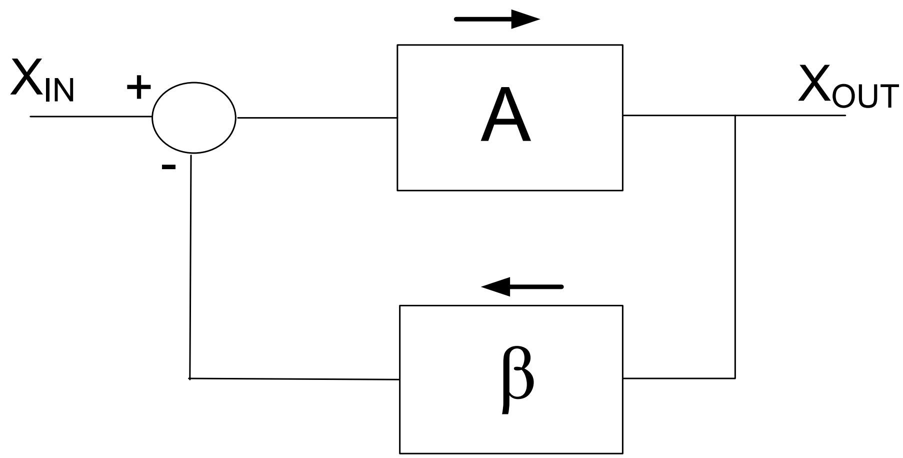
EE 230
Lecture 10

Operational Amplifiers

and Basic Applications

Review from last time

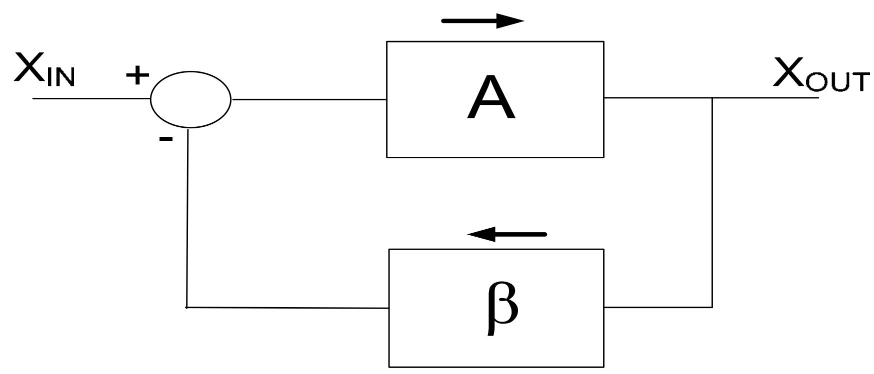


$$A_{FB} = \frac{A}{1 + A\beta}$$

for $A\beta >> 1$

$$A_{FB} \cong \frac{1}{\beta}$$

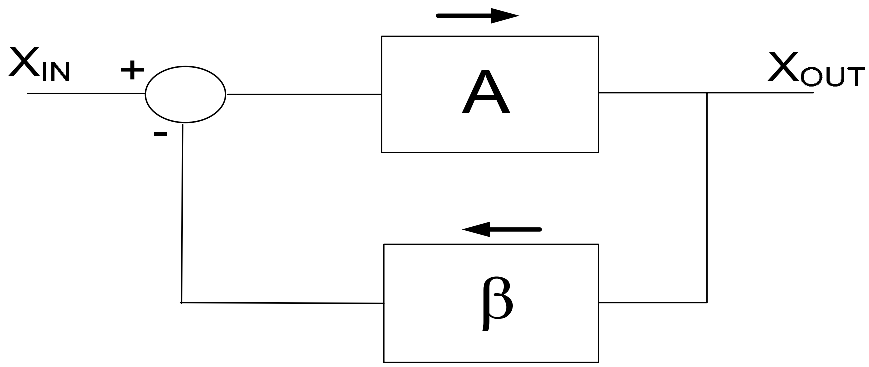
Review from last time



Feedback significantly and simultaneously improves most parameters of interest by a factor of about $1+A\beta$

Feedback properties is the major driving factor behind the evolution and use of operational amplifiers

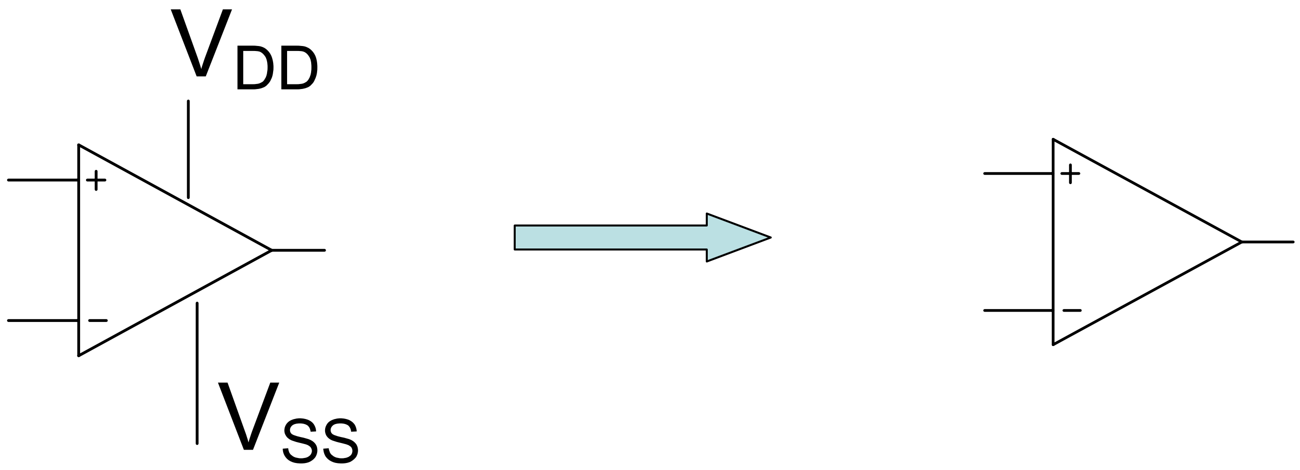
Review from last time



Feedback significantly and simultaneously improves most parameters of interest by a factor of about $1+A\beta$

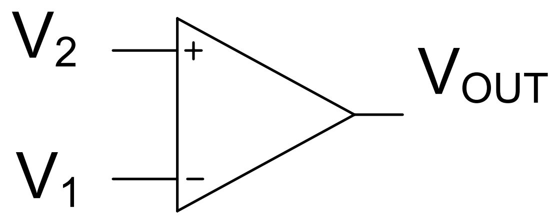
Review from last time

For a VCVS Op Amp



Review from last time

For a VCVS Op Amp



$$V_{OUT} = A\left(V_2 - V_1\right)$$

Ideally

$A \approx \infty$

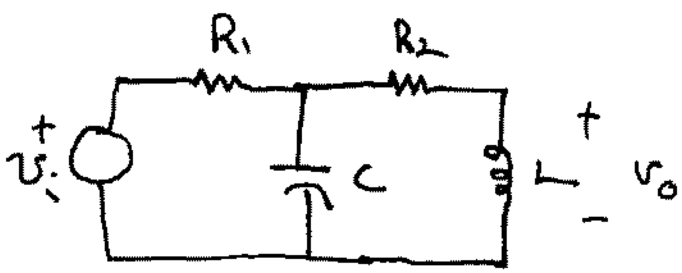
$R_{IN} = \infty$

$R_{OUT} = 0$

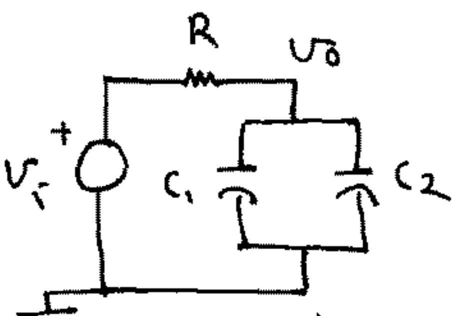
Theorem: If a network has no frequency-dependent amplifiers, then the order of the transfer function of the network is less than or equal to the number of energy storage elements.

(It is usually equal to: except when reduction or pole-zero cancellation occurs)

Examples

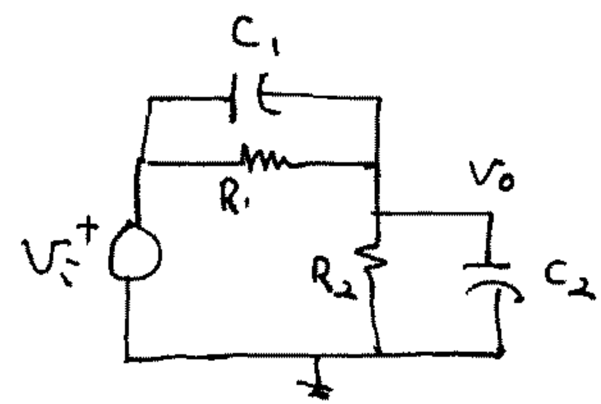


2nd order



1st order

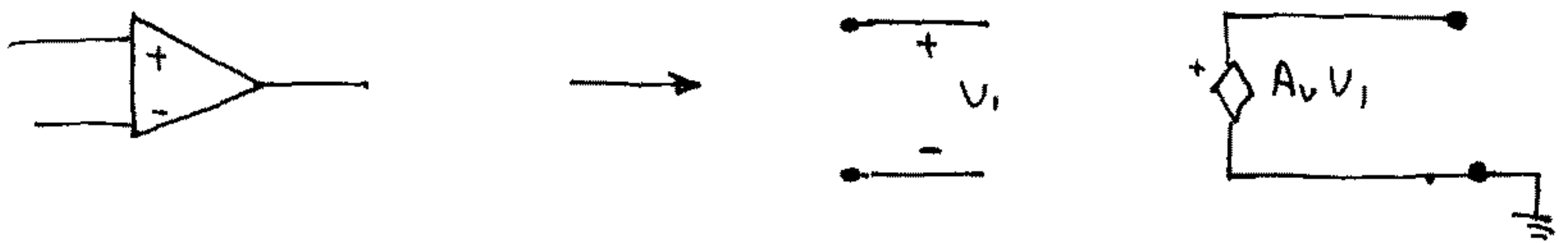
(reduction is possible)



1st order

(a type of reduction is possible - details beyond scope at this time)

Model for Op Amp



The "E" source in SPICE can be used to model the op amp

Ideal Op Amp : Simply make A_V large $(A \simeq \infty)$
(maybe $A_V = 10^8$)

Practical dc op amp model :
$$A_V = \text{data sheet dc gain}$$

Ideal model is adequate in many applications ☺

Multiple models of the op amp will be introduced that emphasize specific characteristics or support specific applications

Invariably, if a nonideal op amp model is necessary to adequately predict the performance of a feedback circuit, the feedback circuit is not very practical!

If V_o is some finite value

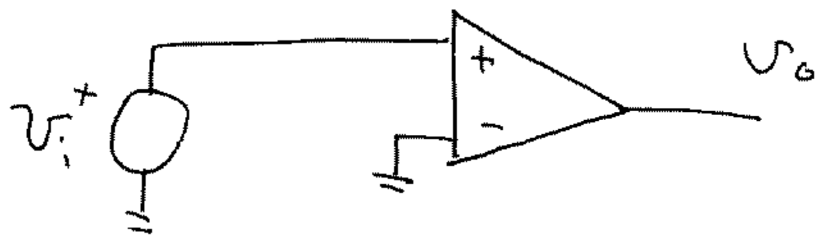
$$V_A = \frac{V_o}{A} \simeq 0 \qquad (\text{typically few } \mu V)$$

"Virtual short" exists between "+" and "−" terminals of op amp

Input port has properties of open circuit ($R_{in} \simeq \infty$) and short circuit ($V_A \simeq 0$) simultaneously

Input port of op amp termed "Null Port"

Op Amp is almost never used without feedback as an amplifier!



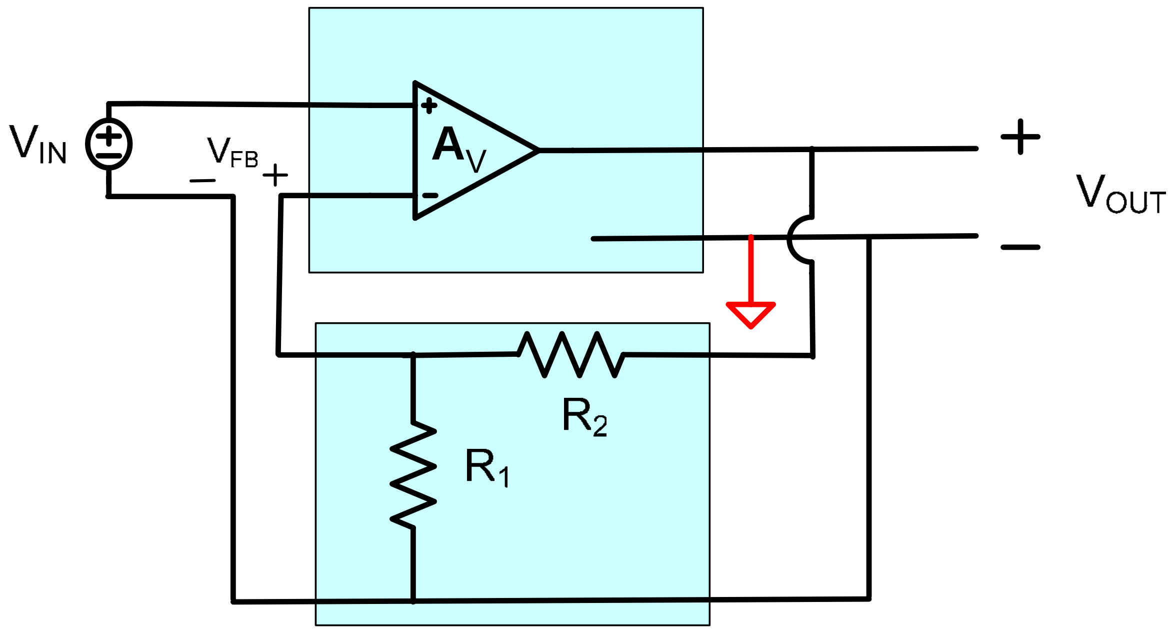
$v_o = A v_i$

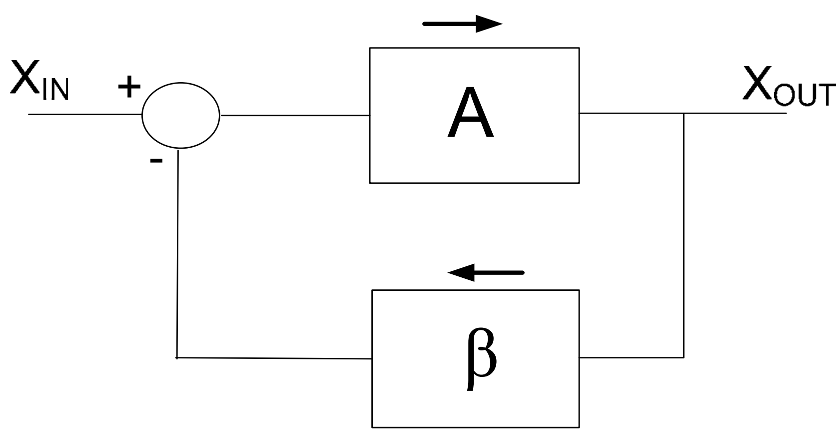
Reasons: A highly variable

"A" highly nonlinear

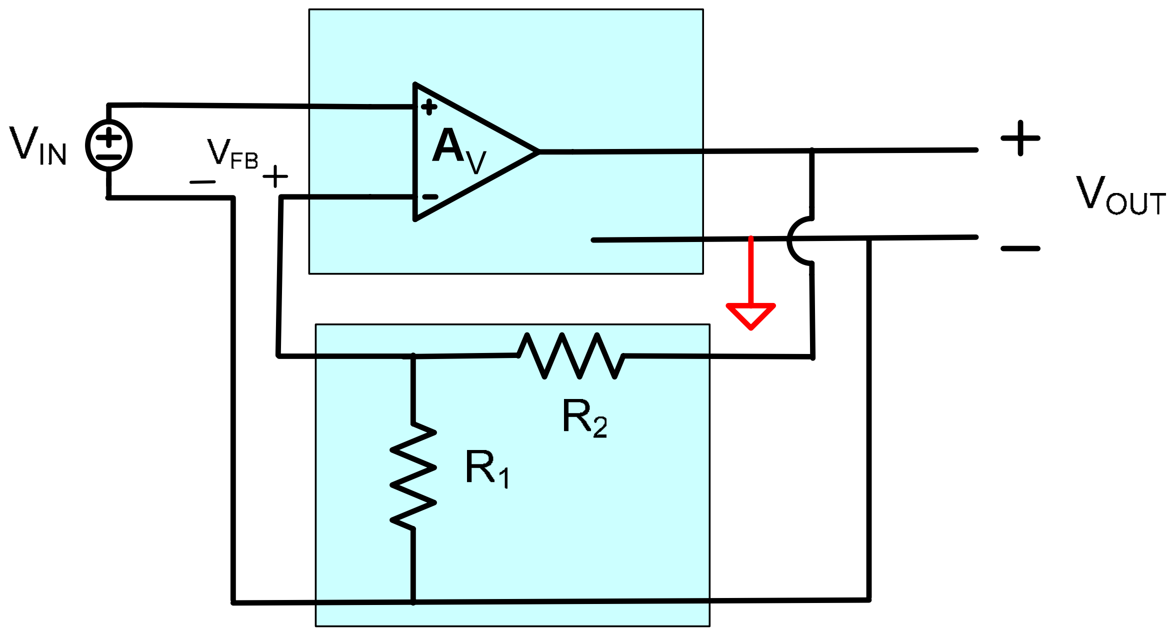
Offset (discussed later) will drive output to saturation

Consider the following circuit





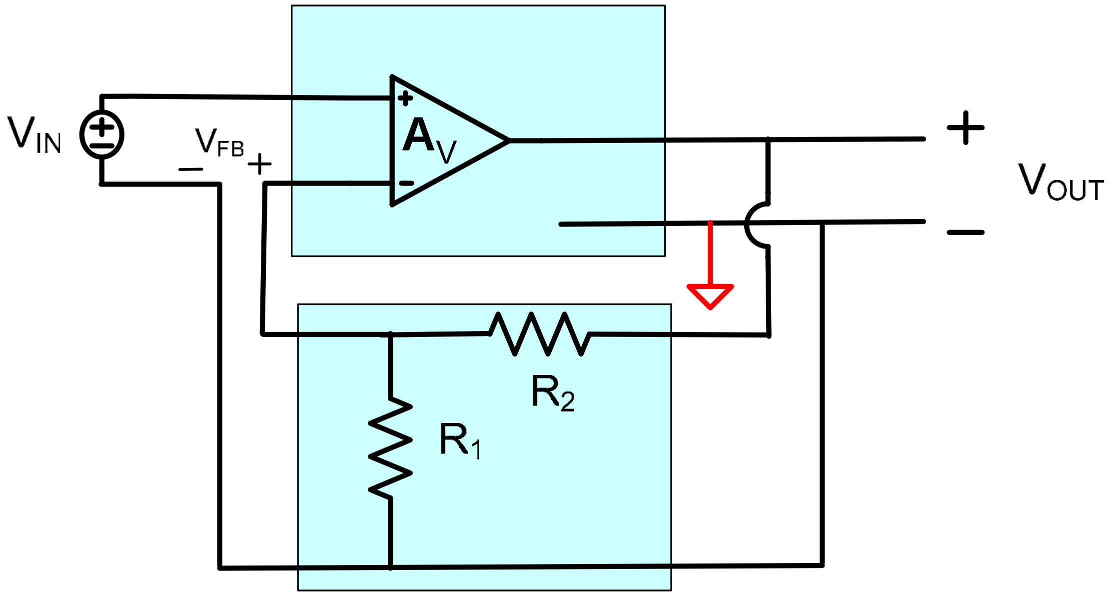
Consider the following circuit



This is exactly the feedback architecture in the case where the input and output variables are voltages

This is a voltage feedback amplifier

Consider the following circuit

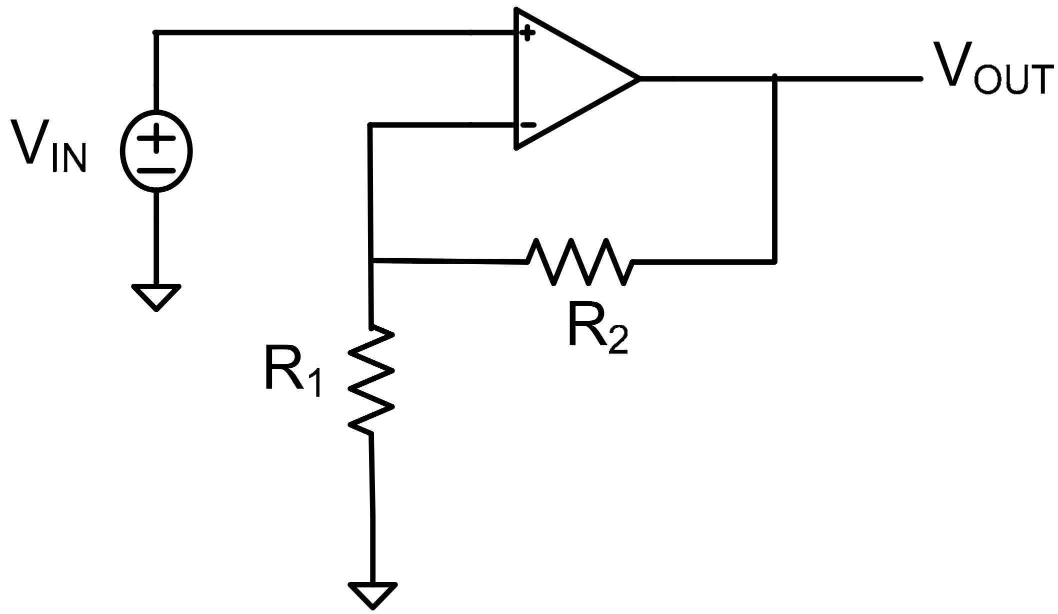


$$A = A_V \qquad \beta = \frac{R_1}{R_1 + R_2}$$

$$A_{FB} = \frac{A}{1 + A\beta}$$

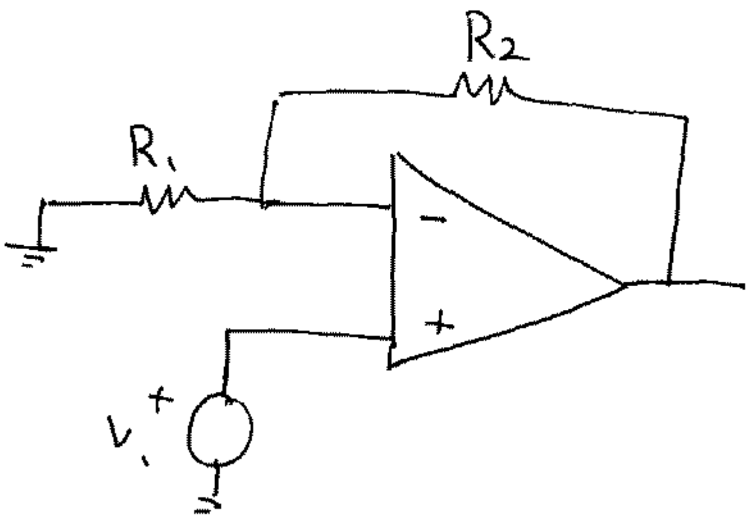
$$A_{FB} \cong \frac{1}{\beta} = 1 + \frac{R_2}{R_1}$$

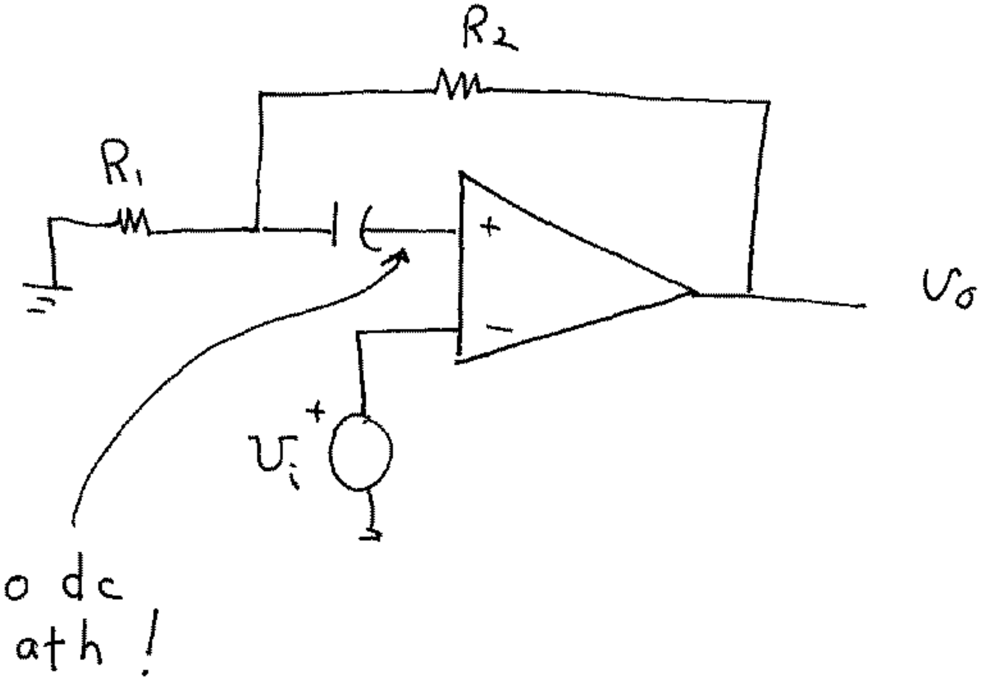
Basic Noninverting Amplifier



$$A_{FB} = \frac{V_{OUT}}{V_{IN}} \cong 1 + \frac{R_2}{R_1}$$

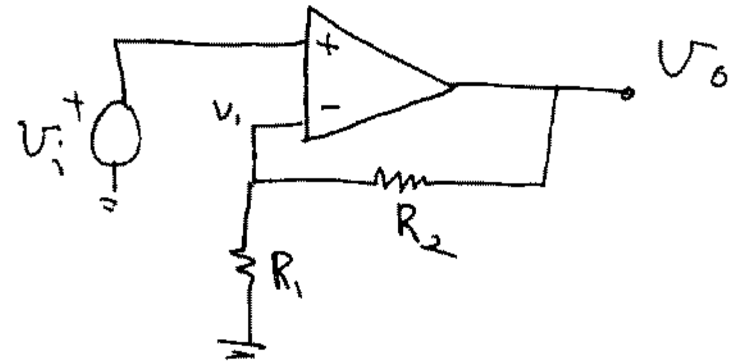
Even though the input current to the op amp is nearly 0, a dc path to each of the op amp input terminals must always be provided.





Basic Inverting Amplifier

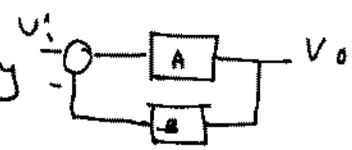
Direct Analysis



$$V_1 = \frac{R_1}{R_1 + R_2} V_o$$

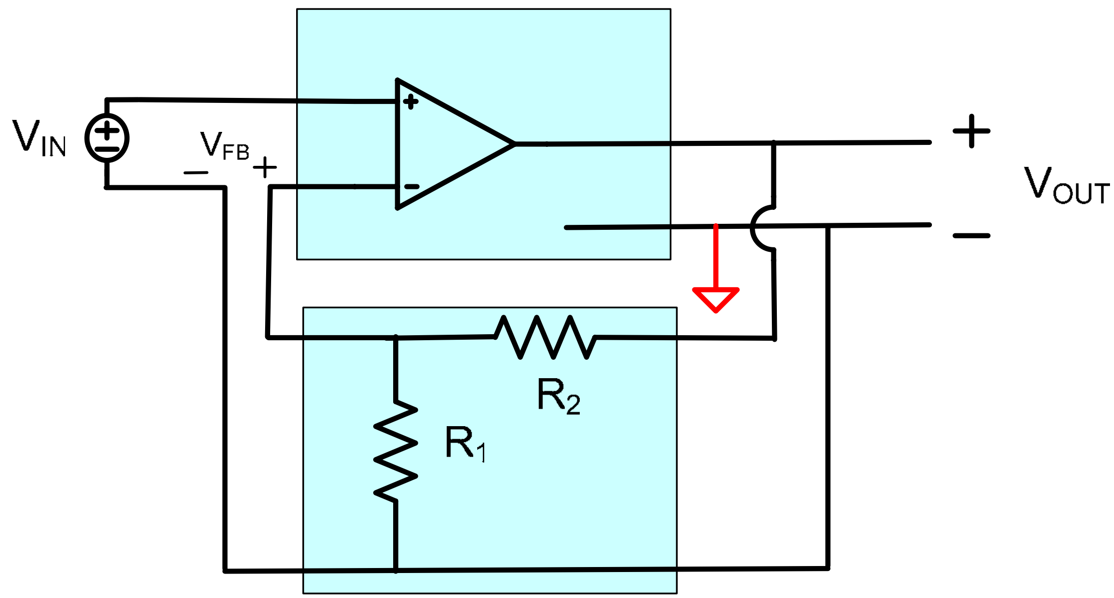
$$V_1 = V_i$$

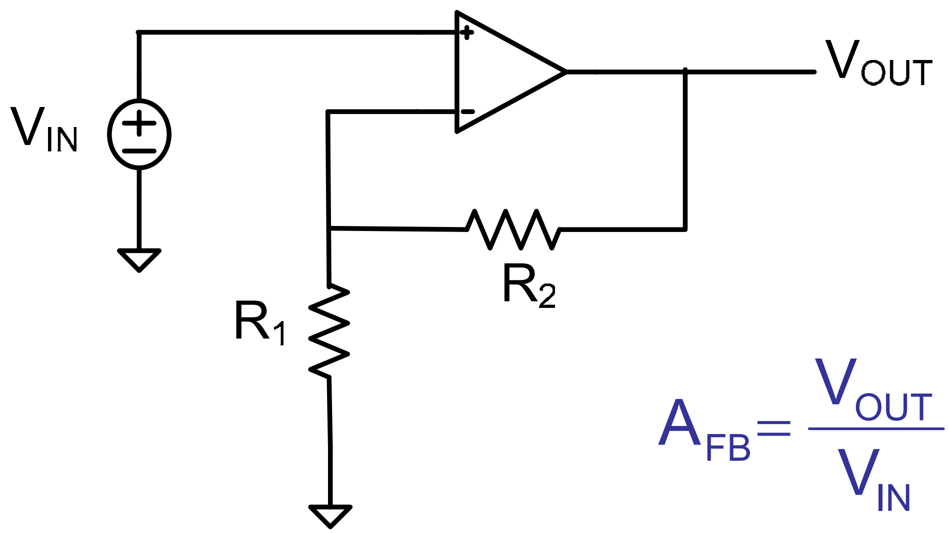
$$\frac{V_o}{V_i} = 1 + \frac{R_2}{R_1}$$

- Direct Analysis is much easier than feedback analysis
- Feedback analysis seldom used when analyzing feedback amplifiers
- Many feedback amplifiers do not satisfy 

architecture but rather modified feedback architectures

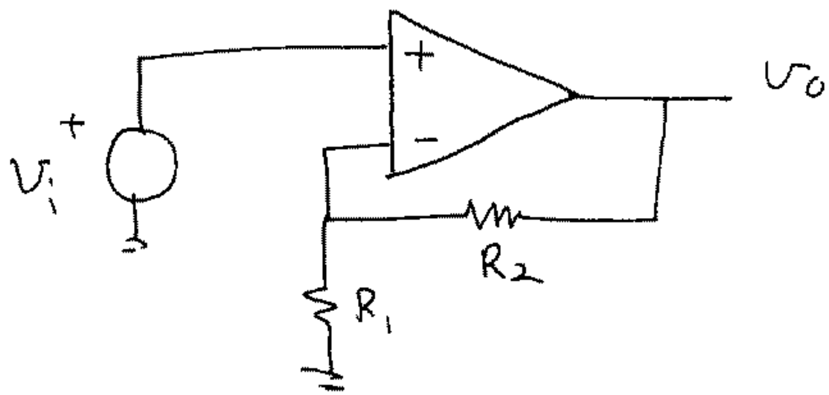
Redraw this feedback circuit





$$A_{FB} = \frac{V_{OUT}}{V_{IN}} \cong 1 + \frac{R_2}{R_1}$$

- All feedback structures do derive their useful properties from the feedback concept



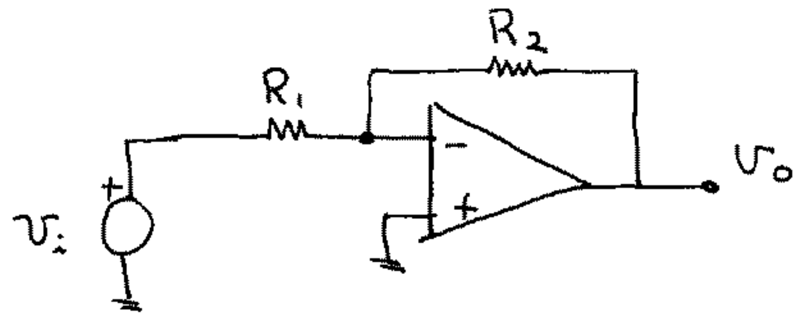
$$\frac{v_o}{v_i} \simeq 1 + \frac{R_2}{R_1}$$

If $\frac{R_2}{R_1} = 9$, how much error was introduced by assuming $A = \infty$? Assume $A_v = 10^5$

$$\frac{v_o}{v_i} = \frac{A_v}{1 + \beta A_v} = \frac{10^5}{1 + \left(\frac{1}{10}\right)10^5} = \frac{10^5}{10{,}001} = 9.9990$$

error 1 part in 10,000 = .01%

Basic Inverting Amplifier

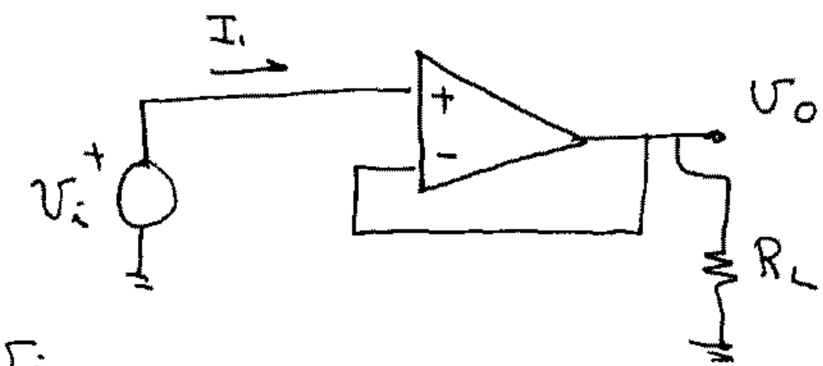


$$\left.\frac{v_i}{R_1} + \frac{v_o}{R_2} = 0 \right\} \Rightarrow \quad \frac{v_o}{v_i} = -\frac{R_2}{R_1}$$

This circuit does not satisfy directly the "A-β" feedback structure as a voltage in / voltage out amplifier

(It can be shown that this is a transresistance feedback amplifier but details will not be provided at this time)

Buffer



$v_o = v_i$

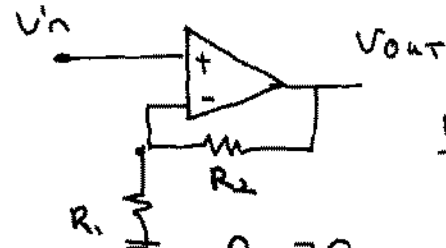
$R_{in} = \infty$ since $I_1 = 0$

$R_{OUT} = 0$ (will show this)

- One of the most widely used op amp circuits

- Provides a signal to a load that is not affected by source impedance

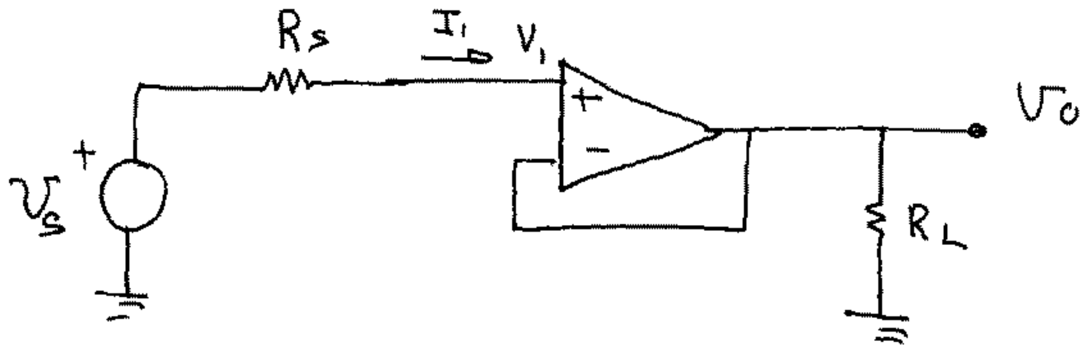
- Buffer is a special case of basic noninverting amplifier



$R_2 = 0$
$R_1 = \infty$

$$\frac{v_o}{v_i} = 1 + \frac{R_2}{R_1} = 1 + \frac{0}{\infty} = 1$$

Effects of R_s

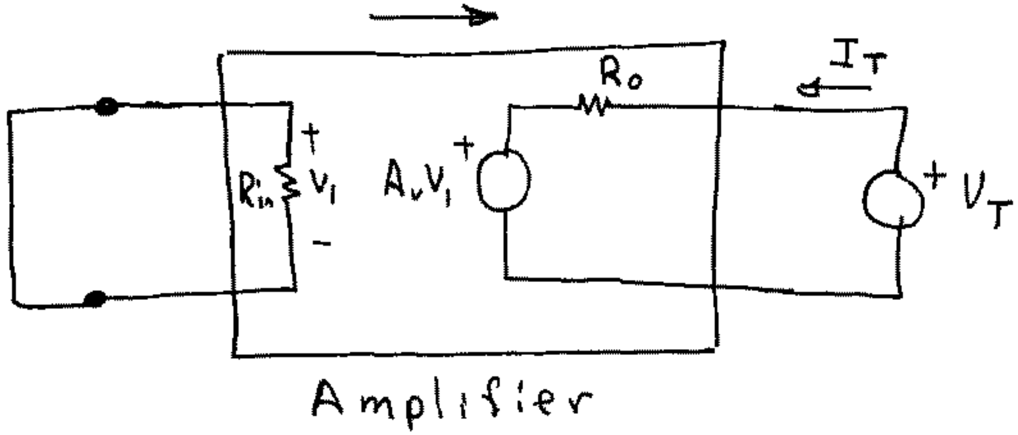


since $I_1 \simeq 0$, $\quad v_1 = v_s$

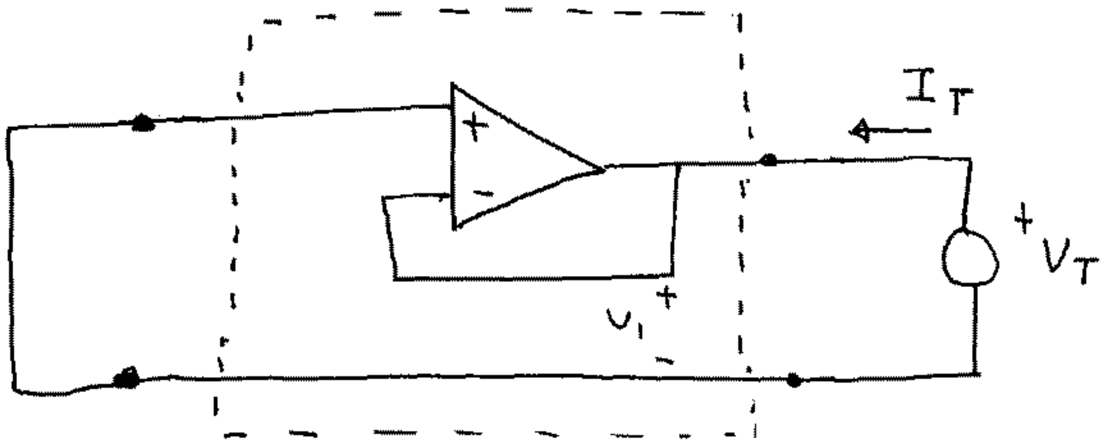
$\therefore \quad v_o = v_1 = v_s$ independent of R_s

Note: Buffer widely used to eliminate (reduce) loading effect of a following stage.

R_{OUT} Derivation.



$$R_{OUT} = \frac{V_T}{I_T}$$

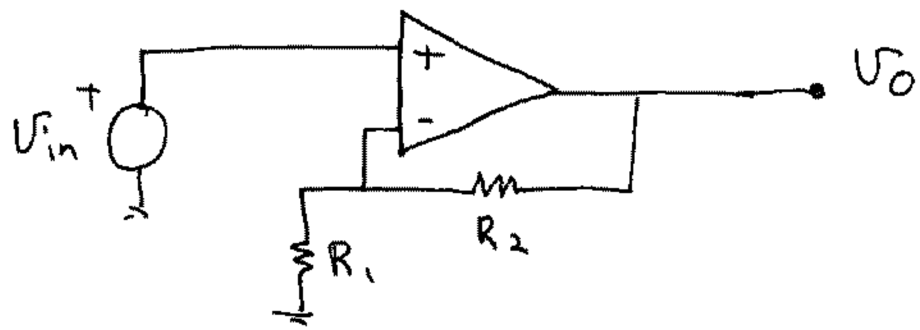


If Op Amp is ideal

$$V_1 = 0 \Rightarrow I_T = \infty$$

$$\therefore \quad R_{OUT} = \frac{V_T}{I_T} = \frac{V_T}{\infty} = 0$$

Basic Noninverting Amplifier

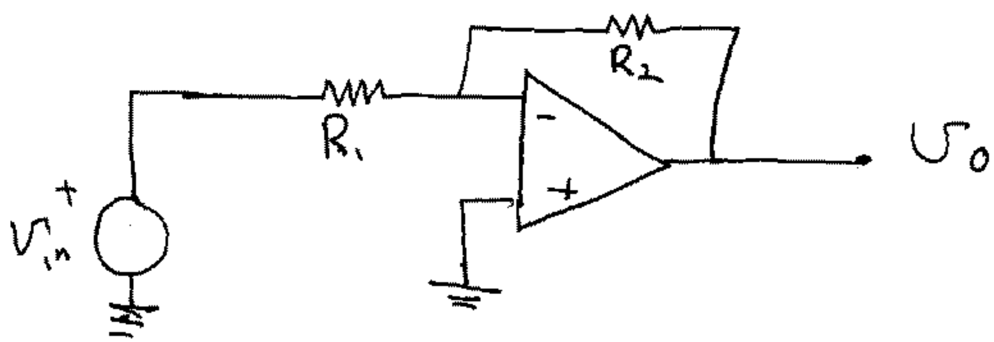


$$\frac{v_o}{v_{in}} = 1 + \frac{R_2}{R_1}$$

$$R_{in} = \infty$$

$$R_{OUT} = 0$$

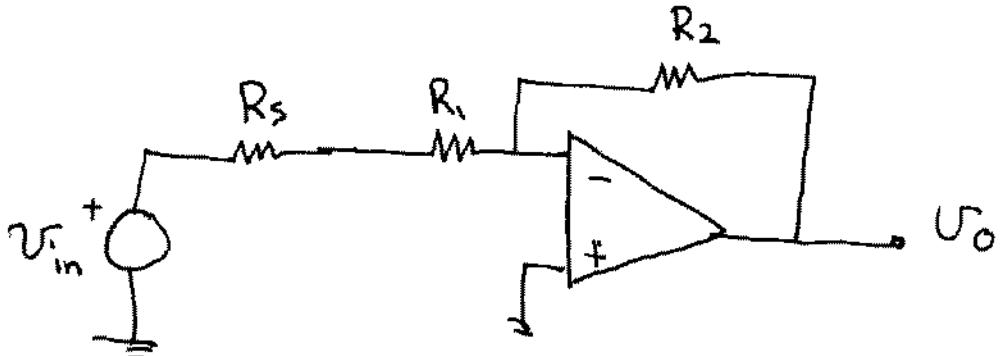
Basic Inverting Amplifier



$$A_v = -\frac{R_2}{R_1}$$

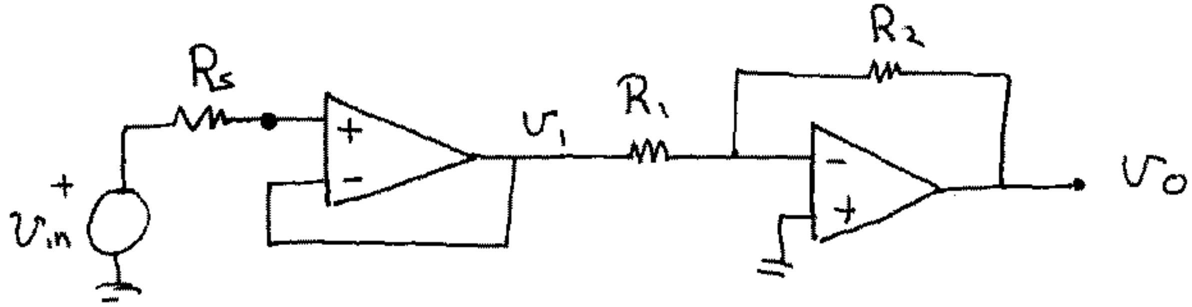
$R_{in} = R_1$ ← Not attractive

$R_{OUT} = 0$



$$A_v = -\frac{R_2}{R_1 + R_s}$$

Consider



$$v_1 = v_i$$
$$v_o = -\frac{R_2}{R_1} v_1$$

$$v_o = -\frac{R_2}{R_1} v_i$$

$$R_{in} = \infty$$

$$R_{OUT} = 0$$

- Buffer has improved input impedance of inverting amplifier
- Widely used if input impedance is a problem