

上海科技大学
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EE115 Analog Circuits Voltage Feedback Amp

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Outline

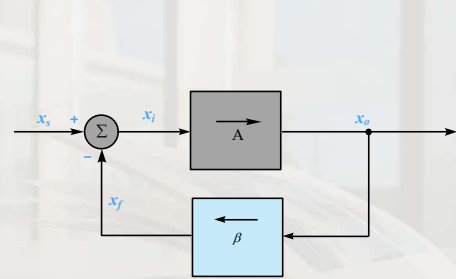
- Feedback 2
 - Analysis of the Feedback Voltage Amplifier
 - Systematic Analysis of Feedback Voltage Amplifiers
- Reading: SEDTRA/SMITH book pages 797-817

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Review: General Feedback Structure



A : open loop gain
 $x_o = Ax_i$

β : feedback factor
 $x_f = \beta x_o$
 $x_i = x_s - x_f = x_s - A\beta x_i$
 $x_s = (1 + A\beta)x_i$

A_f : closed loop gain
 $A_f \equiv \frac{x_o}{x_s} = \frac{A}{1 + A\beta}$

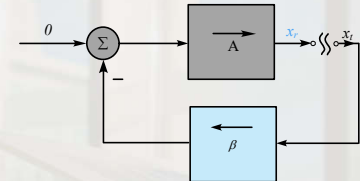
$A\beta$: loop gain. If $A\beta \gg 1$,
 $A_f \cong \frac{1}{\beta}$

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Review: Loop Gain



$x_r = -A\beta x_t$
 $A\beta = -\frac{x_r}{x_t}$

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

- Loop gain $A\beta \gg 1$,
 - The **sign** of $A\beta$ determines the **polarity** of the feedback.
 - The **magnitude** of $A\beta$ determines how **close** the closed-loop gain A_f is to the ideal value of $1/\beta$.
 - The magnitude of $A\beta$ determines the **amount of feedback** ($1 + A\beta$), the magnitude of the various improvements in amplifier performance.

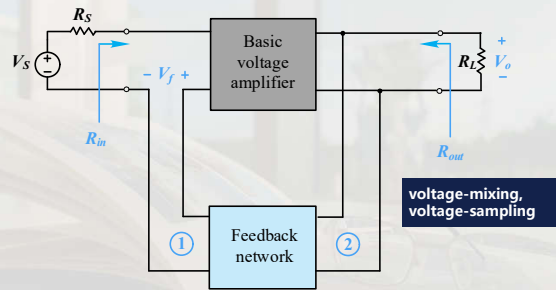
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Review: Feedback Voltage Amplifier

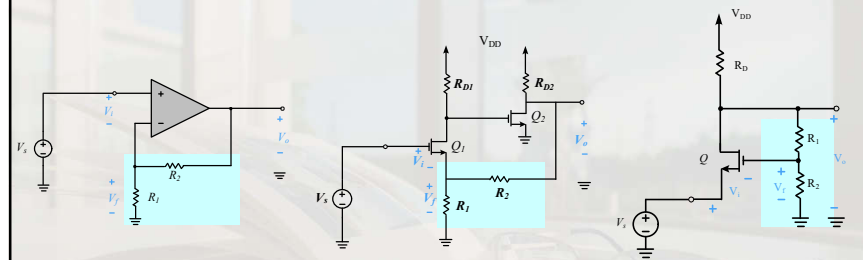


■ Series–Shunt Feedback Topology



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Review: Examples of Series–Shunt Feedback Amp.



V_o increases, V_o increases and V_f increases: negative feedback

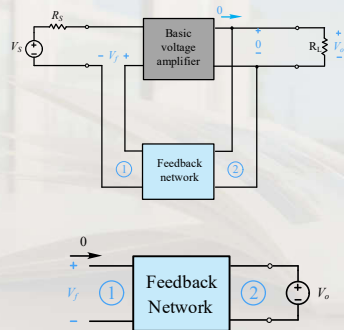


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Analysis of Feedback Voltage Amp. Utilizing Loop Gain



■ Step 1: Identify the feedback network and determine β and $A_f|_{ideal}$



β : feedback factor

$$V_f = \beta V_o$$

$$A_f|_{ideal} = \frac{1}{\beta}$$

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Continued



- Step 2: Determine the loop gain $A\beta$
- Step 3: Determine the closed-loop gain A_f

$$A\beta = -\frac{V_r}{V_t}$$

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

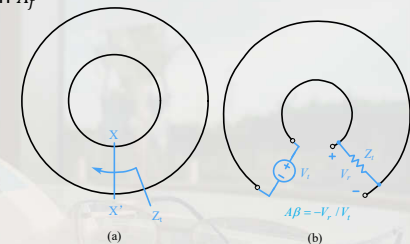


Fig. Breaking the conceptual feedback loop in (a) to determine the loop gain requires the termination of the loop as shown in (b), to ensure that the loop conditions do not change.



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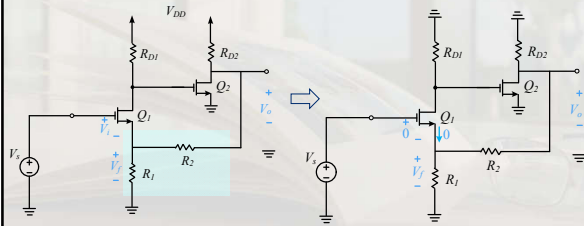
Example: series-shunt feedback amplifier



For the circuit below, neglect the MOSFETs' r_o , and

- (a) Mark the feedback network (β circuit). Derive an expression for β , and ideal closed-loop gain A_f .
 (b) Find the ratio R_2/R_1 that results in an ideal closed-loop gain of 10 V/V. If $R_1 = 1 \text{ k}\Omega$, find R_2 .

Solution:
 assume **infinite** open-loop gain



$$(a) \beta = \frac{V_f}{V_o} = \frac{R_1}{R_1 + R_2}$$

$$|A_f|_{ideal} = \frac{1}{\beta} = 1 + \frac{R_2}{R_1}$$

$$(b) 10 = 1 + \frac{R_2}{R_1}$$

$$\text{Thus, } \frac{R_2}{R_1} = 9$$

$$\text{For } R_1 = 1 \text{ k}\Omega$$

$$R_2 = 9 \text{ k}\Omega$$

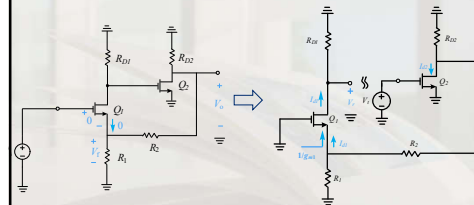


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Example

Solution: (c) $I_{d2} = g_{m2}V_i$ $I_i = -I_{d2} \frac{R_{D2}}{R_{D2} + R_2 + (R_1 || \frac{1}{g_{m1}})}$

- (c) Derive an expression for the loop gain $A\beta$.
 (d) If $g_{m1} = g_{m2} = 4 \text{ mA/V}$ and $R_{D1} = R_{D2} = 10 \text{ k}\Omega$, determine the values of $A\beta$, A , and A_f .



$$I_{d1} = I_i \frac{R_1}{R_1 + \frac{1}{g_{m1}}}$$

$$V_i = I_{d1} R_{D1}$$

$$A\beta \equiv -\frac{V_f}{V_i}$$

$$= (g_{m1} R_{D1})(g_{m2} R_{D2}) \frac{1}{1 + g_{m1} R_1 R_{D2} + R_2 + (R_1 || \frac{1}{g_{m1}})}$$

$$(d) A\beta = 4 \times 10 \times 4 \times 10 \times \frac{1}{1 + 4 \times 1} \times \frac{1}{10 + 9 + (1 || \frac{1}{4})}$$

$$= 16.67$$

$$\beta = \frac{R_1}{R_1 + R_2} = \frac{1}{1 + 9} = 0.1$$

$$A = \frac{A\beta}{\beta} = \frac{16.67}{0.1} = 166.7 \text{ V/V}$$

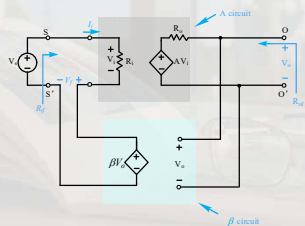
$$A_f = \frac{A}{1 + A\beta} = \frac{166.7}{1 + 16.67} = 9.43 \text{ V/V}$$

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Systematic Analysis of Feedback Voltage Amp-Ideal Case

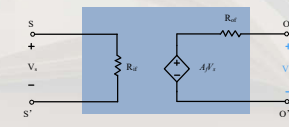
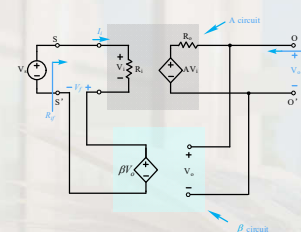


- **Ideal structure** of the series-shunt feedback amplifier: **A circuit + β circuit**
- **A circuit** has an input resistance R_i , an open-circuit voltage gain A , and an output resistance R_o .
- It is assumed that the source is ideal with a zero resistance and that there is no load resistance. Also, **no loading effect** is considered.



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Systematic Analysis of Feedback Voltage Amp-Ideal Case



System equivalent circuit model

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

A_f : open circuit voltage gain of the feedback amplifier
 R_{if} : input resistance
 R_{of} : output resistance

$$V_i = \frac{V_s}{1 + A\beta}$$

$$I_i = \frac{V_i}{R_i} = \frac{V_s}{(1 + A\beta)R_i}$$

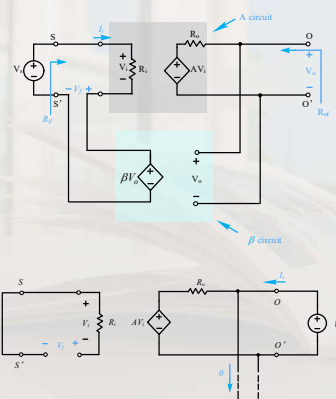
$$R_{if} \equiv \frac{V_s}{I_i}$$

$$R_{if} = (1 + A\beta)R_i$$

Input resistance increased by $1 + A\beta$

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Systematic Analysis of Feedback Voltage Amp-Ideal Case


 R_{of} : output resistance

$$R_{of} \equiv \frac{V_x}{I_x}$$

$$I_x = \frac{V_x - AV_i}{R_o}$$

$$V_i = -V_f$$

$$V_f = \beta V_o = \beta V_x$$

$$V_i = -\beta V_x$$

$$I_x = \frac{V_x(1 + A\beta)}{R_o} \Rightarrow R_{of} = \frac{R_o}{1 + A\beta}$$

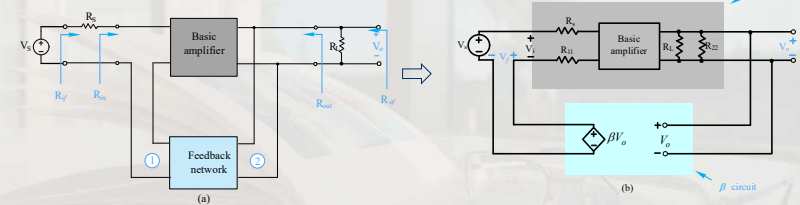
Output resistance decreased by $1 + A\beta$

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Systematic Analysis of Feedback Voltage Amp-Practical Case

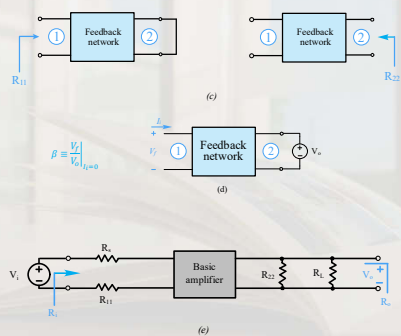


- In a **practical** series-shunt feedback amplifier, the **feedback network** is usually **resistive** and hence will **load** the basic amplifier and thus affect the values of A , R_{if} and R_{out}
- In addition, there will be finite **source and load resistances**, which in turn will affect these three parameters


 R_{11} and R_{22} represent the loading effect of the feedback network on the basic amplifier

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Continued

Definition of R_{11} and R_{22} .

$$\beta \equiv \frac{V_f}{V_o} \Big|_{I_i=0}$$

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

$$R_{if} = R_i(1 + A\beta)$$

$$R_{of} = R_o(1 + A\beta)$$

$$R_{in} = R_{if} - R_s$$

$$R_{out} = 1 / \left(\frac{1}{R_{of}} - \frac{1}{R_i} \right)$$

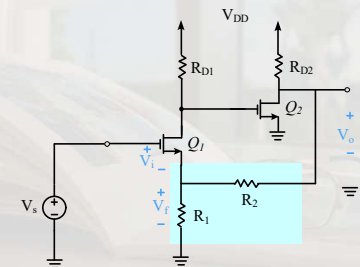
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Example: series-shunt feedback amplifier



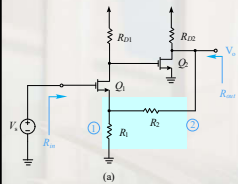
Consider the circuit shown below. Analyze the circuit using systematic procedure. Compare the results to those obtained previously.

- Obtain the voltage gain V_o/V_s , input resistance R_{in} , and output resistance R_{out} .
- Find numerical values for the case $g_{m1} = g_{m2} = 4 \text{ mA/V}$, $R_{D1} = R_{D2} = 10 \text{ k}\Omega$, $R_1 = 1 \text{ k}\Omega$, and $R_2 = 9 \text{ k}\Omega$. Neglect early effect.



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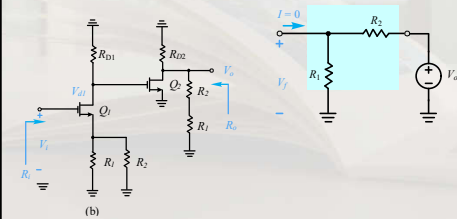
Solution



Loading effect:

a) looking into port 1 (short port 2), we see $R_1 || R_2$.

b) looking into port 2 (open port 1), we see $R_1 + R_2$.



Solution:

$$A_1 = \frac{V_{d1}}{V_i} = -\frac{R_{D1}}{\frac{1}{g_{m1}} + (R_1 || R_2)} = -\frac{g_{m1} R_{D1}}{1 + g_{m1}(R_1 || R_2)}$$

$$A_2 = \frac{V_o}{V_{d1}} = -g_{m2}[R_{D2} || (R_1 + R_2)]$$

$$A = \frac{V_o}{V_i} = A_1 A_2 = \frac{g_{m1} R_{D1} g_{m2} [R_{D2} || (R_1 + R_2)]}{1 + g_{m1}(R_1 || R_2)}$$

$$A = \frac{4 \times 10 \times 4[10 || (1 + 9)]}{1 + 4(1 || 9)} = \frac{173.9V}{V}$$

$$\beta \equiv \frac{V_f}{V_o} = \frac{R_1}{R_1 + R_2} = \frac{1}{1 + 9} = 0.1$$

$$\frac{V_o}{V_s} = A_f = \frac{A}{1 + A\beta} = \frac{173.9}{1 + 173.9 \times 0.1} = \frac{9.46V}{V}$$

$$R_{out} = R_{of} = \frac{R_o}{1 + A\beta}$$

$$R_o = R_{D2} || (R_1 + R_2) = 10 || 10 = 5k\Omega$$

$$1 + A\beta = 1 + (173.9 \times 0.1) = 18.39$$

$$R_{out} = \frac{5000}{18.39} = 272\Omega$$

$$R_{in} \text{ infinite}$$