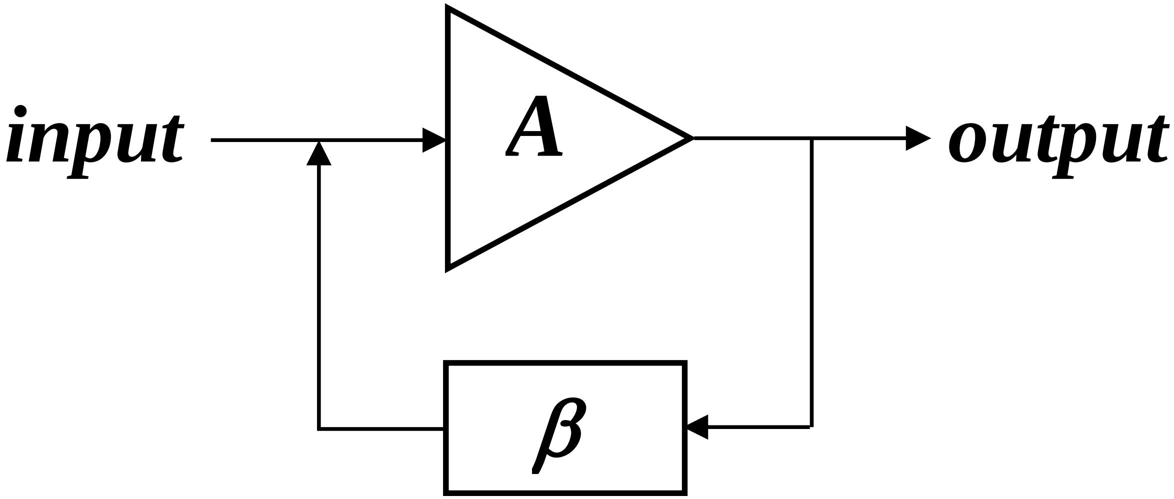
Chapter 2
Feedback Amplifiers

Feedback Amplifier

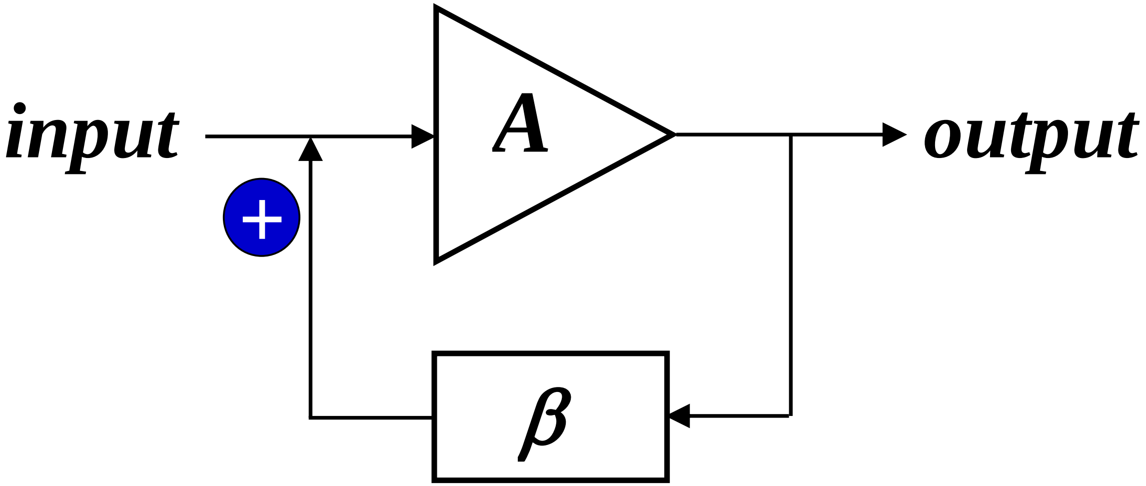
- ***Feedback*** **is a technique where a proportion of the output of a system (amplifier) is fed back and recombined with input**



- **There are 2 types of feedback amplifier:**
  - Positive feedback
  - Negative feedback

Positive Feedback

- Positive feedback is the process when the output is *added* to the input, amplified again, and this process continues.



- Positive feedback is used in the design of oscillator and other application.

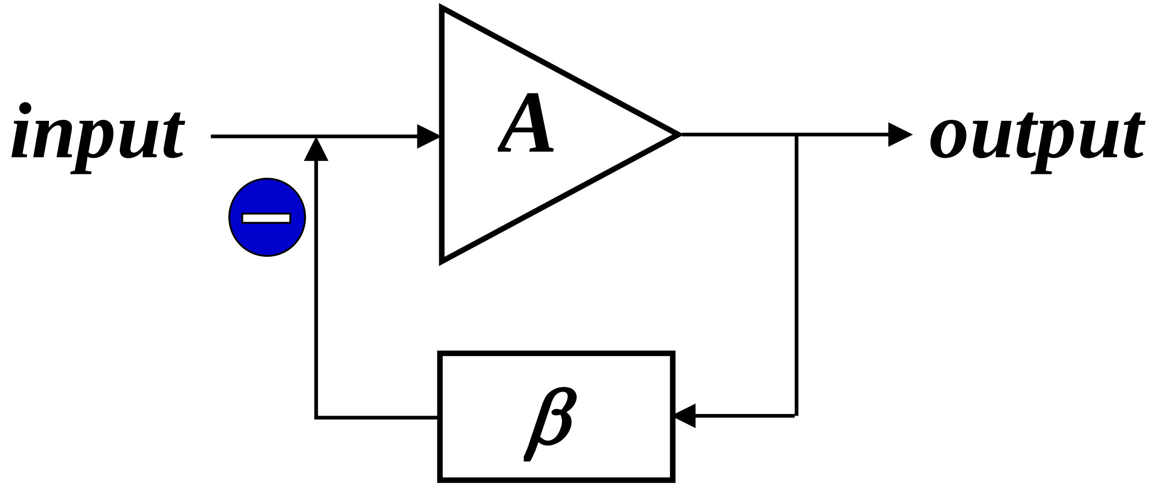
Positive Feedback - Example

- In a PA system

get feedback when you put the microphone in front of a speaker and the sound gets uncontrollably loud (you have probably heard this unpleasant effect).

Negative Feedback

- Negative feedback is when the output is subtracted from the input.



- The use of negative feedback reduces the gain. Part of the output signal is taken back to the input with a negative sign.

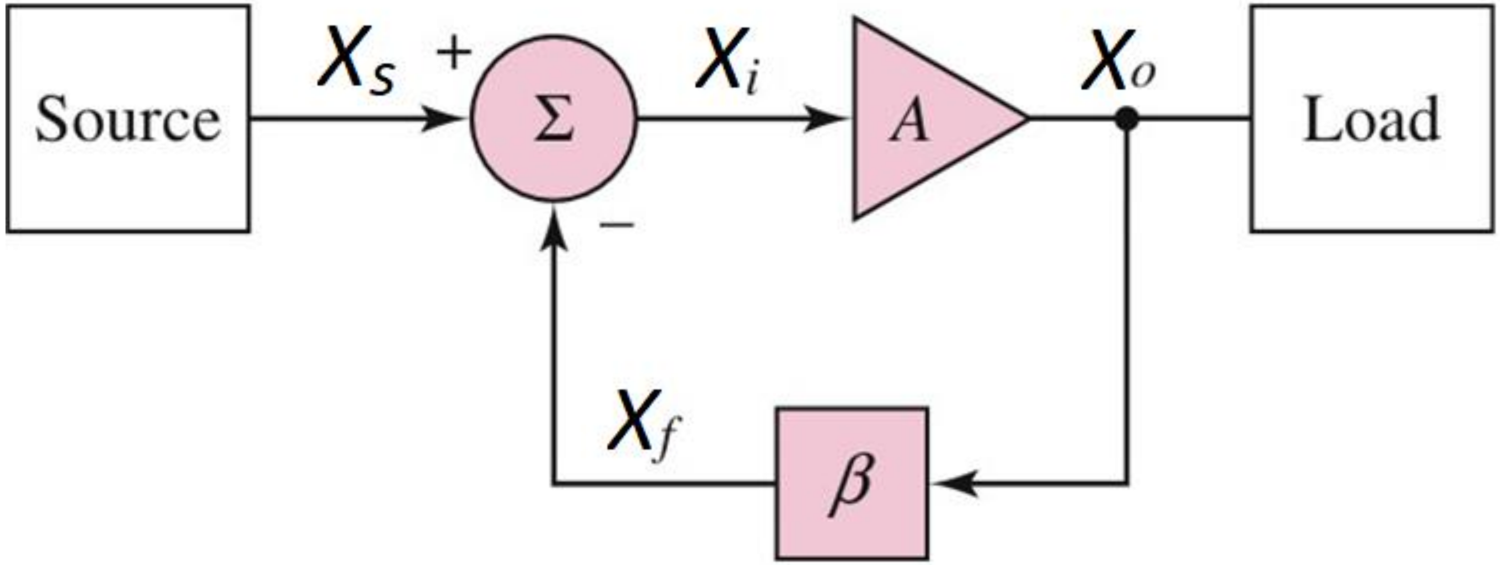
Advantages of Negative Feedback

1. **Gain desensitization (variations in gain is reduced).**
2. **Control of Impedance Levels – input and output impedances can be increased or decreased.**
3. **Bandwidth Extension (larger than that of basic amplified).**
4. **Reduction of Nonlinear Distortion**
5. **Reduction of noise effects (may increase S/N ratio).**

Disadvantages of Negative Feedback

1. **Circuit Gain – overall amplifier gain is reduced compared to that of basic amplifier.**
2. **Stability – possibility that feedback circuit will become unstable and oscillate at <u>high frequencies.</u>**

Basic Feedback Concept



Basic configuration of a feedback amplifier

Basic Feedback Concept

- The output signal is: $X_o = AX_i$

  where A is the amplification factor (the open-loop amplifier gain)
- Feedback signal is $X_f = \beta X_o$

  where ß is the feedback transfer function
- At summing node: $X_i = X_s - X_f$
- Closed-loop transfer function or gain is $A_f = \frac{X_o}{X_s} = \frac{A}{1+\beta A}$

if $\beta A >> 1 \quad then \quad A_f \cong \frac{A}{\beta A} = \frac{1}{\beta}$

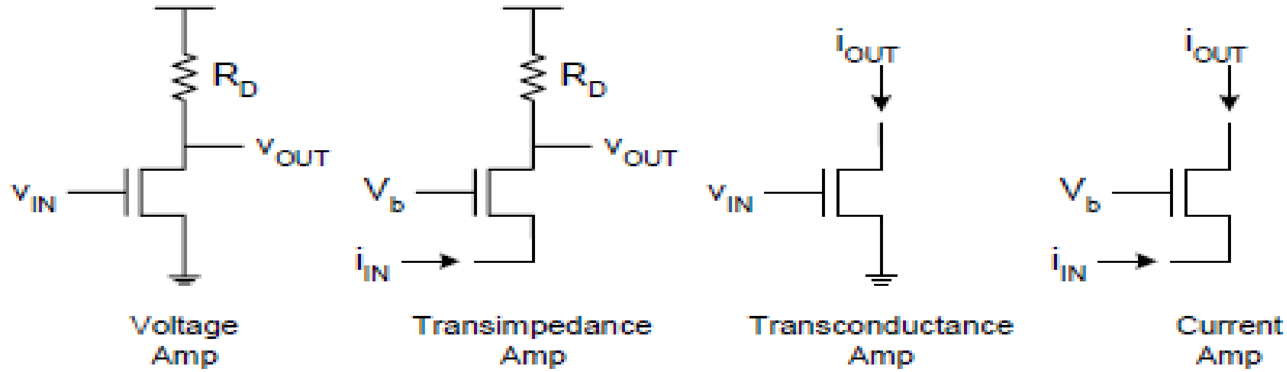
- Where Aβ is called the loop gain and 1+Aβ is called the amount of feedback

Classification of Amplifiers

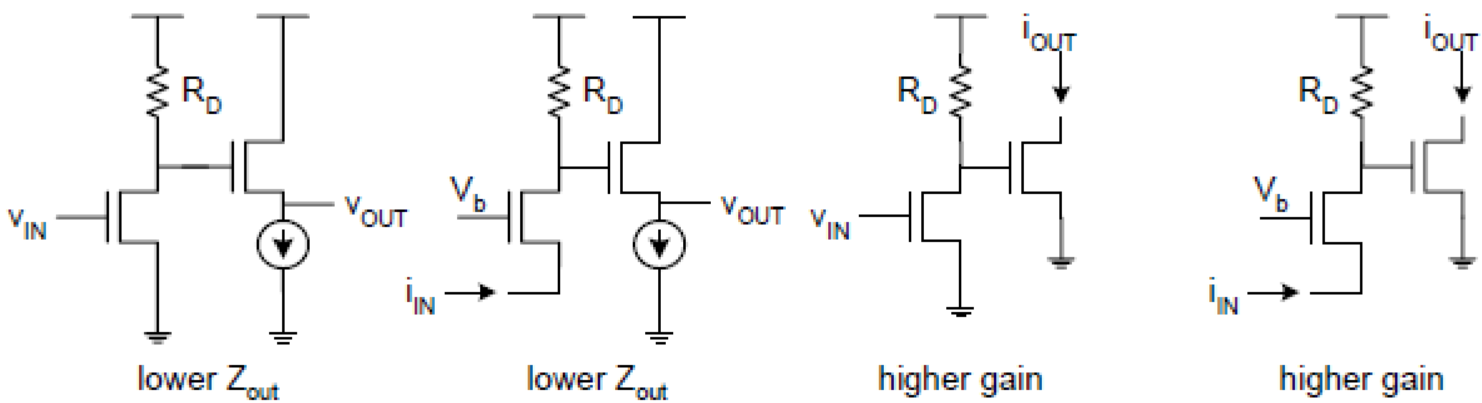
Classify amplifiers into 4 basic categories based on their input (parameter to be amplified; voltage or current) & output signal relationships:

- Voltage amplifier (series-shunt)
- Current amplifier (shunt-series)
- Transconductance amplifier (series-series)
- Transresistance amplifier (shunt-shunt)

Examples of the Four Types of Amplifiers



Shown above are simple examples of the four types of amplifiers. Often, these amplifiers alone do not have good performance (high output impedance, low gain, etc.) and are augmented by additional amplifier stages (see below) or different configurations (e.g., cascoding).



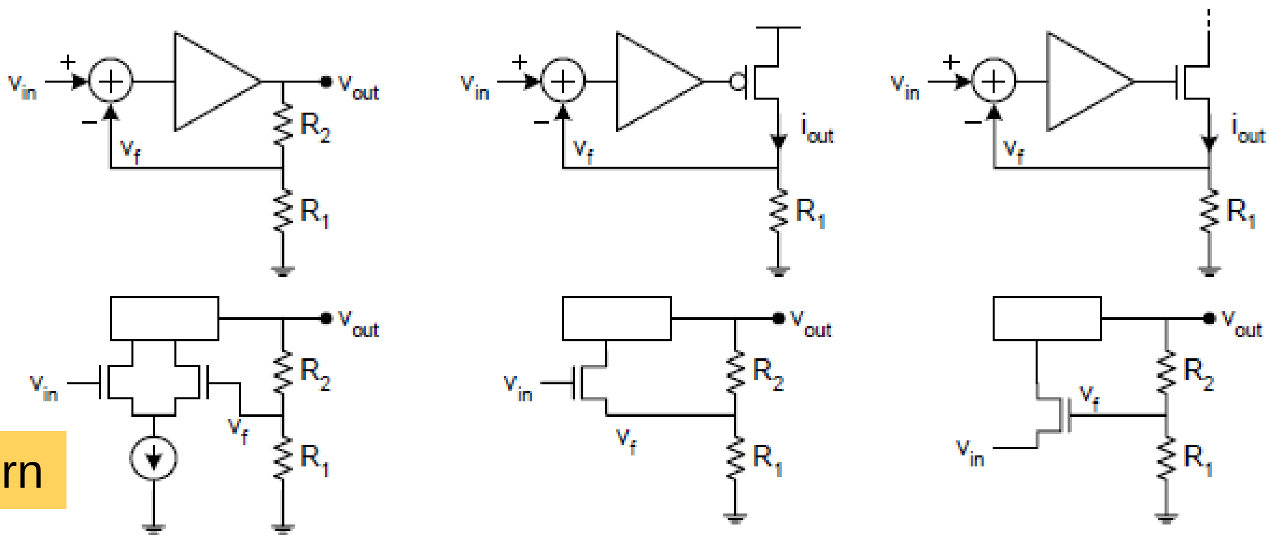
Adding a feedback loop consists of sensing the output signal and returning (a fraction) of the result to the summing node at the input.

– Given the inputs and outputs can be either voltages or currents, there are four types of feedback: voltage-voltage, voltage-current, current-voltage, and current-current

• where the first part denotes the quantity sensed at the output and the second denotes the type of signal returned

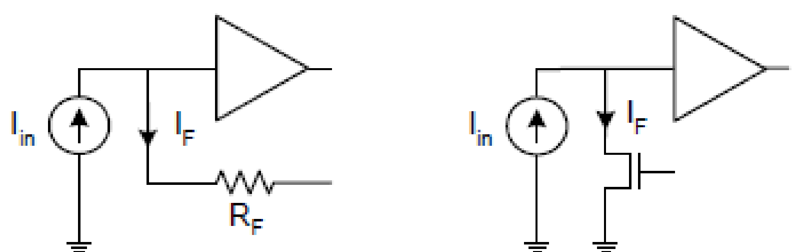
Sense and Return Mechanisms

- Here are some circuit examples of sensing and returning voltages and currents:

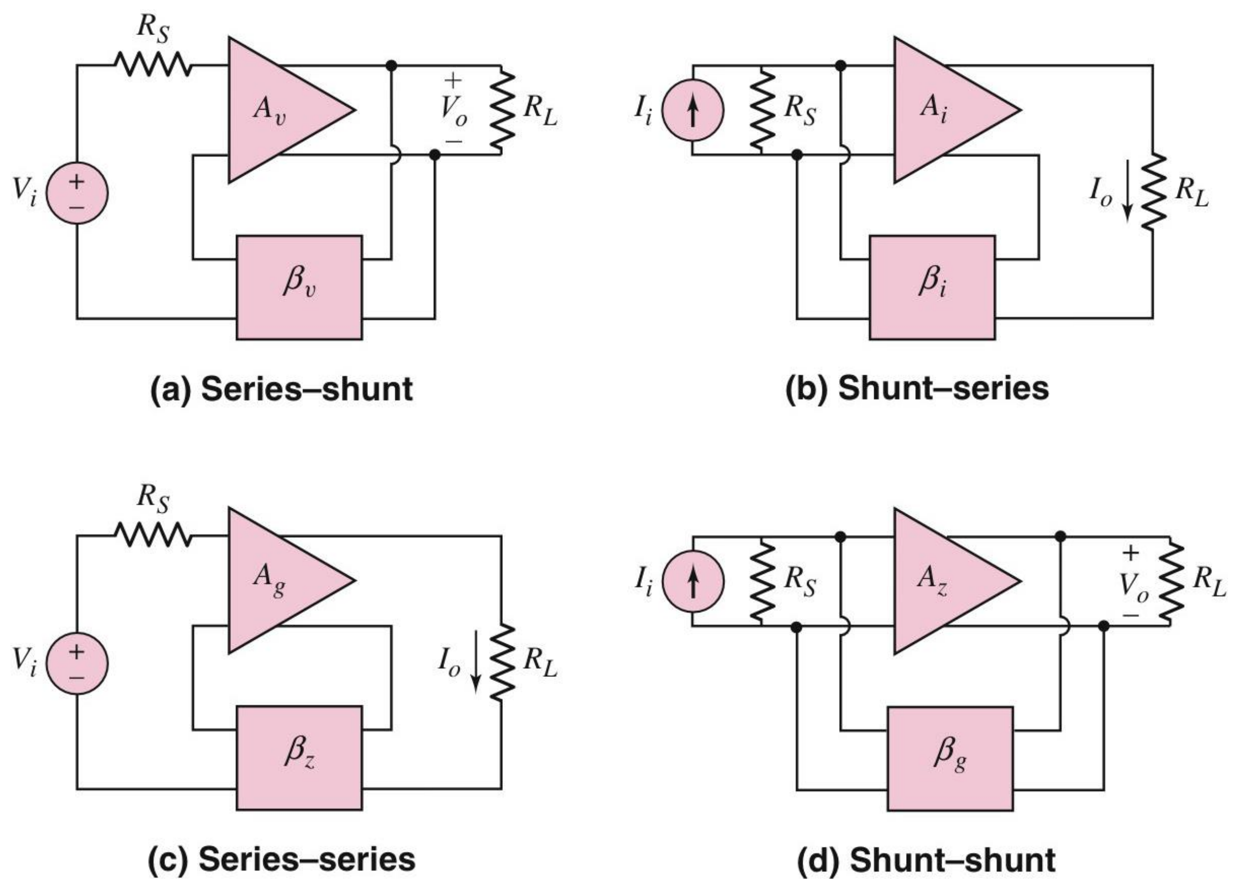


Voltage return

Current return



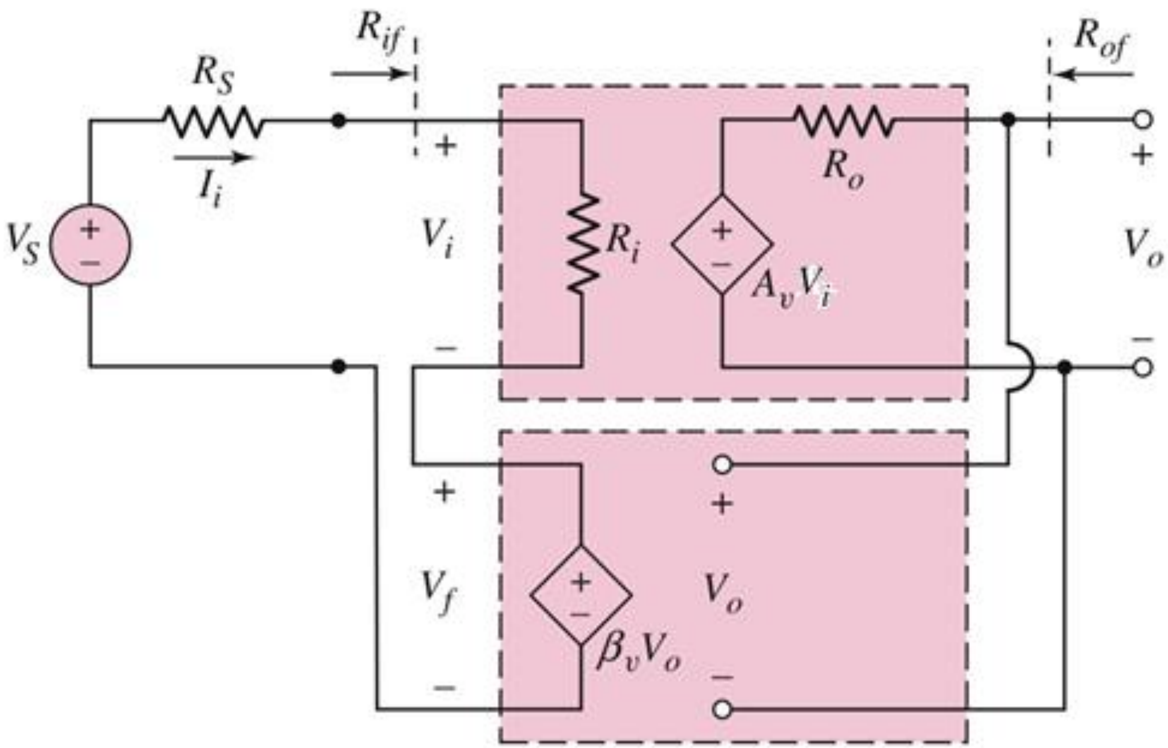
Feedback Configurations



Series:
connecting the feedback signal in series with the input signal voltage.

Shunt:
connecting the feedback signal in shunt (parallel) with an input current source

Series - Shunt Configuration



$$A_{vf} = \frac{A_v}{1+\beta_v A_v}$$

Series - Shunt Configuration (cont.)

if $\boldsymbol{R_o} << \boldsymbol{R_L}$

then the output of feedback network is an open circuit;

Output voltage is:

$$\boldsymbol{V_o} = \boldsymbol{A_v V_i}$$

feedback voltage is:

$$\boldsymbol{V_f} = \beta_v \boldsymbol{V_o}$$

where ßv is closed-loop voltage transfer function

By neglecting R_s due to $\boldsymbol{R_i} >> \boldsymbol{R_s}$; error voltage is:

$$\boldsymbol{V_i} = \boldsymbol{V_s} - V_f$$

$$\therefore A_{vf} = \frac{V_o}{V_i} = \frac{A_v}{1 + \beta_v A_v}$$

Series - Shunt Configuration (cont.)

Input Resistance, R_{if}

$$\boldsymbol{V_s} = V_i + V_f = V_i + \beta_v (A_v V_i)$$

Or

$$V_i = \frac{V_s}{(1 + \beta_v A_v)}$$

- Input current

$$I_i = \frac{V_i}{R_i} = \frac{V_s}{R_i (1 + \beta_v A_v)}$$

- R_{if} with feedback

$$R_{if} = \frac{V_s}{I_i} = R_i (1 + \beta_v A_v)$$

Output Resistance, R_{of}

Assume Vs=o and Vx applied to output terminal.

$$V_i + V_f = V_i + \beta_v V_x = 0$$

Or

$$V_i = -\beta_v V_x$$

- Input current

$$I_i = \frac{V_x - A_v V_i}{R_o} = \frac{V_x (1 + \beta_v A_v)}{R_o}$$

- R_{of} with feedback

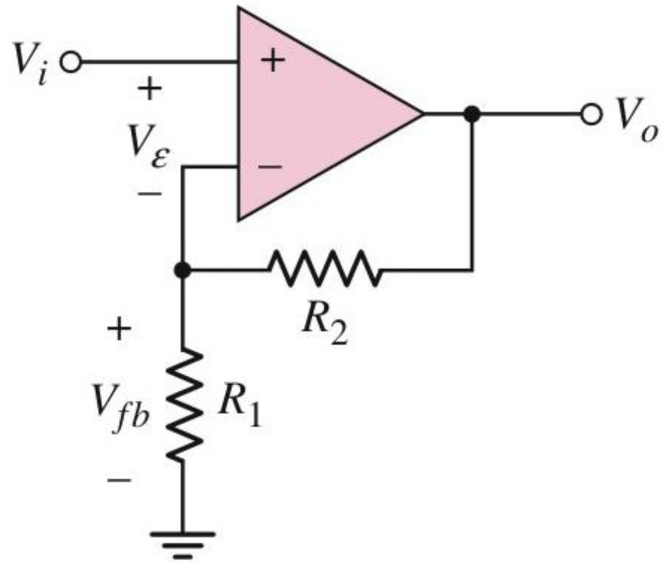
$$R_{of} = \frac{V_x}{I_x} = \frac{R_o}{(1 + \beta_v A_v)}$$

Series - Shunt Configuration (cont.)

- **Series input connection increase input resistance – avoid loading effects on the input signal source.**
- **Shunt output connection decrease the output resistance - avoid loading effects on the output signal when output load is connected.**

Series - Shunt Configuration (cont.)

- **Non-inverting op-amp is an example of the series-shunt configuration.**



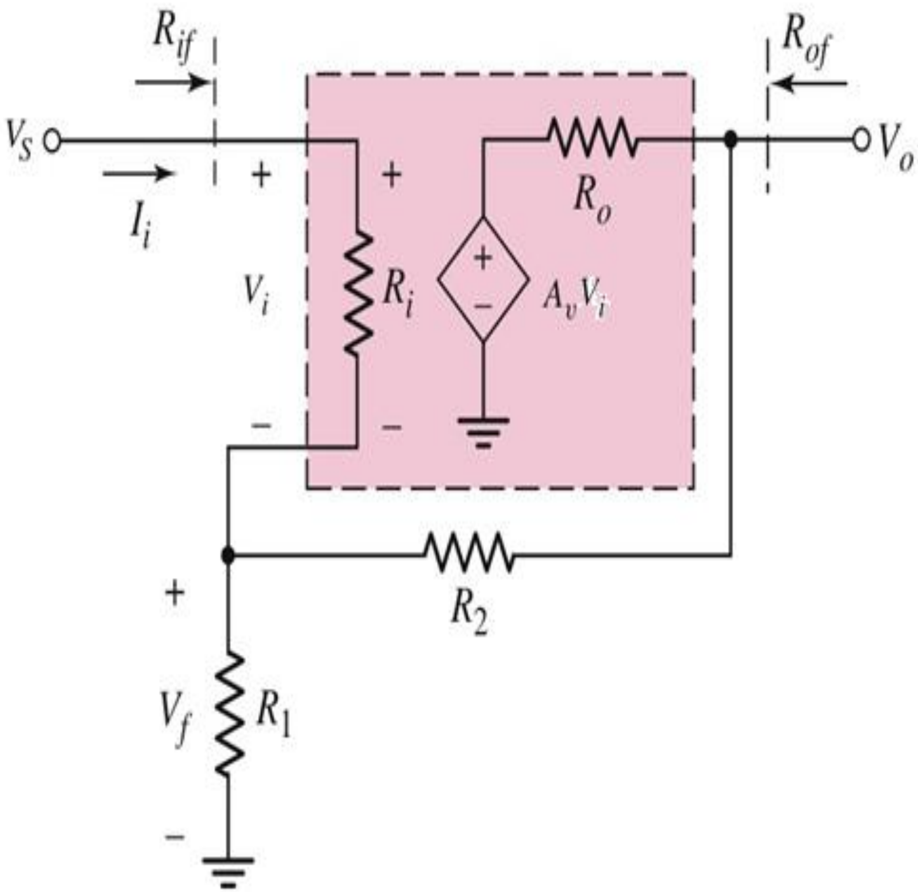
For ideal non-inverting op-amp amplifier

$$A_{vf} = \frac{V_o}{V_i} = \left(1 + \frac{R_2}{R_1}\right)$$

Feedback transfer function;

$$\beta = \frac{1}{\left(1 + \frac{R_2}{R_1}\right)}$$

Series - Shunt Configuration (cont.)



Equivalent circuit

$$\boldsymbol{V_o} = \boldsymbol{A_v V_i}$$

$$\boldsymbol{V_i} = V_s - V_f$$

$$V_f \cong \left(\frac{R_1}{R_1 + R_2}\right) V_o$$

$$A_{vf} = \frac{V_o}{V_i} = \frac{A_v}{1 + \dfrac{A_v}{\left(\dfrac{R_1}{R_1 + R_2}\right)}} = \frac{A_v}{1 + \beta A_v}$$

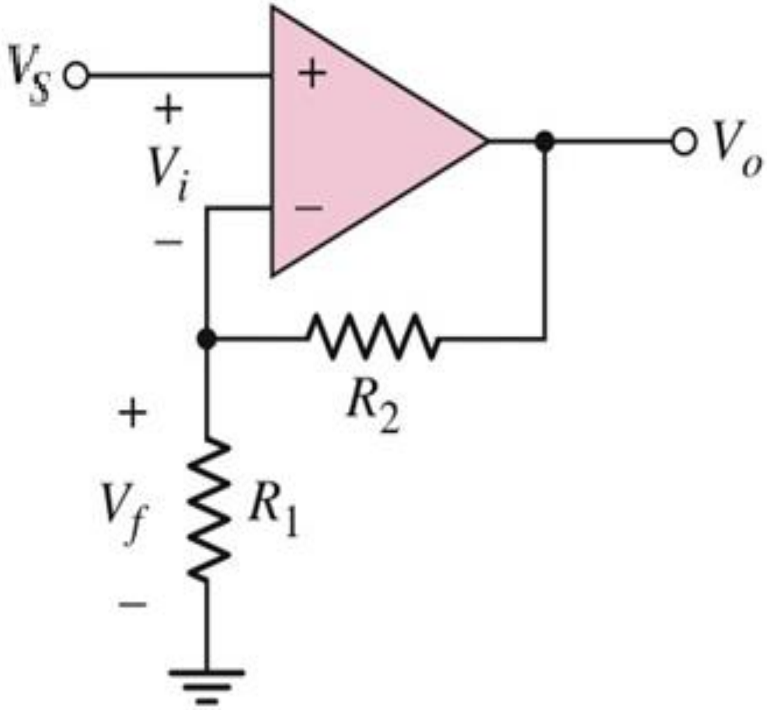
$$V_s = V_i + \left(\frac{R_1}{R_1 + R_2}\right) V_o = V_i + \frac{A_v V_i}{\left(1 + \dfrac{R_2}{R_1}\right)}$$

$$R_{if} = \frac{V_s}{I_i} = \frac{V_s}{V_i / R_i} = R_i (1 + \beta A_v)$$

Series - Shunt Configuration (cont.)

Example:

Calculate the feedback amplifier gain of the circuit below for op-amp gain, A=100,000; R1=200 Ω and R2=1.8 kΩ.



Solution: A_{vf} **= 9.999 or 10**

Feedback Amplifier

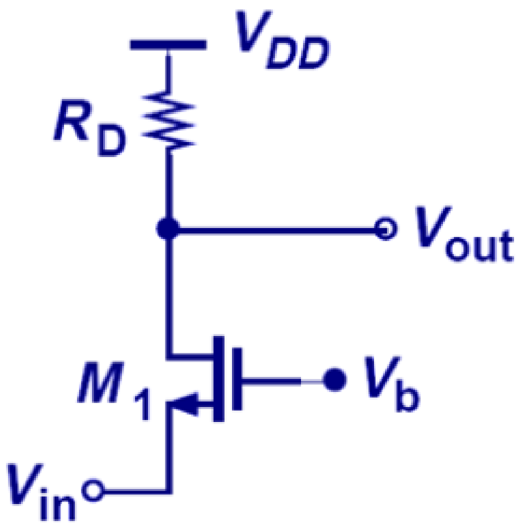
Input and output Impedances Summary

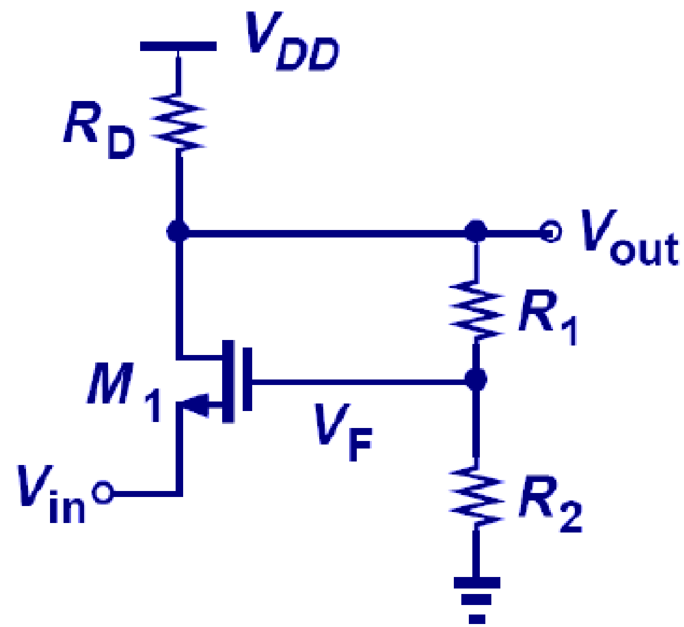
1. For a series connection at input or output, the resistance is increased by $(1+\beta A)$.
2. For a shunt connection at input or output, the resistance is lowered by $(1+\beta A)$.

Feedback Amplifier

Feedback amplifier	Source signal	Output signal	Transfer function	Input Resistance	Output Resistance
Series-Shunt (voltage amplifier)	Voltage	Voltage	$A_{vf} = \frac{A_v}{1+\beta_v A_v}$	$(1+\beta_v A_v)R_i$	$\frac{R_o}{(1+\beta_v A_v)}$
Shunt-Series (current amplifier)	Current	Current	$A_{if} = \frac{A_i}{1+\beta_i A_i}$	$\frac{R_i}{(1+\beta_i A_i)}$	$(1+\beta_i A_i)R_o$
Series-Series (transconductance amplifier)	Voltage	Current	$A_{gf} = \frac{A_g}{1+\beta_g A_g}$	$(1+\beta_g A_g)R_i$	$(1+\beta_g A_g)R_o$
Shunt-Shunt (transresistance amplifier)	Current	Voltage	$A_{zf} = \frac{A_z}{1+\beta_z A_z}$	$\frac{R_i}{(1+\beta_z A_z)}$	$\frac{R_o}{(1+\beta_z A_z)}$

Examples:



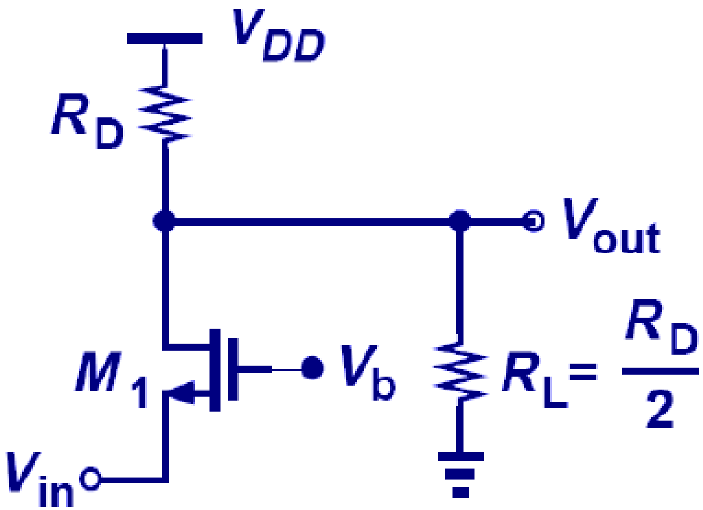


Open Loop Gain

$$A_1 \approx g_m R_D$$

Closed Loop Gain

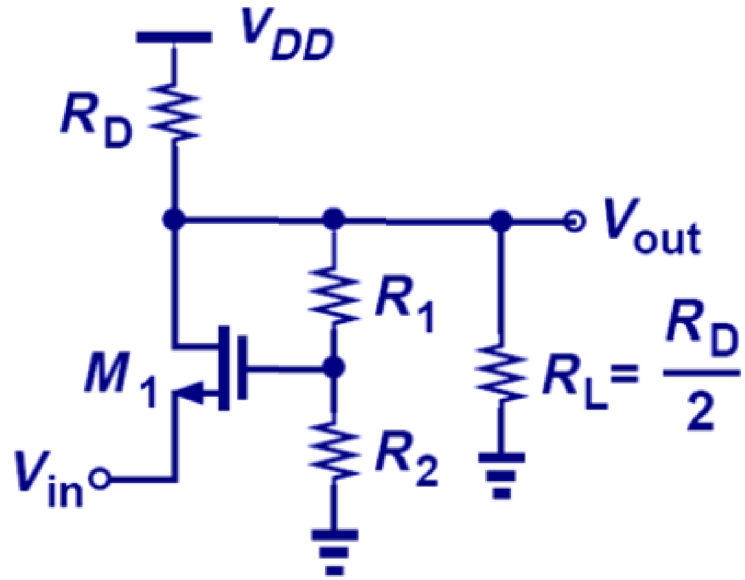
$$\frac{v_{out}}{v_{in}} = \frac{g_m R_D}{1 + \frac{R_2}{R_1 + R_2} g_m R_D}$$



w/o Feedback

Large Difference

$$g_m R_D \rightarrow g_m R_D / 3$$



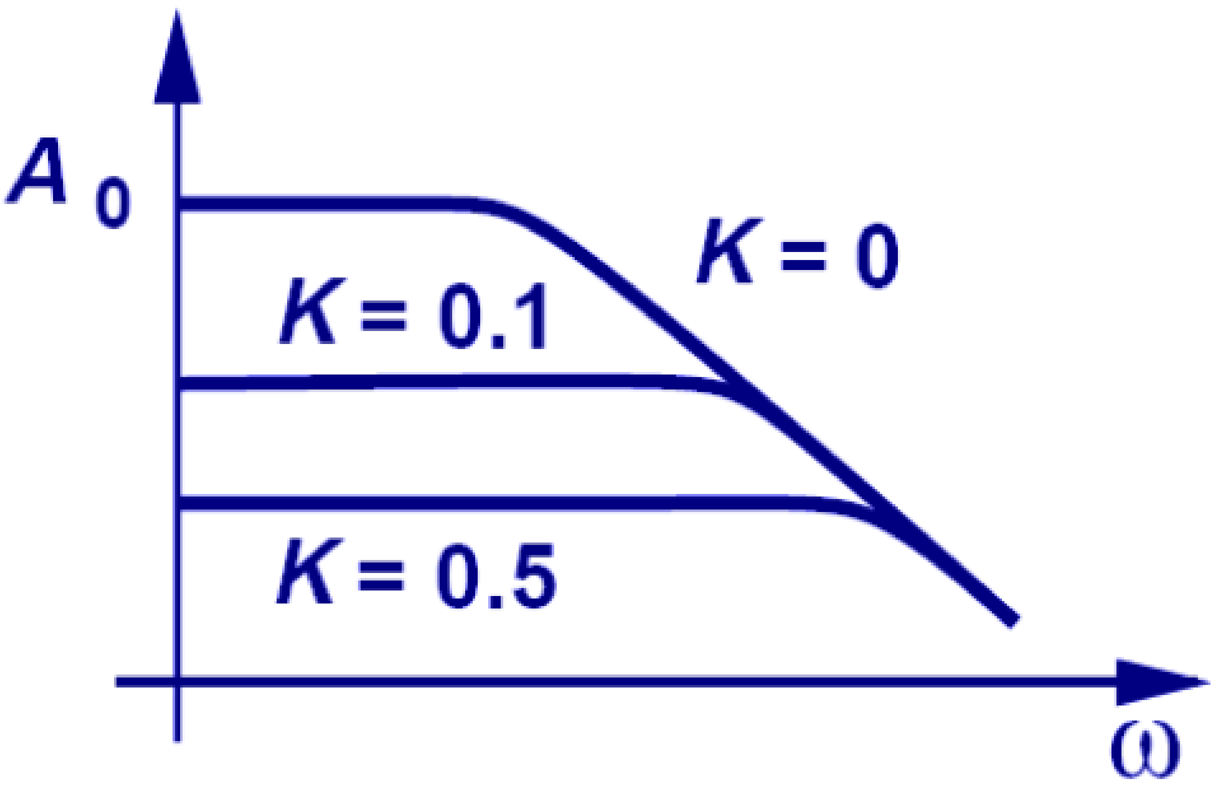
with Feedback

Small Difference

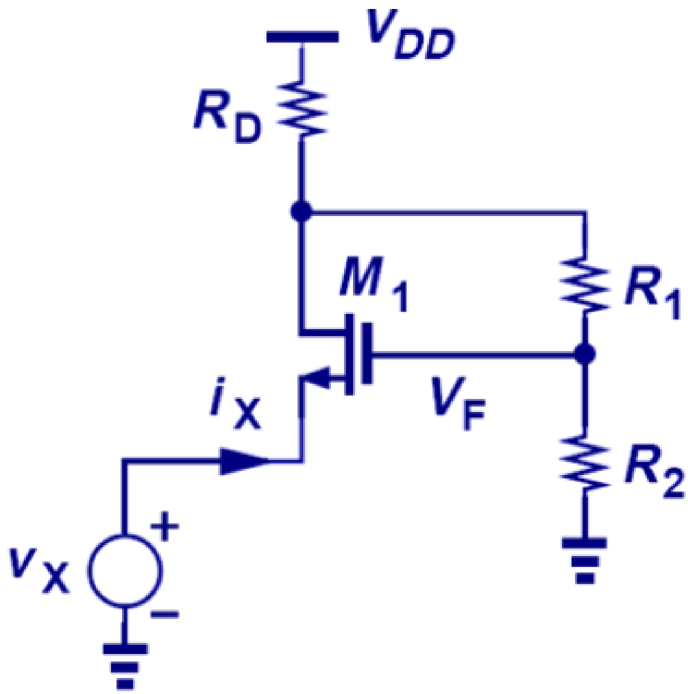
$$\frac{g_m R_D}{1+\frac{R_2}{R_1+R_2} g_m R_D} \rightarrow \frac{g_m R_D}{3+\frac{R_2}{R_1+R_2} g_m R_D}$$

Bandwidth Enhancement Example

- As the loop gain increases, the low-frequency gain decreases and the bandwidth increases.



Modification of I/O Impedances Examples

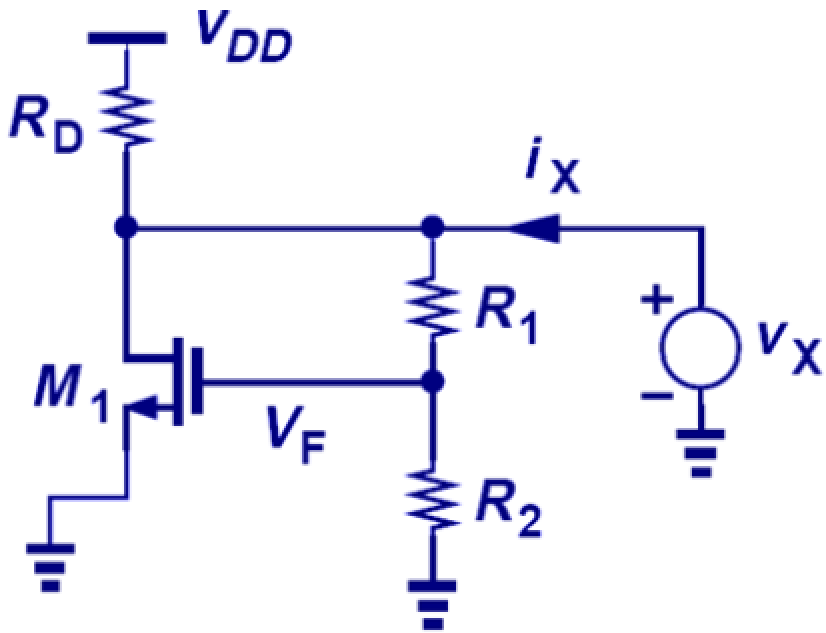


Open Loop

$$R_{in} = \frac{1}{g_m}$$

Closed Loop

$$R_{in} = \frac{1}{g_m}\left(1 + \frac{R_2}{R_1 + R_2} g_m R_D\right)$$



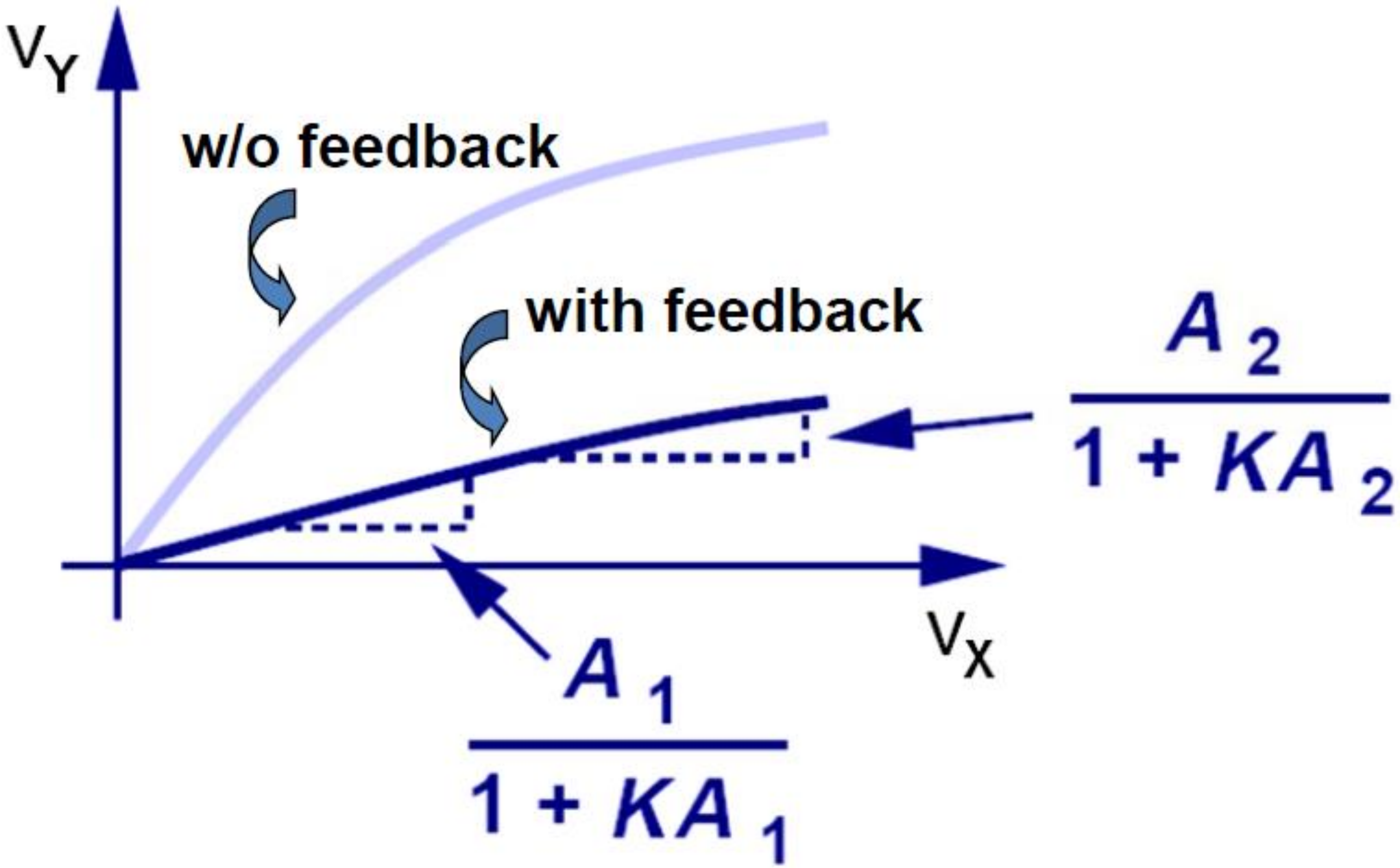
Open Loop

$$R_{out} = R_D$$

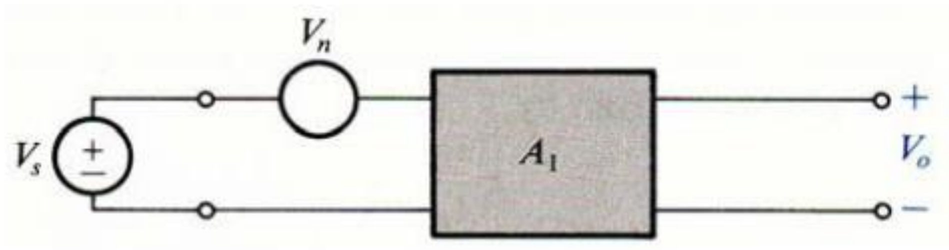
Closed Loop

$$R_{out} = \frac{R_D}{1 + \frac{R_2}{R_1 + R_2} g_m R_D}$$

Linearity Improvement Examples



Noise Reduction



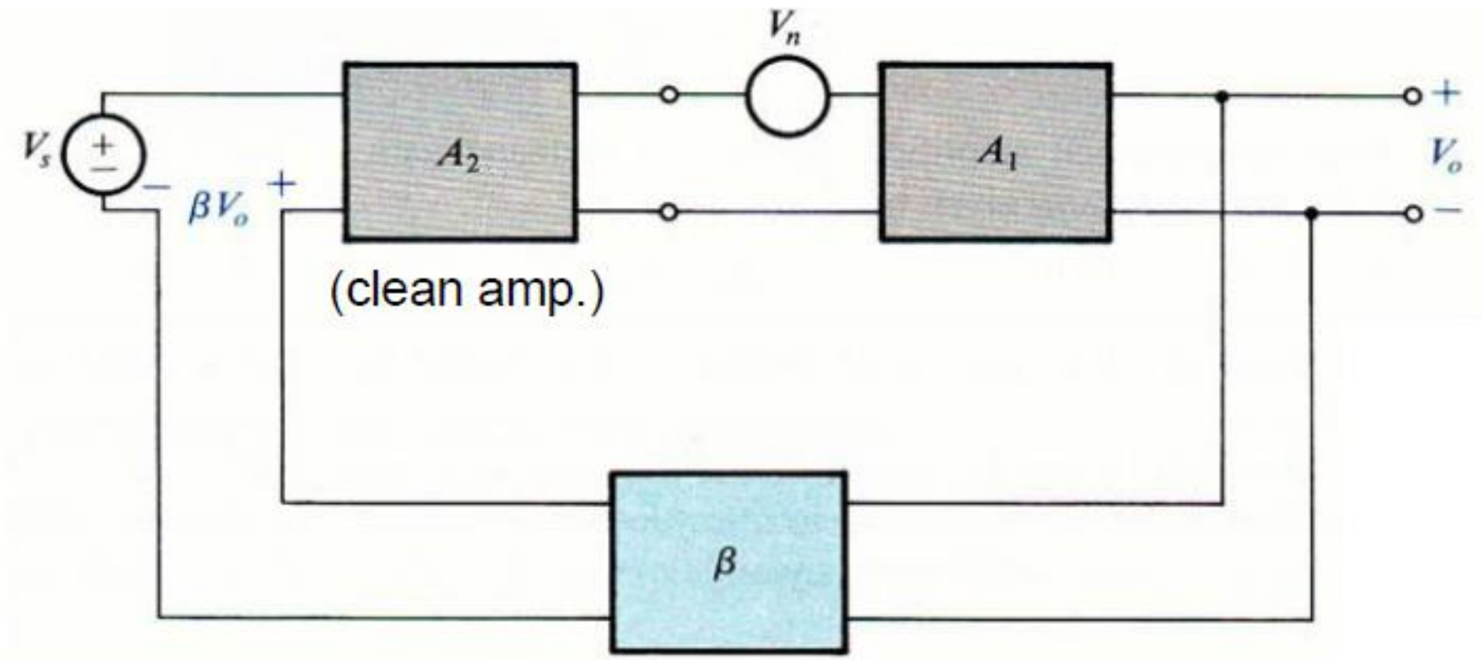
V_s : input signal
V_o : output signal
V_n : noise or interference
A_1 : gain

- The amplifier suffers from noise and the noise can be assumed to be introduced at the input of the amplifier.

$$\text{Singal - to - noise ratio } \frac{S}{N} = \frac{V_s}{V_n}$$

Noise Reduction (cont.)

- Negative feedback is applied to improve SNR:



$$V_o = V_s \frac{A_1 A_2}{1 + A_1 A_2 \beta} + V_n \frac{A_1}{1 + A_1 A_2 \beta}$$

$$\therefore \quad \frac{S}{N} = \frac{V_s}{V_n} A_2$$