Lecture #6

Operational Amplifiers (Op Amps)

Outline/Learning Objectives:

- Analyze and design simple signal-conditioning circuits based on OpAmps.
- Assess and understand some practical limitations of OpAmps.
- Use the electronics laboratory to investigate the electrical behavior of simple circuits and devices in co-requisite course.

From Chapter 11 in Jaeger, Chapter 5 in Spencer

Selected problems:

11.7, 11.13, 11.15, 11.41, 11.58, 11.78, 11.87

Why study operational amplifiers?

The operational amplifier is a fundamental building block of analog circuit design.

The name "operational amplifier" originates from the use of this type of amplifier to perform specific electronic circuit functions or operations, such as scaling, summation, and integration, in analog computers.

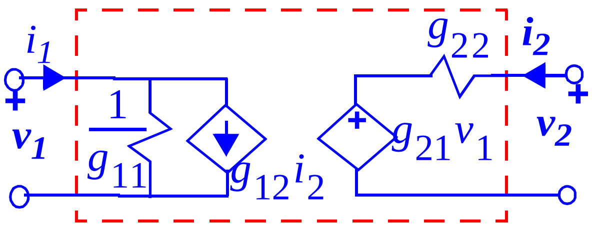
The Differential Amplifier

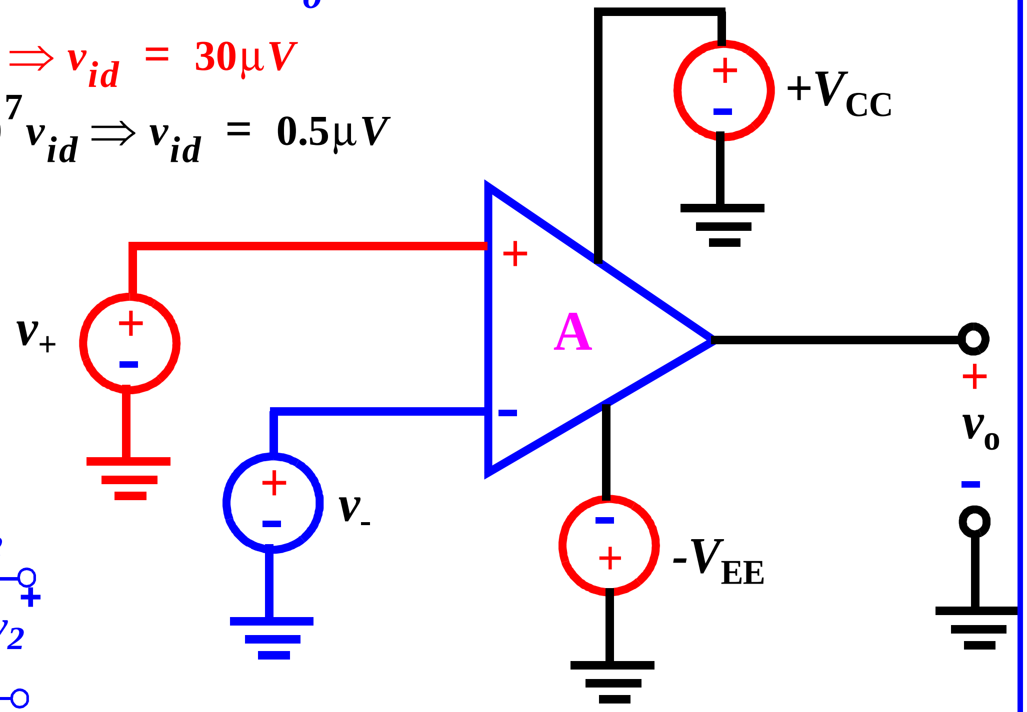
$v_o = A(v_+ - v_-) = A \cdot v_{id}$ $\quad$ $v_o = 6V$

For 741 OA: $v_o = 2x10^5 v_{id} \Rightarrow v_{id} = 30\mu V$

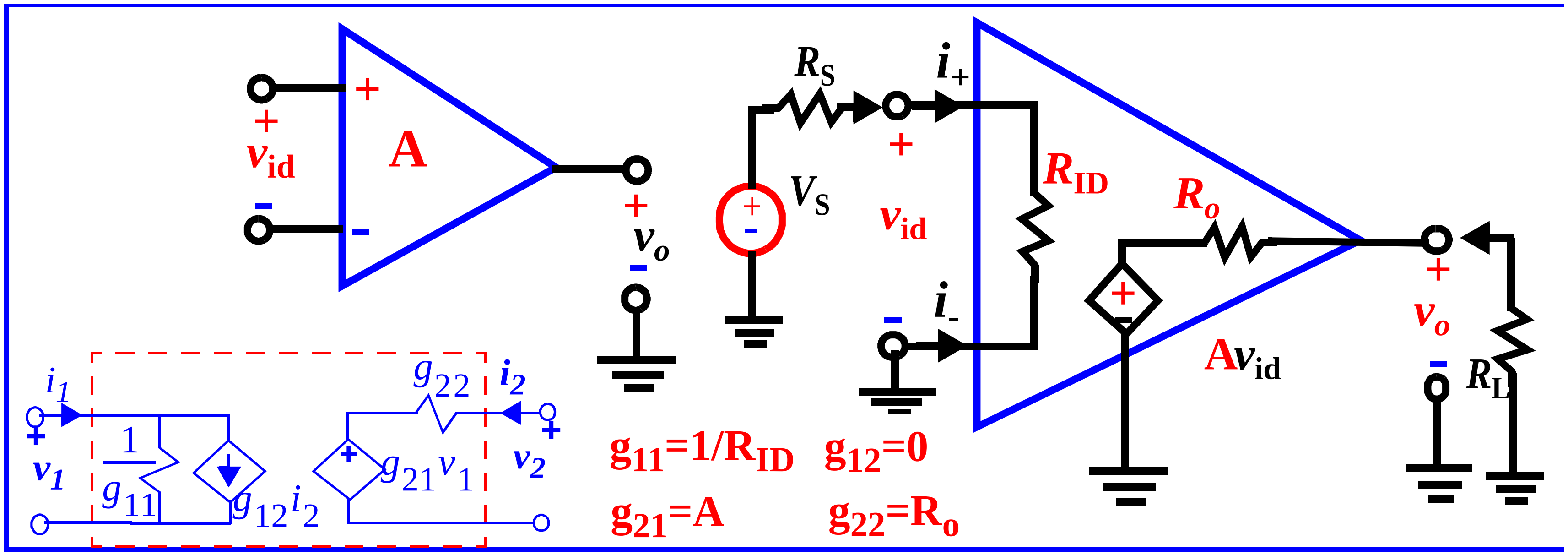
For OP 77 OA: $v_o = 1.2x10^7 v_{id} \Rightarrow v_{id} = 0.5\mu V$

$$\begin{bmatrix} i_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} \bullet \begin{bmatrix} v_1 \\ i_2 \end{bmatrix}$$





The Differential Amplifier_



Define - A, v_{id}, R_{ID} and R_o.

Explain the simplified g-parameter representation of the diff. amp.

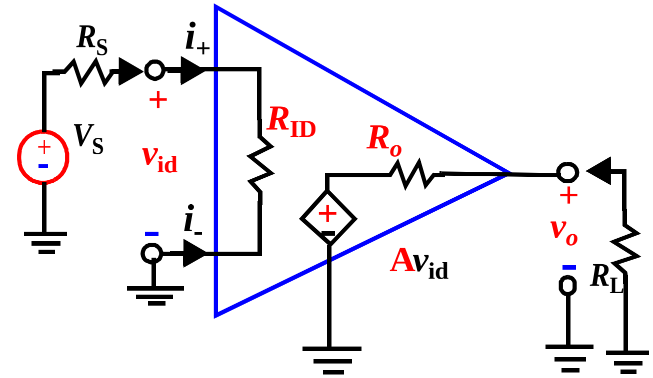
Diff. amp., $v_o = Av_{id} \bullet \frac{R_L}{R_O + R_L}$; $v_{id} = v_s \bullet \frac{R_{ID}}{R_{ID} + R_s}$. Note $v_s = v_{id} \bullet \frac{R_{ID} + R_s}{R_{ID}}$

Therefore, $A_V = \frac{v_o}{v_s} = A\frac{R_L}{R_O + R_L} \bullet \frac{R_{ID}}{R_{ID} + R_s}$.

In an ideal diff. amp, $R_{ID} \gg R_s$ and $R_O \ll R_L$ (fully mismatched R case), we have

$v_o = Av_{id}$, $v_{id} = v_s$ and $A_V = A$.

The Ideal Differential Amplifier



- Infinite gain (A); $A \to \infty \Rightarrow v_{id} \to 0$.
- Infinite input resistance; $R_{ID} \to \infty$.
- Zero output resistance; $R_O \to 0$.
- Zero input-offset voltage; $\pm v_{os} \to 0$.
- Zero IP-bias currents & offset current; $i_+ \to 0;\ i_- \to 0;\ i_{os} \to 0\ (i_{os} = i_+ - i_-)$.
- Infinite common-mode rejection ratio (CMRR).
- Infinite power supply rejection ratio (PSRR).
- Infinite output voltage range.
- Infinite output current capability.
- Infinite open-loop bandwidth.
- Infinite slew-rate.

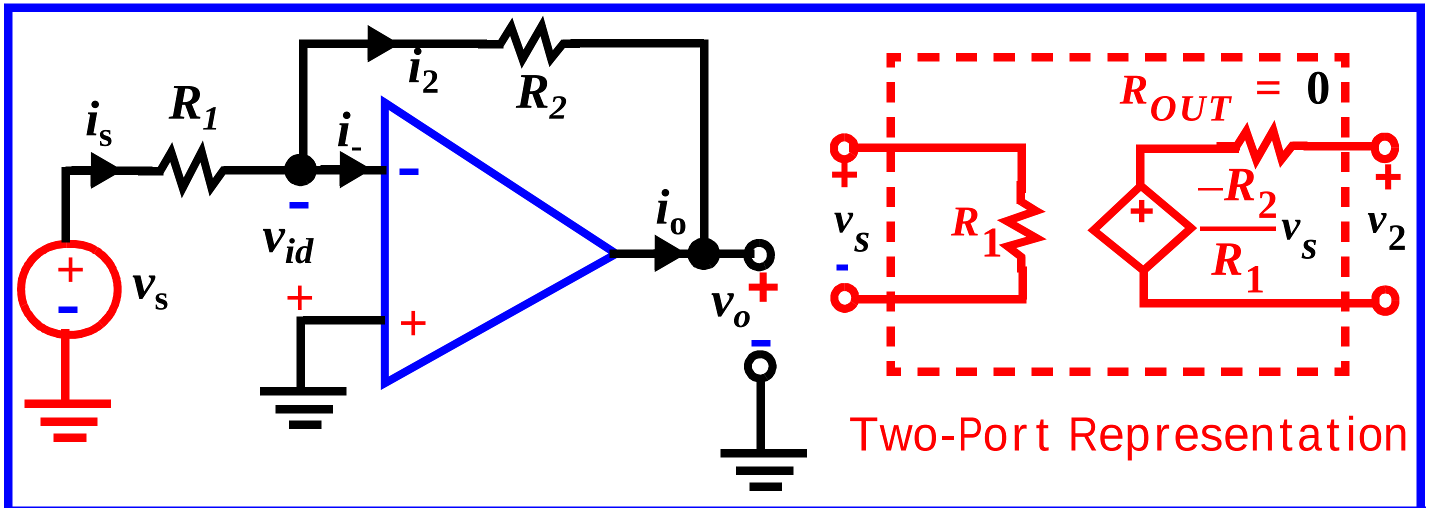
Real OA depart from ideal. However, the ideal characteristics implies that we need not be bothered by, for example, the OP loading characteristics.

Some conceptualizations to simplify OA analysis

(1) For V purposes, IP port appears as a SC, i.e., $v_{id} \to 0$

(2) For I purposes, IP port appears as an OC, i.e., $i_+ \to 0;\ i_- \to 0$.

The Inverting Amplifier



$$A_V = \frac{v_o}{v_s} = -\left(\frac{R_2}{R_1}\right) \qquad R_{IN} = \frac{v_s}{i_s} = R_1 \qquad R_{OUT} = \frac{v_x}{i_x} = 0$$

$v_+ = 0$ and $v_- = \frac{R_2}{R_1 + R_2} v_s + \frac{R_1}{R_1 + R_2} v_o = (1 - \beta) v_s + \beta v_o$

For inv. amp., $A_V = \frac{v_o}{v_s} = \left(1 - \frac{1}{\beta}\right) \bullet \frac{1}{1 + (A\beta)^{-1}}$. β - feedback factor.

$$\boxed{A_{V,\,ideal} = \lim_{A\beta \to \infty} (A_V) = \left(1 - \frac{1}{\beta}\right) = -\frac{R_2}{R_1}}.$$

The Inverting Amplifier

Suffers from low R_{IN} since cannot make R_{IN} too large because of A_V.

OP is phase shifted by π radians (180°) from IP. A_V depends only on the ratio of R's. This is important, e.g., R's can vary with temperature, but their ratio remains the same. That is, we can make a stable circuit using unstable components.

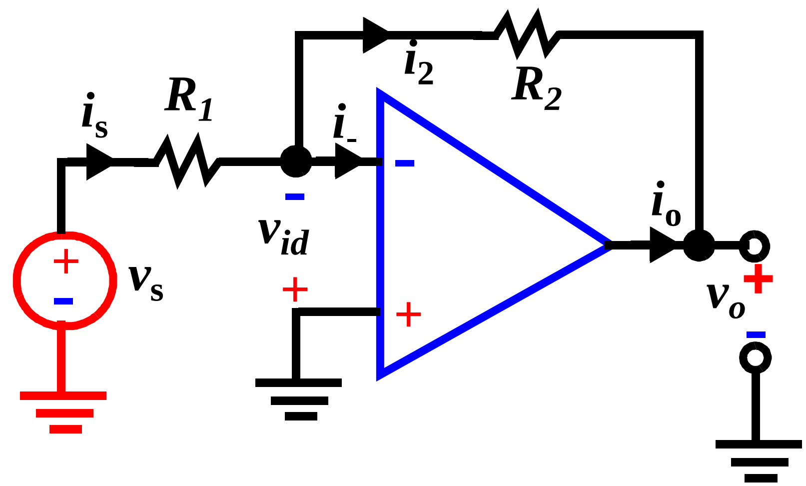
Example: Refer to the inverting amplifier circuit on the previous page, what is the voltage gain A_V if $R_1 = 80\ \Omega$, $R_2 = 8\ \text{k}\Omega$, and $v_S(t) = 0.15\sin(3000t)$ V. Write an expression for the current $i_S(t)$ and output voltage $v_O(t)$.

$$A_V = -\frac{R_2}{R_1} = -\frac{8k}{80} = -100$$

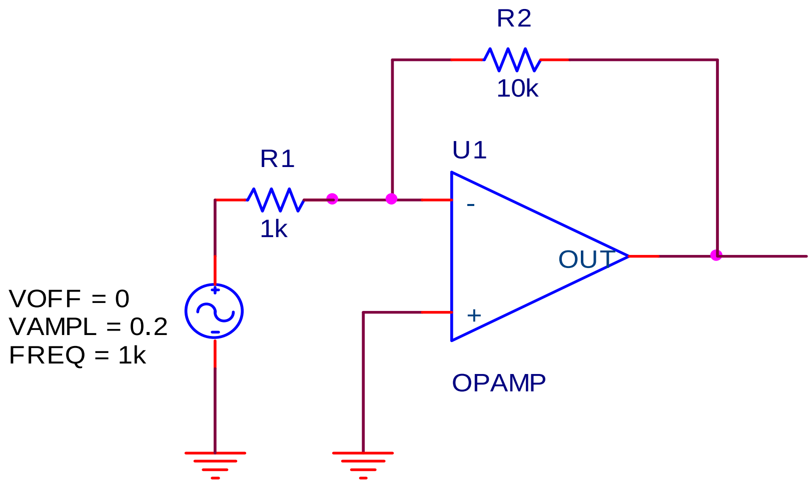
$$I_S = \frac{V_S}{R_1} = \frac{0.15}{80} = 1.875mA$$

$$\therefore i_S(t) = 1.875\sin(3000t)mA$$

$$v_O(t) = -15\sin(3000t)V$$



PSPICE EXAMPLE



Libraries:

*** Local Libraries :**

*** From [PSPICE NETLIST] section of C:\Program Files\OrcadLite\PSpice\PSpice.ini file:**

.lib "nom.lib"

***Analysis directives:**

.TRAN 0 20ms 0

.PROBE V(*) I(*) W(*) D(*) NOISE(*)

.INC ".\example2-SCHEMATIC1.net"

****** INCLUDING example2-SCHEMATIC1.net ******

*** source EXAMPLE2**

PSPICE EXAMPLE (Cont'd)

```
E_U1      N00043 0 VALUE {LIMIT(V(0,N00136)*1E6,-15V,+15V)}
R_R2      N00136 N00043  10k
R_R1      N00248 N00136  1k
V_V1      N00248 0
+SIN 0 0.2 1k 0 0 0
**** RESUMING example2-SCHEMATIC1-Example2Profile.sim.cir ****
.END
```