Feedback

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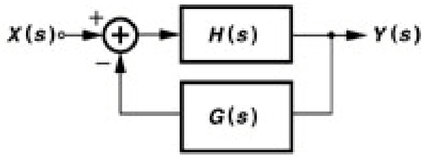
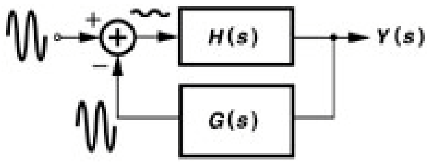
References

- B. Razavi, "Design of Analog CMOS Integrated Circuits", McGraw-Hill, 2001.

Feedback

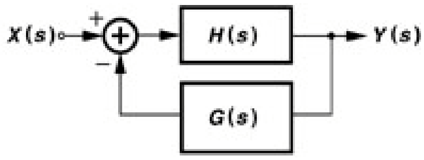
$$\frac{Y(s)}{X(s)} = \frac{H(s)}{1+G(s)H(s)}$$

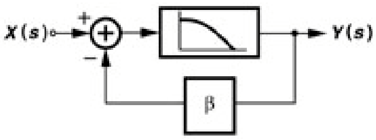


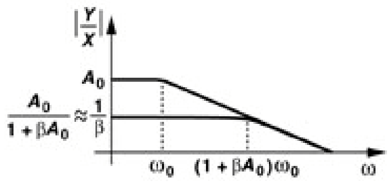


Feedback

$$\frac{Y(s)}{X(s)} = \frac{H(s)}{1+G(s)H(s)}$$







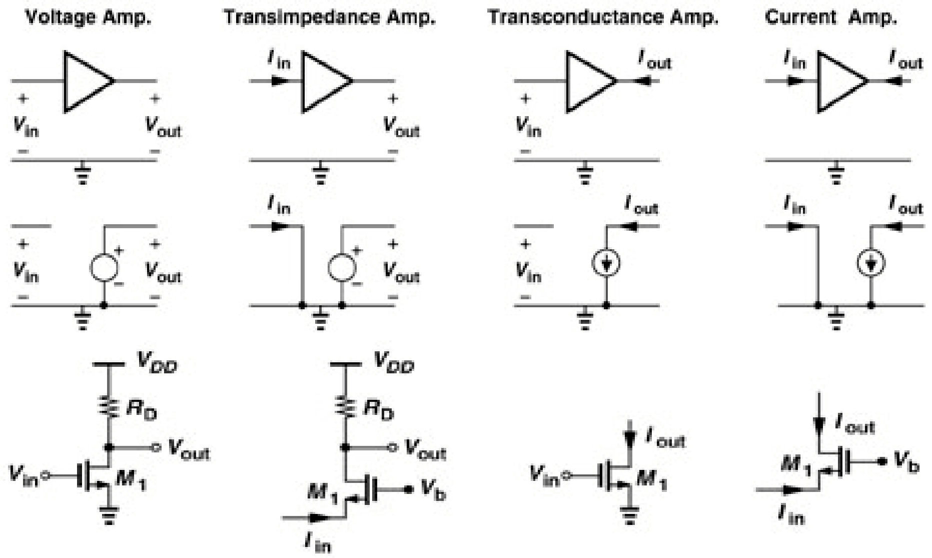
$$H(s) = \frac{A_0}{1+s/\omega_0} \qquad G(s) = \beta$$

$$\frac{Y(s)}{X(s)} = \frac{\dfrac{A_0}{1+\beta A_0}}{1+\dfrac{s}{(1+\beta A_0)\omega_0}}$$

- **Gain is decreased**
- **Bandwidth is increased by the same factor:**

➡ $1+\beta A_0$

Types of Amplifiers



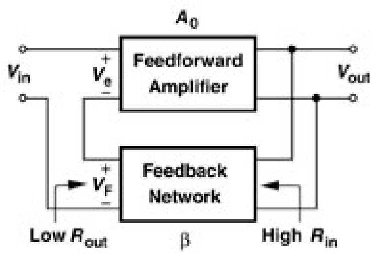
$Z_{in} \uparrow\uparrow \; Z_{out} \downarrow\downarrow$ $\quad$ $Z_{in} \downarrow\downarrow \; Z_{out} \downarrow\downarrow$ $\quad$ $Z_{in} \uparrow\uparrow \; Z_{out} \uparrow\uparrow$ $\quad$ $Z_{in} \downarrow\downarrow \; Z_{out} \uparrow\uparrow$

Voltage-Voltage Feedback (series-shunt)

$V_F = \beta V_{out}$ $\qquad$ $V_e = V_{in} - V_F$

$$V_{out} = A_0 \left(V_{in} - \beta V_{out}\right)$$

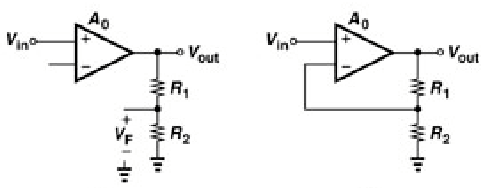
$$\boxed{\frac{V_{out}}{V_{in}} = \frac{A_0}{1+\beta A_0}}$$



- **Example:**

$$\beta = \frac{V_F}{V_{out}} = \frac{R_2}{R_1+R_2}$$

$$\Rightarrow \quad \frac{V_{out}}{V_{in}} = \frac{A_0}{1+\dfrac{A_0 R_2}{R_1+R_2}}$$



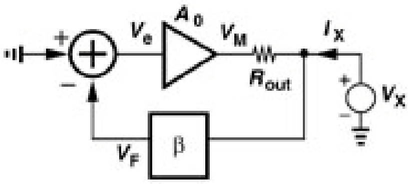
(a) (b)

Output Resistance of Voltage-Voltage Feedback

$$V_F = \beta V_X$$

$$V_e = -\beta V_X$$

$$V_M = -\beta A_0 V_X$$



Neglecting the current in the feedback path:

$$I_X = \frac{V_X - V_M}{R_{out}}$$

$$\Rightarrow \quad \boxed{Z_{out} = \frac{V_X}{I_X} = \frac{R_{out}}{1 + \beta A_0}}$$

Example

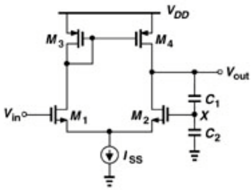
Open loop Gain:

$$A_0 = g_{m1}\left(r_{O2} // r_{O4}\right)$$

Depends on $r_{O1}//r_{O2}$

Feedback Gain:

$$\beta = \frac{V_X}{V_{out}} = \frac{C_1}{C_1 + C_2}$$



Closed loop Gain:

$$\frac{V_{out}}{V_{in}} = \frac{A_0}{1 + \beta A_0} = \frac{g_{m1}\left(r_{O1} // r_{O2}\right)}{1 + \frac{C_1}{C_1 + C_2} g_{m1}\left(r_{O1} // r_{O2}\right)} \approx 1 + \frac{C_2}{C_1}$$

Independent of $r_{O1}//r_{O2}$

Closed loop Output Resistance:

$$\frac{V_X}{I_X} = \frac{R_{out}}{1 + \beta A_0} = \frac{r_{O2} // r_{O4}}{1 + \frac{C_1}{C_1 + C_2} g_{m1}\left(r_{O2} // r_{O4}\right)} \approx \left(1 + \frac{C_2}{C_1}\right)\frac{1}{g_{m1}}$$

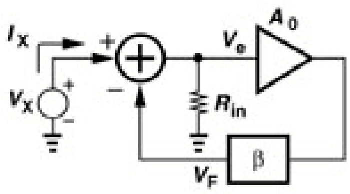
Independent of $r_{O1}//r_{O2}$

Input Resistance of Voltage-Voltage Feedback

$V_F = \beta A_0 I_X R_{in}$

$V_e = I_X R_{in} = V_X - V_F$

$I_X R_{in} = V_X - \beta A_0 I_X R_{in}$



Neglecting the current in the feedback path:

$$Z_{in} = \frac{V_X}{I_X} = R_{in}\left(1 + \beta A_0\right)$$

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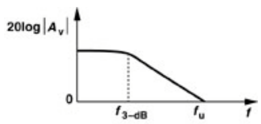
Operational Amplifier: Performance Parameters

Gain: the open loop gain of an op-amp determines the precision of the feedback system employing the op-amp

Small Signal Bandwith:
Unity-Gain freq., f_u, and the 3dB freq., $f_{3\text{-}dB}$.



Large Signal Bandwidth (slew rate):
Op-Amp response to large transient signals.

Output Swing:

Linearity: non-linearity can be reduced by using a differential circuit and by increasing the open-loop gain in a feedback system

Noise and Offset: input noise and offset determine the minimum signal level that can be processed with reasonable quality.

Supply Rejection:

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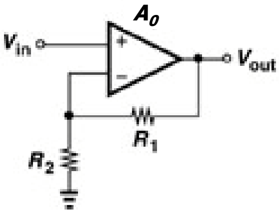
Op-Amp Gain

Example: This circuit is designed for a gain of 10. Determine the minimum value of A_0 for a gain error of 1%.

$$\frac{V_{out}}{V_{in}} = \left(1+\frac{R_1}{R_2}\right)\frac{1}{1+\frac{1+R_1/R_2}{A_0}}$$



$$Ideally, \quad A_0 \rightarrow \infty \quad \Rightarrow \quad gain = 1 + R_1/R_2$$

$$Taking, \quad A_0 >> 1 + R_1/R_2 \quad , \quad we\ have$$

$$\frac{V_{out}}{V_{in}} \approx \left(1+\frac{R_1}{R_2}\right)\left(1-\frac{1+R_1/R_2}{A_0}\right) \Rightarrow \boxed{gain\ error = \frac{1+R_1/R_2}{A_0}}$$

Compare with the gain error of a CS stage!