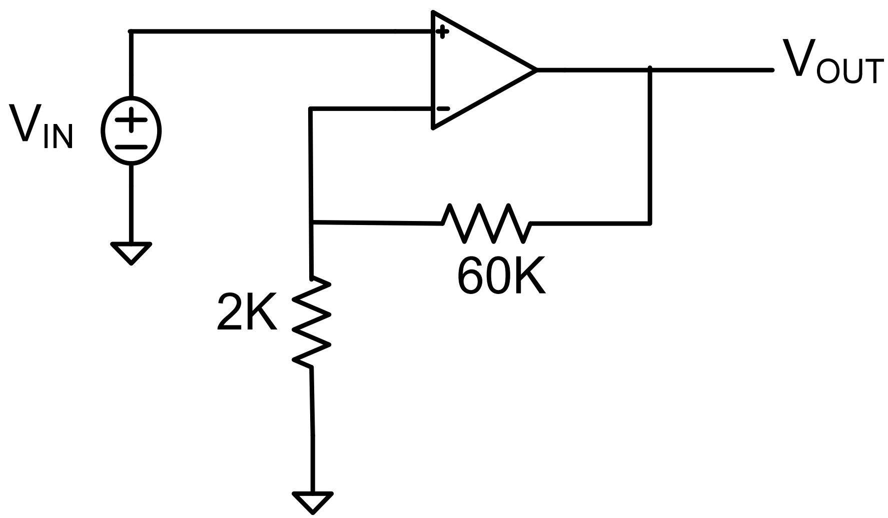
EE 230
Lecture 11

Basic Feedback Configurations

- Input/Output Impedance
- Inverting Amplifiers
- Summing Amplifiers

Quiz 9

Determine the voltage gain of this amplifier.
Assume the Op Amp is ideal



And the number is ?

1 3 8

5 4

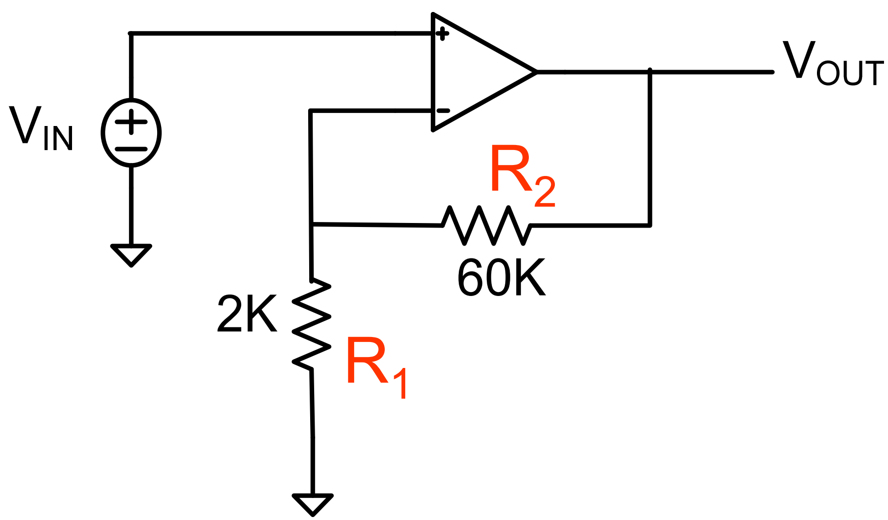
?

2 6

9 7

Quiz 9

Determine the voltage gain of this amplifier.
Assume the Op Amp is ideal



Solution: $A_{VF} = 1 + \frac{R_2}{R_1} = 31$

Reminder: Exam 1 on Wednesday

Students may bring one sheet (front and back) of notes

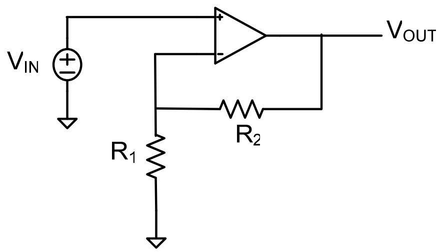
There will be no 11:00 lectures next week but will resume the week of Feb 14

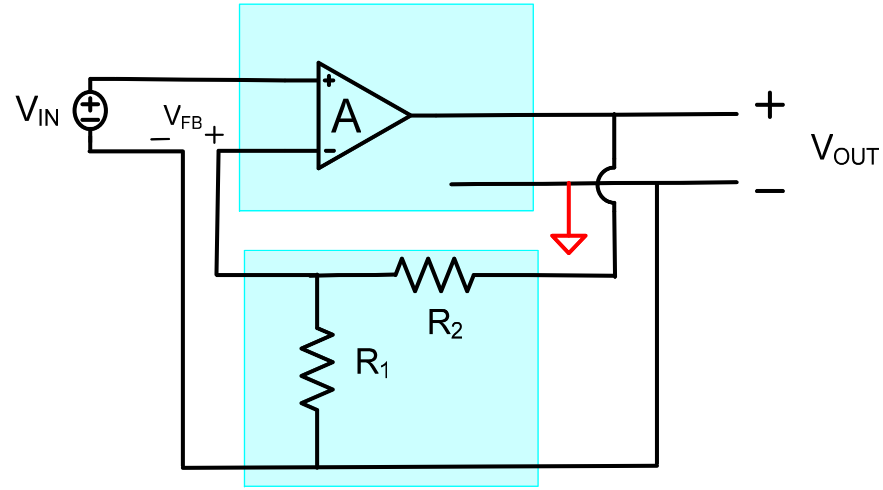
I will have limited email access after noon today so return email messages may be delayed

Laboratory 4 - Purpose

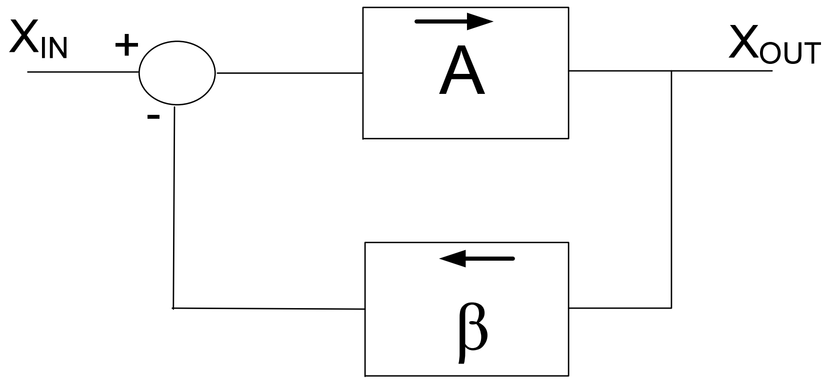
Finite Gain Feedback Amplifiers

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

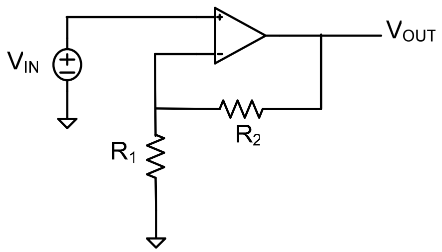
$$A_{FB}\simeq\frac{1}{\beta}$$

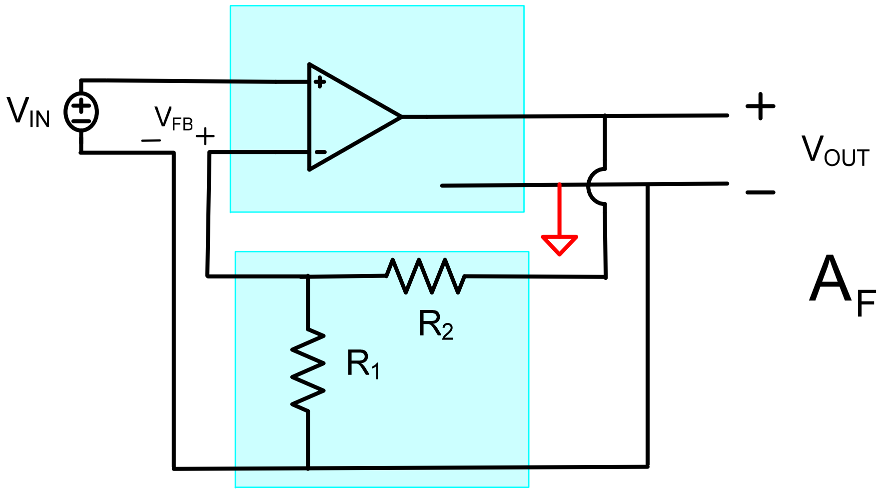
This is a Voltage Feedback Amplifier

Review from Last Time

Finite Gain Feedback Amplifiers

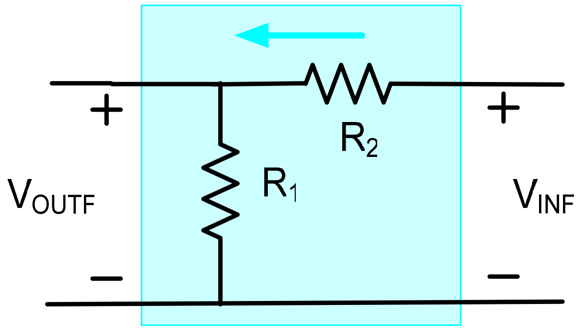
Consider the following circuit





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

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

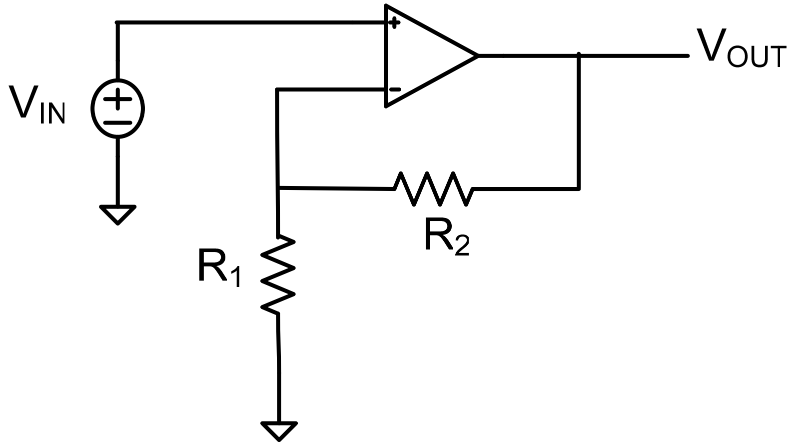


$$\beta=\frac{R_1}{R_1+R_2}$$

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

Observe this serves as a basic finite-gain noninverting amplifier

Basic Noninverting Amplifier

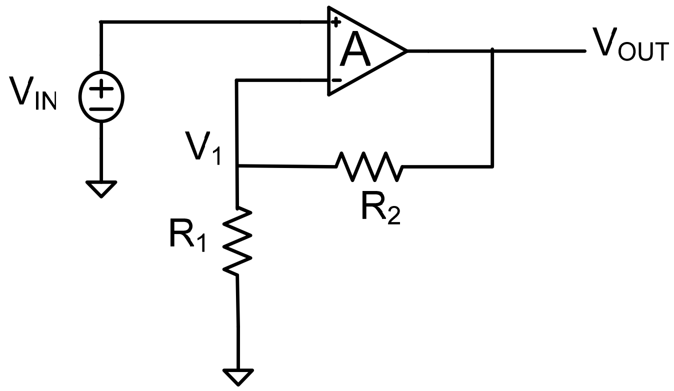


$$A_{FB} = 1 + \frac{R_2}{R_1}$$

Gain can be accurately determined by resistors

Circuit has excellent linearity

Basic Noninverting Amplifier



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

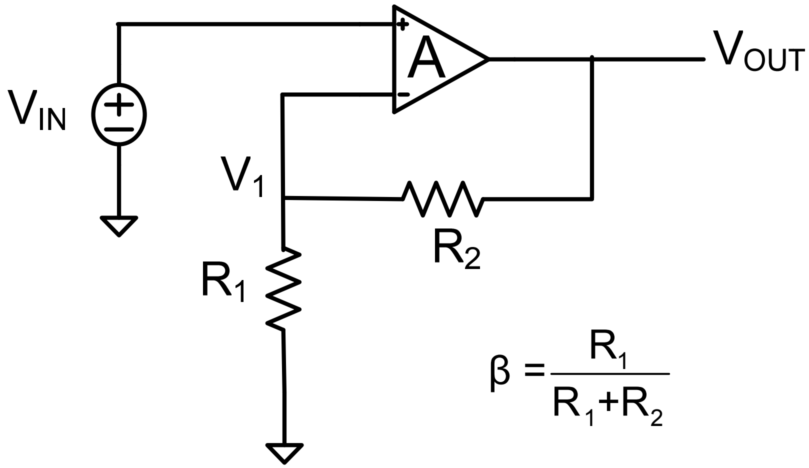
Will you impress your boss if you were to use the more accurate gain expression

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

instead of the approximation

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

Input and Output Impedances with Feedback

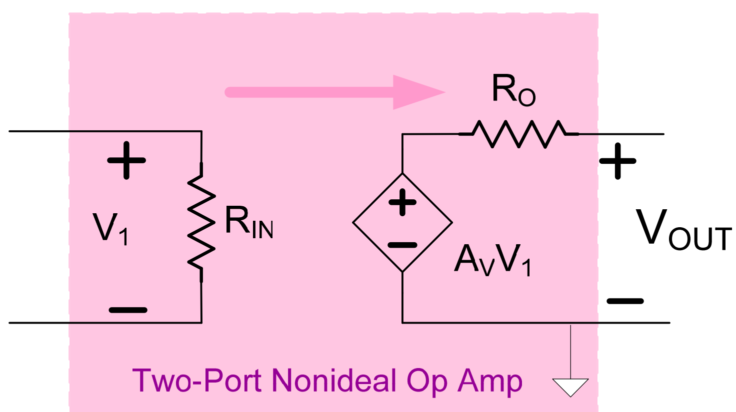


$$\beta = \frac{R_1}{R_1+R_2}$$

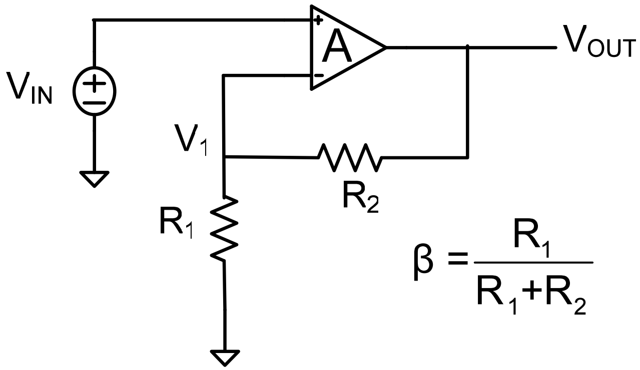
R_{INF}=?

R_{OF}=?

Model of A amplifier including R_{IN} and R_0



Input and Output Impedances with Feedback



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

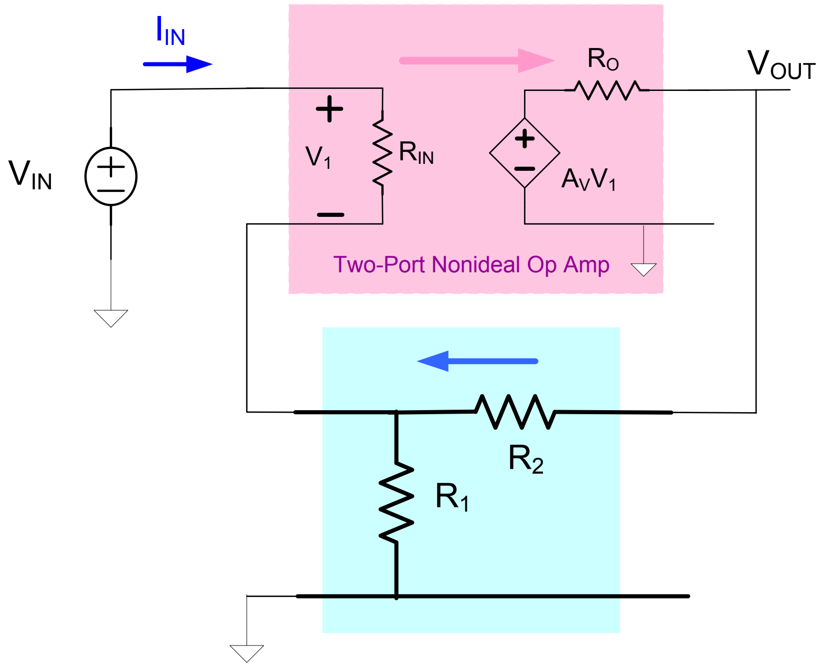
R_{INF}=?

R_{OF}=?

Approximate analysis for R_{INF}:

Assume

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



$$R_{INF} = \frac{V_{IN}}{I_{IN}}$$

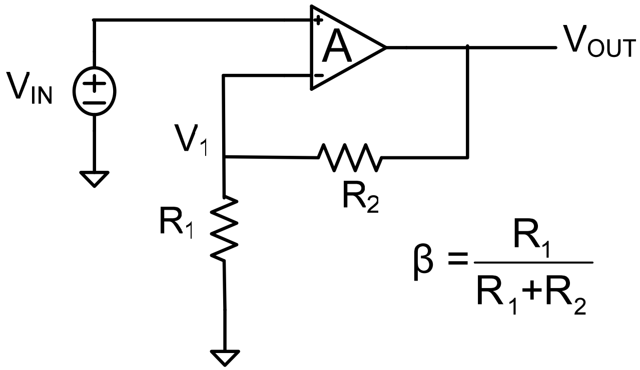
$$V_{IN} = I_{IN}R_{IN} + \beta V_{OUT}$$

$$\frac{V_{OUT}}{V_{IN}} = \frac{A_V}{1+A_V\beta}$$

$$R_{INF} = R_{IN}\left(1+A_V\beta\right)$$

Note the dramatic increase (improvement) in R_{INF} over what was already a very large R_{IN}

Input and Output Impedances with Feedback

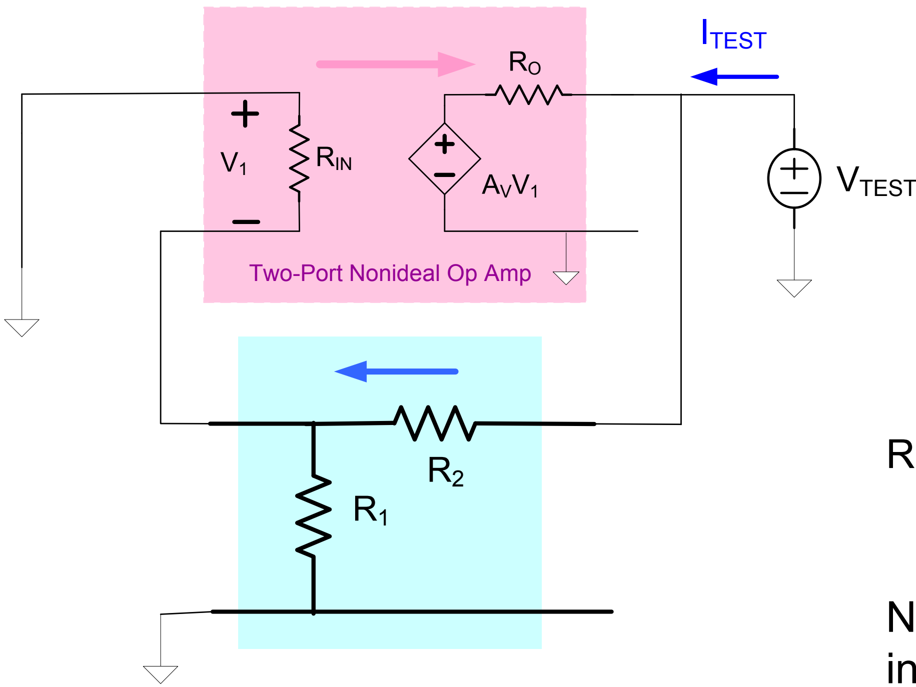


$$\beta = \frac{R_1}{R_1 + R_2}$$

R_{INF}=?

R_{OF}=?

Approximate analysis for R_{OF}:



Assume $V_1 \simeq -\beta V_{TEST}$

$$R_{0F} = \frac{V_{TEST}}{I_{TEST}}$$

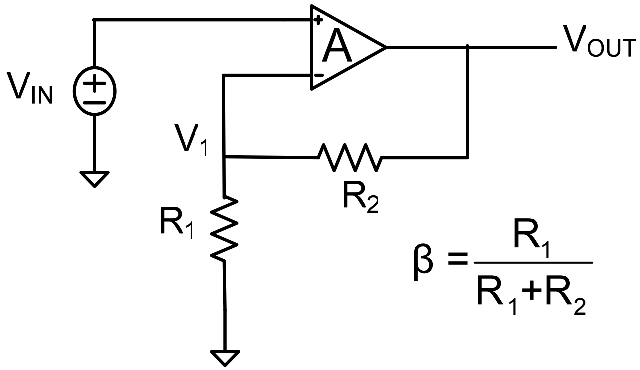
$$V_1 = -\beta V_{TEST}$$

$$I_{TEST} = \frac{V_{TEST} - A_V V_1}{R_0} + \frac{V_{TEST} - -V_1}{R_2}$$

$$R_{0F} = \frac{1}{\frac{1}{R_0} + \frac{1}{R_2} + \beta\left(\frac{A_V}{R_0} - \frac{1}{R_2}\right)} \simeq \frac{R_0}{1+\beta A_V}$$

Note the dramatic decrease (improvement) in R_0 over what was already a very low R_0

Input and Output Impedances with Feedback

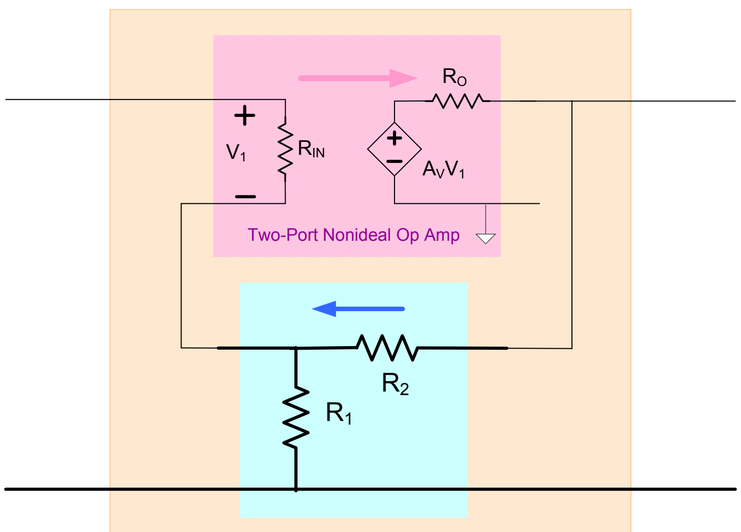


$$\beta = \frac{R_1}{R_1+R_2}$$

R_{INF}=?

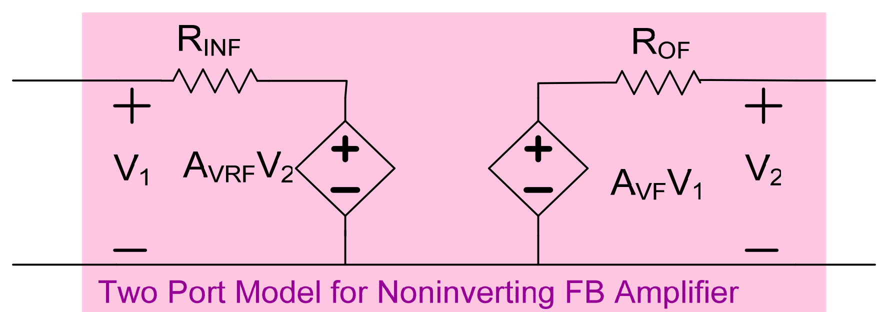
R_{OF}=?

Exact analysis : Consider amplifier as a two-port and use open/short analysis method



Will find R_{INF}, R_{OF}, A_V almost identical to previous calculations

Will see a small A_{VR} present but it plays almost no role since R_{INF} is so large (effectively unilateral)



$$A_{VF} \simeq \frac{1}{\beta} \qquad R_{0F} \simeq \frac{R_0}{1+\beta A_V} \qquad R_{INF} = R_{IN}\left(1+A_V\beta\right) \qquad A_{VRF} \simeq \beta$$

Basic Linear Applications

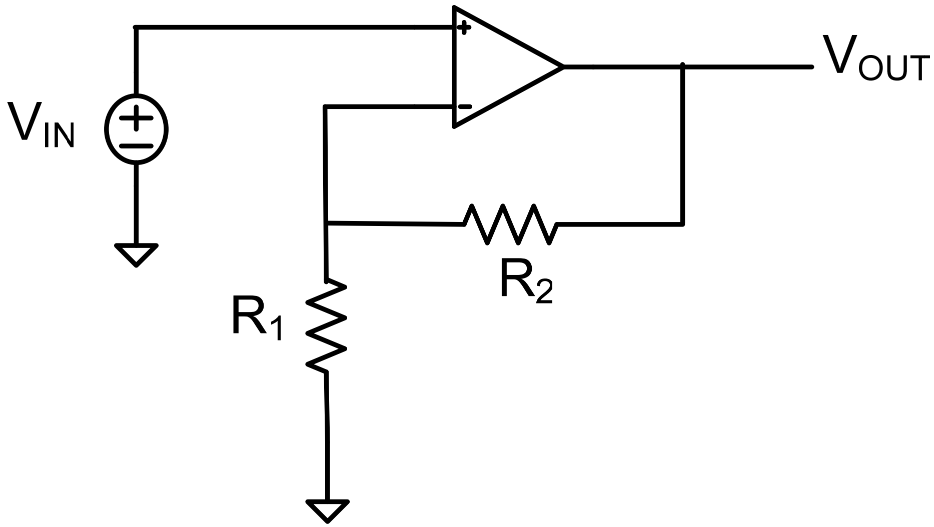
Will now focus on introducing several useful linear circuits and will assume op amps are ideal

- 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

Basic Noninverting Amplifier

(already introduced)

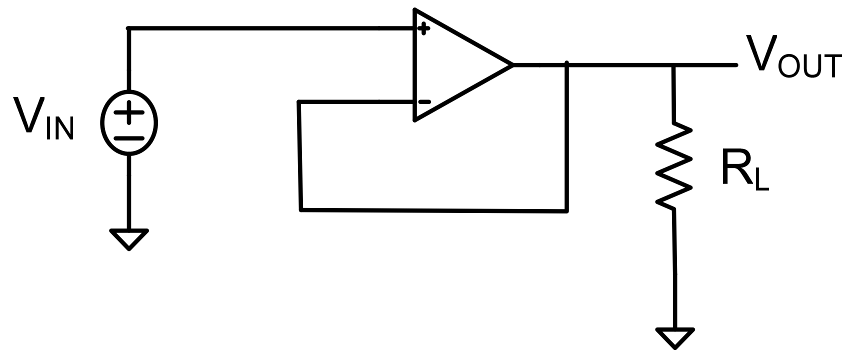


$$A_V = \frac{V_{OUT}}{V_{IN}} = 1 + \frac{R_2}{R_1}$$

$R_{IN} = \infty$

$R_{OUT} = 0$

Buffer Amplifier



$$A_V = \frac{V_{OUT}}{V_{IN}} = 1$$

$R_{IN} = \infty$

One of the most widely used Op Amp circuits

$R_{OUT} = 0$

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

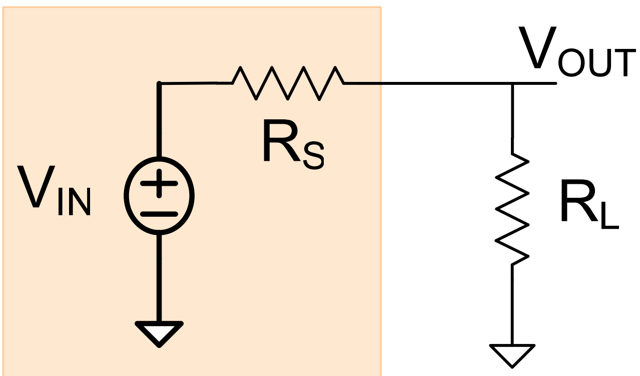
This provides for decoupling between stages in many circuits

Special case of basic noninverting amplifier with $R_1 = \infty$ and $R_2 = 0$

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

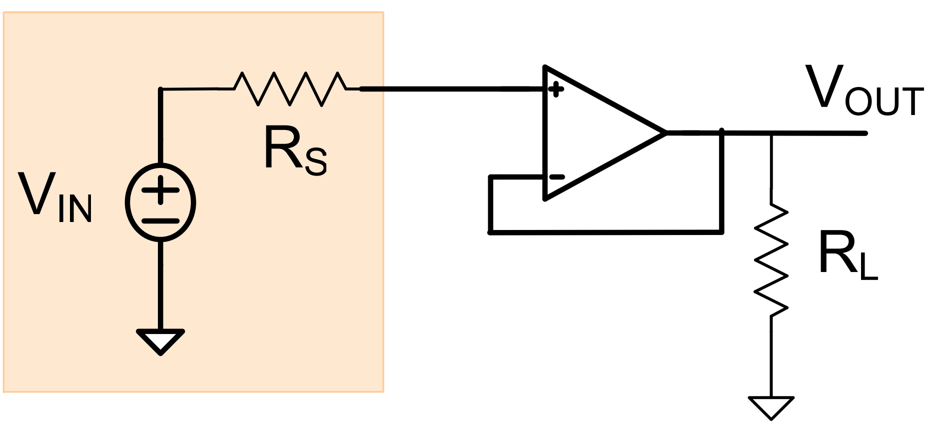
Buffer Amplifier Application

Goal: Drive R_L with V_{IN}



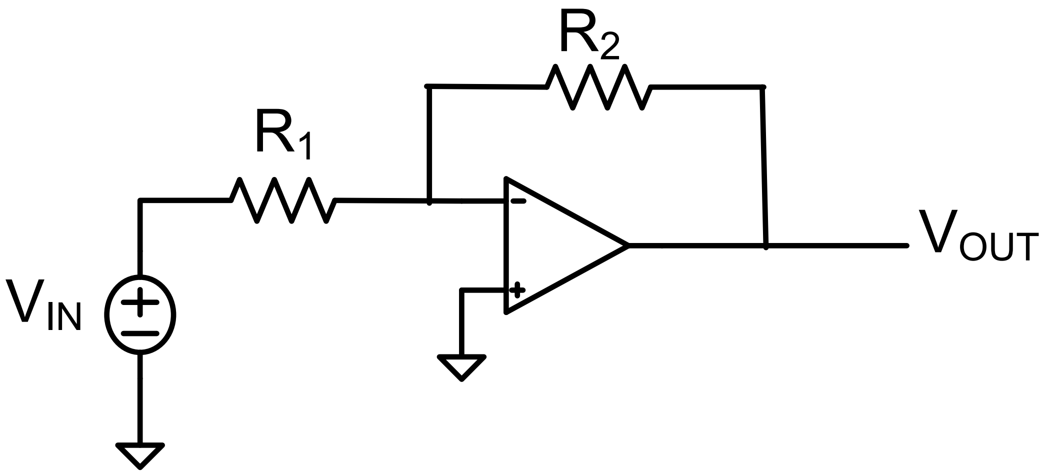
$$A_V = \frac{V_{OUT}}{V_{IN}} = \frac{R_L}{R_S + R_L} \neq 1$$

With buffer amplifier



$$A_V = \frac{V_{OUT}}{V_{IN}} = 1$$

Basic Inverting Amplifier



$$\frac{V_{IN}}{R_1} + \frac{V_{OUT}}{R_2} = 0$$

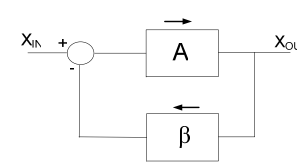
$$\frac{V_{OUT}}{V_{IN}} = -\frac{R_2}{R_1}$$

$$R_{OUT} = 0$$

$$R_{IN} = R_1$$

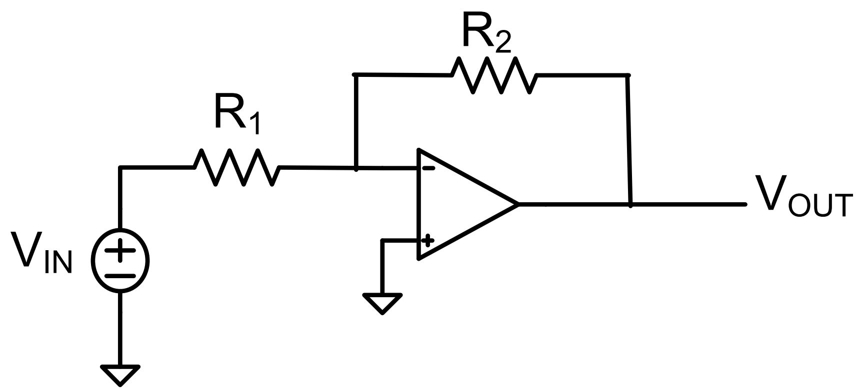
Input impedance of R_1 is unacceptable in many (but not all) applications

This is not a voltage feedback amplifier (it is a feedback amplifier) of the type (note R_{IN} is not high!)



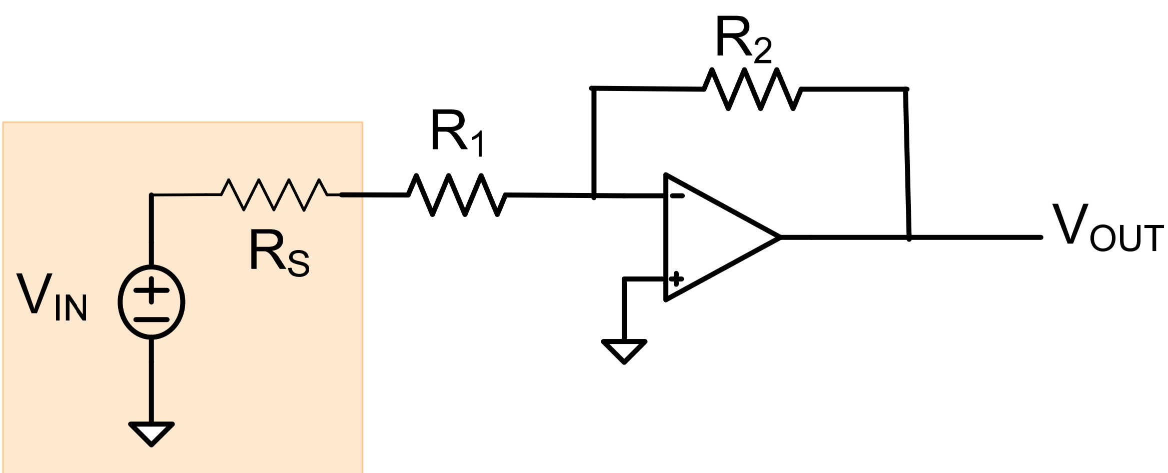
Feedback concepts could be used to analyze this circuit but lots of detail required

Limitations of Input Impedance of Basic Inverting Amplifier



$$\frac{V_{OUT}}{V_{IN}} = -\frac{R_2}{R_1}$$

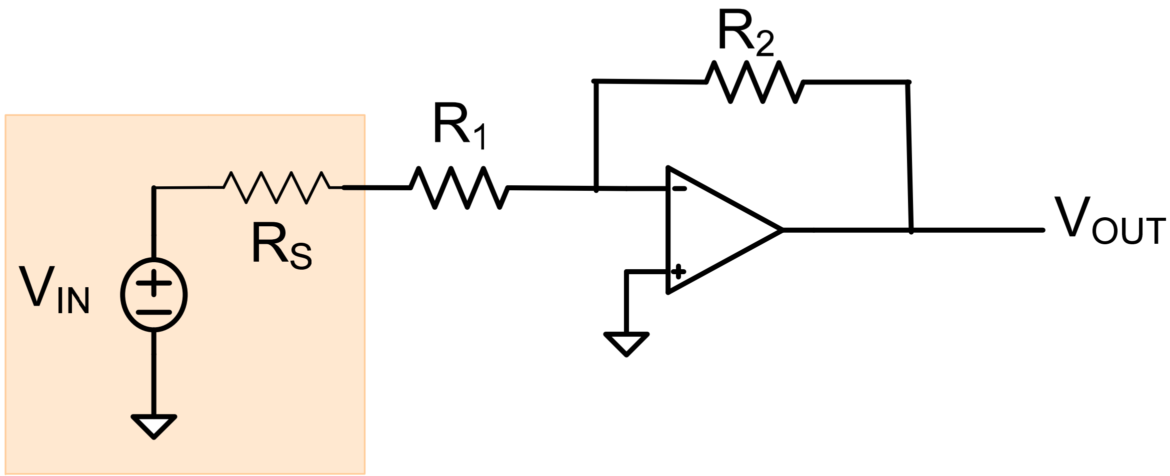
$$R_{IN} = R_1$$



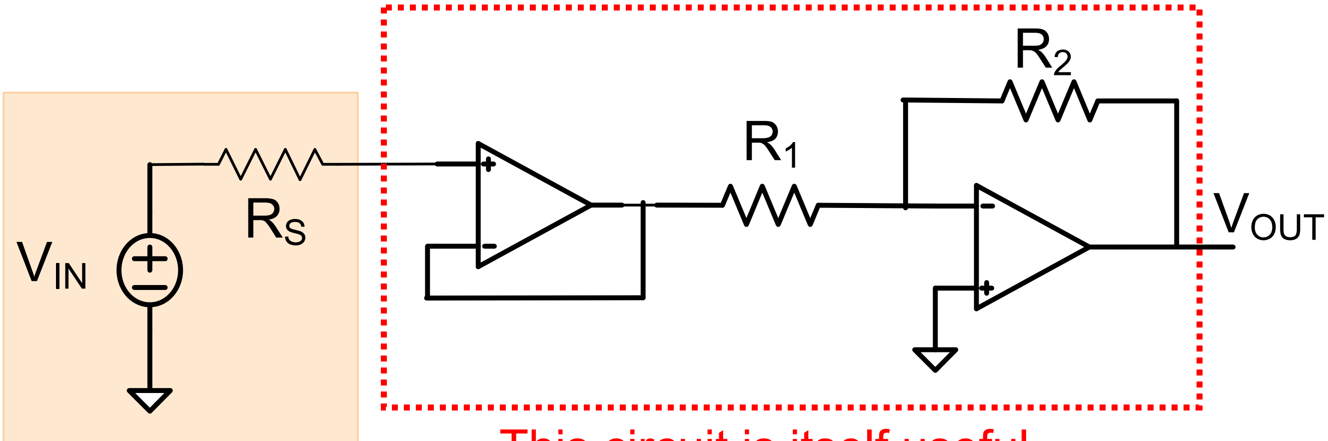
$$\frac{V_{OUT}}{V_{IN}} = -\frac{R_2}{R_1 + R_S}$$

Gain dependent on R_S and this is undesirable in many applicatons

Limitations of Input Impedance of Basic Inverting Amplifier



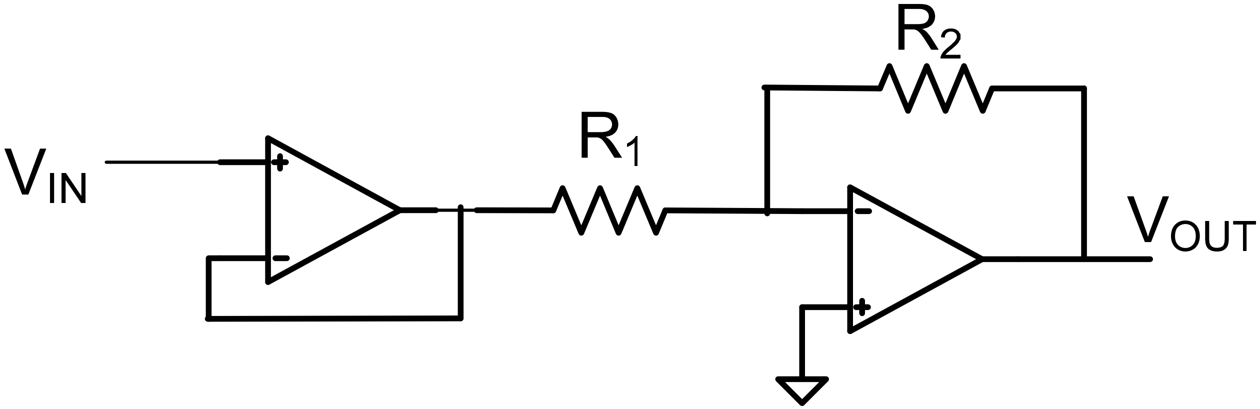
$$\frac{V_{OUT}}{V_{IN}} = -\frac{R_2}{R_1 + R_S}$$



This circuit is itself useful

$$\frac{V_{OUT}}{V_{IN}} = -\frac{R_2}{R_1}$$

Buffered Inverting Amplifier

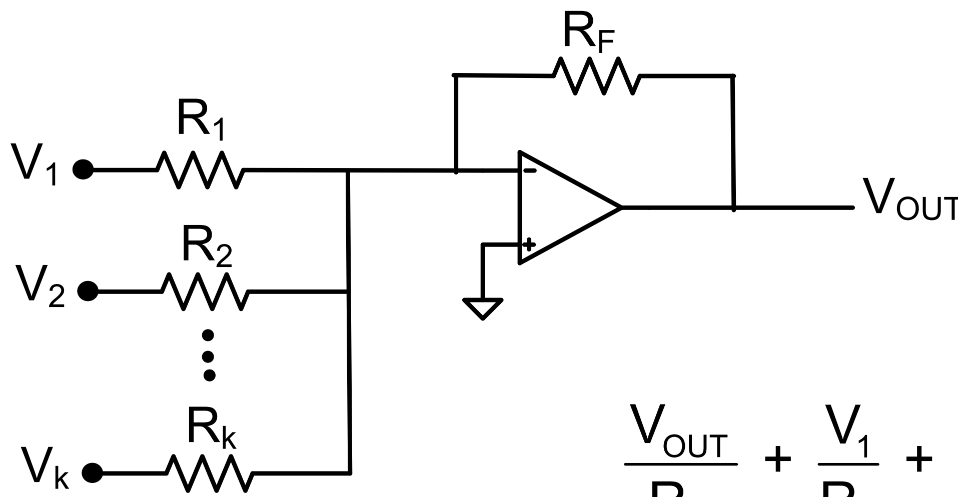


$$\frac{V_{OUT}}{V_{IN}} = -\frac{R_2}{R_1}$$

$R_{IN} = \infty$

$R_{OUT} = 0$

Summing Amplifier

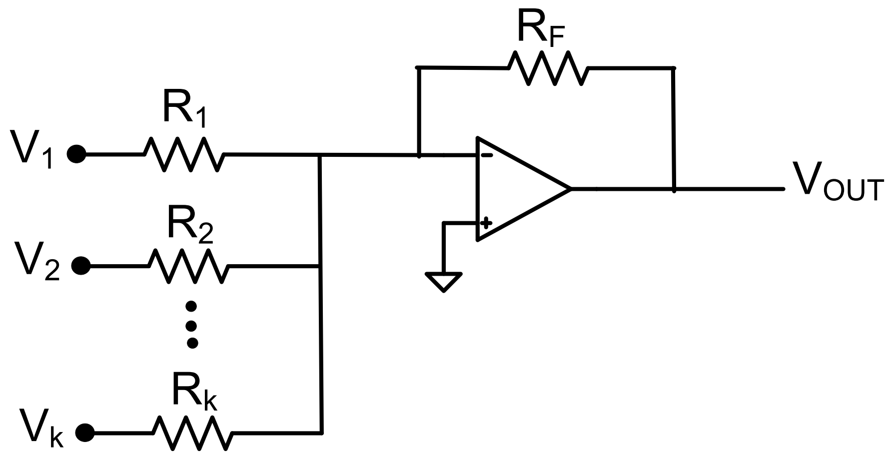


$$\frac{V_{OUT}}{R_F} + \frac{V_1}{R_1} + \frac{V_2}{R_2} + \ldots + \frac{V_k}{R_k} = 0$$

$$V_{OUT} = -\frac{R_F}{R_1}V_1 - \frac{R_F}{R_2}V_2 - \ldots - \frac{R_F}{R_k}V_k$$

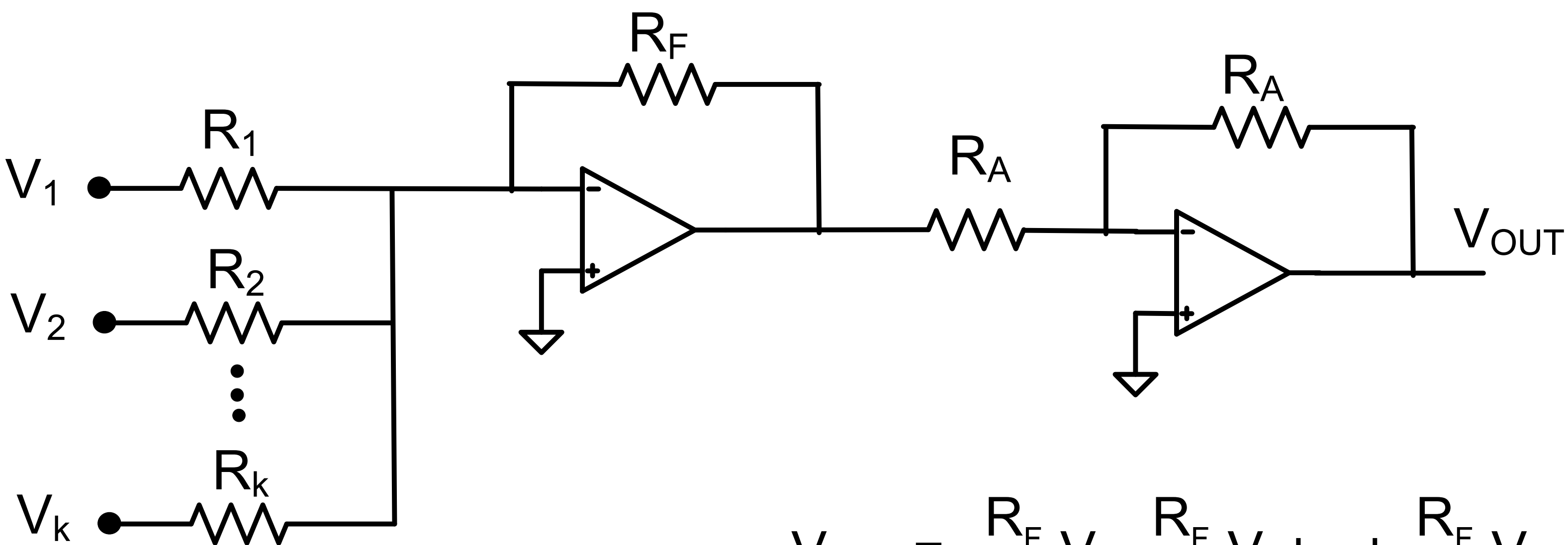
- Output is a weighted sum of the input voltages
- Any number of inputs can be used
- Gains from all inputs can be adjusted together with R_F
- Gain for input V_i can be adjusted independently with R_i for $1 \le I \le k$
- All weights are negative
- Input impedance on each input is R_i

Summing Amplifier



Behringer Commercial Mixer

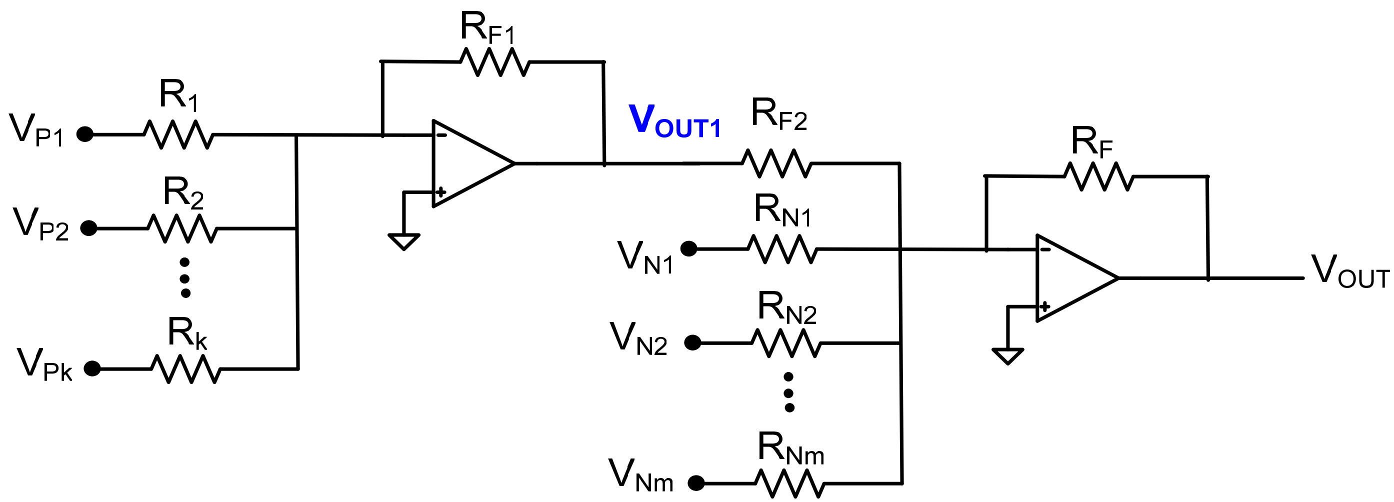
Noninverting summing amplifier



$$V_{OUT} = \frac{R_F}{R_1}V_1 \quad \frac{R_F}{R_2}V_2 + \ldots + \frac{R_F}{R_k}V_k$$

Weights are now all positive

Summing Amplifier with Inverting and Noninverting Weights



$$V_{OUT1} = -\frac{R_{F1}}{R_1}V_1 - \frac{R_{F1}}{R_2}V_2 - \ldots - \frac{R_{F1}}{R_k}V_k$$

$$V_{OUT} = -\frac{R_F}{R_{N1}}V_1 - \frac{R_F}{R_{N2}}V_2 - \ldots - \frac{R_F}{R_{Nm}}V_k + \frac{R_F}{R_{F2}}\left(\frac{R_{F1}}{R_1}V_1 + \frac{R_{F1}}{R_2}V_2 + \ldots + \frac{R_{F1}}{R_k}V_k\right)$$

End of Lecture 11