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EECS140

Analog Circuit Design

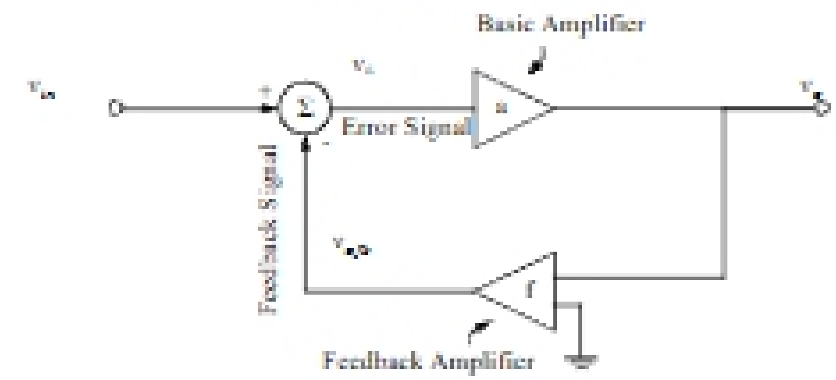
# Lectures on FEEDBACK





## Feedback

FB-1




f – gain of feedback amplifier

a – gain of basic amplifier





## Feedback (Cont.)

FB-2

$v_i = v_{in} - v_{fb}$

$v_{fb} = f \cdot v_o$

$v_i = v_{in} - f \cdot v_o$

$v_o = a \cdot v_i$

$A_v = v_o / v_{in} = \dfrac{a}{(1 + a \cdot f)} = \dfrac{1}{f} \cdot \left( \dfrac{T}{1 + T} \right) \leftarrow$ Closed loop gain

$T$ = Loop Gain $= a \cdot f$

$a$ = Open Loop Gain

$f$ = Feedback Factor

$A_v|_{\ldots} = \dfrac{1}{f} \qquad T \gg 1$





## Feedback (Cont.)

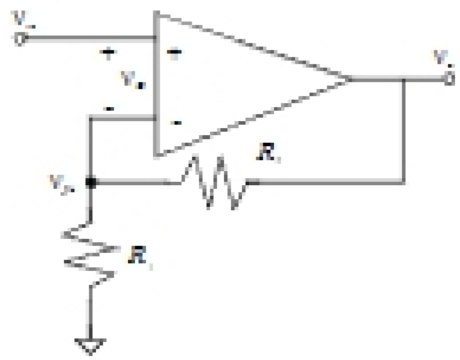
FB-3

There are 4 basic kinds of Feedback Circuits :

| | (Type of Feedback) | | (Type of Sensing) |
|---|---|---|---|
| 1) | Series (Voltage) | - | Shunt (Voltage) |
| 2) | Shunt (Current) | - | Shunt (Voltage) |
| 3) | Shunt (Current) | - | Series (Current) |
| 4) | Series (Voltage) | - | Series (Current) |

## Series-Shunt ($v_{out}/v_{in}$) FB-6

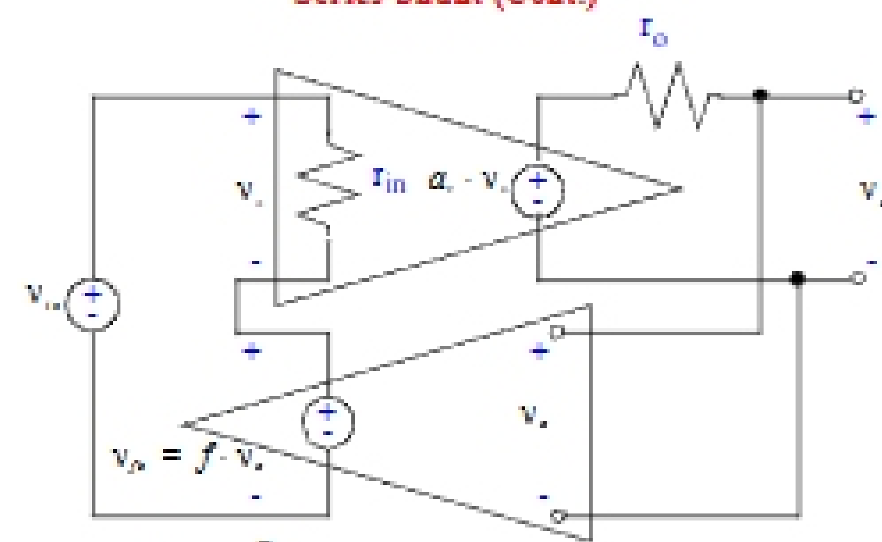
This is a voltage amplifier, a typical example is the well known configuration shown below :








## Series-Shunt (Cont.) FB-7




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





## Series-Shunt (Cont.) FB-8

**Gain Calculation :**

$$v_o = a_v \cdot v_e$$

$$v_{fb} = f_v \cdot v_o$$

$$v_{in} = v_e + v_{fb} = \frac{v_o}{a_v} + f_v \cdot v_o$$

$$\frac{v_o}{v_{in}} = \frac{1}{f_v} \cdot \left(\frac{T}{1+T}\right) = A_v \quad \text{Closed Loop Gain}$$

$$v_e = \frac{v_{in} \cdot a_v}{1 + a_v \cdot f_v}$$

$$v_{in} = v_e \cdot (1 + a_v \cdot f_v)$$



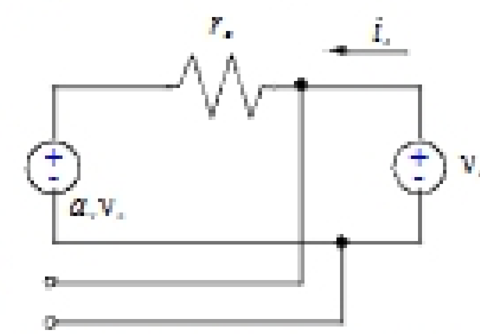


## Series-Shunt (Cont.) FB-9

**Rout Calculation (Closed Loop Output Resistance) :**

$$R_{out}|_{v_{in}=0} = \frac{v_t}{i_t}$$

Drive output with $v_t$, measure $i_t$




$$i_t = \frac{v_t - a_v \cdot v_e}{r_o}$$

$$v_e + f_v \cdot v_t = v_{in} = 0 \; ; \; v_e = -f_v \cdot v_t$$

$$v_{in} = 0$$

$$i_t = \frac{v_t + a_v \cdot f_v \cdot v_t}{r_o}$$

$$\frac{v_t}{i_t} = R_{out} = \frac{r_o}{1 + a_v \cdot f_v} = \frac{r_o}{1+T}$$

$A_v = 10 \quad f_v = 0.1 \quad a_v = 50,000$

$T = 0.1 \cdot 50,000 = 5000 \quad r_o = 100\Omega$

$$R_{out} = \frac{r_o}{1+T} = 0.02\,\Omega$$

## Series-Shunt (Cont.)

FB-10

**Rin Calculation :**

$$R_{in} = \frac{v_{in}}{i_{in}}$$

$$v_{in} = (1+T)\cdot v_i$$

$$i_{in} = \frac{v_i}{r_i} = \frac{v_{in}}{(1+T)\cdot r_i}$$

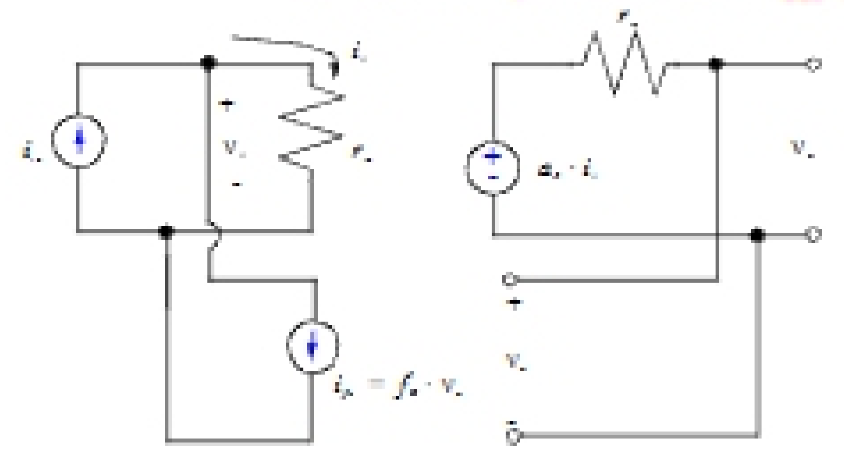
$$R_{in} = \frac{v_{in}}{i_{in}} = (1+T)\cdot r_i$$





## Shunt-Shunt (Transresistance $v_{out}/i_{in}$)

FB-11







## Shunt-Shunt (Cont.)

FB-13

**Gain Calculation :**

$$i_{fb} = f_R \cdot v_o$$

$$f_R = \frac{i_{fb}}{v_o}$$

$$i_i = i_{in} - i_{fb}$$

$$v_o = a_R \cdot i_i$$

$a_R$ has units of resistance

$$v_o = a_R \cdot (i_{in} - \underbrace{f_R \cdot v_o}_{i_{fb}})$$

$$\frac{v_o}{i_{in}} = \frac{1}{f_R}\cdot\left(\frac{T}{1+T}\right)$$





## Shunt-Shunt (Cont.)

FB-14