上海科技大学
ShanghaiTech University

EE115 Analog Circuits
Voltage Feedback Amp

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Outline

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- 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

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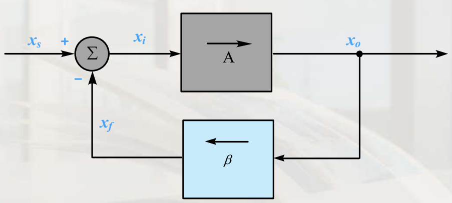

A: open loop gain

$$x_o = Ax_i$$

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

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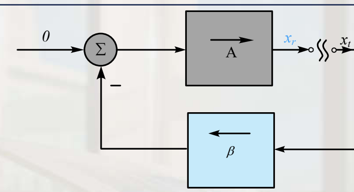


$$x_r = -A\beta x_t$$

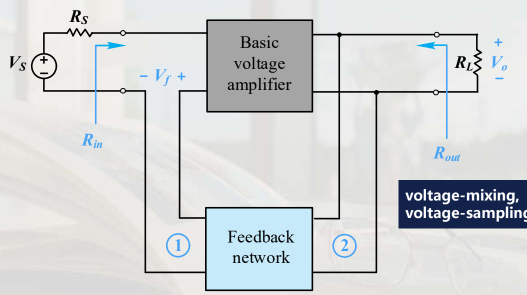
$$A\beta = -\frac{x_r}{x_t}$$

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

- 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.

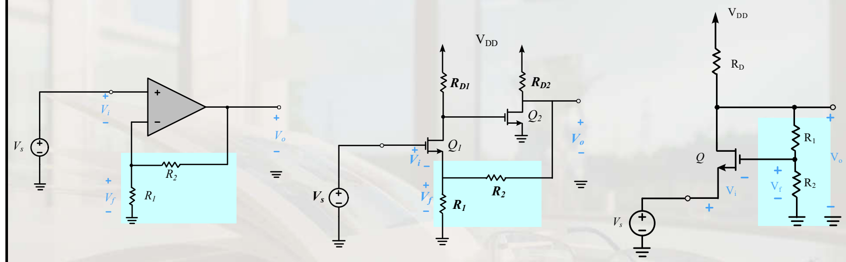
Review: Feedback Voltage Amplifier

- Series–Shunt Feedback Topology



voltage-mixing, voltage-sampling

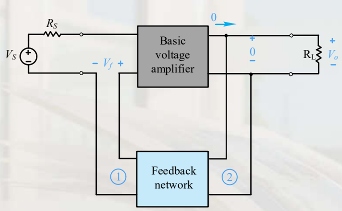
Review: Examples of Series–Shunt Feedback Amp.



V_s increases, V_o increases and V_f increases: negative feedback

Analysis of Feedback Voltage Amp. Utilizing Loop Gain

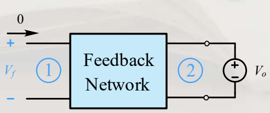
- Step 1: Identify the feedback network and determine β and $A_f\big|_{ideal}$



β: feedback factor

$$V_f = \beta V_o$$

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



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- Step 2: Determine the loop gain Aβ
- Step 3: Determine the closed-loop gain A_f

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

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

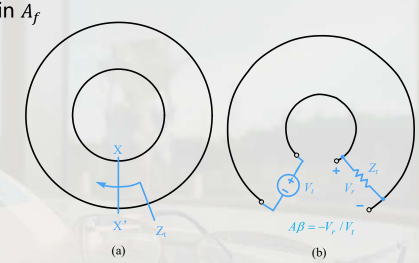

Fig. Breaking the conceptual feedback loop in (a) to determine the loop gain requires the termination of the loop as shown in (b), to ensure that the loop conditions do not change.

Example: series-shunt feedback amplifier

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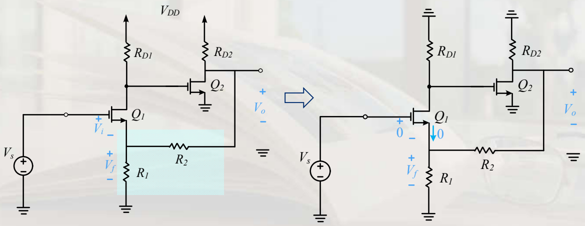
For the circuit below, neglect the MOSFETs' r_o, and
(a) Mark the feedback network (β circuit). Derive an expression for β, and ideal closed-loop gain A_f.
(b) Find the ratio R_2/R_1 that results in an ideal closed-loop gain of 10 V/V. If R_1= 1 kΩ, find R_2.



Solution:
assume *infinite* open-loop gain

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

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

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

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

$For\ R_1 = 1k\Omega$
$R_2 = 9k\Omega$

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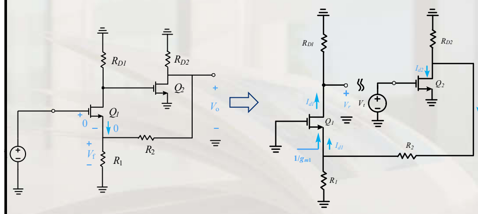
Example

Solution:

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



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

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

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

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

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

$$(d) A\beta$$

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

$$= 16.67$$

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

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

$$A_f = \frac{A}{1 + A\beta} = \frac{166.7}{1 + 16.67} = \frac{166.7}{17.67} = 9.43V/V$$

Systematic Analysis of Feedback Voltage Amp-Ideal Case

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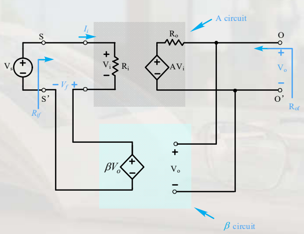
- **Ideal structure** of the series–shunt feedback amplifier: **A circuit + β circuit**
- **A circuit** has an input resistance R_i, an open-circuit voltage gain A, and an output resistance R_o.
- It is assumed that the source is ideal with a zero resistance and that there is no load resistance. Also,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



Systematic Analysis of Feedback Voltage Amp-Ideal Case

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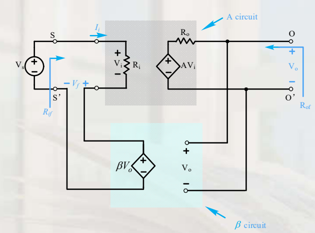


$$A_f \equiv \frac{V_o}{V_s} = \frac{A}{1 + A\beta}$$

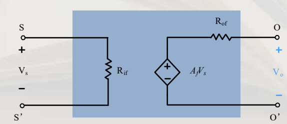
A_f: open circuit voltage gain of the feedback amplifier
R_{if}: input resistance
R_{of}: output resistance

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

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

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

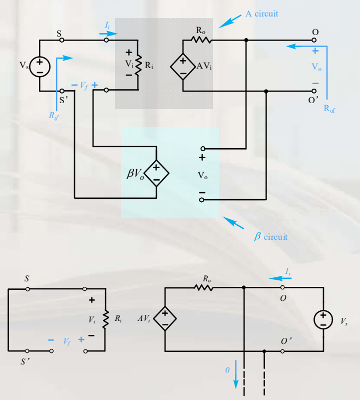
$$R_{if} = (1 + A\beta)R_i$$



System equivalent circuit model

Input resistance increased by $1 + A\beta$

Systematic Analysis of Feedback Voltage Amp-Ideal Case



R_{of}: output resistance

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

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

$$V_i = -V_f$$

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

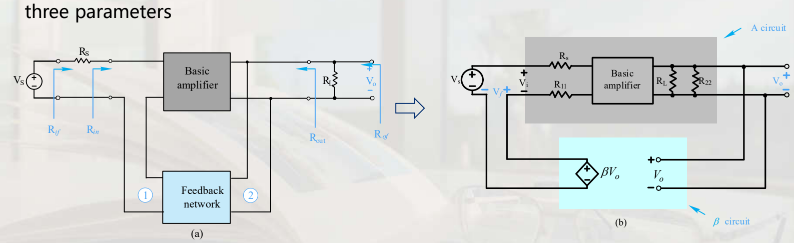
$$V_i = -\beta V_x$$

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

Output resistance decreased by $1 + A\beta$

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_{in}, 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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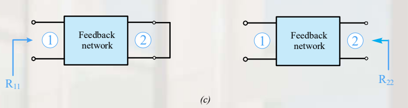
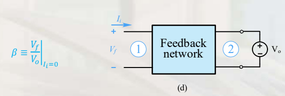
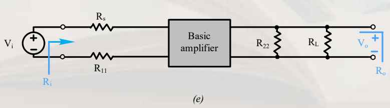


Definition of R_{11} and R_{22}.



$$\beta \equiv \left.\frac{V_f}{V_o}\right|_{I_i=0}$$



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

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

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

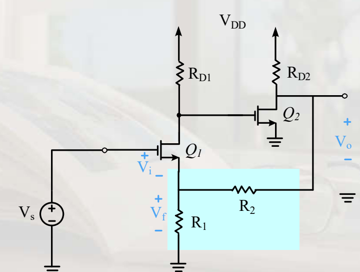
$$R_{in} = R_{if} - R_s$$

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

Example: series-shunt feedback amplifier

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

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



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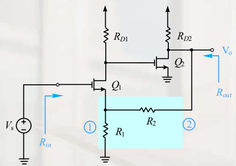
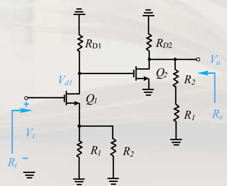
Solution



(a)

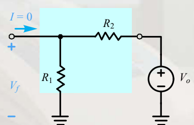


(b)

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:

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

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

$$A = \frac{V_o}{V_i} = A_1A_2 = \frac{g_{m1}R_{D1}g_{m2}[R_{D2}||(R_1 + R_2)]}{1 + g_{m1}(R_1||R_2)}$$

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

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

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

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

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

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

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

R_{in} infinite