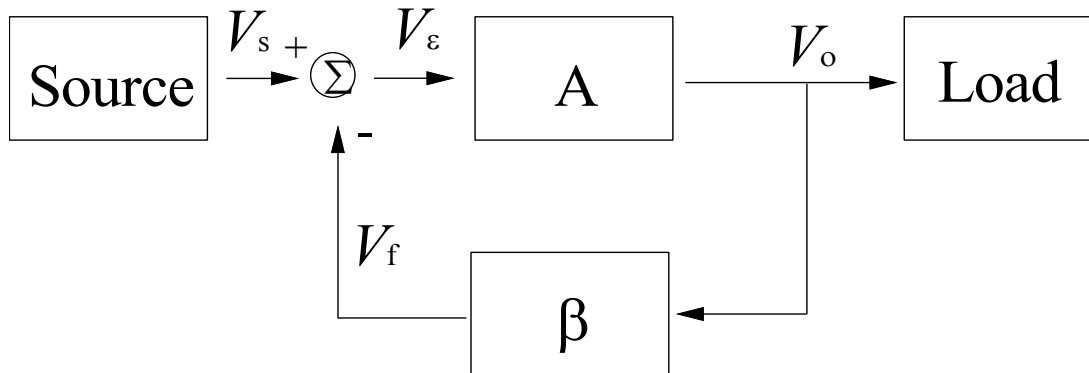# Lecture 29

Feedback amplifier

Lecture Feedback Amplifier

- Negative Feedback

- Feedback Topology

- Analysis of feedback applications
  - Close-Loop Gain
  - Input/Output resistances

General Feedback Structure

Source $\xrightarrow{V_{s}\ +}$ Σ $\xrightarrow{V_{\varepsilon}}$ A $\xrightarrow{V_o}$ Load

V_f — β (-)

A : Open Loop Gain
$$A = V_o\,/\,V_\varepsilon$$

β : feedback factor
$$\beta = V_f\,/\,V_o$$

$$V_\varepsilon = V_s - V_f$$

$$V_f = \beta \cdot V_o$$

$$V_\varepsilon = V_S - \beta \cdot V_o$$

$$V_o = A \cdot V_\varepsilon$$

Close loop gain : $A_{CL} = \dfrac{V_o}{V_s} = \dfrac{A}{1+A\beta} = \dfrac{1}{\beta}(\dfrac{T}{1+T})$

Loop Gain : $T = A \cdot \beta$

Amount of feedback : $1 + A \cdot \beta$

Note: $A_{CL}\big|_{A\to\infty} = \dfrac{1}{\beta}$

Negative Feedback Properties

- Negative feedback takes a sample of the output signal and applies it to the input to get several desirable properties. In amplifiers, negative feedback can be applied to get the following properties

  - Desensitized gain : gain less sensitive to circuit component variations

  - Reduce nonlinear distortion : output proportional to input (constant gain independent of signal level)

  - Reduce effect of noise

  - Control input and output impedances by applying appropriate feedback topologies

  - Extend bandwidth of amplifier

- All of these properties can be achieved by trading off gain

Gain De-sensitivity

- Feedback can be used to desensitize the closed-loop gain to variations in the basic amplifiler.

- Assume β is constant. Take differentials of the closed loop gain equation gives,

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

Differential respected with A $\Rightarrow$ $\frac{dA_{CL}}{dA} = \frac{1}{(1 + A\beta)^2}$ or $dA_{CL} = \frac{dA}{(1 + A\beta)^2}$

- Divided by A_v, the close loop gain sensitivity is equal to,

$$\frac{dA_{CL}}{A_{CL}} = \frac{dA}{(1 + A\beta)^2}\frac{(1 + A\beta)}{A} = \frac{1}{1 + A\beta}\frac{dA}{A}$$

- This result shows the effects of variations in A on A_{CL} is mitigated by the feedback amount.

- $(1+A\beta)$ is also called the desensitivity amount.

Basic Feedback Topologies

Depending on the input signal (voltage or current) to be amplified and form of the output (voltage or current), amplifiers can be classified into four categories. Depending on the amplifier category, one of four types of feedback structures should be used.
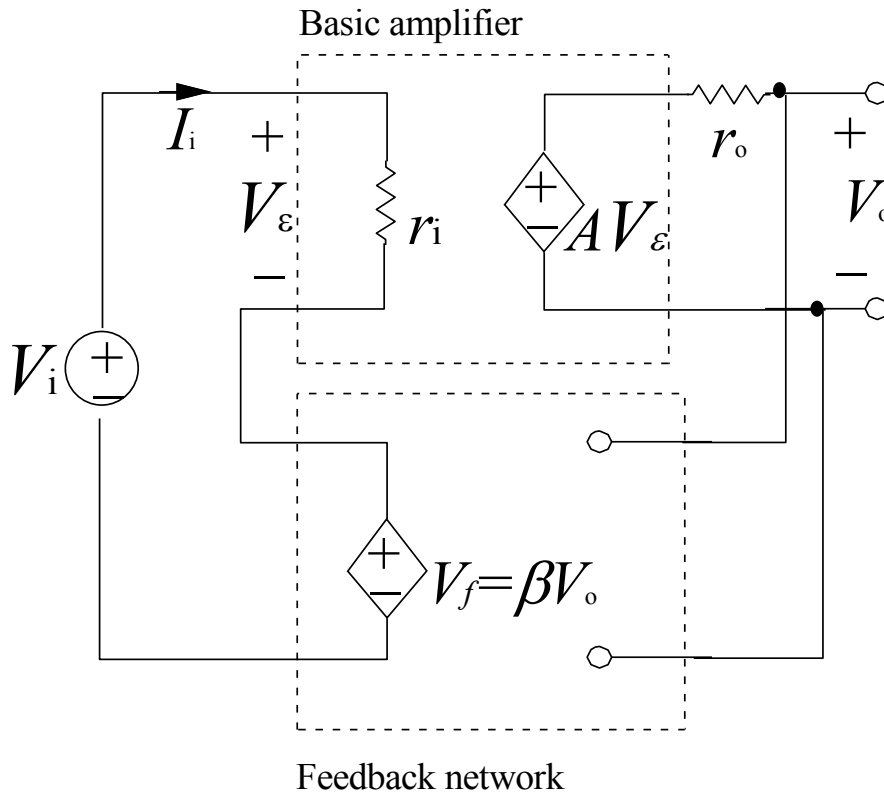
(Type of Feedback)	**(Type of Sensing)**
(1) Series (Voltage)	Shunt (Voltage)
(2) Series (Voltage)	Series (Current)
(3) Shunt (Current)	Shunt (Voltage)
(4) Shunt (Current)	Series (Current)

Feedback Structure (Series-Shunt)

Basic amplifier

Feedback network

- ➤ Voltage amplifier voltage-controlled voltage source
- ➤ Requires high input impedance, low output impedance
- ➤ Voltage-voltage feedback

Voltage Gain Calculation:

$$V_o = A \cdot V_\varepsilon$$

$$V_f = \beta \cdot V_o$$

$$V_i = V_\varepsilon + V_f = \frac{V_o}{A} + \beta \cdot V_o$$

(Close Loop Voltage Gain)

$$\Rightarrow A_{CL} = \frac{V_o}{V_i} = \frac{1}{\beta}\left(\frac{T}{1+T}\right)$$

where $T = A\beta$

And, we get

$$V_o = \frac{V_i \cdot A}{1 + A \cdot \beta}$$

$$V_i = V_\varepsilon (1 + A \cdot \beta)$$

Input/Output Resistance (Series-Shunt)

Input Resistance:

$$R_{\text{in}} = \frac{V_i}{I_i}$$

$$V_i = (1+T) \cdot V_\varepsilon$$

$$I_i = \frac{V_\varepsilon}{r_i} = \frac{V_i}{(1+T) \cdot r_i}$$

$$R_{\text{in}} = \frac{V_i}{I_i} = (1+T) \cdot r_i$$

Output Resistance
(Closed loop output resistance with zero input voltage)

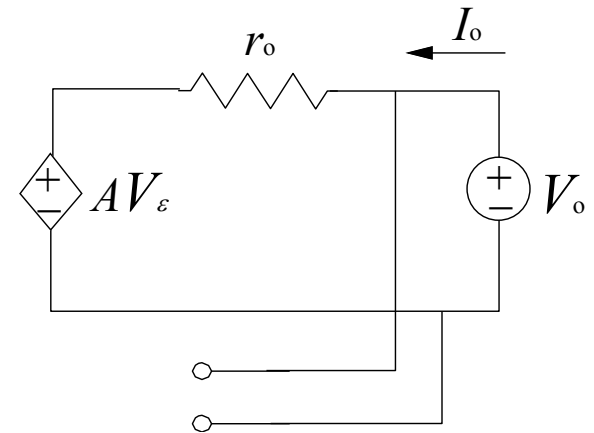$$R_{\text{out}}\big|_{V_i=0} = \frac{V_o}{I_o}$$

$$I_o = \frac{V_o - A \cdot V_\varepsilon}{r_o}$$

$$V_\varepsilon + \beta \cdot V_o = V_i = 0$$
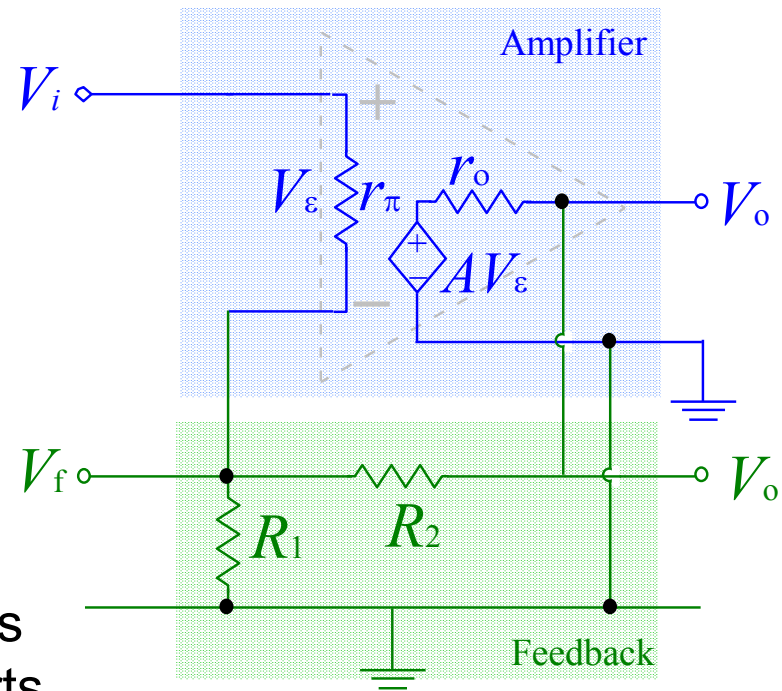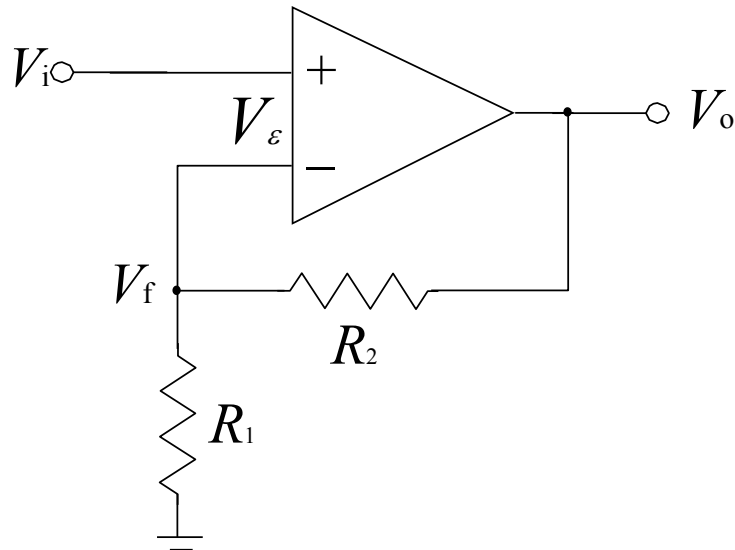
$$V_\varepsilon = -\beta \cdot V_o$$

$$I_o = \frac{V_o + A \cdot \beta \cdot V_o}{r_o}$$

$$\Rightarrow R_{\text{out}} = \frac{V_o}{I_o} = \frac{r_o}{1 + A \cdot \beta} = \frac{r_o}{1+T}$$

Series-Shunt Example

Given : $A = 10^5, R_1 = 1k\Omega, R_2 = 9k\Omega, r_\pi = 10M\Omega$ and $r_o = 40\Omega$

Equivalent circuit

It is observed that:
(1) Series connection in input ports
(2) Shunt connection in output ports
$\Rightarrow$ Series-Shunt connection
   h-parameter should be used.