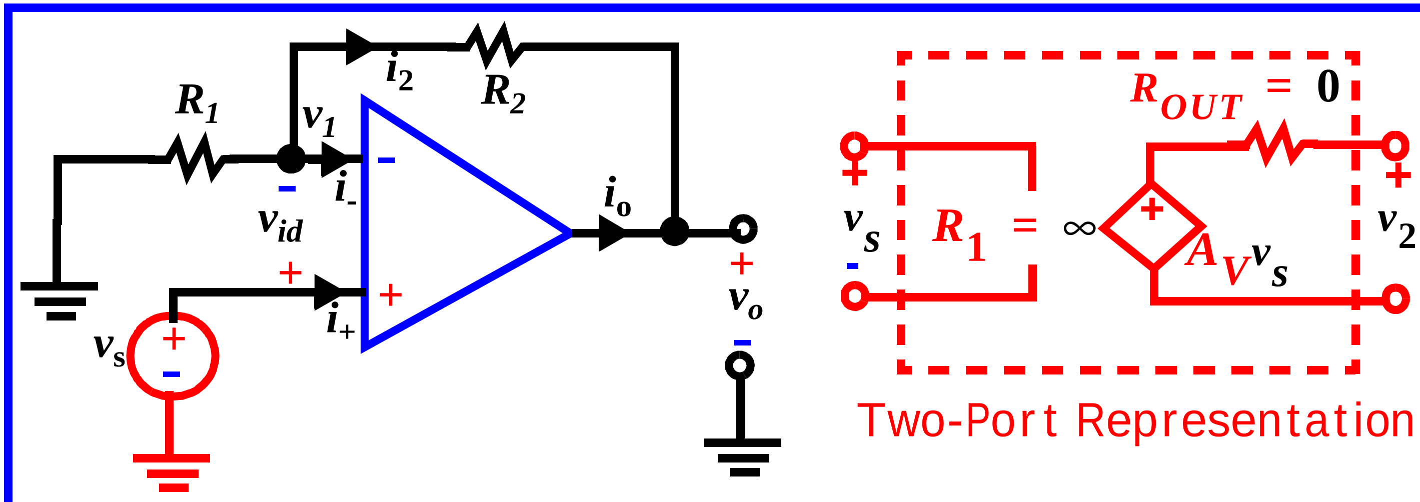
ECE 2EI4 - Lecture 7

We will discuss the following topics

- **Non-inverting amplifier**
- **Voltage follower**
- **Low Pass filter**
- **Integrator**
- **Two-port representation of amplifier**
- **Non-ideal non-inverting amplifier**
- **Gain error**

The Non-Inverting Amplifier



Two-Port Representation

$$A_V = \frac{v_o}{v_s} = 1 + \frac{R_2}{R_1} \qquad R_{IN} = \frac{v_s}{i_+} = \infty \qquad R_{OUT} = \frac{v_x}{i_x} = 0$$

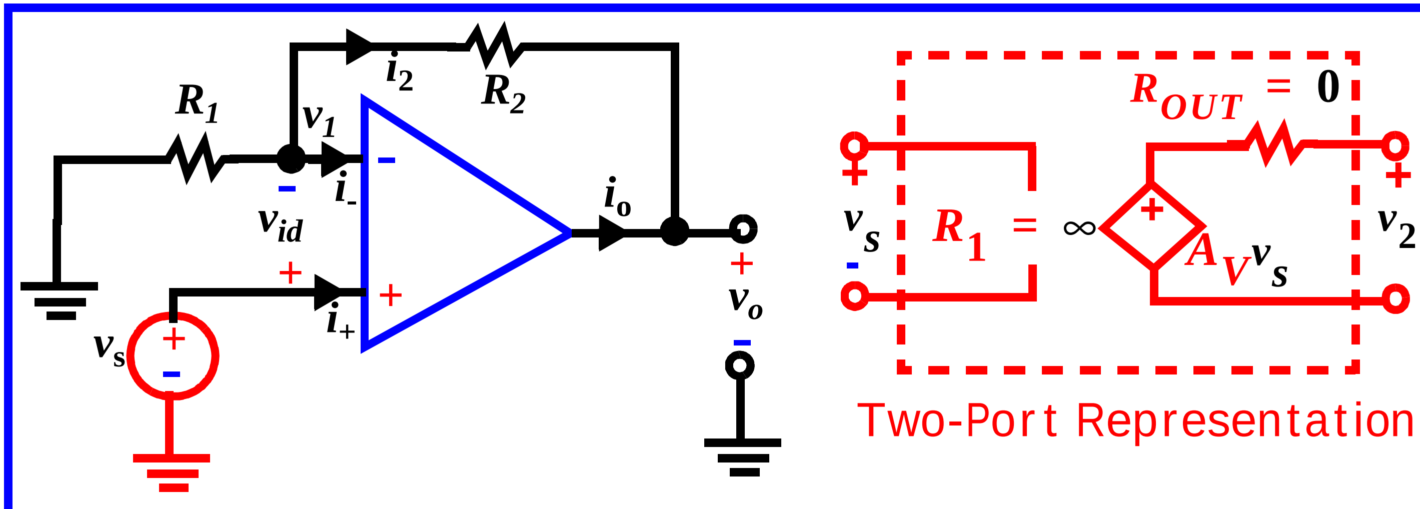
Non-inv amp $v_- = \frac{R_1}{R_1 + R_2} v_o = \beta v_o$ & $v_o = A(v_+ - v_-) = A(v_s - \beta v_o)$.

Non-inv. amp., $A_V = \frac{v_o}{v_s} = \frac{A}{1 + A\beta} = \frac{1}{\beta} \bullet \frac{1}{1 + (A\beta)^{-1}}$.

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

β is the feedback factor. It is the portion of the OP feedback to the IP.

The Non-Inverting Amplifier



$$A_V = \frac{v_o}{v_s} = 1 + \frac{R_2}{R_1}$$

$$R_{IN} = \frac{v_s}{i_+} = \infty$$

$$R_{OUT} = \frac{v_x}{i_x} = 0$$

Now 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.

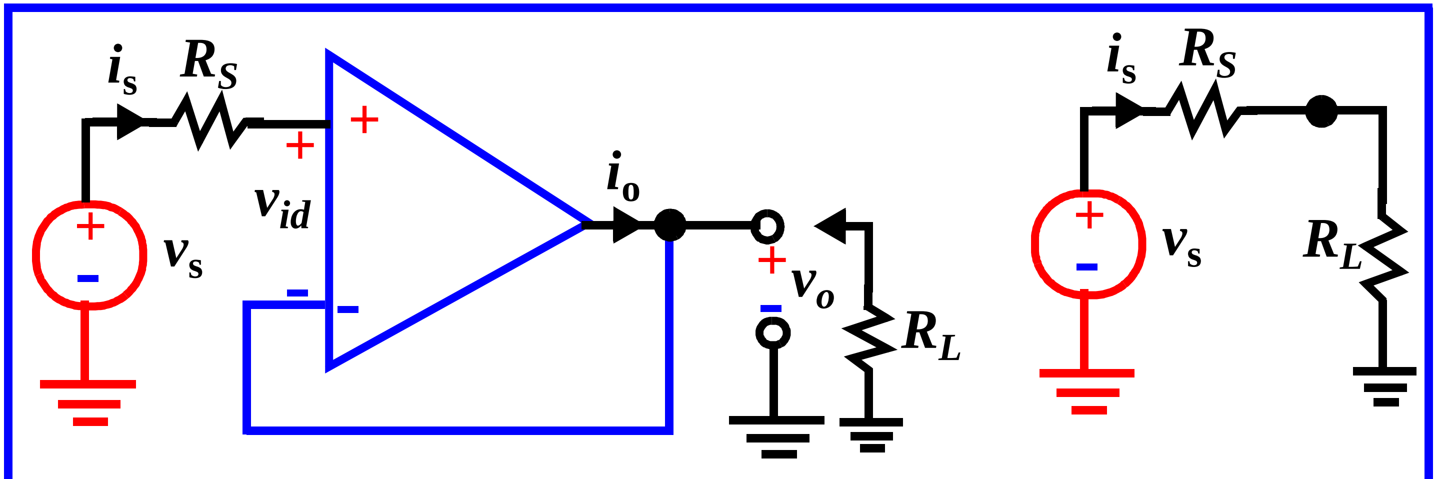
Also, OP and IP are in phase with each other (no phase shift).

Explain the unity-gain buffer or voltage follower used for impedance transformation with unity voltage gain.

The Voltage-Follower or Unity-Gain Amplifier

It is an ideal circuit that does not require any input current and can drive any R_L without loss of signal.

Found in many sensor and data acquisition applications.



$$A_V = 1;\ R_{IN} = \infty;\ R_{OUT} = 0 \Rightarrow v_0 = v_s$$

$$v_0 = \frac{R_L}{R_L + R_S} v_s$$

This is a resistance translator. The source delivers no current; dissipates no energy; current and energy absorbed by R_L is supplied by OA.

Table 1: Summary of Ideal Amplifier Characteristics

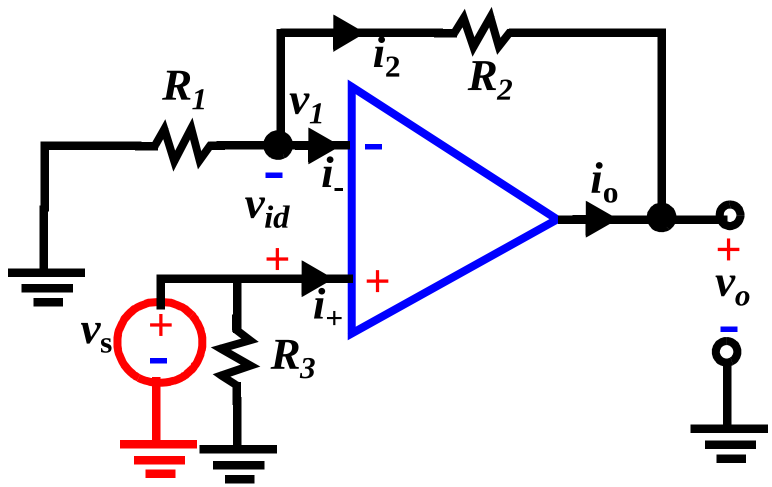
Characteristic	Inverting	Non-Inverting	Buffer
Voltage Gain A_V	$-(R_2/R_1)$	$1+(R_2/R_1)$	1
Input Resistance R_{IN}	R_1	∞	∞
Output Resistance R_{OUT}	0	0	0

Please read - summing, difference & instrumentation amplifiers

(p. 497 - 500)

Example:

What are the voltage gain, input resistance, and output resistance of the following circuit if $R_1 = 10k\Omega$, $R_2 = 100k\Omega$, and $R_3 = 200k\Omega$?

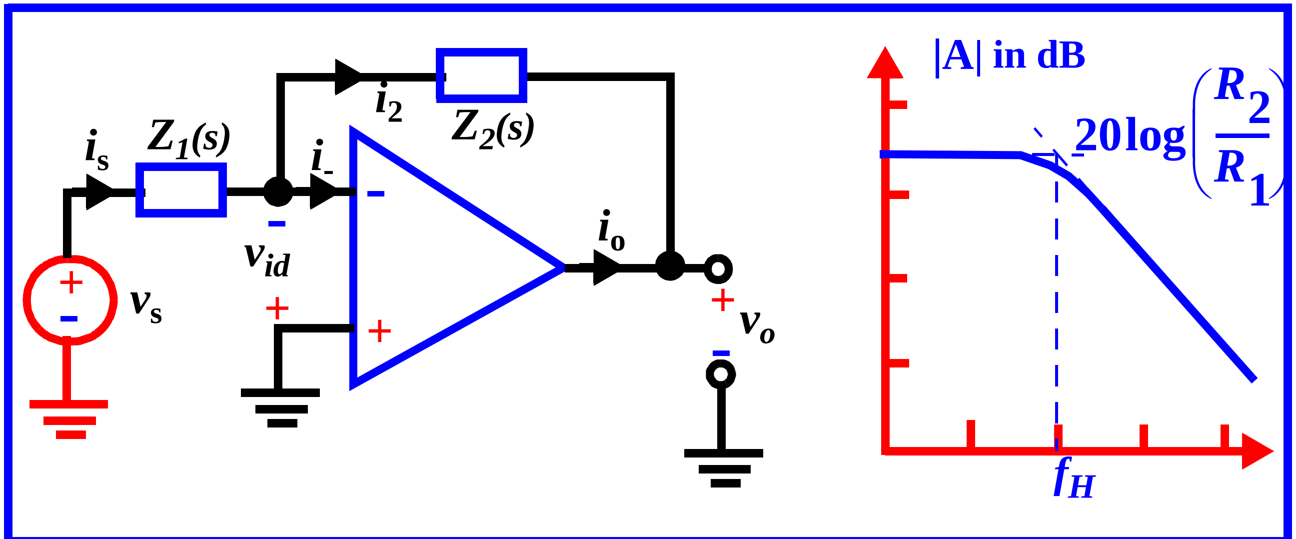


$$A_V = 1 + \frac{R_2}{R_1} = 1 + \frac{100k}{10k} = 11$$

$$R_{IN} = R_3 \| \infty = R_3 = 200k\Omega$$

$$R_{OUT} = 0\Omega$$

Low Pass Filter



$$A_V = \frac{V_o}{V_s} = -\left(\frac{Z_2(s)}{Z_1(s)}\right) \qquad Z_1(s) = R_1 \qquad Z_2(s) = R_2 \| \frac{1}{sC}$$

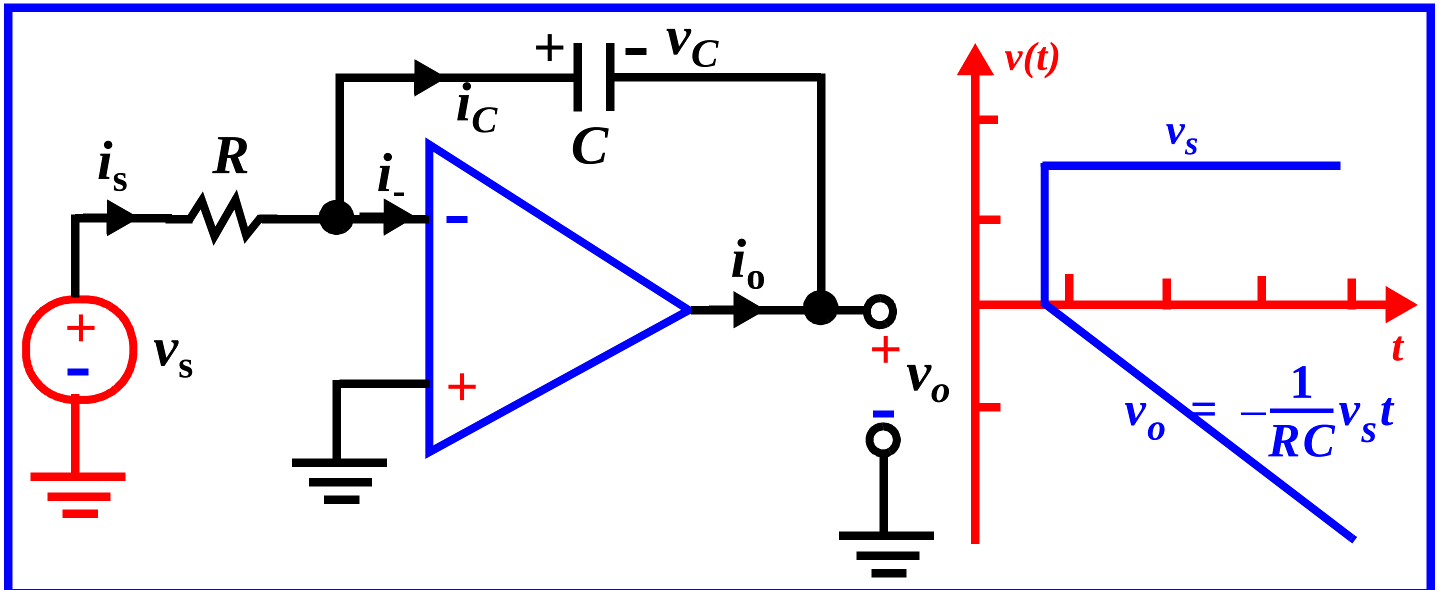
$$A_V(s) = -\left(\frac{Z_2(s)}{Z_1(s)}\right) = -\left(\frac{R_2}{R_1}\right) \cdot \frac{1}{1 + sCR_2} = -\left(\frac{R_2}{R_1}\right) \cdot \frac{1}{1 + \frac{s}{\omega_H}}$$

Two design parameters - low frequency gain and 3dB frequency can be set independently since we have 3 parameters - R_1, R_2 and C.

Input resistance $R_{IN} = R_1$ can be third design parameter.

The 3-dB frequency is $f_H = 1/2\pi R_2 C$. Question: What happens if $R_2 \gg R_1$?

Integrator (Please read carefully)



$$i_s = \frac{v_s}{R}$$

$$i_C = -C\frac{dvo}{dt} = i_s$$

$$v_o = -\left(\frac{1}{RC}\right)\int_0^t v_s(\tau)d\tau + v_C(0)$$

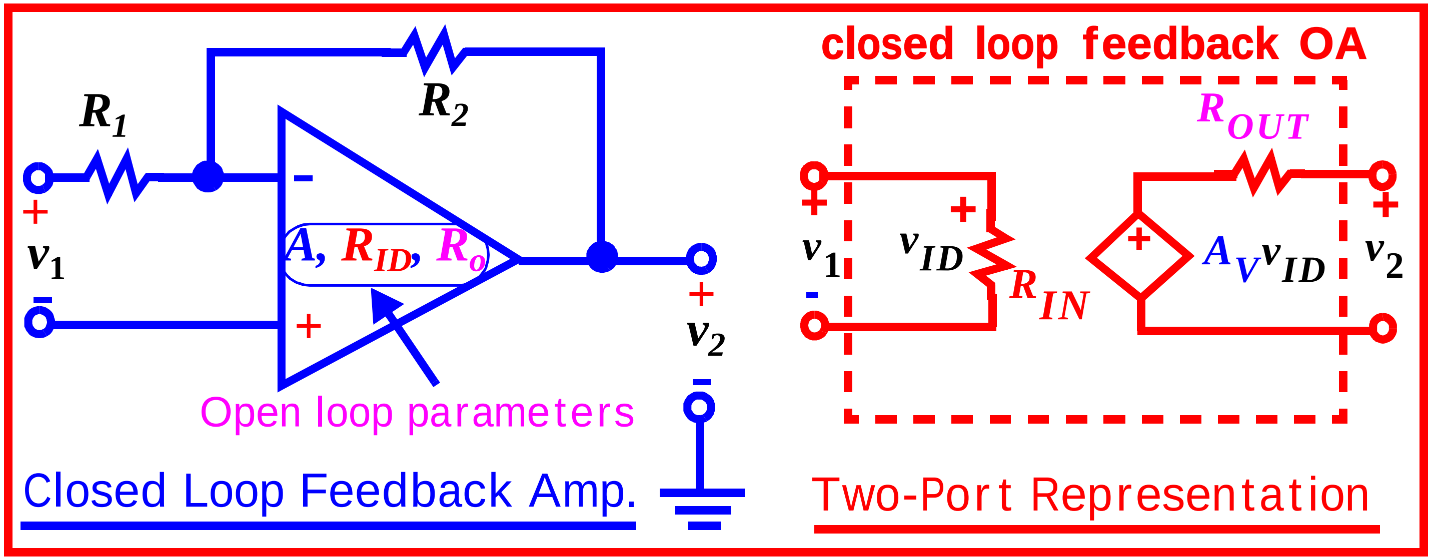
Used in function generators (triangular and sawtooth wave generators), active filters, ADC and analog control.

Two design parameters - R and C.

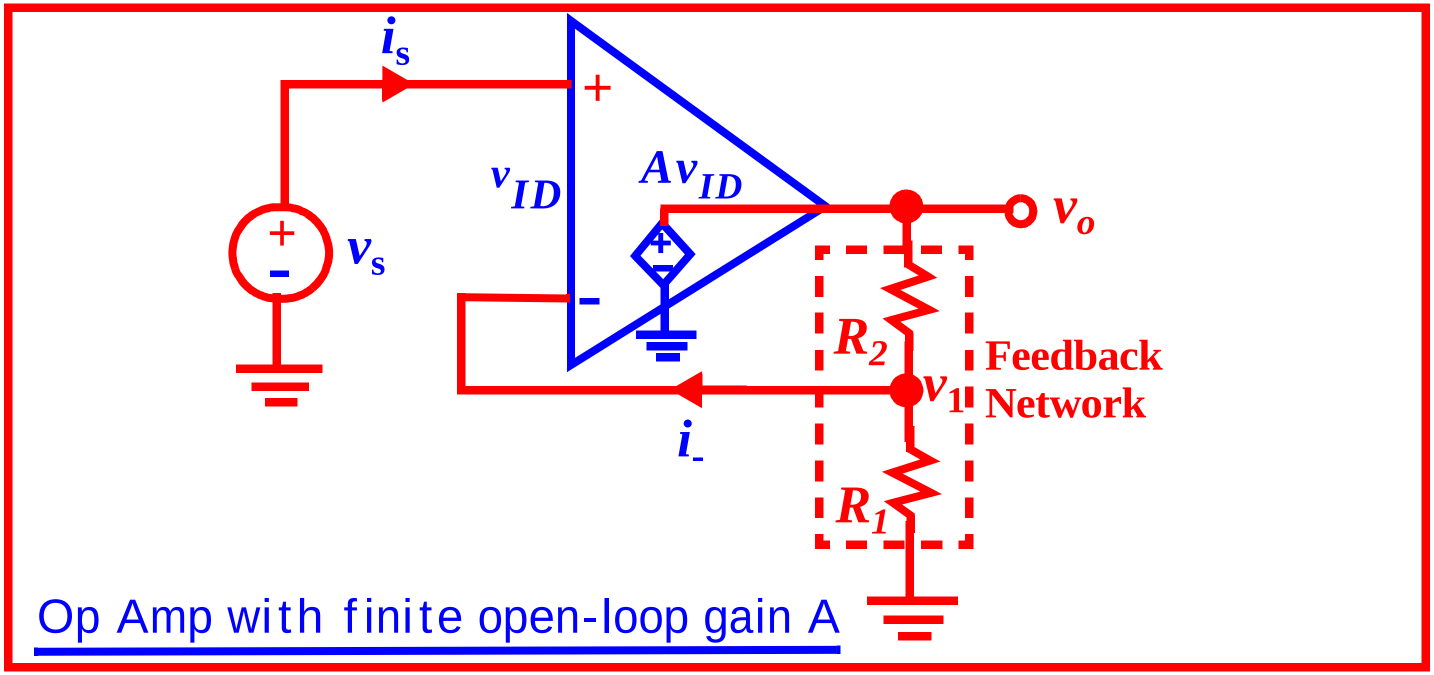
Input resistance $R_{IN} = R_1$ can be third design parameter.

Two Port Representations - The Inverting Amplifier

(Please read carefully)



Non-Ideal Non-Inverting Amplifier (Please read carefully)



$$v_o = A \cdot v_{id} = A \cdot (v_s - v_1);\ v_1 = \frac{R_1}{R_1 + R_2} \cdot v_o = \beta \cdot v_o.$$

$$v_o = A \cdot (v_s - \beta \cdot v_o);\ A_V = \frac{v_o}{v_s} = \frac{A}{1 + A\beta};\ A_{ideal} = \frac{1}{\beta} = 1 + \frac{R_2}{R_1}.$$

$$\boxed{v_{id} = v_s - v_1 = v_s - \beta \cdot v_o = v_s - \frac{A\beta}{1 + A\beta} v_s = \frac{v_s}{1 + A\beta}}.$$

Gain Error

Gain Error= Ideal Gain-Actual Gain

Relative Gain Error=(Ideal Gain-Actual Gain)/(Ideal Gain)

$$GE = \frac{1}{\beta} - \frac{A}{1+A\beta} = \frac{1}{\beta(1+A\beta)}$$

$$FGE = \frac{\frac{1}{\beta} - \frac{A}{1+A\beta}}{\beta^{-1}} = \frac{1}{(1+A\beta)} \approx \frac{1}{A\beta} \quad \text{for} \quad A\beta \gg 1$$

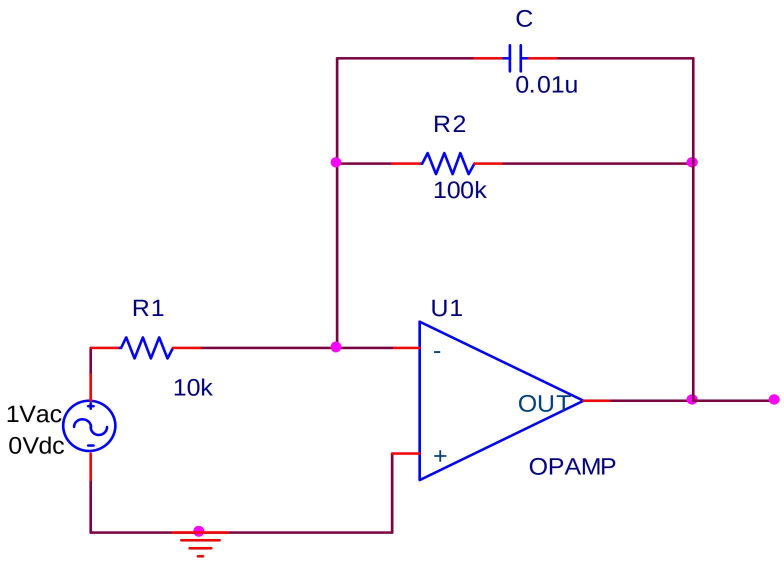
Example: For a non-inverting amplifier, find v_{id}, v_o and FGE if A = 10^5, β = 10^{-2}, v_s = 100mV.

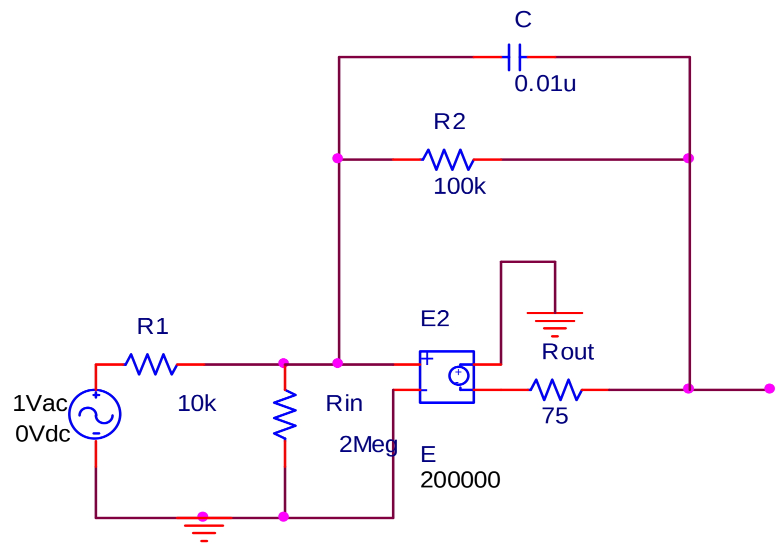
$$v_{id} = \frac{v_s}{1+A\beta} \approx 100\mu V$$ Recall $$v_{id} = v_s - v_1 = v_s - \beta \cdot v_o = v_s - \frac{A\beta}{1+A\beta}v_s = \frac{v_s}{1+A\beta}.$$

$$v_o = A_v \times v_s \approx 10V$$ Recall $$A_V = \frac{v_o}{v_s} = \frac{A}{1+A\beta}$$

$$FGE = \frac{1}{(1+A\beta)} \approx 10^{-3}$$

PSpice Example





*Libraries:

* Local Libraries :

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

.lib "nom.lib"

*Analysis directives:

.AC LIN 50 1 1k

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

.INC ".\example3-SCHEMATIC1.net"

**** INCLUDING example3-SCHEMATIC1.net ****

* source EXAMPLE3

E_E2 0 N004843 N00983 0 200000

V_V7 N042211 0 DC 0Vdc AC 1Vac

PSpice Example (Cont'd)

```
R_Rout        N004843 N04056  75
R_R1          N042211 N00983  10k
R_Rin         0 N00983  2Meg
C_C           N00983 N04056  0.01u
R_R2          N00983 N04056  100k
**** RESUMING example3-SCHEMATIC1-Exampl3Profile.sim.cir ****
.END
```