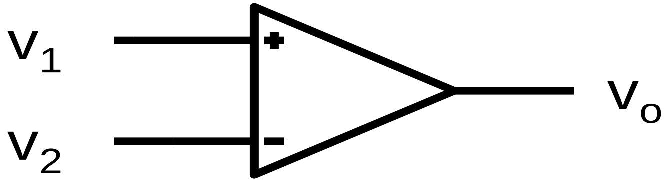


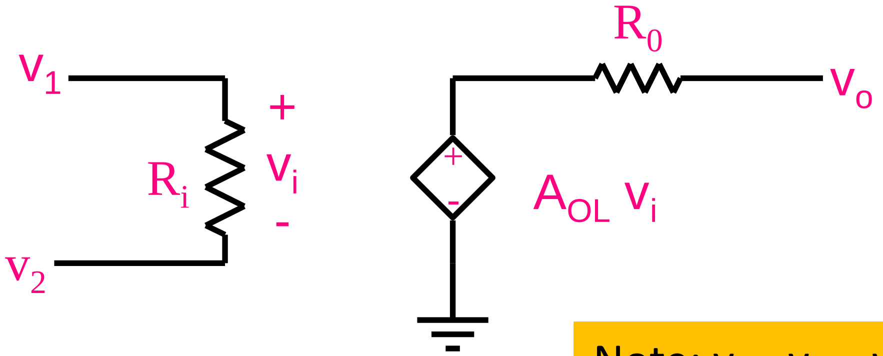


Note: $v_i = v_1 - v_2$



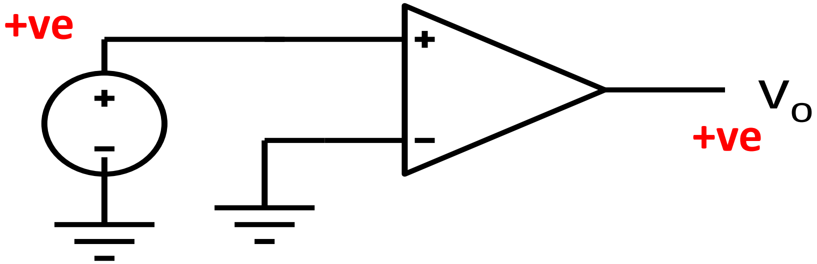
Choice of Input Terminals



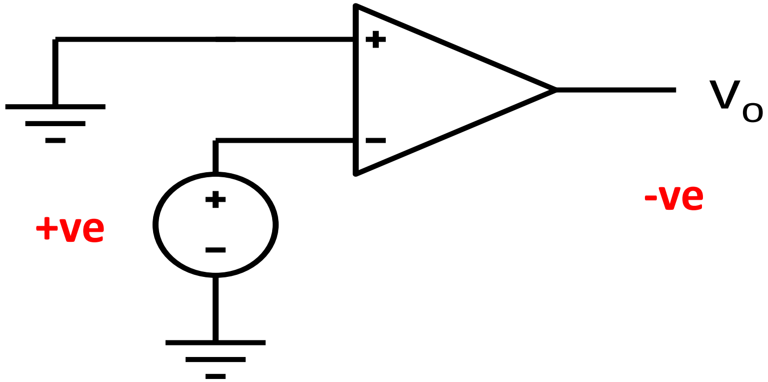


Note: $v_i = v_1 - v_2$

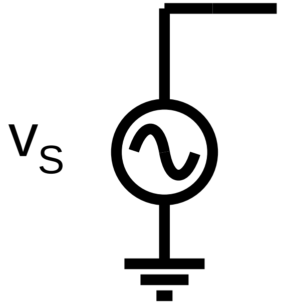
Input to positive terminal

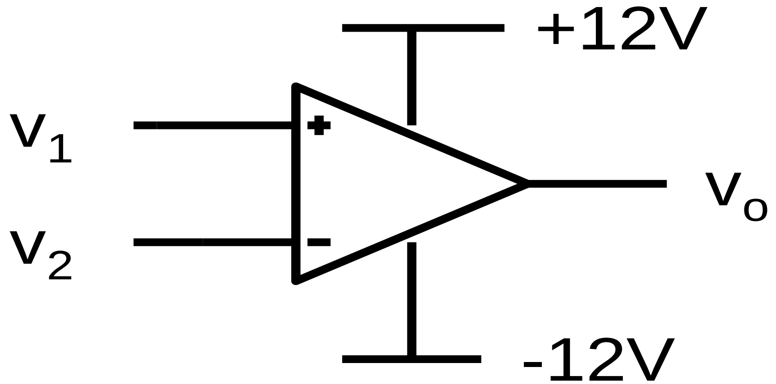


Input to negative terminal

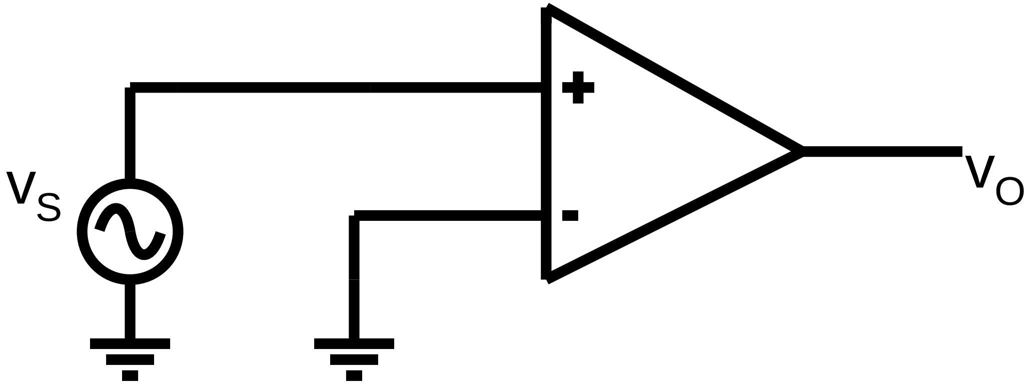


Amplifying an Input Signal

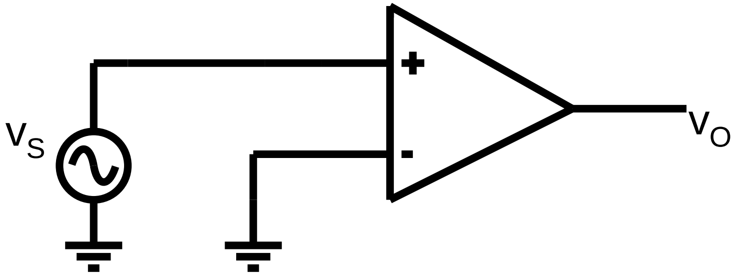




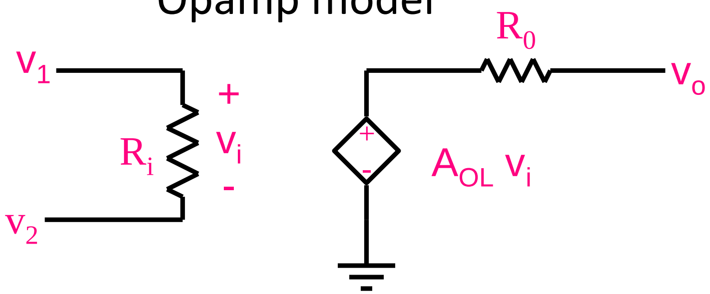
$v_s = 1 \cdot \sin(\omega t)$ mV

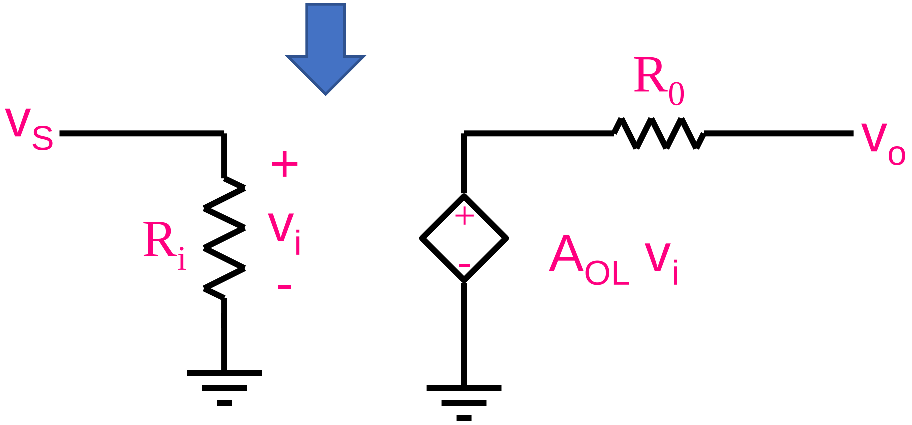


The Output value?



Opamp model





We know gain $A_{OL} \sim 10^5$

$$v_o \;=\; A_{OL} \cdot v_s \;=\; 10^2 \cdot \sin(\omega t)\ \text{V}$$

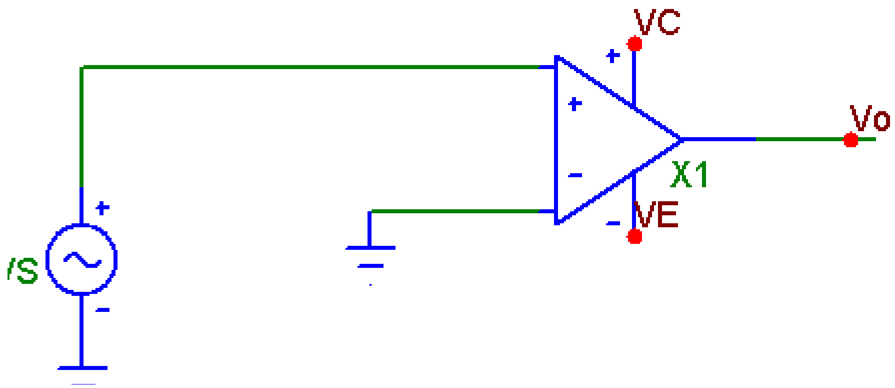
But opamp voltage is limited to* $\pm 12V$

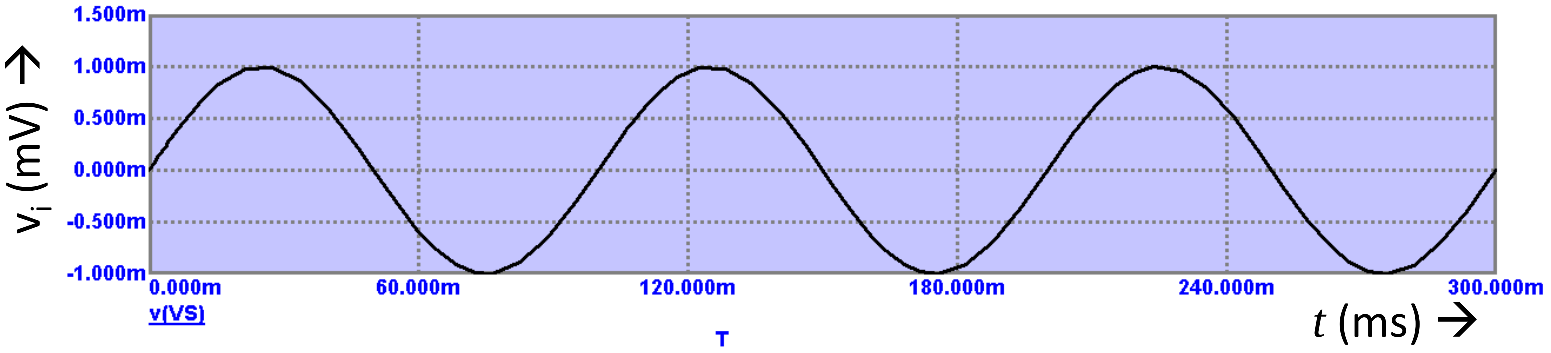
* Op-amp supply voltage may vary depending on the op-amp

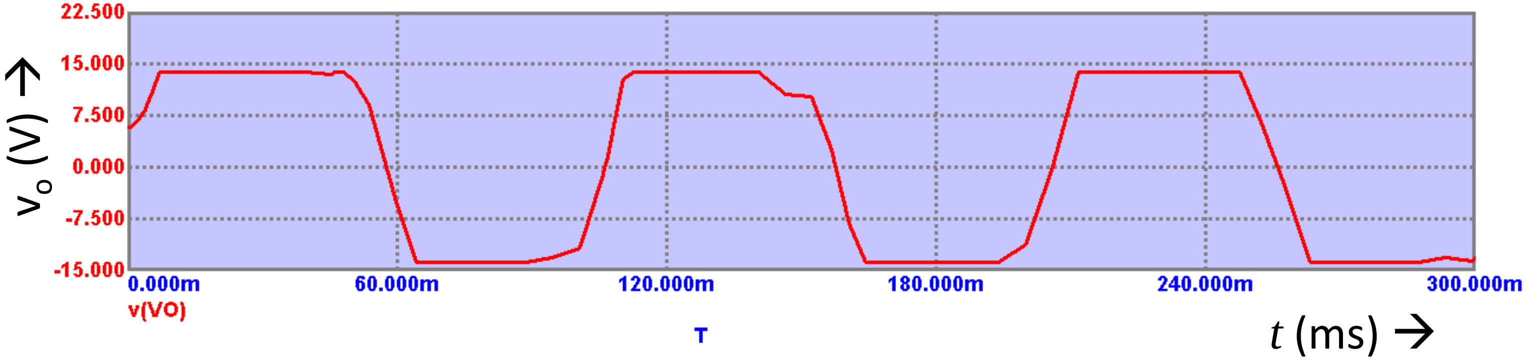
So, op-amp will enter saturation region of operations for some input voltages!

Also to note that A_{OL} is not precisely defined and can vary with op-amps

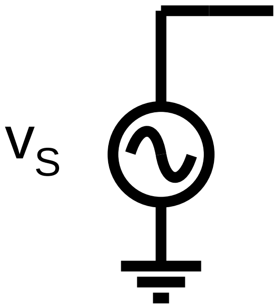
Simulation Results



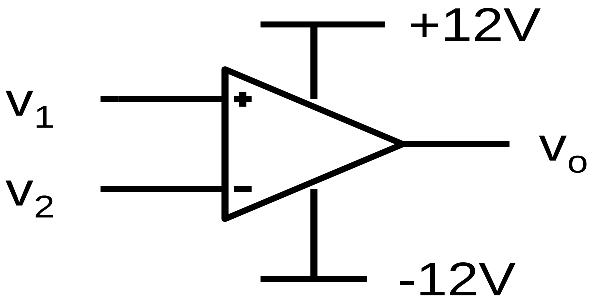


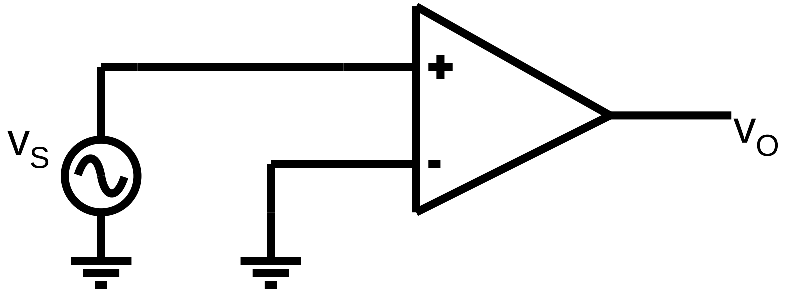


How to amplify not so small signals?



$v_s = 1 \cdot \sin(\omega t)$ mV



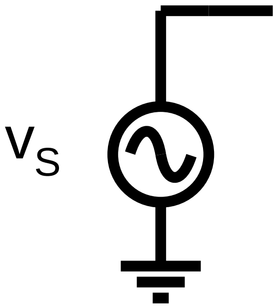


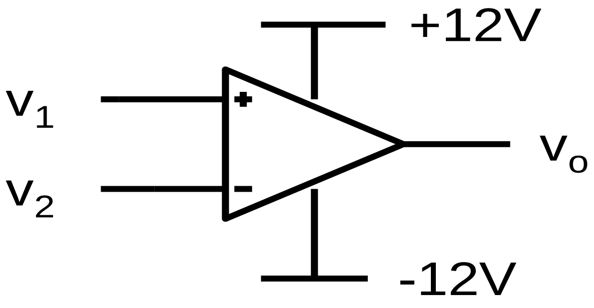
1. Attenuate the signal to 0.1mV and then amplify ? ☺
2. Or …….

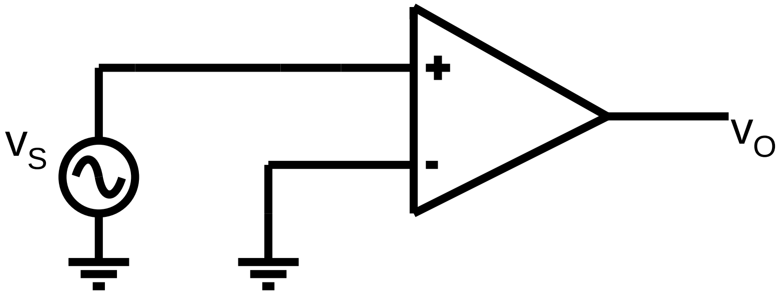
And how do we tackle the variation in value of A_{OL}?
Precise value of A_{OL} varies from device to device

The electronic circuit designers again come to the rescue!

How to amplify not so small signals?







$v_s = 1 \cdot \sin(\omega t)$ mV

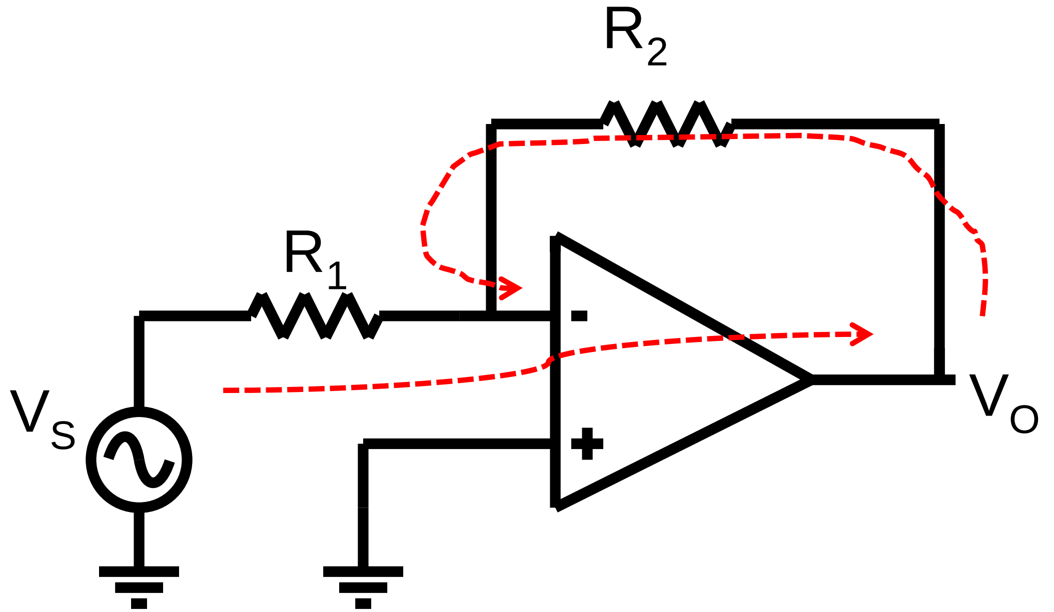
1. Attenuate the signal to 0.1mV and then amplify ? ☺
2. Or …….

And how do we tackle the variation in value of A_{OL}?
Precise value of A_{OL} varies from device to device

The electronic circuit designers again come to the rescue!

A Better Solution

Use amplifier with negative **feedback**



$$\frac{v_O}{v_S} = -\frac{R_2}{R_1}$$

Feedback signal helps input voltage: positive feedback

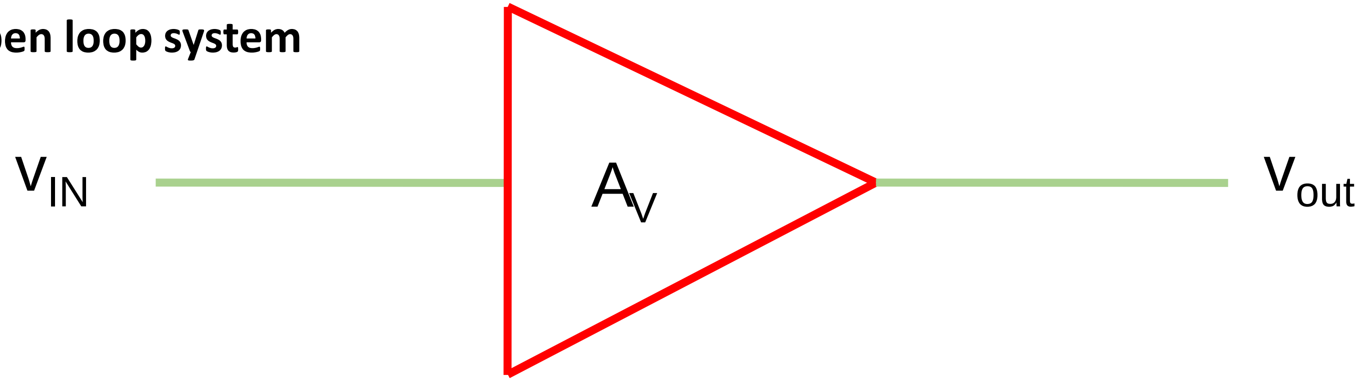
Feedback signal opposes input voltage: negative feedback (as in the circuit above)

Negative feedback helps overcome requirement of small signal restrictions!

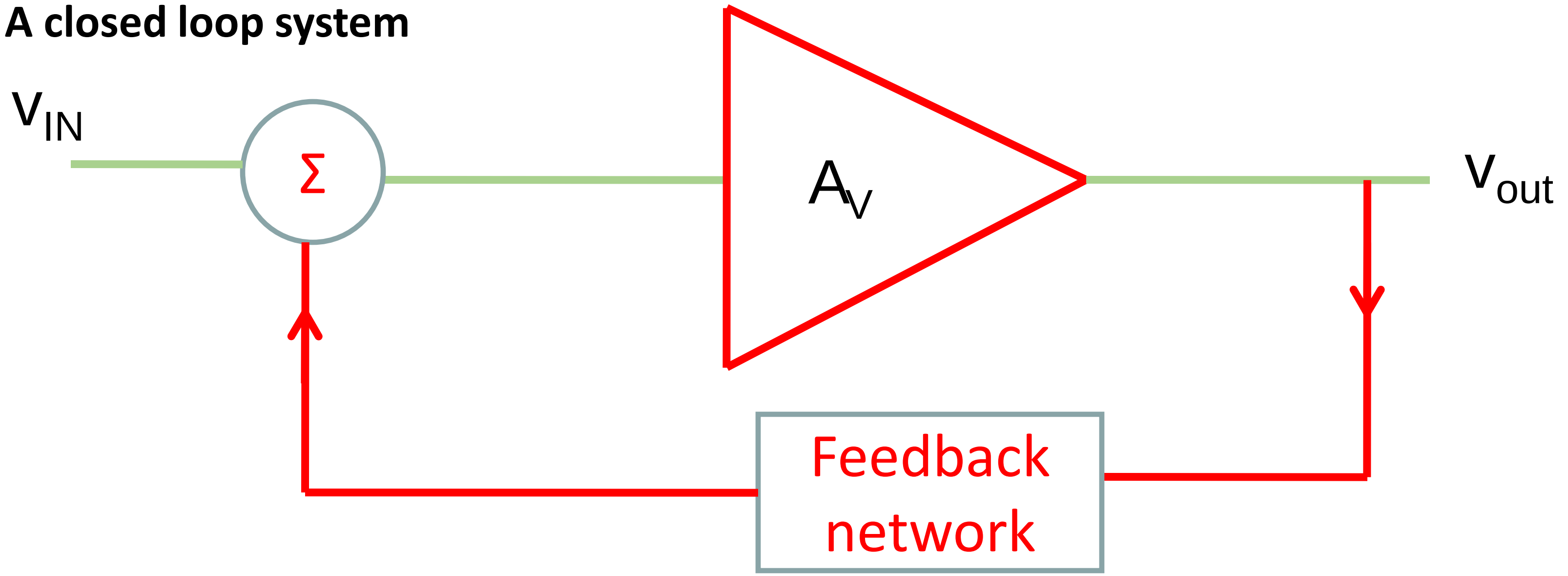
The actual gain here will depend overwhelmingly on resistances attached.
The amplification gain has to be high, but its precise value is not significant.

Feedback

Open loop system

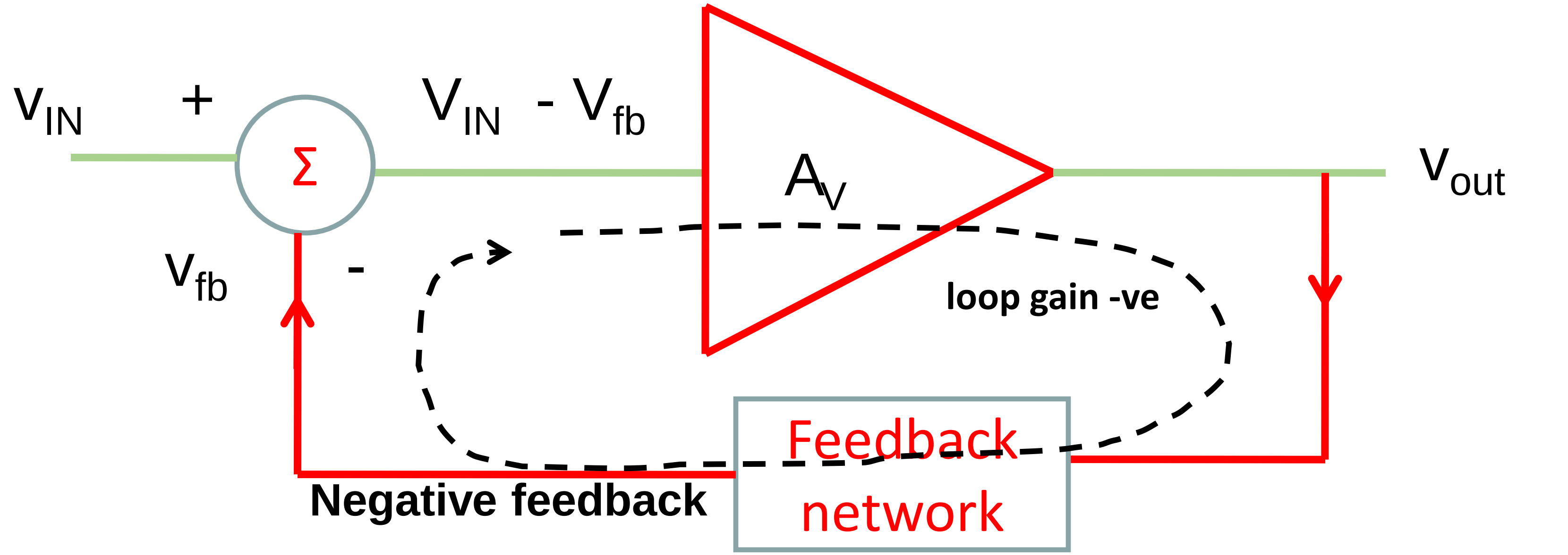


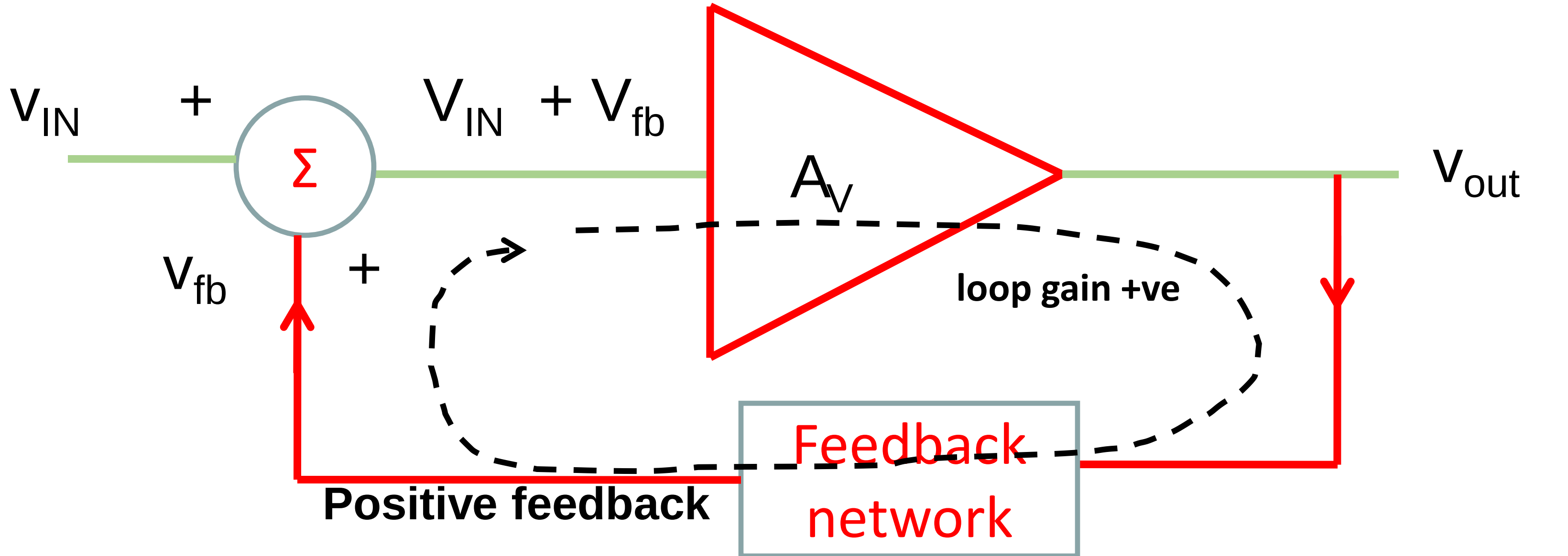
A closed loop system



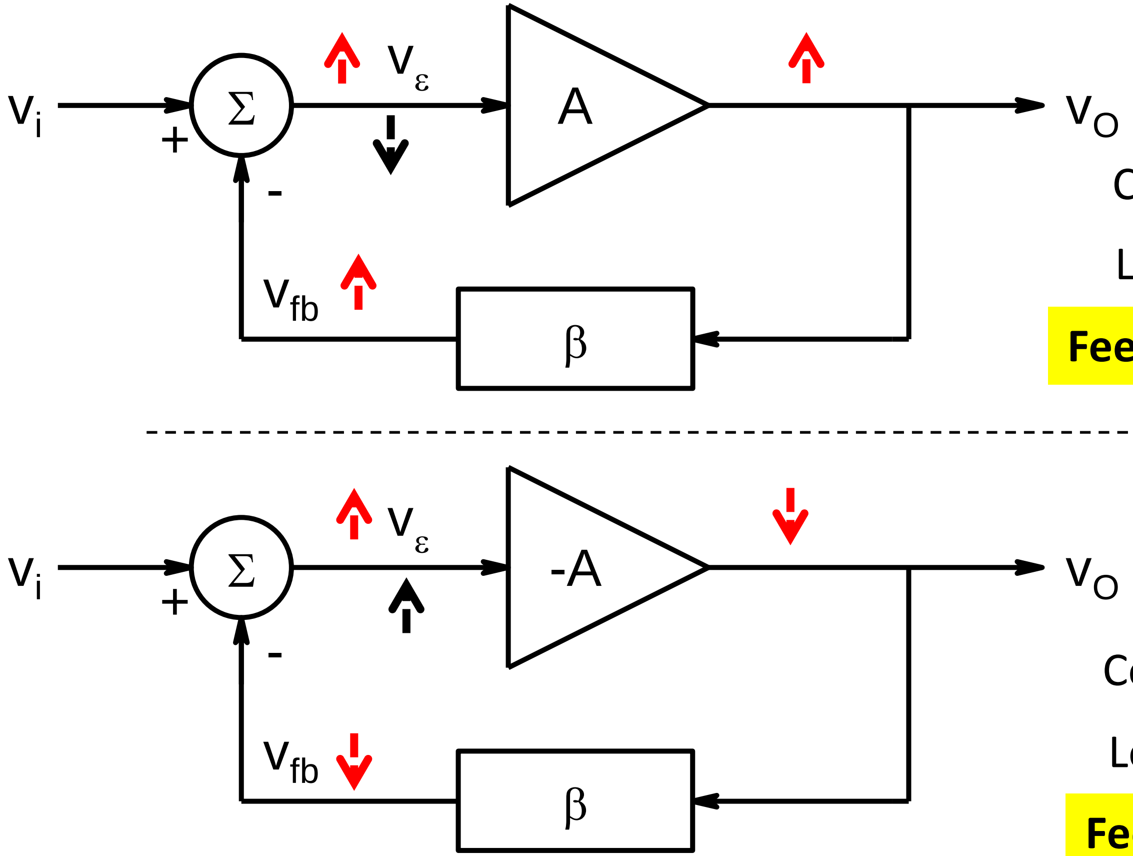
The summing circuit in closed loop system may add be adding or subtracting

Negative and Positive Feedback





Negative and Positive Feedback



Correction $v_\varepsilon \propto$ loop gain: $- A \cdot \beta$

Loop gain tries to make **$v_\varepsilon \rightarrow 0$**

Feedback Loop Gain: negative

Correction $v_\varepsilon \propto$ loop gain: $+ A \cdot \beta$

Loop gain keeps increasing $|v_\varepsilon|$

Feedback Loop Gain: positive

Note:

- The loop gain is evaluated by going around the feedback loop.
- Its sign will depend on signs of forward gain, feedback gain and add/substrate operation at the ‘summation’ point