EE 230
Lecture 10

Feedback Concepts

Basic Feedback Configurations

Quiz 8

In what year did Black introduce the concept of Feedback?

And the number is ?

1 3 8

5 4

?

2 6

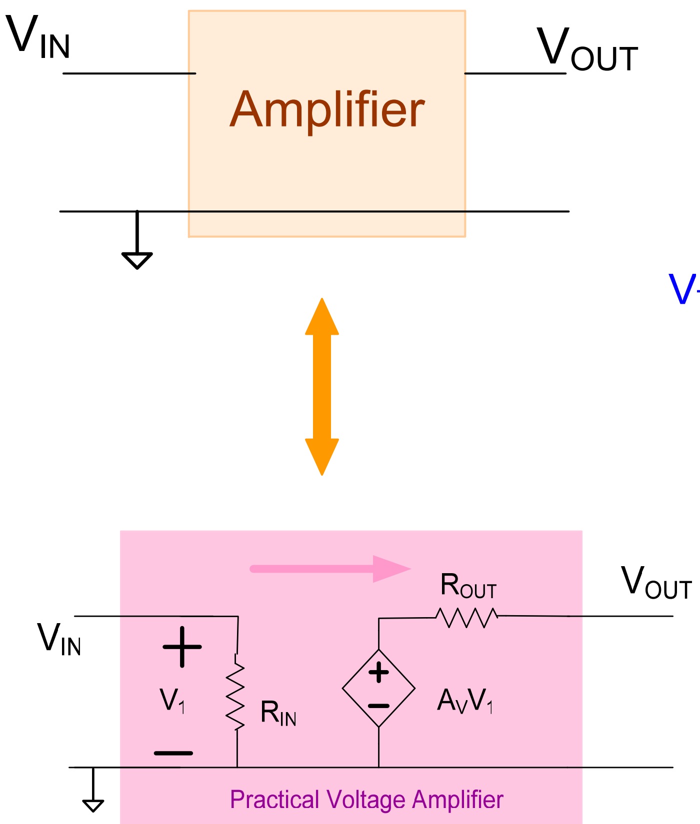
9 7

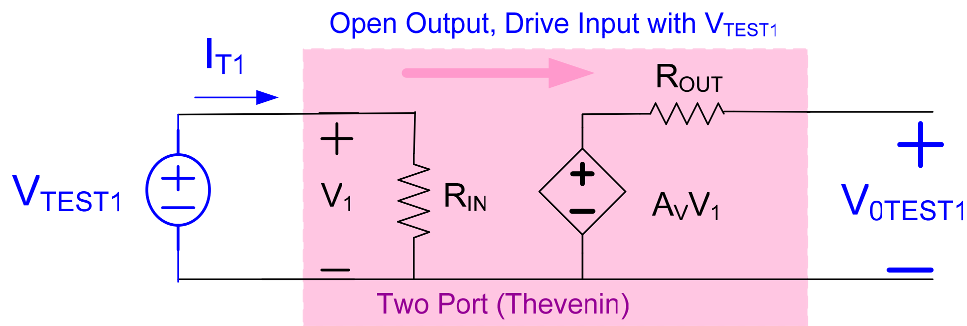
Quiz 8

In what year did Black introduce the concept of Feedback?

1927

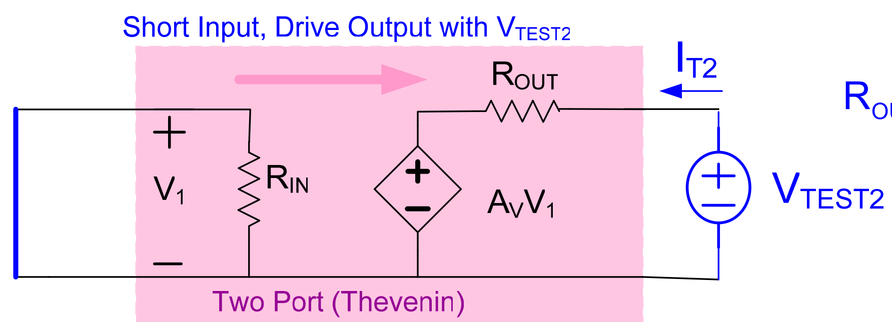
Obtaining R_{IN}, R_{OUT} and A_V in unliateral two-ports





$$R_{IN} = \frac{V_{TEST1}}{I_{T1}}$$

$$A_V = \frac{V_{0TEST1}}{V_{TEST1}}$$



$$R_{OUT} = \frac{V_{TEST2}}{I_{T2}}$$

Amplifiers – where do they come from?

It is a challenge to build amplifiers that have good linearity, accurate gains, and that operate over a wide range of frequencies

Electronic components that are used to build amplifiers

Vacuum tubes (1878)

Bipolar transistors (1948)

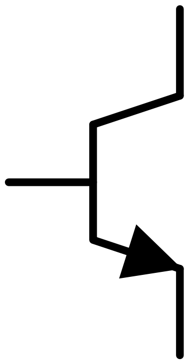
MOSFETs (~1920 conceived, ~1970 implemented)

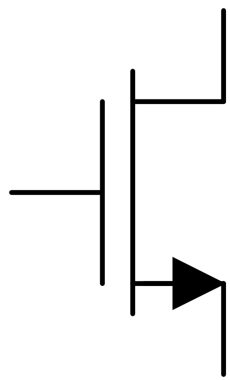
Almost all electronic amplifiers are built with one of these three types of devices

Review from Last Time

Amplifiers – where do they come from?

It is a challenge to build amplifiers that have good linearity, accurate gains, and that operate over a wide range of frequencies





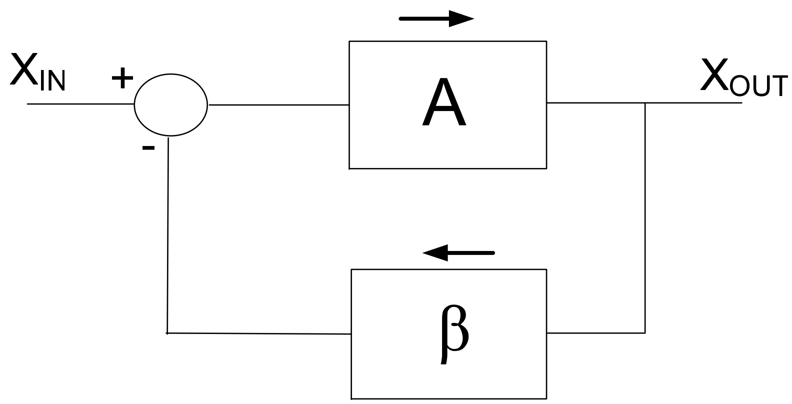
Engineers struggled for nearly 5 decades struggling to build amplifiers with

- Accurate Gains
- Good Linearity
- Good frequency response
- Minimal impact on insertion

The feedback concept

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

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



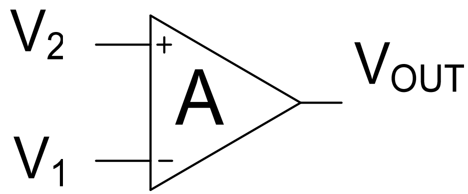
Feedback has shifted the performance requirements from the A amplifier to the β amplifier.

The performance improvements in most things of interest is often improved by a factor of $1+A\beta$ (will show this later)

$D=1+A\beta$ is called the desensitivity

Example: If $A=10^5$ and $\beta=1/2$ $\quad A_{FB} \simeq 2 \quad D=1+50{,}000 \approx 50{,}000$

The Operational Amplifier



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

Alternate notation $V_2=V^+$, $V_1=V^-$

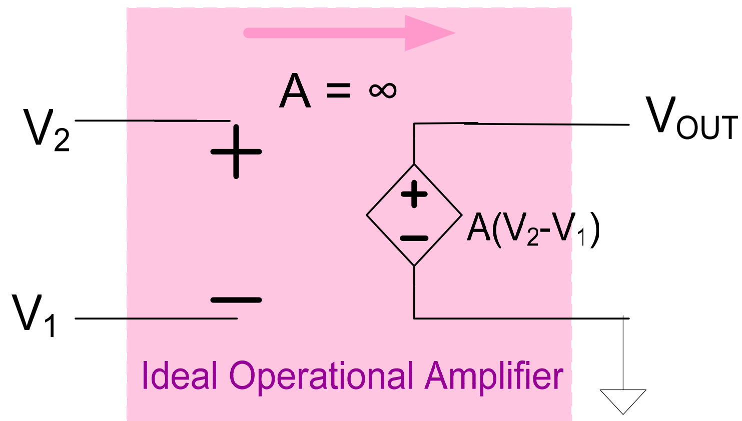
The ideal Op Amp

$A \approx \infty$

$R_{IN} = \infty$

$R_{OUT} = 0$

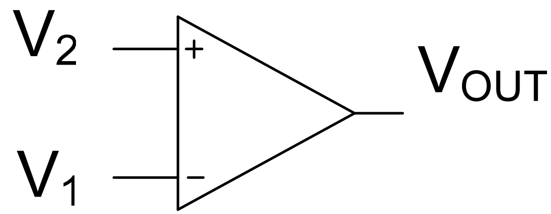
$V^+ = V^-$



“E” source model in SPICE or SPECTRE can be used to model the Op Amp

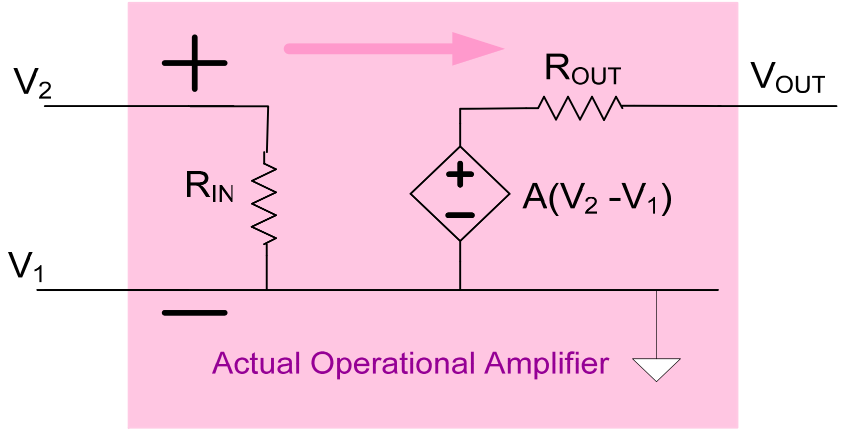
Just make A large (maybe 10^8) to model ideal op amp

The Operational Amplifier



The actual Op Amp

Many different products (1000's) with a wide variety of specifications



Typical for catalog parts:

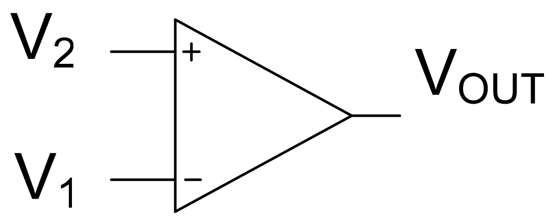
$A \sim 10^5$ to 10^6

$R_{OUT} \sim 50\Omega$ to 100Ω

$R_{IN} \sim \begin{cases} 1M\Omega & \text{bipolar OpAmps} \\ >100M\Omega & \text{FET input OpAmps} \end{cases}$

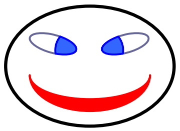
The Operational Amplifier

Op Amp Models



Several different models of the op amp will be introduced throughout the course

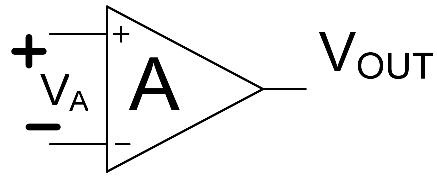
The ideal model is adequate in many applications



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

But, often the use of a more accurate model is needed to ascertain the simpler ideal model is adequate

The Operational Amplifier

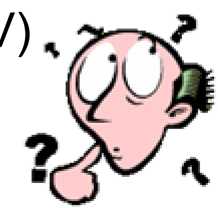


If $A=10^6$ and V_{OUT}=10V, observe V_A~ 10uV ~ 0V

"Virtual" short exists between input terminals since V_A is nearly 0V

Input port has properties of open circuit ($R_{IN}\approx\infty$) and a short circuit ($V_A\approx$0V)

(ideally no current flows into either input terminal)

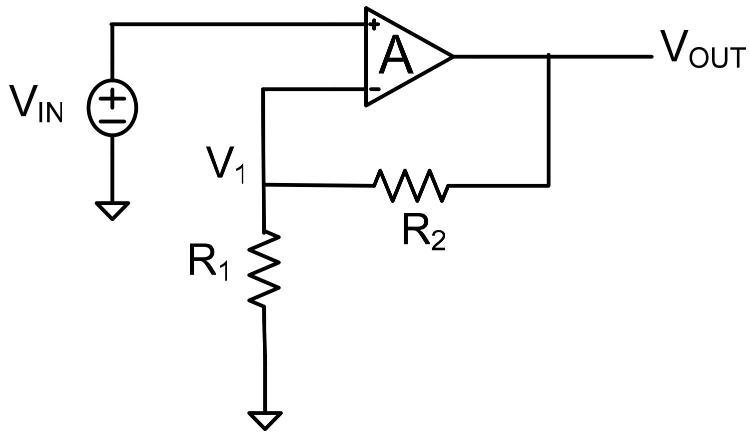


Input port of an ideal op amp is termed a "Null Port"

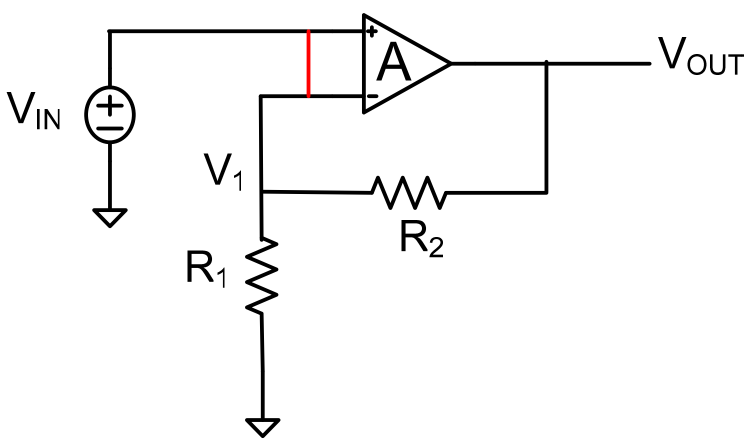
But MUST not put a real short between input terminals !

But MUST have dc path to both op amp inputs !

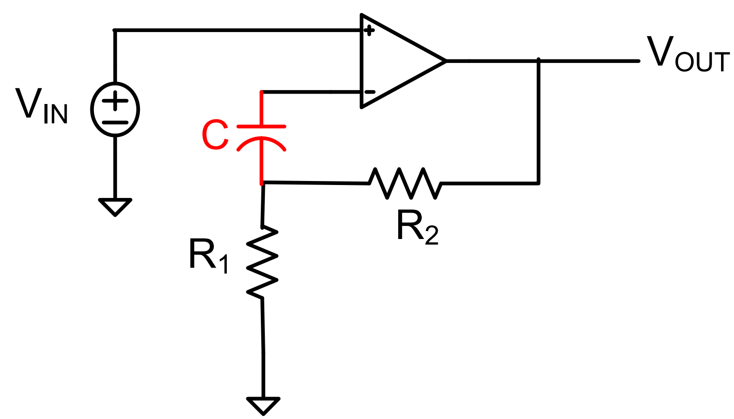
Basic Noninverting Amplifier



Good Circuit

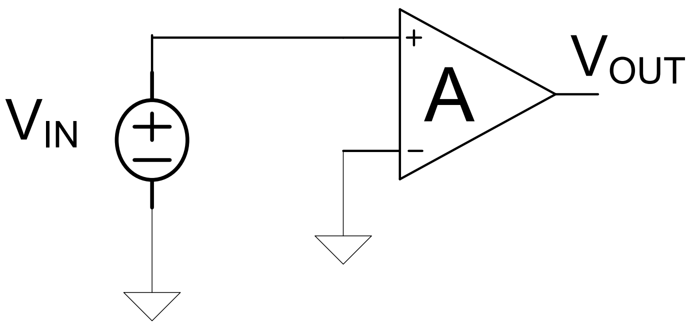


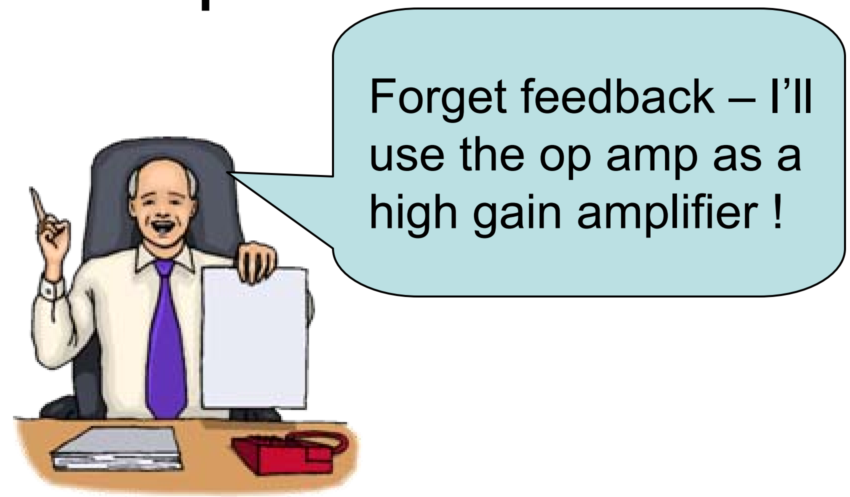
Won’t work, real short between input terminals



Won’t work, no dc path to “-” input

The Operational Amplifier





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

Reasons:

A is highly variable

"A" is highly nonlinear

Offset (discussed later) will drive output to saturation

Basic Operational Amplifier Applications

- The operational amplifier is the key active device in most analog signal processing circuits
- Will consider two classes of applications
  - Linear Applications (stable circuits)
  - Nolinear Applications (unstable circuits or some nonlinear devices)

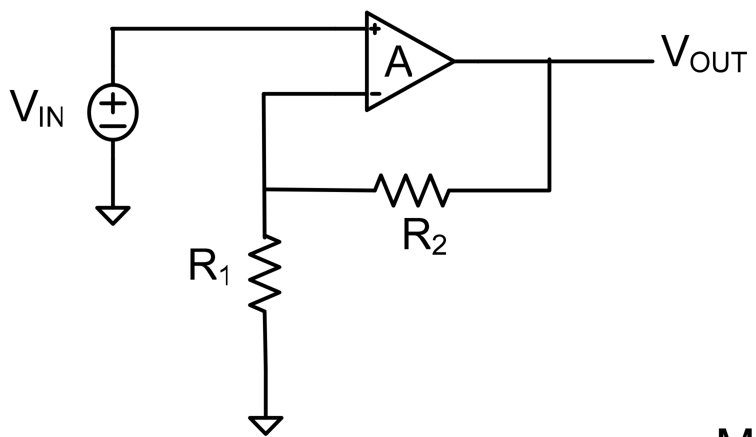
Basic Linear Applications

- Finite gain (feedback) amplifiers
- Summing amplifiers
- Integrators
- Filters
- And some others

Note: Essentially all linear applications of operational amplifiers involve large amounts of feedback though the concepts of feedback is often not emphasized

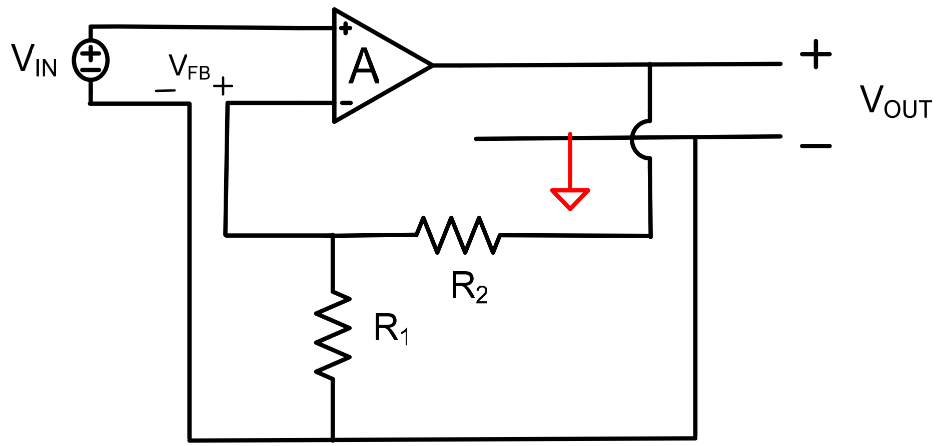
Finite Gain Feedback Amplifiers

Consider the following circuit

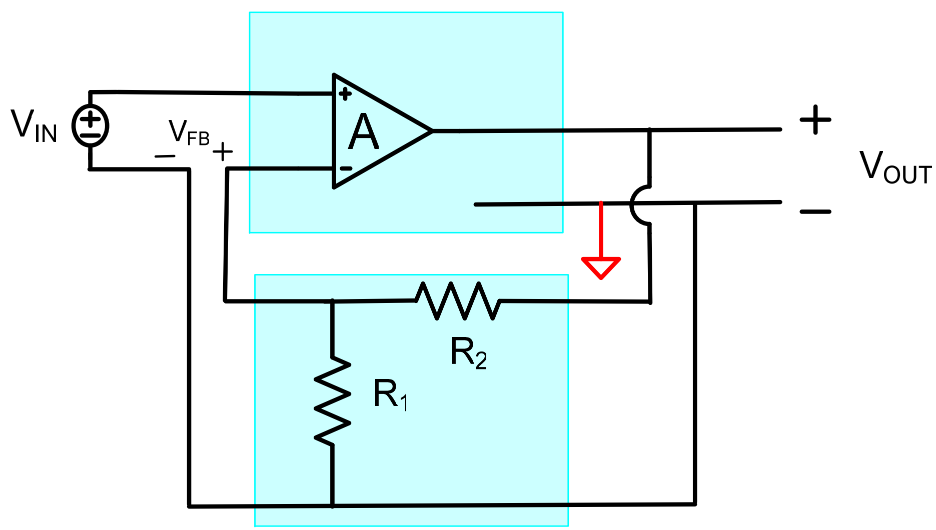


Assume the gain of the op amp is very large

Redraw this as

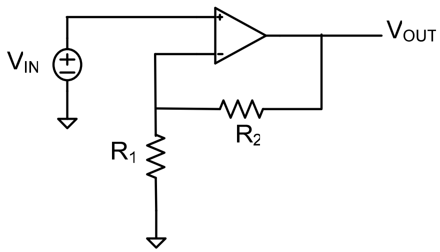


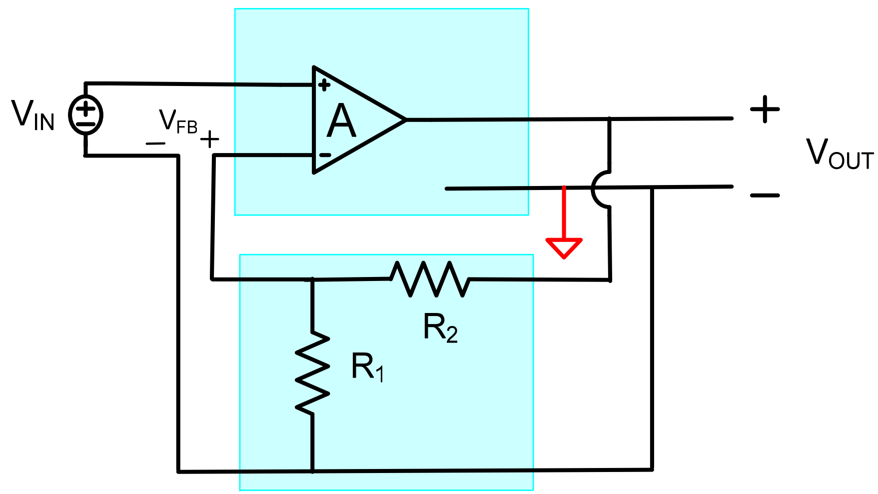
Make the associations shown in blue



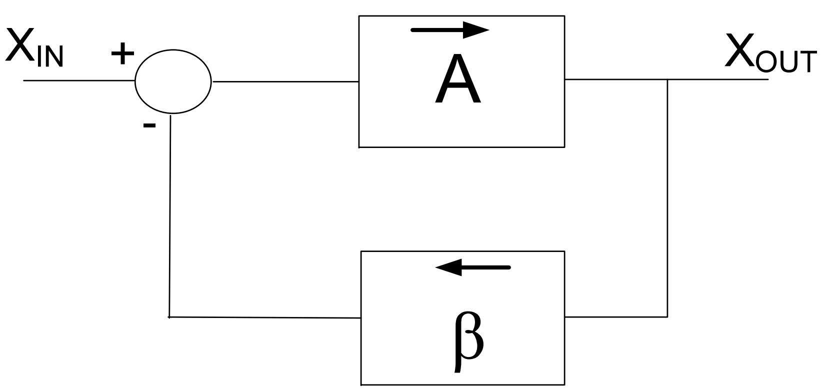
Finite Gain Feedback Amplifiers

Consider the following circuit





For $R_{IN}=\infty$ and $R_0=0$, this is an EXACT representation of Black feedback structure



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

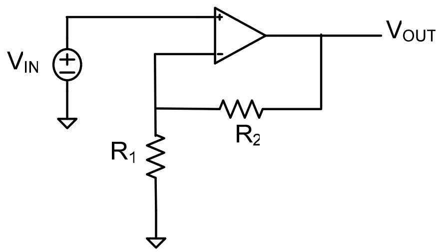
For A large

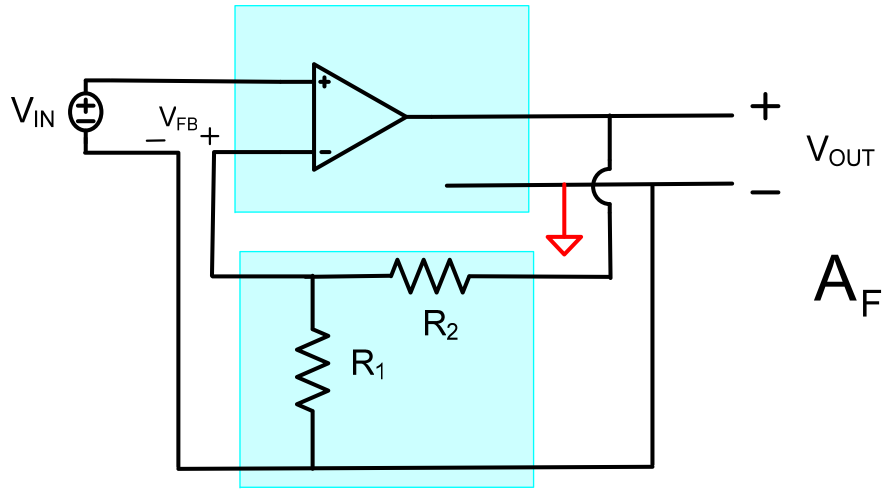
$$A_{FB} \simeq \frac{1}{\beta}$$

This is a <u>Voltage</u> Feedback Amplifier

Finite Gain Feedback Amplifiers

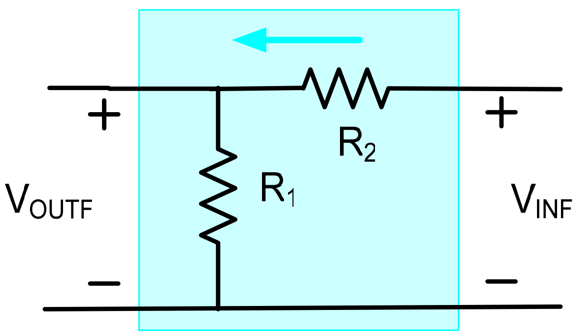
Consider the following circuit





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

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

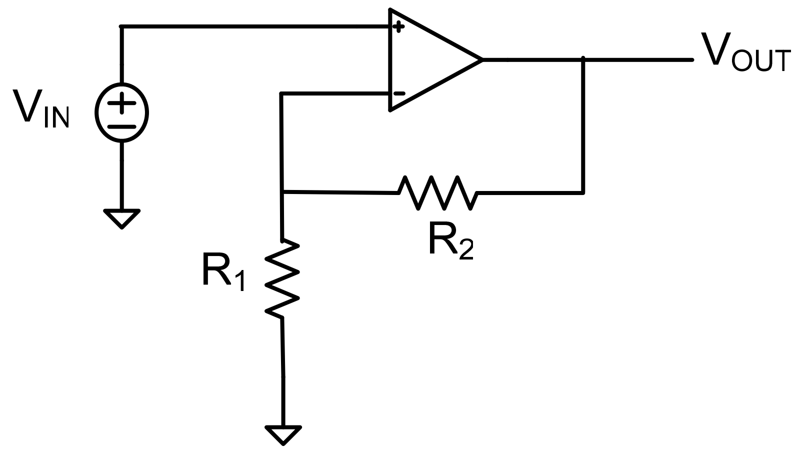


$$\beta = \frac{R_1}{R_1 + R_2}$$

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

Observe this serves as a basic finite-gain noninverting amplifier

Basic Noninverting Amplifier

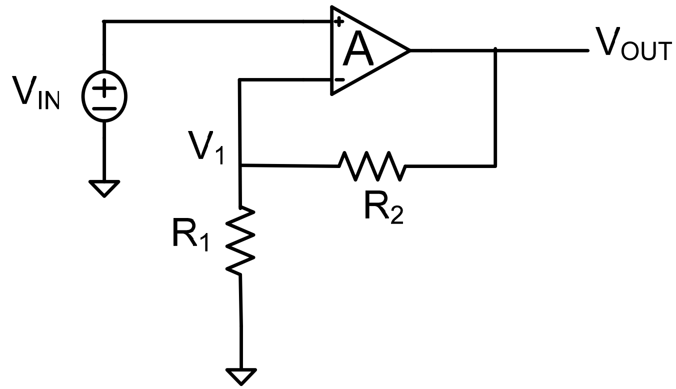


$$A_{FB} = 1 + \frac{R_2}{R_1}$$

Gain can be accurately determined by resistors

Circuit has excellent linearity

Basic Noninverting Amplifier



Alternate Analysis:

$$V_1\left(G_1+G_2\right) = G_2 V_{OUT}$$

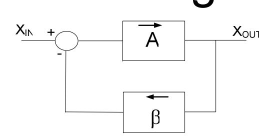
$$V_{OUT} = A\left(V_{IN}-V_1\right)$$

$$A_{FB} = \frac{V_{OUT}}{V_{IN}} = \frac{1+\frac{R_2}{R_1}}{1+\left(\frac{1}{A}\right)\left(1+\frac{R_2}{R_1}\right)}$$

As A goes to ∞,   this reduces to

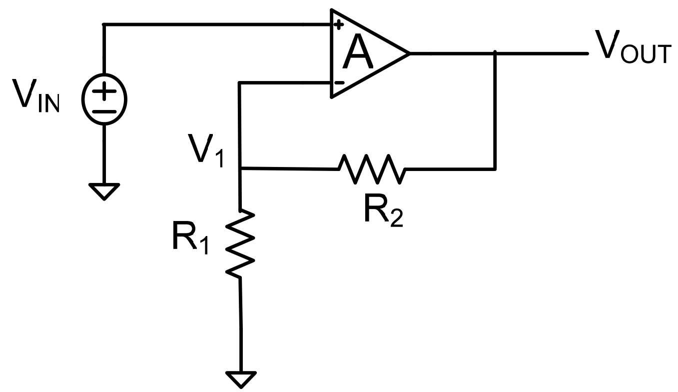
$$A_{FB} = 1+\frac{R_2}{R_1}$$

- Same gain as before
- Feedback concepts were not used yet feedback is present
- Often much simpler to analyze a FB network directly rather than using FB concepts
- Many (most) feedback circuits can not be drawn exactly as so FB analysis results can not be directly applied



- Even if FB concepts do not apply exactly, good performance obtain from feedback

Basic Noninverting Amplifier



Yet another alternate analysis (ideal Op Amp):

Recall for an ideal op amp, $V^+=V^-$, so $V_{IN}=V_1$

Since no current flows into the terminals of Op Amp, can use voltage divider equation

$$V_{IN}=\left(\frac{R_1}{R_1+R_2}\right)V_{OUT}$$

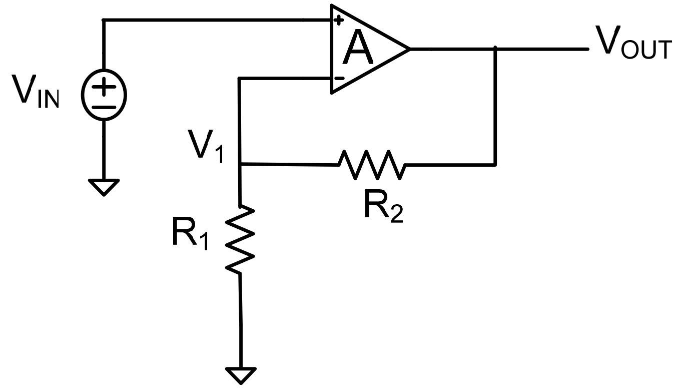
$$\therefore \quad A_{FB}=\frac{V_{OUT}}{V_{IN}}=1+\frac{R_2}{R_1}$$

Basic Noninverting Amplifier

Input Impedance ?

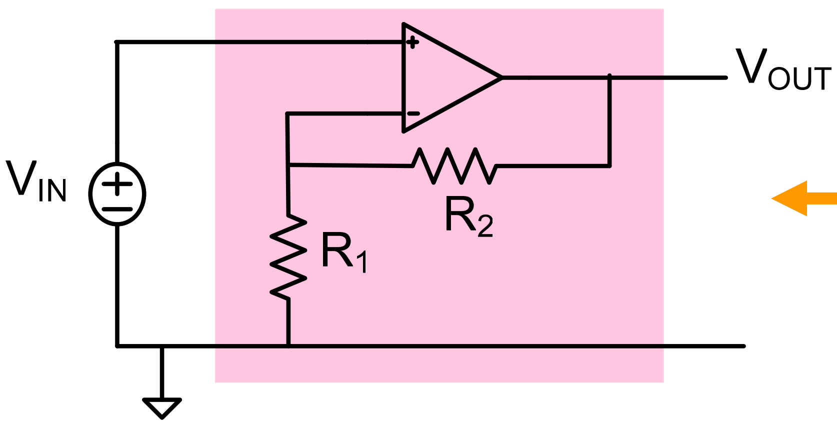
Output Impedance?

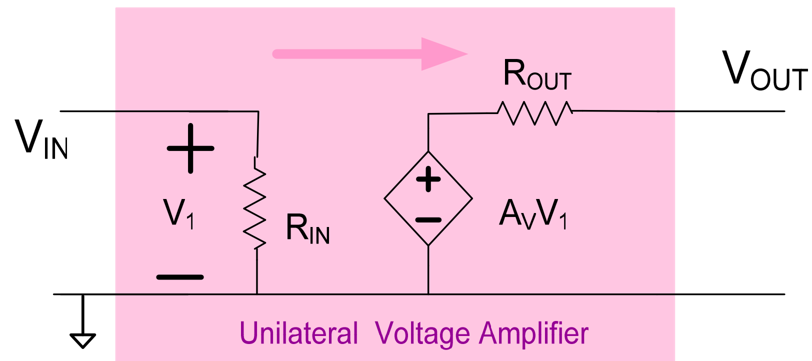
A_V ?



$$\frac{V_{OUT}}{V_{IN}} \simeq 1+\frac{R_2}{R_1}$$

It can be shown that the basic noninverting amplifier is (very nearly) unilateral



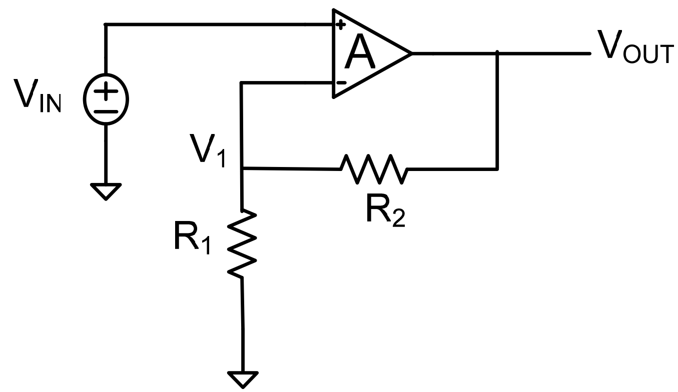


$R_{IN}=\infty$

$R_{OUT}= 0$

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

Basic Noninverting Amplifier



$$\frac{V_{OUT}}{V_{IN}} \simeq 1+\frac{R_2}{R_1}$$

If $R_2/R_1 = 9$, how much error was introduced by assuming $A=\infty$ if the actual op amp has a gain of $A=10^5$?

$$\frac{V_{OUT}}{V_{IN}} \simeq 1+9 = 10$$

From the alternate analysis we derived the expression

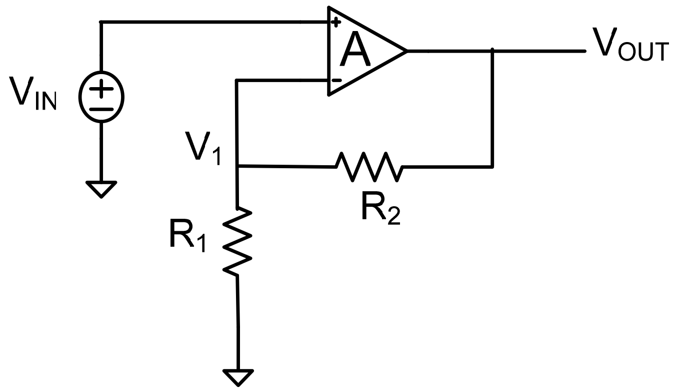
$$\frac{V_{OUT}}{V_{IN}} = \frac{1+\frac{R_2}{R_1}}{1+\left(\frac{1}{A}\right)\left(1+\frac{R_2}{R_1}\right)}$$

$$\frac{V_{OUT}}{V_{IN}} = \frac{1+\frac{R_2}{R_1}}{1+\left(\frac{1}{A}\right)\left(1+\frac{R_2}{R_1}\right)} = \frac{10}{1+10^{-5}(10)} = 9.9990$$

Error is 1 part in 10,000 which is .01%

Seldom (almost never) need t include the finite gain A in the analysis of the Op Amp

Basic Noninverting Amplifier



$$\frac{V_{OUT}}{V_{IN}} \simeq 1+\frac{R_2}{R_1}$$

Will you impress your boss if you were to use the more accurate gain expression

$$\frac{V_{OUT}}{V_{IN}} = \frac{1+\frac{R_2}{R_1}}{1+\left(\frac{1}{A}\right)\left(1+\frac{R_2}{R_1}\right)}$$

instead of the approximation

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

End of Lecture 10