INTRODUCTION TO FEEDBACK SYSTEM

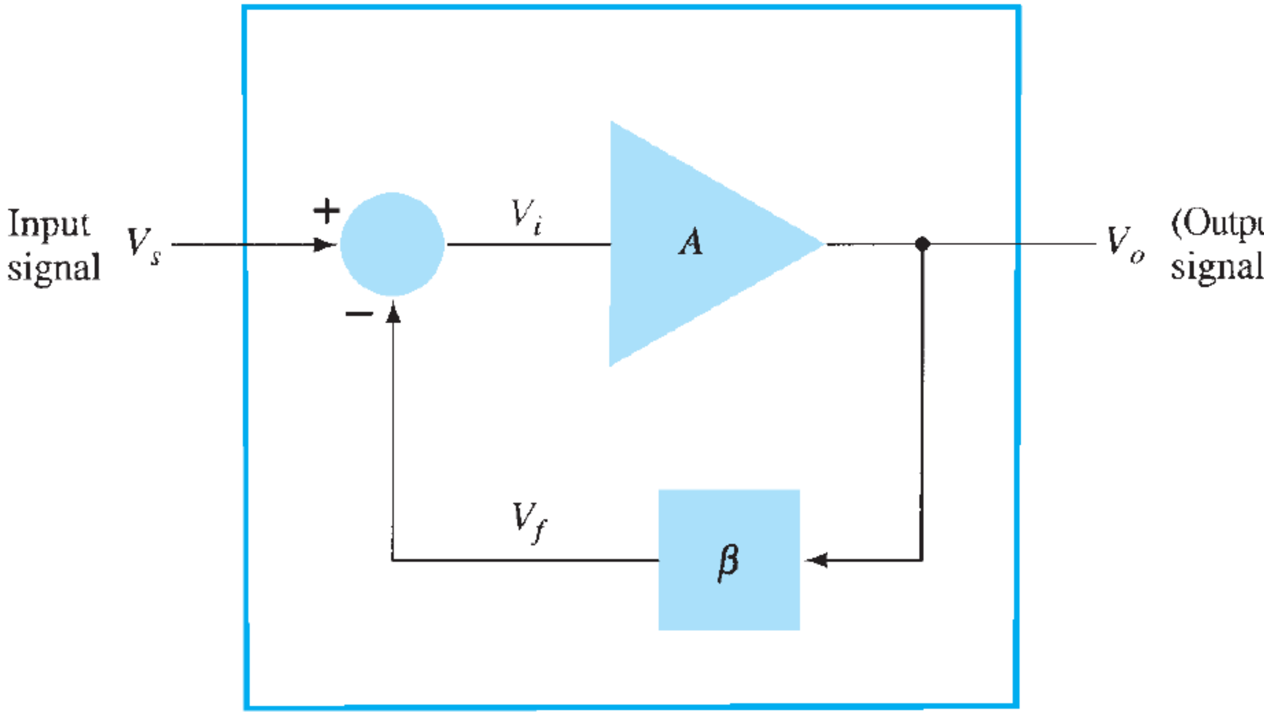
Topic Outcomes

- Discuss the concept of negative feedback
- Differentiate feedback connection types
- Compute parameters with feedback connections

Feedback

Feedback

- A circuit may have positive or negative feedback depending on the polarity of the signal being fed back to the system.
- Positive feedback drives a circuit into oscillation, while negative feedback decreases the voltage gain of the system but improves a number of circuit features.
- A simple block diagram of a feedback amplifier system is shown in the figure. Input Signal V_s is applied to mixer circuit combined with the feedback signal, V_f .
- The difference of V_s and V_f is the input voltage of the amplifier A. Then the output voltage V_{out} is connected to the feedback circuit that causes reduction to the output signal as feedback signal to the input mixer network.



Feedback amplifier

Feedback

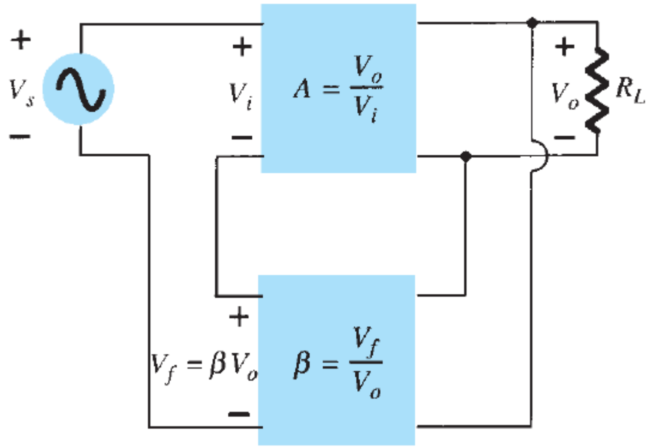
- In negative feedback, the polarity of the input signal is opposite to the feedback signal.
- Negative feedback reduces overall voltage gain but improves the following areas:

  1. Higher input impedance
  2. Better stabilized voltage gain
  3. Improved frequency response
  4. Lower output impedance
  5. Noise Reduction
  6. More linear operation

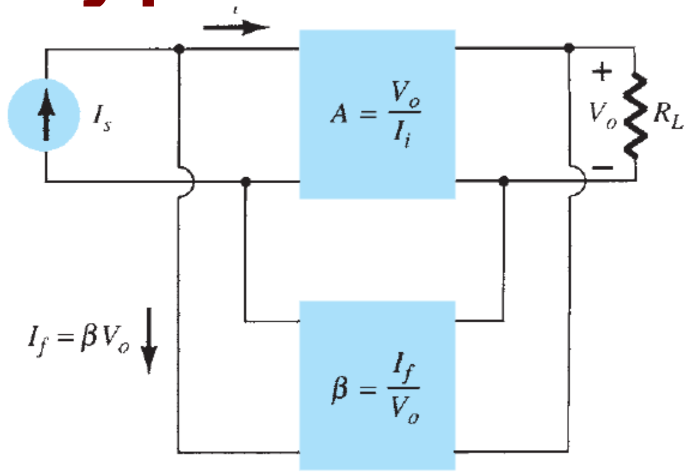
Feedback

- There are four basic ways to implement feedback signal to other system. Both voltage and current may be fed back to the input to a system either in series or parallel.
  - Voltage refers to connecting the output voltage as input to the feedback network.
  - Current refers to tapping off some output current through the feedback network.
  - Series refers to connecting the feedback signal in series with the input signal voltage.
  - Shunt refers to connecting the feedback signal in shunt (parallel) with an input current source.

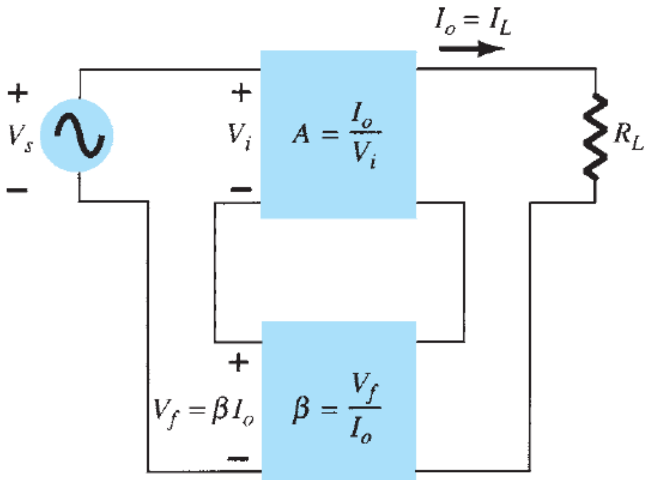
Feedback Connection Types



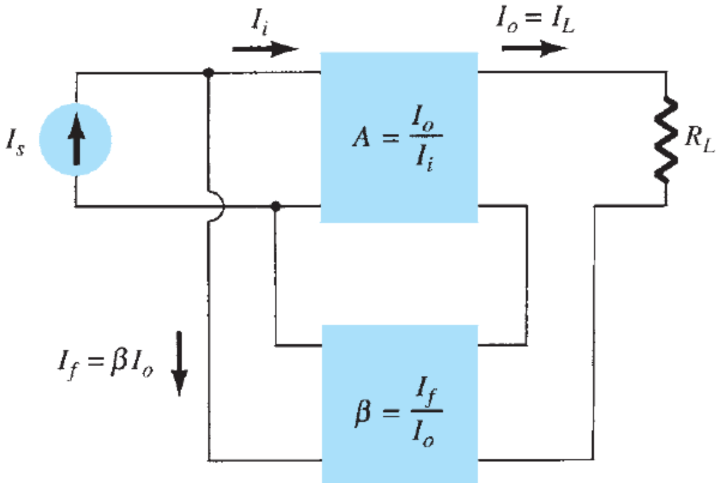
Voltage-series feedback



Voltage-shunt feedback



Current-series feedback



Current-shunt feedback

Feedback Connection Types

Summary of Gain, Feedback and Gain with Feedback

		Voltage-Series	Voltage-Shunt	Current-Series	Current-Shunt
Gain without feedback	A	$\frac{V_o}{V_i}$	$\frac{V_o}{I_i}$	$\frac{I_o}{V_i}$	$\frac{I_o}{I_i}$
Feedback	β	$\frac{V_f}{V_o}$	$\frac{I_f}{V_o}$	$\frac{V_f}{I_o}$	$\frac{I_f}{I_o}$
Gain with feedback	A_f	$\frac{V_o}{V_s}$	$\frac{V_o}{I_s}$	$\frac{I_o}{V_s}$	$\frac{I_o}{I_s}$

Voltage-Series Feedback

When there is no feedback:

$$A = \frac{V_o}{V_S} = \frac{V_o}{V_i}$$

When V_f is connected in series with the input:

$$V_i = V_s - V_f$$

$$V_o = AV_i = A(V_s - V_f) = AV_s - AV_f$$

$$V_o = AV_s - A\beta V_o$$

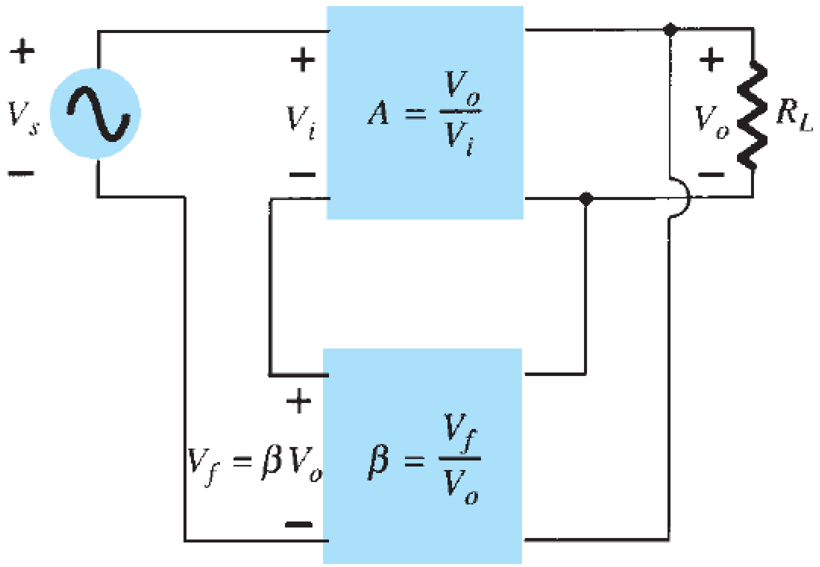
$$(1 + \beta A)V_O = AV_S$$

$$A \rightarrow A_f$$

$A_f = \frac{V_o}{V_s} = \frac{A}{1+\beta A}$ = overall gain of feedback amplifier (decreased by $1 + \beta A$)

$A = \frac{V_o}{V_i}$ = gain of amplifier when there is no feedback

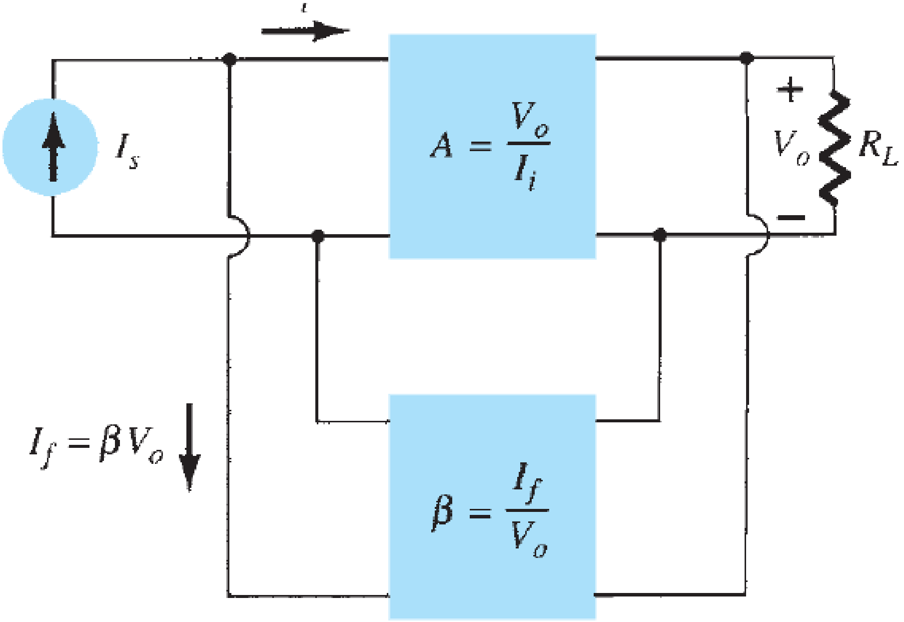
$\beta = \frac{V_f}{V_o}$ = feedback



Voltage-Shunt Feedback

When there is no feedback:

$$A = \frac{V_o}{I_S} = \frac{V_o}{I_i}$$



When a feedback signal is connected in parallel with the input is connected in parallel with the input:

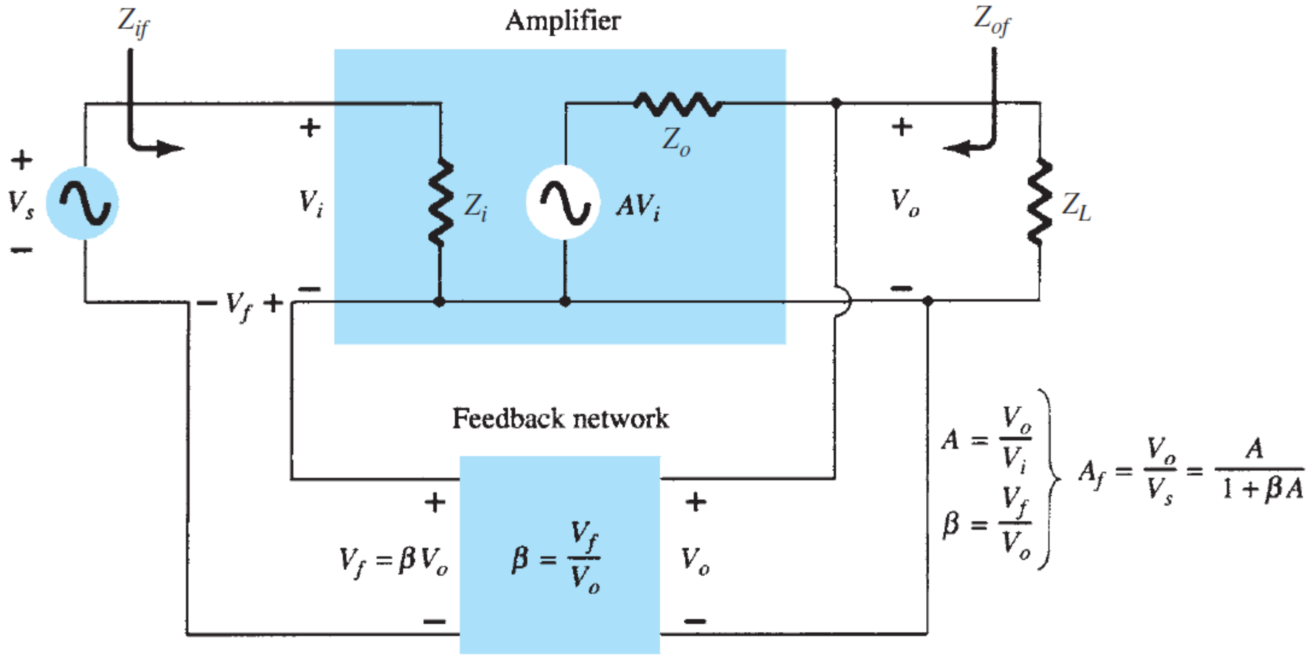
$$A_f = \frac{V_o}{I_s} = \frac{AI_i}{I_i + I_f} = \frac{AI_i}{I_i + \beta V_o} = \frac{AI_i}{I_i + \beta AI_i}$$

$A_f = \frac{A}{1+\beta A}$ = overall gain of feedback amplifier (decreased by $1 + \beta A$)

$A = \frac{V_o}{I_i}$ = gain of amplifier when there is no feedback

$\beta = \frac{I_f}{V_o}$ = feedback

Input Impedance (Voltage Series)



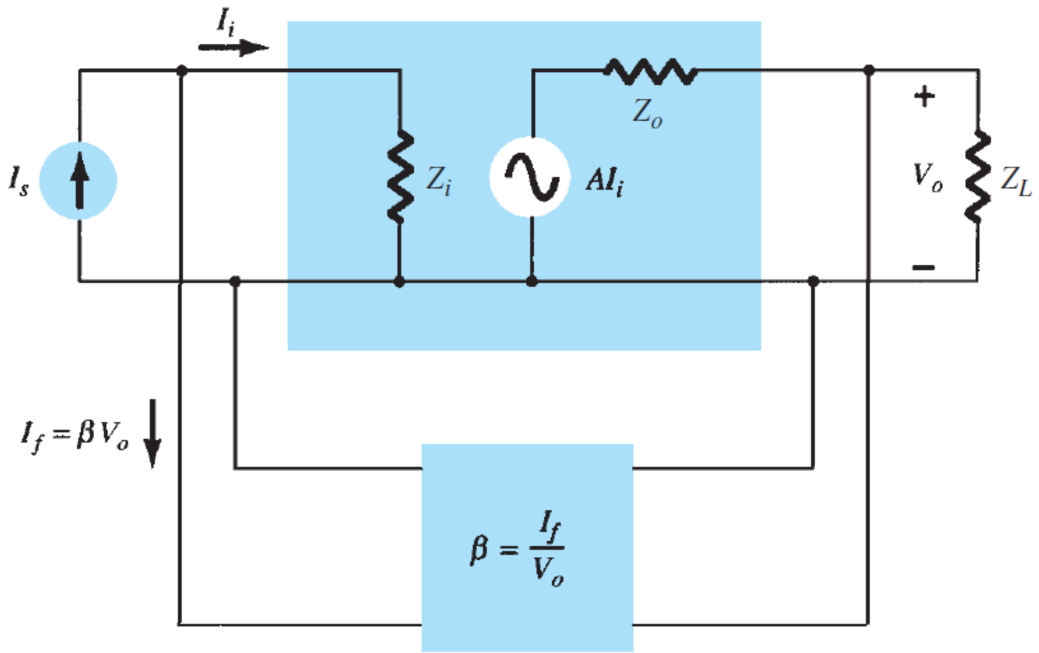
$$I_i = \frac{V_i}{Z_i} = \frac{V_S - V_f}{Z_i} = \frac{V_S - \beta V_o}{Z_i} = \frac{V_S - \beta A V_i}{Z_i}$$

$$I_i Z_i = V_s - \beta A V_i$$

$$V_S = I_i Z_i + \beta A V_i = I_i Z_i + \beta A I_i Z_i$$

$$Z_{if} = \frac{V_S}{I_i} = Z_i + (\beta A) Z_i = Z_i(1 + \beta A)$$

Input Impedance (Voltage Shunt)



$$Z_{if} = \frac{V_i}{I_s} = \frac{V_i}{I_i + I_f} = \frac{V_i}{I_i + \beta V_o}$$

$$Z_{if} = \frac{V_i/I_i}{I_i/I_i + \beta V_o/I_i}$$

$$Z_{if} = \frac{Z_i}{1 + \beta A}$$

Output Impedance

Voltage Series Feedback

$$Z_{of} = \frac{Z_o}{(1 + \beta A)}$$

Voltage Shunt Feedback

$$Z_{of} = \frac{Z_o}{(1 + \beta A)}$$

Current Series Feedback

$$Z_{of} = Z_o(1 + \beta A)$$

Current Shunt Feedback

$$Z_{of} = Z_o(1 + \beta A)$$

Impedances Summary

Voltage-Series	Current-Series	Voltage-Shunt	Current-Shunt
$Z_{if}\ Z_i(1+\beta A)$ (increased)	$Z_i(1+\beta A)$ (increased)	$\dfrac{Z_i}{1+\beta A}$ (decreased)	$\dfrac{Z_i}{1+\beta A}$ (decreased)
$Z_{of}\ \dfrac{Z_o}{1+\beta A}$ (decreased)	$Z_o(1+\beta A)$ (increased)	$\dfrac{Z_o}{1+\beta A}$ (decreased)	$Z_o(1+\beta A)$ (increased)

Effects of Negative Feedback

Reduction in Frequency Distortion

- For a negative-feedback amplifier having $\beta A \gg 1$, the gain with feedback is $A_f \cong 1/\beta$
- This value indicates that the feedback network is purely resistive and the gain of the feedback is not dependent on frequency (even the gain is dependent on the frequency).
- The frequency distortion arising because of varying amplifier gain with frequency is considerably reduced in a negative-voltage feedback amplifier circuit.

Reduction in Noise and Nonlinear Distortion

- Signal feedback tends to hold down the amount of noise signal (such as power-supply hum) and nonlinear distortion.
- The factor $(1+\beta A)$ reduces the input noise and improvement of nonlinear distortion. As trade-off, there is a reduction in overall gain.
- An additional amplifier stage will increase the overall gain but it will introduce as much noise (reduced by the feedback amplifier).
- This may be improved by readjusting the gain of the feedback amplifier circuit to obtain higher gain while also providing reduced noise signal.

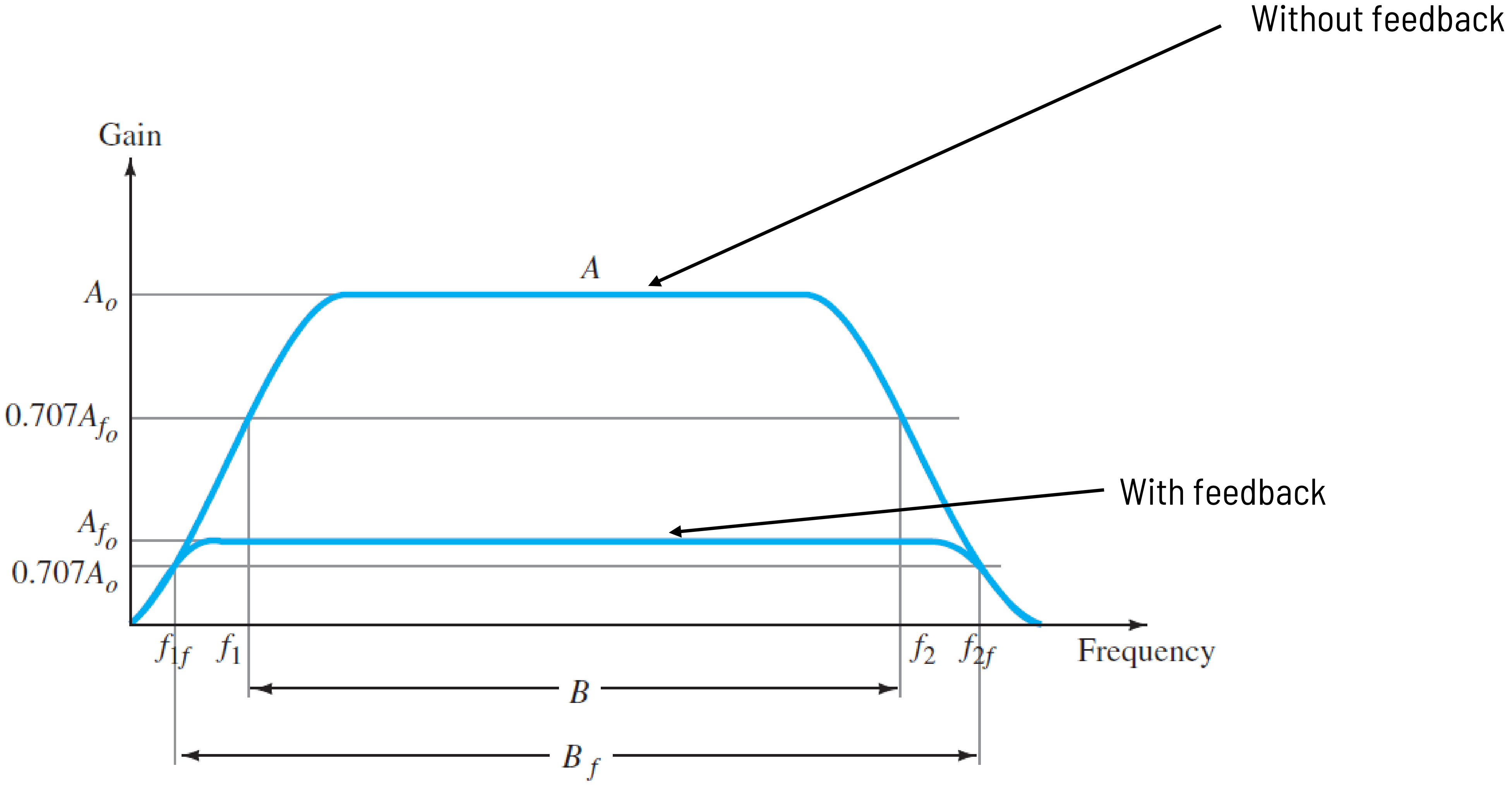
Gain and Bandwidth

- The overall gain with negative feedback is described by the equation:

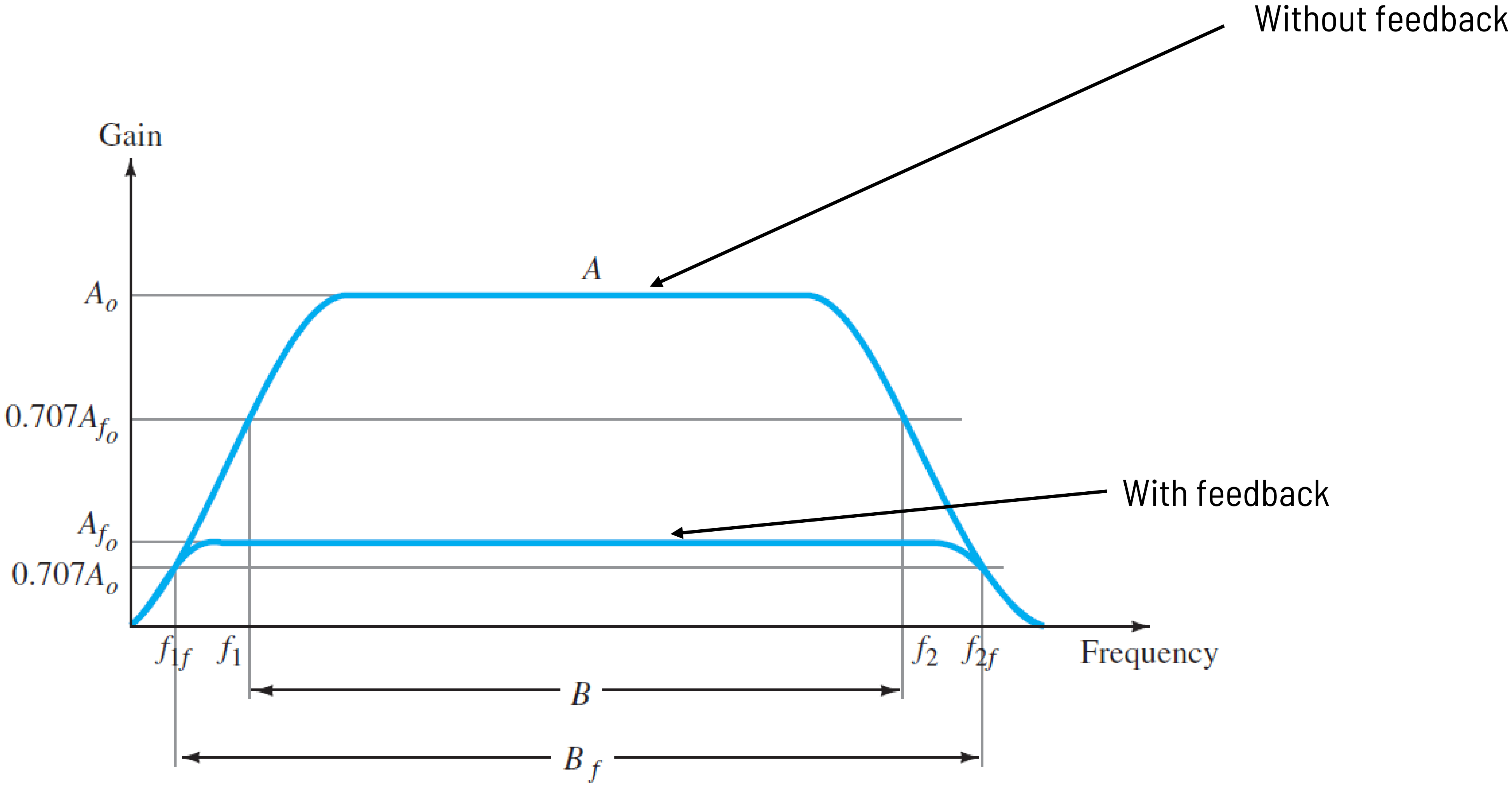
$$A_f = \frac{A}{1+\beta A} \cong \frac{A}{\beta A} = \frac{1}{\beta} \text{ for } \beta A >> 1$$

- As long $\beta A \gg 1$, the overall gain is approximately $1/\beta$.
- In a basic amplifier, the open loop gain has open-loop drops because of the active devices and capacitances at high frequencies.
- At low frequencies for capacitively coupled amplifier stages the gain may also drop.
- Once the open-loop gain A drops low enough and the factor $\beta A \gg 1$, then based on the equation described by $A_f \cong 1/\beta$ is no longer holds true.

Gain and Bandwidth



Gain and Bandwidth



Gain Stability

- Differentiating the gain equation with feedback:

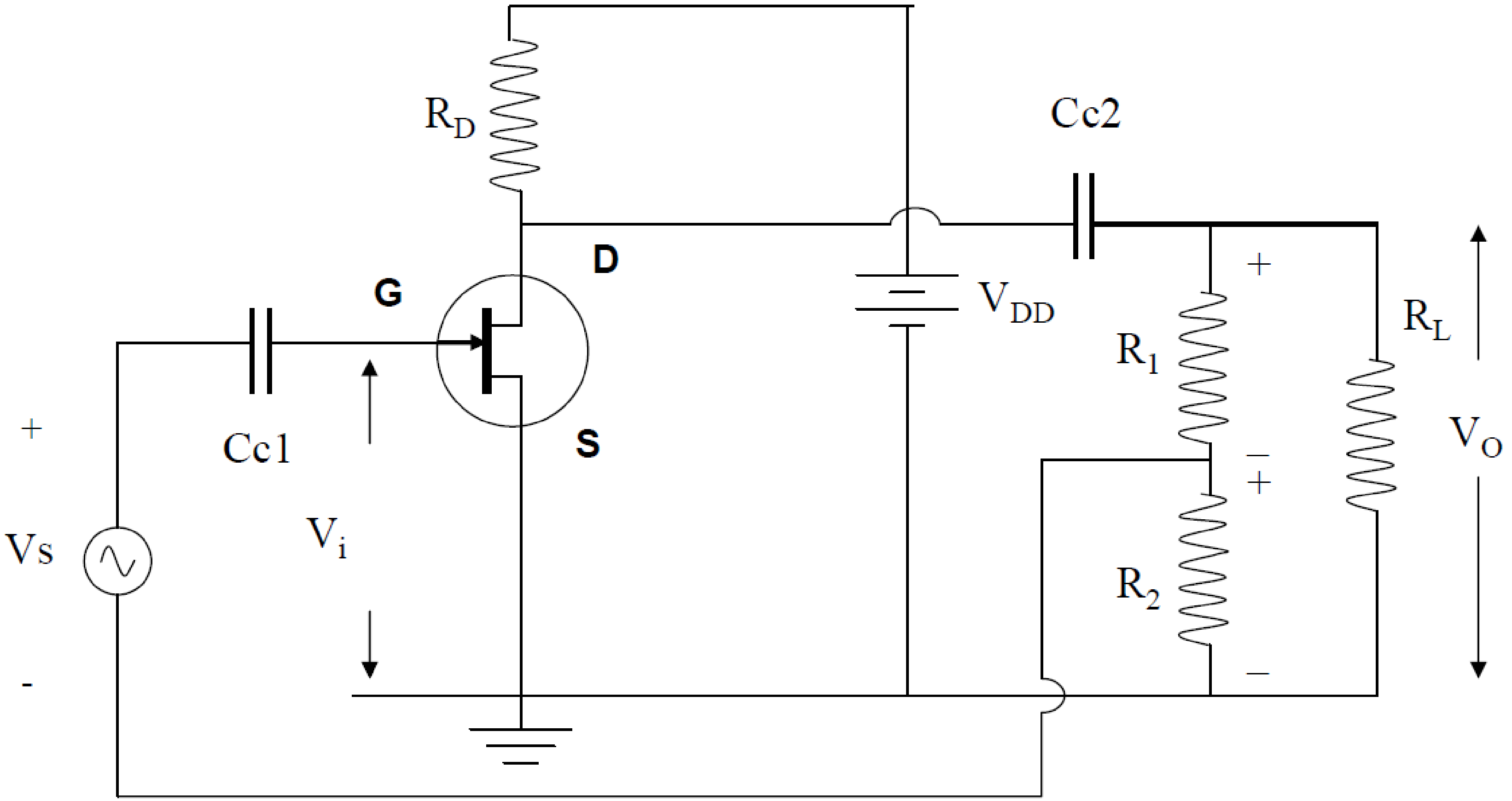
$$\left|\frac{dA_F}{A_f}\right| = \frac{1}{|1+\beta A|}\left|\frac{dA}{A}\right|$$

$$\left|\frac{dA_f}{A_f}\right| \cong \left|\frac{1}{\beta A}\right| \left|\frac{dA}{A}\right| \text{ for} \beta A >> 1$$

- The magnitude of the relative change in gain ($\left|\frac{dA_F}{A_f}\right|$) is reduced by the factor $|\beta A|$ compared to that with feedback ($\left|\frac{dA}{A}\right|$)

Feedback Amplifier Circuits

Voltage Series Feedback

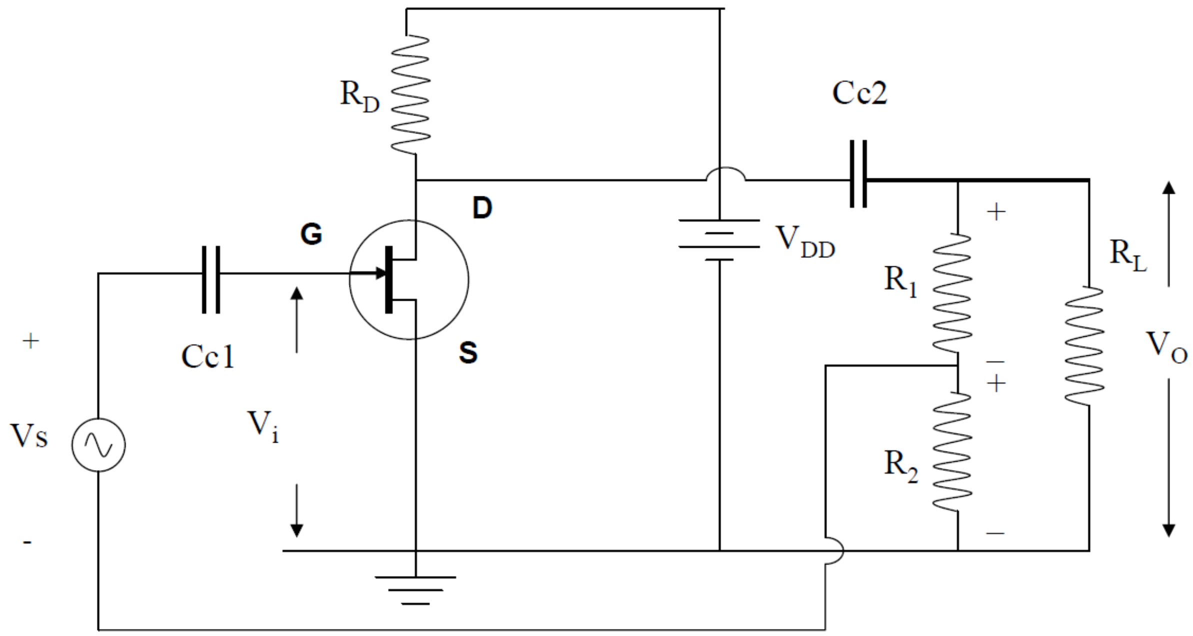


Voltage Series Feedback

$$A = \frac{V_o}{V_s} = \frac{V_o}{V_i} =$$

$$A = -g_m\left(r_d \parallel R_D \parallel R_L \parallel (R_1 + R_2)\right)$$

$$\beta = \frac{V_f}{V_o} = -\frac{R_2}{R_1 + R_2}$$



The overall gain of the feedback FET Amplifier is:

$$A_f = \frac{V_o}{V_s} = \frac{A}{1 + \beta A}$$

$$A_f = \frac{-g_m\left(r_d \parallel R_D \parallel R_L \parallel (R_1 + R_2)\right)}{1 + \left[\frac{R_2}{R_1 + R_2}\right] g_m\left(r_d \parallel R_D \parallel R_L \parallel (R_1 + R_2)\right)}$$

Voltage Shunt Feedback

$$A = \frac{V_o}{I_i} = \infty$$

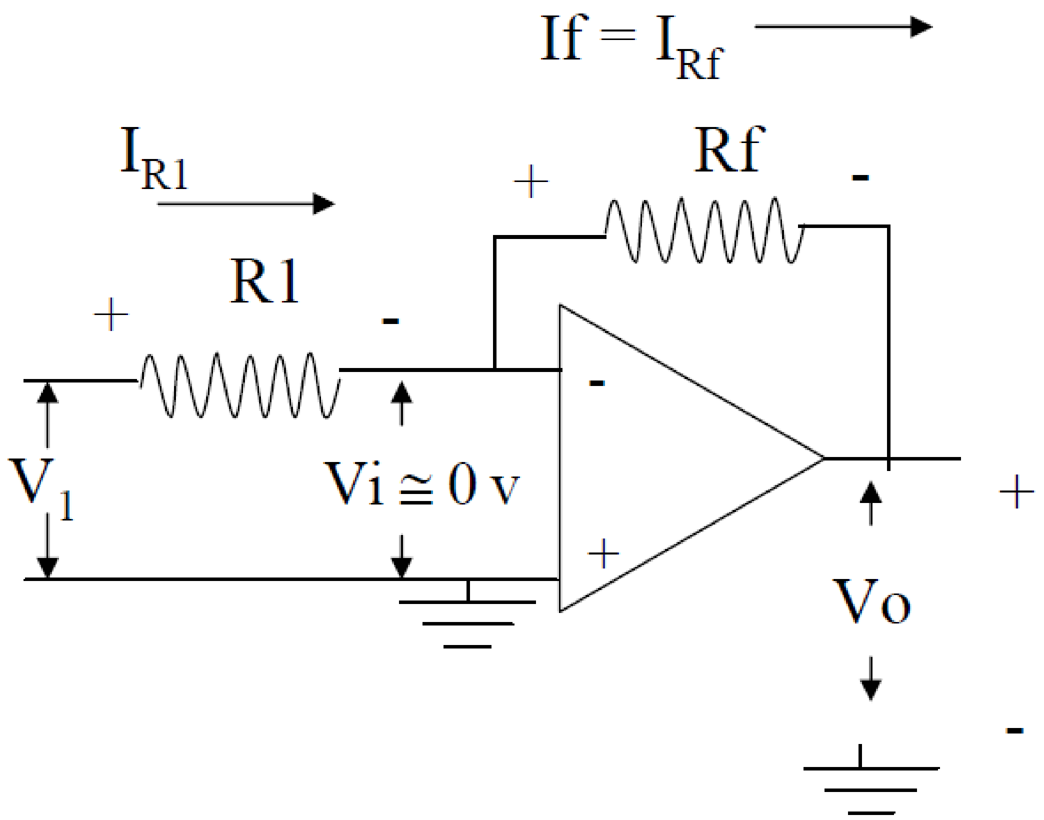
$$\beta = \frac{I_f}{V_o} = -\frac{1}{R_o}$$

The transfer resistance gain with feedback

$$A_f = \frac{V_o}{V_s} = \frac{V_o}{I_i} = \frac{A}{1+\beta A} = \frac{1}{\beta} = -R_o$$

The usual gain

$$A_f = \frac{V_o}{I_s}\frac{I_s}{V_1} = (-R_o)\frac{1}{R_1} = \frac{-R_o}{R_1}$$



Current Series Feedback

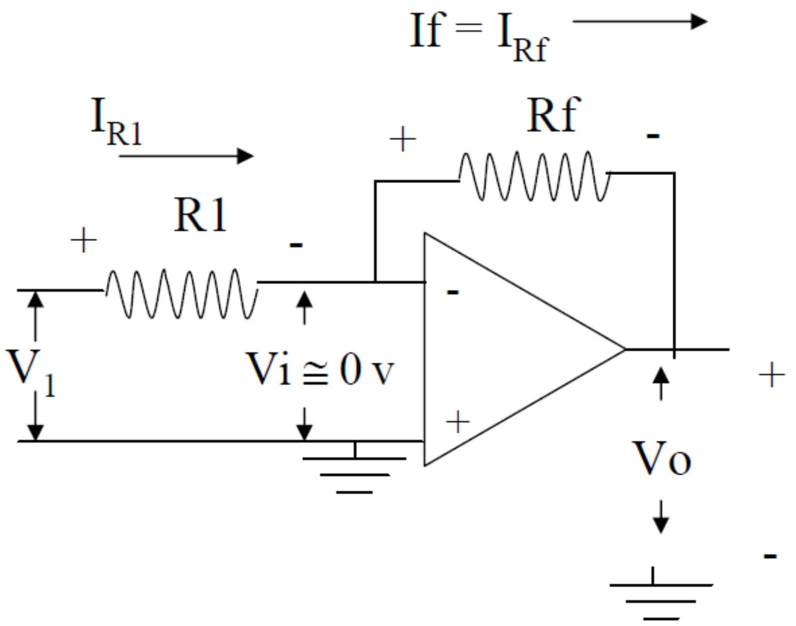
$$I_{R1} = I_s = \frac{V_1}{R_1}$$

$$A = \frac{V_o}{I_i} = \infty$$

$$\beta = \frac{I_f}{V_o} = -\frac{1}{R_f}$$

$$A_f = \frac{V_o}{I_s} = \frac{V_o}{I_i} = \frac{A}{1+\beta A} = -R_f$$

$$A_{vf} = \frac{V_o}{V_1} = \frac{V_o}{I_s}\frac{I_s}{V_1} = -\frac{R_f}{R_1}$$



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