Indian Institute of Technology Jodhpur, Year 2018

Analog Electronics

(Course Code: EE314)

Lecture 36-37: Feedback

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Course related documents will be uploaded on http://home.iitj.ac.in/~sptiwari/EE314/

Note: The information provided in the slides are taken form text books for microelectronics (including Sedra & Smith, B. Razavi), and various other resources from internet, for **teaching/academic use only**

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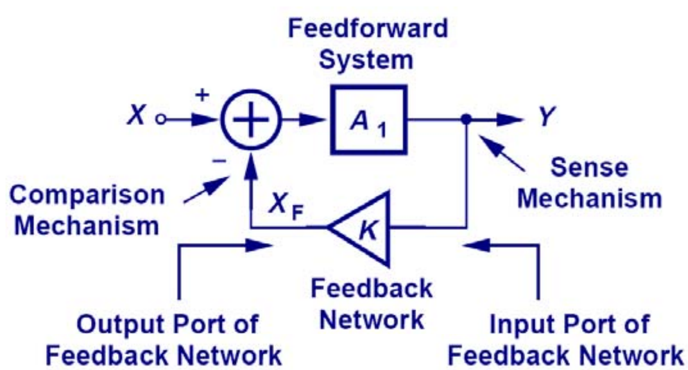
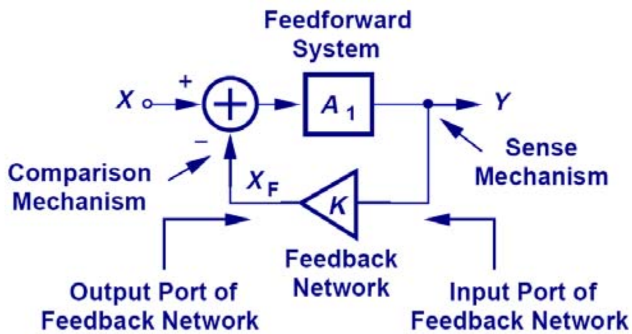
Negative Feedback System



- A negative feedback system consists of four components: 1) feedforward system, 2) sense mechanism, 3) feedback network, and 4) comparison mechanism.

2

Close-loop Transfer Function



$$\frac{Y}{X} = \frac{A_1}{1 + KA_1}$$

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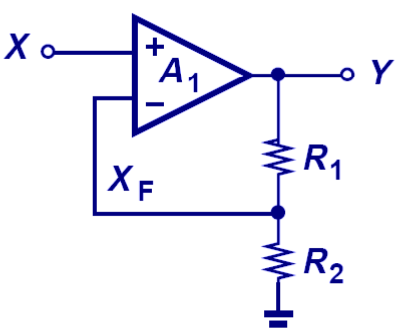
Feedback Example



$$\frac{Y}{X} = \frac{A_1}{1 + \frac{R_2}{R_1 + R_2} A_1}$$

- A_1 is the feedforward network, R_1 and R_2 provide the sensing and feedback capabilities, and comparison is provided by differential input of A_1.

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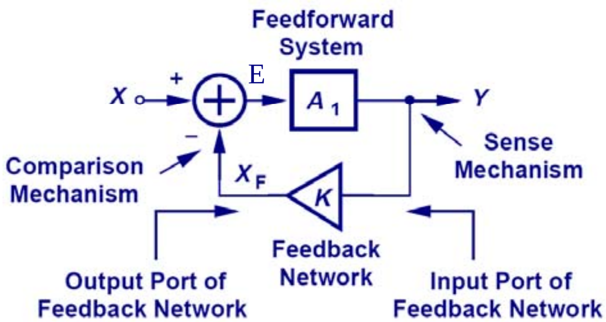
Comparison Error



$$E = \frac{X}{1 + A_1 K}$$

- As A_1K increases, the error between the input and fed back signal decreases. Or the fed back signal approaches a good replica of the input.

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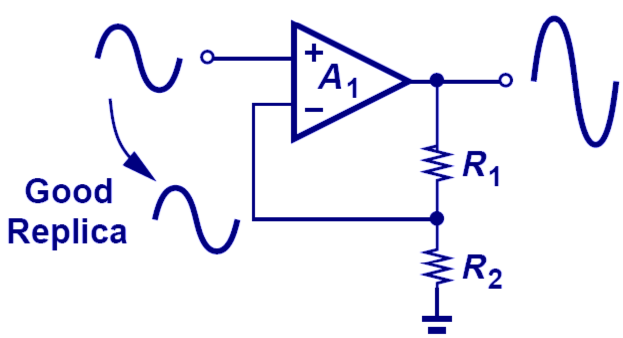
Comparison Error



$$\frac{Y}{X} \approx 1 + \frac{R_1}{R_2}$$

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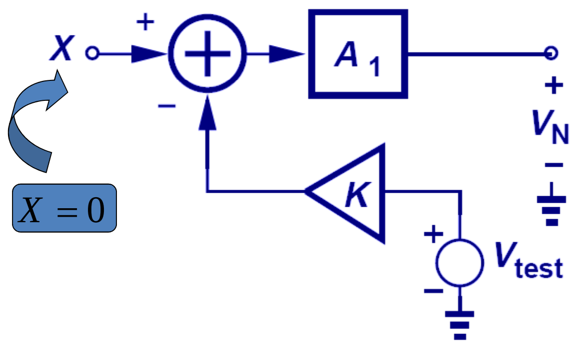
Loop Gain



$$KA_1 = -\frac{V_N}{V_{test}}$$

- When the input is grounded, and the loop is broken at an arbitrary location, the loop gain is measured to be KA_1.

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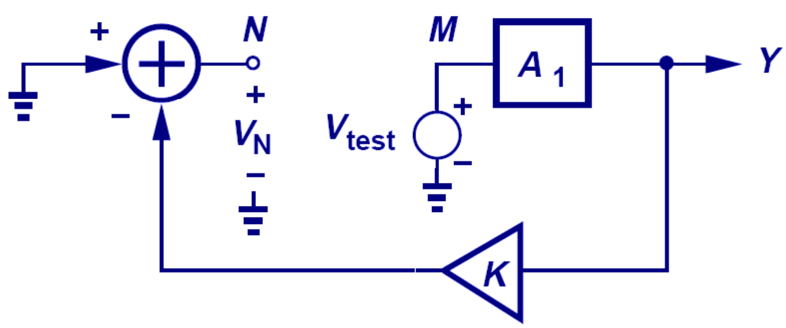
Example: Alternative Loop Gain Measurement



$$V_N = -KA_1V_{test}$$

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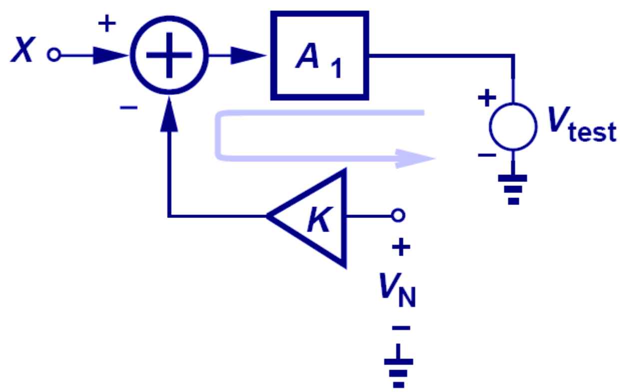
Incorrect Calculation of Loop Gain



- Signal naturally flows from the input to the output of a feedforward/feedback system. If we apply the input the other way around, the "output" signal we get is not a result of the loop gain, but due to poor isolation.

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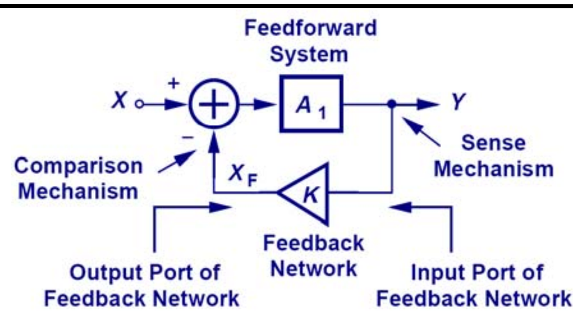
Gain Desensitization



$A_1 K >> 1$ → $\frac{Y}{X} \approx \frac{1}{K}$

- A large loop gain is needed to create a precise gain, one that does not depend on A_1, which can vary by ±20%.

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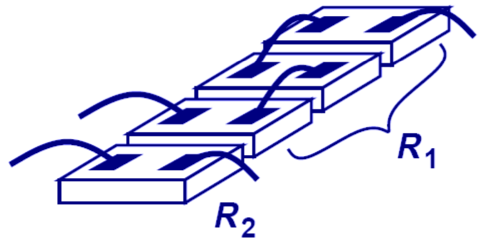
Ratio of Resistors



- When two resistors are composed of the same unit resistor, their ratio is very accurate. Since when they vary, they will vary together and maintain a constant ratio.

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Merits of Negative Feedback

- 1) Bandwidth enhancement
- 2) Modification of I/O Impedances
- 3) Linearization

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Bandwidth Enhancement

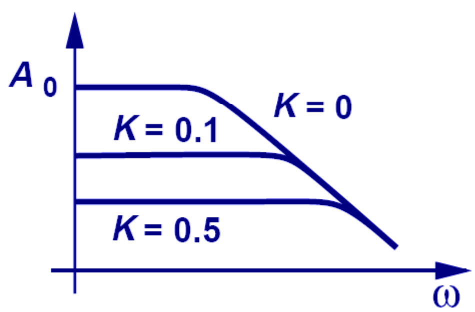
Open Loop — ***Negative Feedback*** → ***Closed Loop***

$$A(s) = \frac{A_0}{1 + \frac{s}{\omega_0}}$$

$$\frac{Y}{X}(s) = \frac{\frac{A_0}{1 + KA_0}}{1 + \frac{s}{(1 + KA_0)\omega_0}}$$

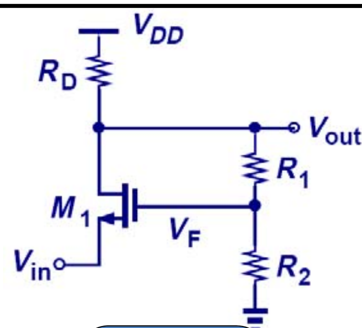
- Although negative feedback lowers the gain by $(1+KA_0)$, it also extends the bandwidth by the same amount.

Bandwidth Extension Example



- As the loop gain increases, we can see the decrease of the overall gain and the extension of the bandwidth.

Example: Open Loop Parameters



$$A_0 \approx g_m R_D$$

$$R_{in} = \frac{1}{g_m}$$

$$R_{out} = R_D$$

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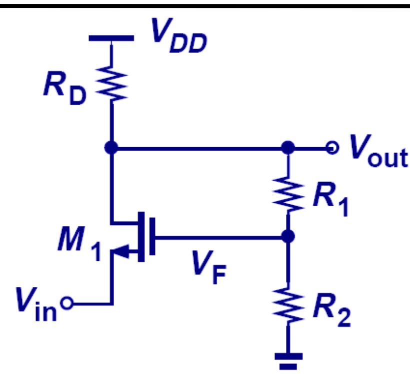
Example: Closed Loop Voltage Gain



$$\frac{v_{out}}{v_{in}} = \frac{g_m R_D}{1 + \frac{R_2}{R_1 + R_2} g_m R_D}$$

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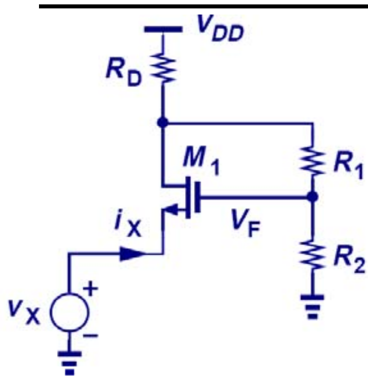
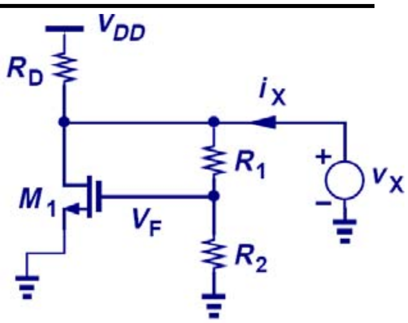
Example: Closed Loop I/O Impedance





$$R_{in} = \frac{1}{g_m}\left(1 + \frac{R_2}{R_1 + R_2} g_m R_D\right)$$

$$R_{out} = \frac{R_D}{1 + \frac{R_2}{R_1 + R_2} g_m R_D}$$

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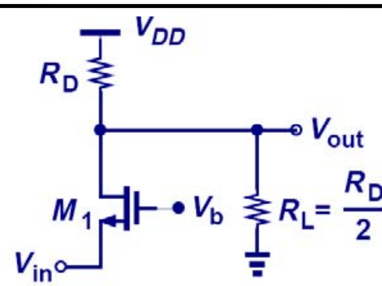
Example: Load Desensitization



W/O Feedback
Large Difference

$$g_m R_D \rightarrow g_m R_D / 3$$

With Feedback
Small Difference

$$\frac{g_m R_D}{1 + \frac{R_2}{R_1 + R_2} g_m R_D} \rightarrow \frac{g_m R_D}{3 + \frac{R_2}{R_1 + R_2} g_m R_D}$$

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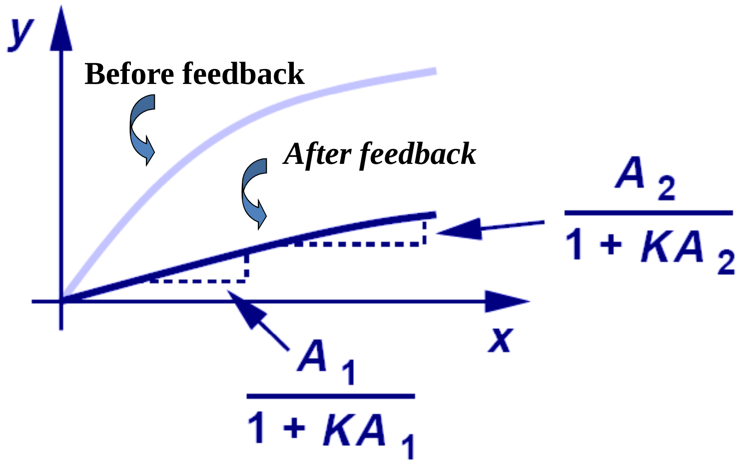
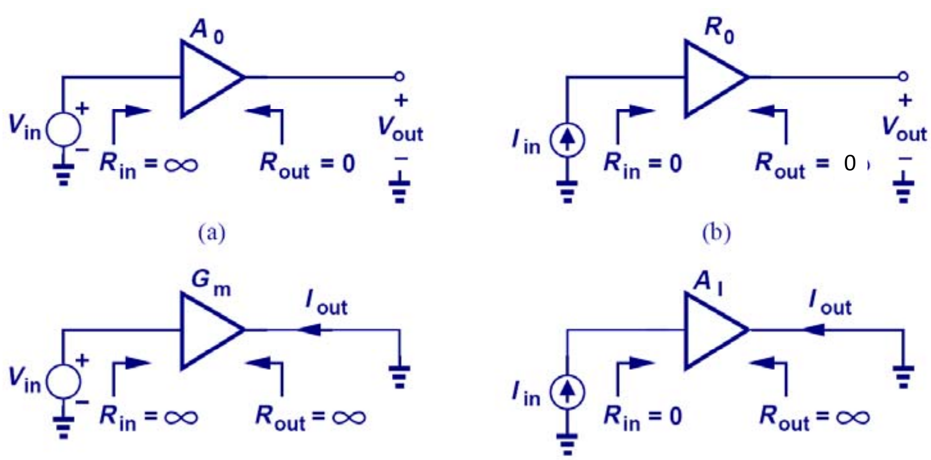
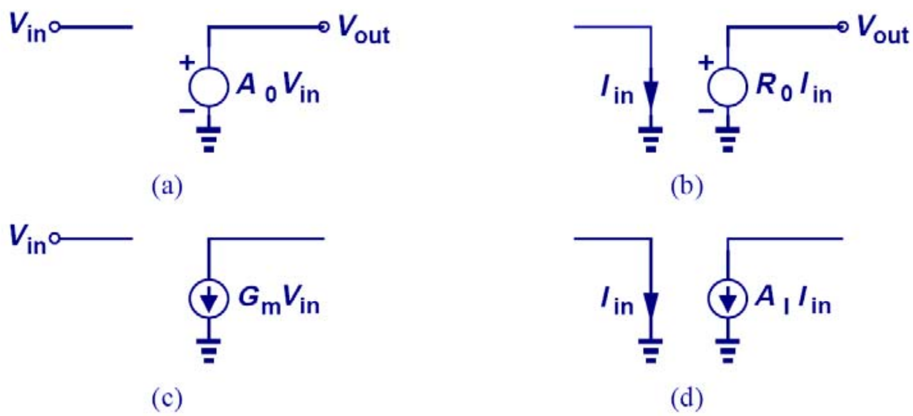
Linearization



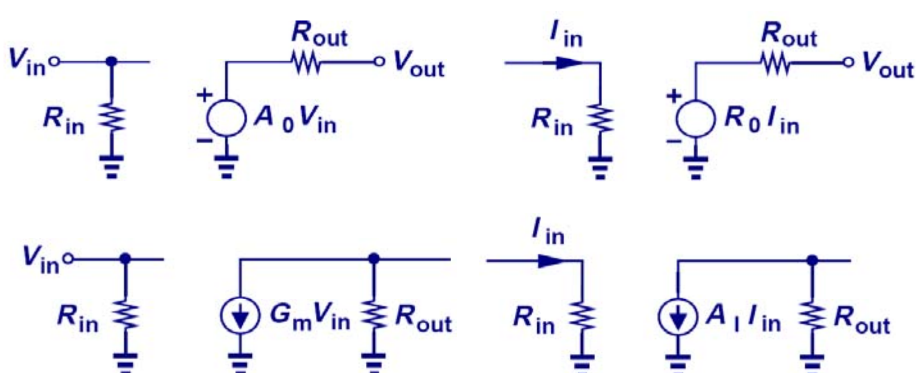
Four Types of Amplifiers



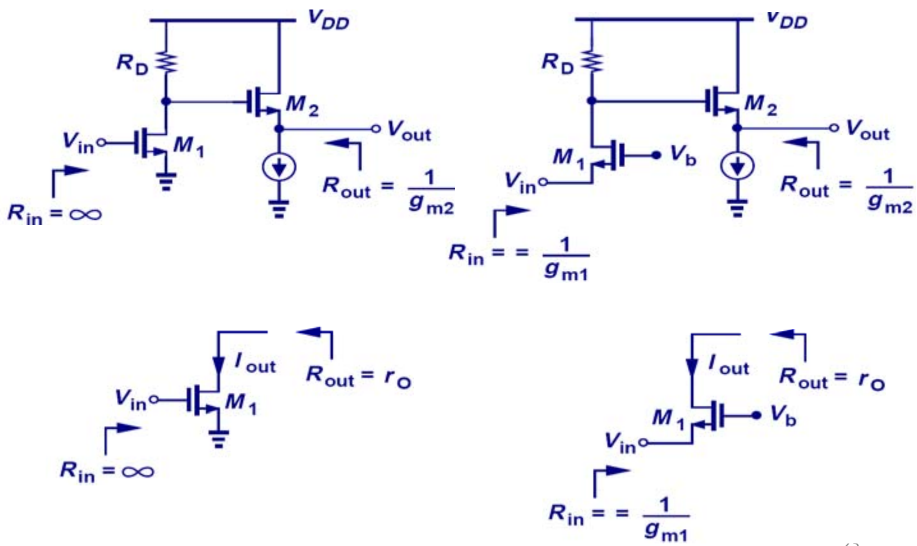
Ideal Models of the Four Amplifier Types



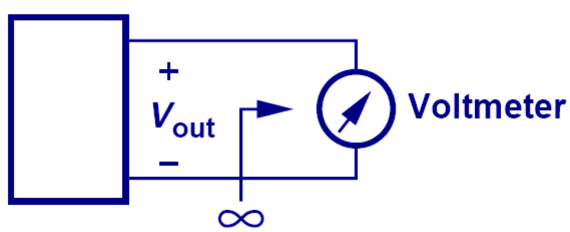
Realistic Models of the Four Amplifier Types



Examples of the Four Amplifier Types

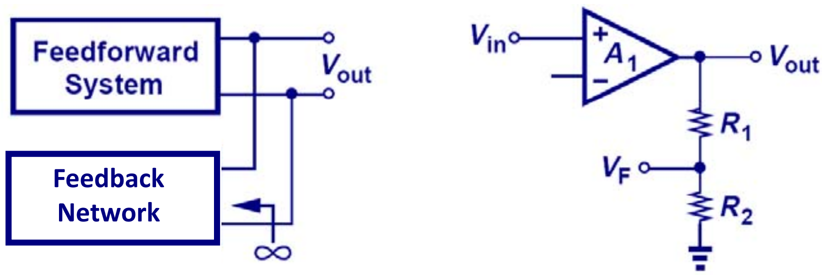


Sensing a Voltage



- In order to sense a voltage across two terminals, a voltmeter with ideally infinite impedance is used.

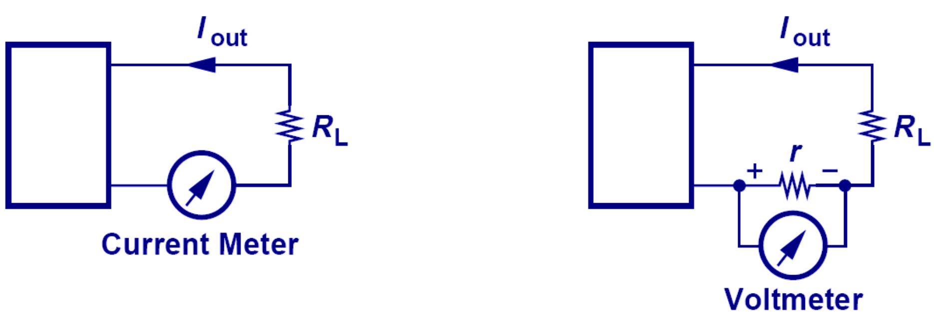
Sensing and Returning a Voltage



$$R_1 + R_2 \approx \infty$$

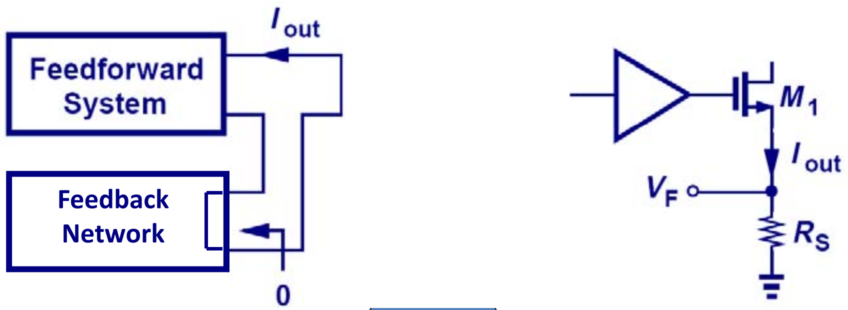
- Similarly, for a feedback network to correctly sense the output voltage, its input impedance needs to be large.
- R_1 and R_2 also provide a mean to return the voltage.

Sensing a Current



- A current is measured by inserting a current meter with ideally zero impedance in series with the conduction path.
- The current meter is composed of a small resistance r in parallel with a voltmeter.

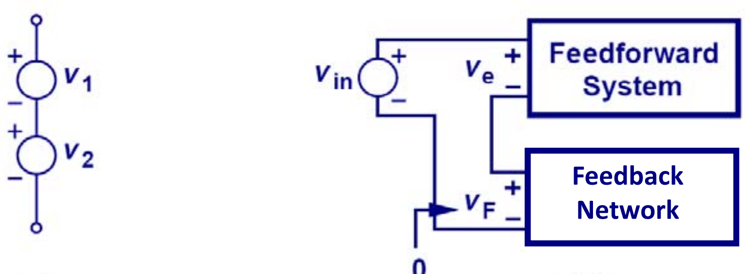
Sensing and Returning a Current



$R_S \approx 0$

- Similarly for a feedback network to correctly sense the current, its input impedance has to be small.
- R_S has to be small so that its voltage drop will not change I_{out}.

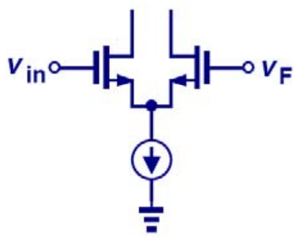
Addition of Two Voltage Sources



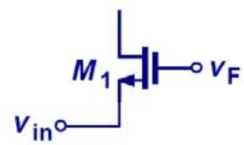
(a) (b)

- In order to add or subtract two voltage sources, we place them in series. So the feedback network is placed in series with the input source.

Practical Circuits to Subtract Two Voltage Sources



(c)



(d)

- Although not directly in series, V_{in} and V_F are being subtracted since the resultant currents, differential and single-ended, are proportional to the difference of V_{in} and V_F.

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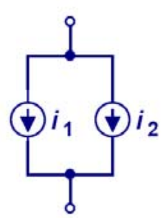
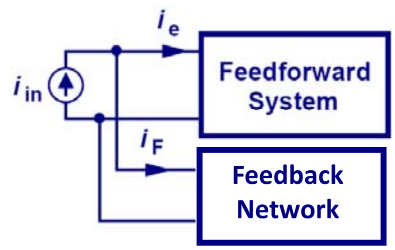
Addition of Two Current Sources



(a)



(b)

- In order to add two current sources, we place them in parallel. So the feedback network is placed in parallel with the input signal.

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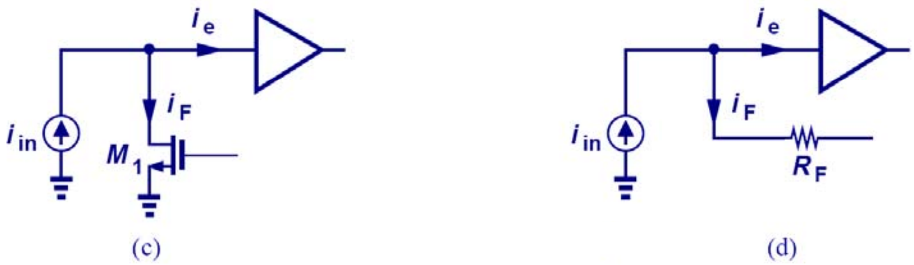
Practical Circuits to Subtract Two Current Sources



- Since M_1 and R_F are in parallel with the input current source, their respective currents are being subtracted. Note, R_F has to be large enough to approximate a current source.

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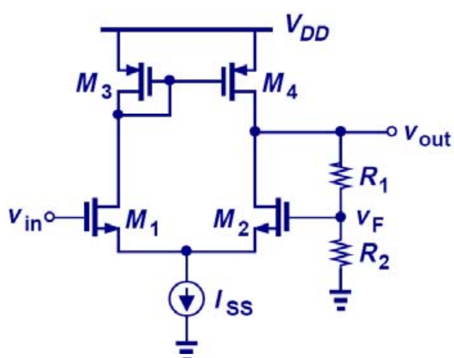
Example: Sense and Return



- R_1 and R_2 sense and return the output voltage to feedforward network consisting of M_1- M_4.
- M_1 and M_2 also act as a voltage subtractor.

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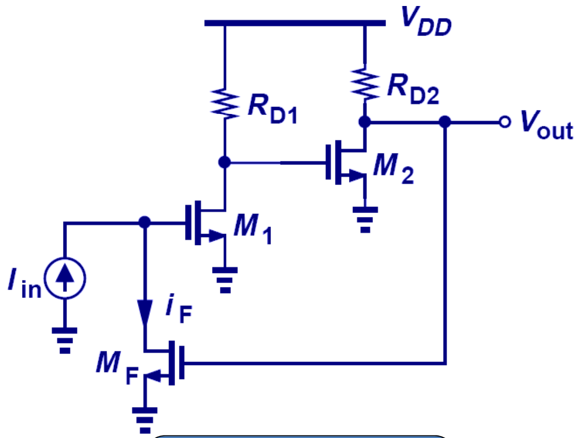
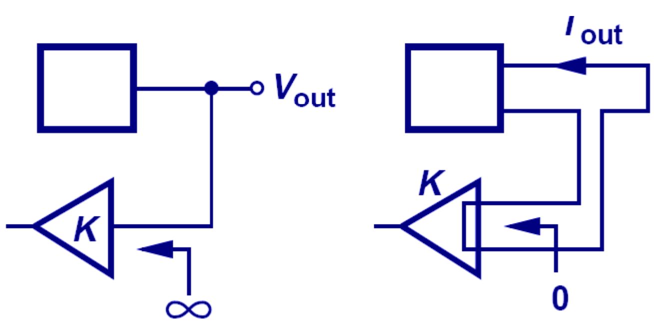
Example: Feedback Factor



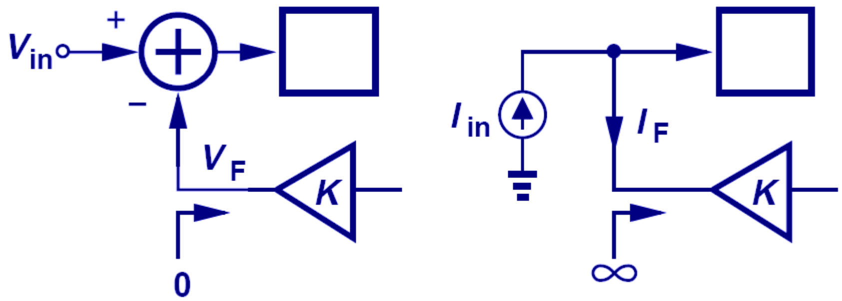
$$K = \frac{i_F}{v_{out}} = g_{mF}$$

Input Impedance of an Ideal Feedback Network



- To sense a voltage, the input impedance of an ideal feedback network must be infinite.
- To sense a current, the input impedance of an ideal feedback network must be zero.

Output Impedance of an Ideal Feedback Network



- To return a voltage, the output impedance of an ideal feedback network must be zero.
- To return a current, the output impedance of an ideal feedback network must be infinite.

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Determining the Polarity of Feedback

- 1) Assume the input goes either up or down.
- 2) Follow the signal through the loop.
- 3) Determine whether the returned quantity enhances or opposes the original change.

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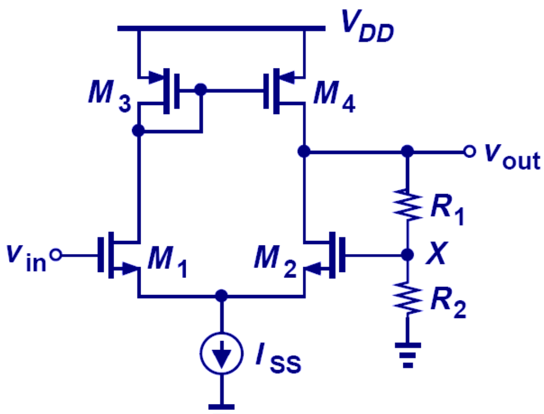
Polarity of Feedback Example I



$V_{in}\uparrow \Rightarrow I_{D1}\uparrow, I_{D2}\downarrow \Rightarrow V_{out}\uparrow, V_x\uparrow \Rightarrow I_{D2}\uparrow, I_{D1}\downarrow$

Negative Feedback

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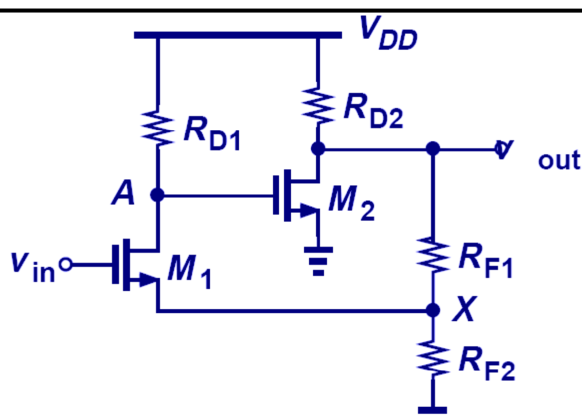
Polarity of Feedback Example II



$V_{in}\uparrow \Rightarrow I_{D1}\uparrow, V_A\downarrow \Rightarrow V_{out}\uparrow, V_x\uparrow \Rightarrow I_{D1}\downarrow, V_A\uparrow$

Negative Feedback

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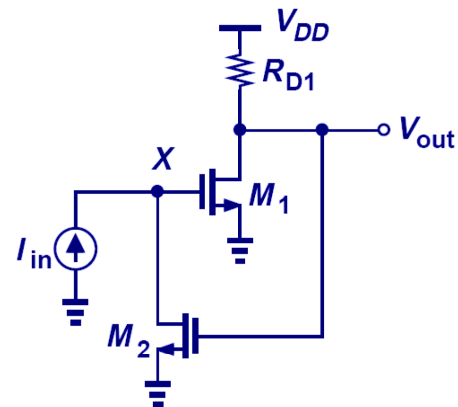
Polarity of Feedback Example III



$$I_{in}\uparrow \Rightarrow I_{D1}\uparrow, V_X\uparrow \Rightarrow V_{out}\downarrow, I_{D2}\downarrow \Rightarrow I_{D1}\uparrow, V_X\uparrow$$

Positive Feedback

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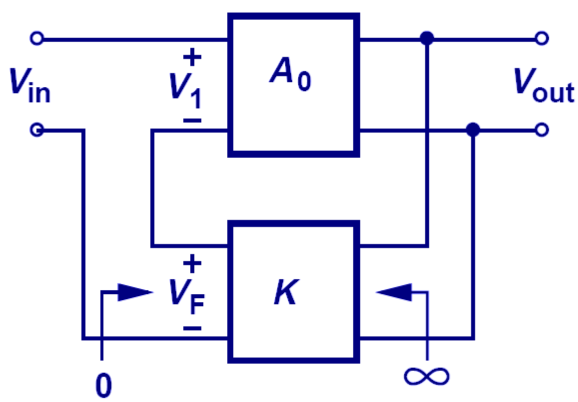
Voltage-Voltage Feedback



$$\frac{V_{out}}{V_{in}} = \frac{A_0}{1+KA_0}$$

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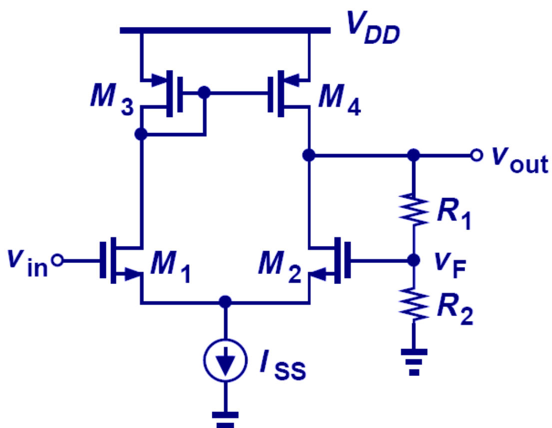
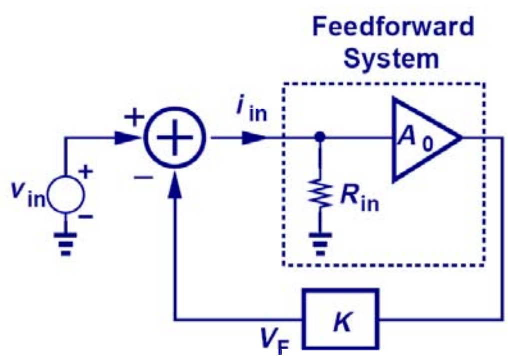
Example: Voltage-Voltage Feedback



$$\frac{V_{out}}{V_{in}} = \frac{g_{mN}(r_{ON} \parallel r_{OP})}{1 + \frac{R_2}{R_1 + R_2} g_{mN}(r_{ON} \parallel r_{OP})}$$

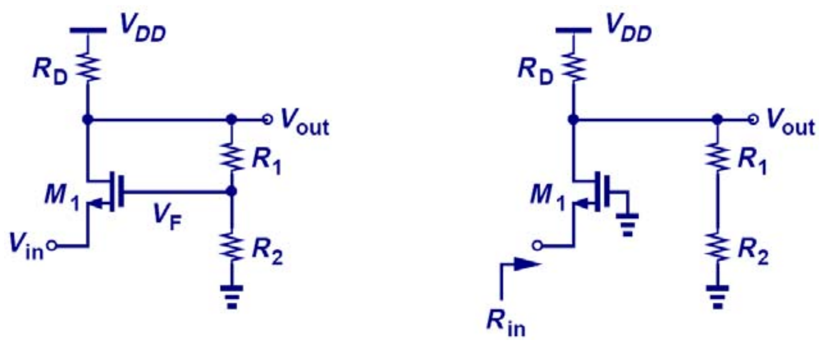
Input Impedance of a V-V Feedback



$$\frac{V_{in}}{I_{in}} = R_{in}(1 + A_0 K)$$

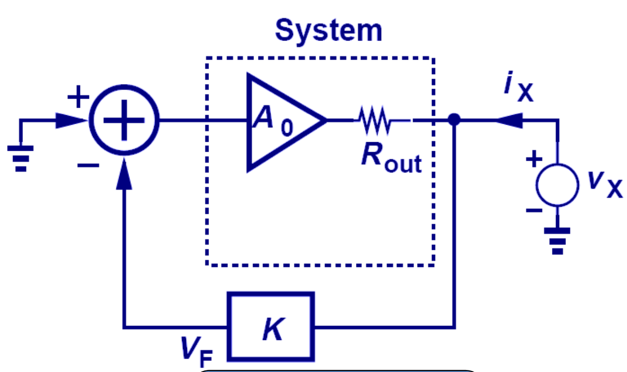
- A better voltage sensor

Example: V-V Feedback Input Impedance



$$\frac{V_{in}}{I_{in}} = \frac{1}{g_m}\left(1 + \frac{R_2}{R_1 + R_2} g_m R_D\right)$$

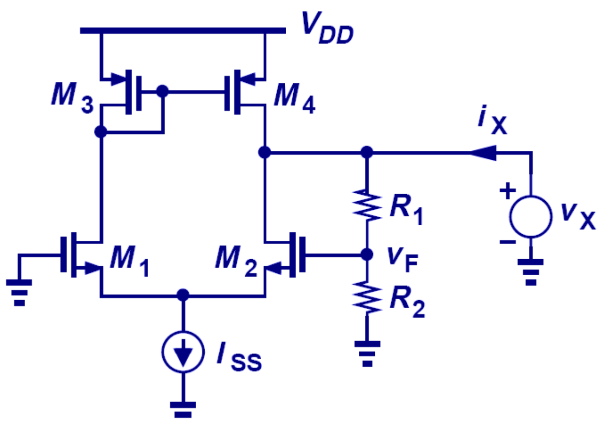
Output Impedance of a V-V Feedback



$$\frac{V_X}{I_X} = \frac{R_{out}}{(1 + KA_0)}$$

- A better voltage source

Example: V-V Feedback Output Impedance



$$R_{out,closed} \approx \left(1+\frac{R_1}{R_2}\right)\frac{1}{g_{mN}}$$

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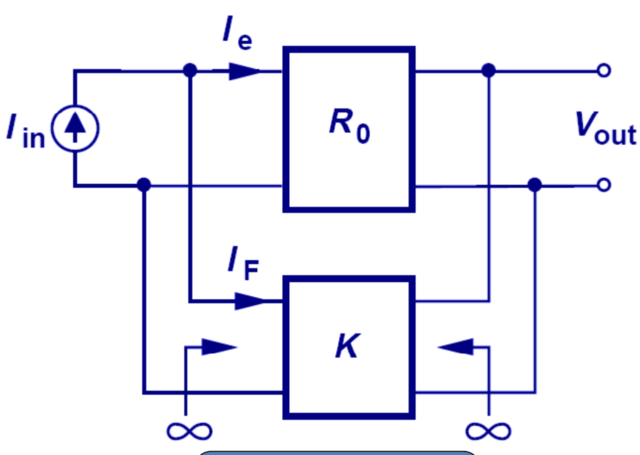
Voltage-Current Feedback



$$\frac{V_{out}}{I_{in}} = \frac{R_O}{1+KR_O}$$

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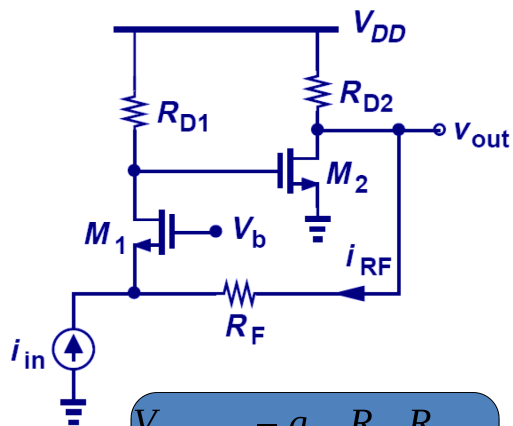
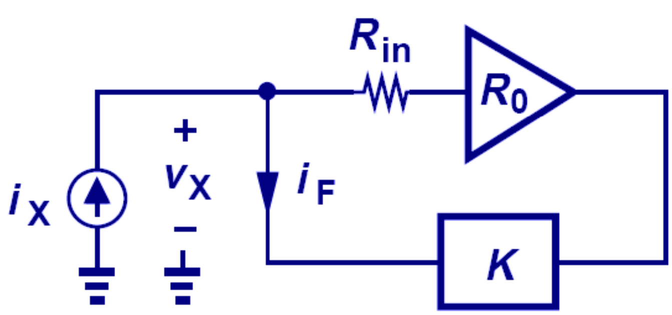
Example: Voltage-Current Feedback



$$\frac{V_{out}}{I_{in}} = \frac{-g_{m2}R_{D1}R_{D2}}{1+\frac{g_{m2}R_{D1}R_{D2}}{R_F}}$$

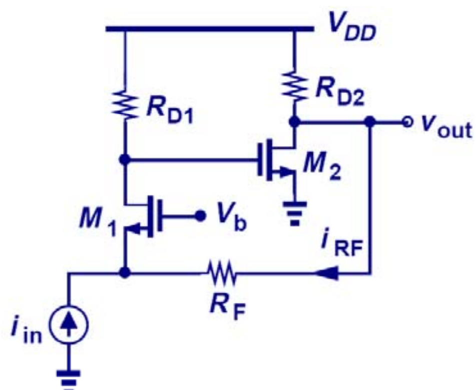
Input Impedance of a V-C Feedback



$$\frac{V_X}{I_X} = \frac{R_{in}}{1+R_0K}$$

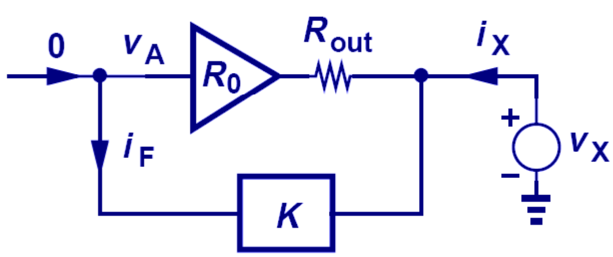
- A better current sensor.

Example: V-C Feedback Input Impedance



$$R_{in,closed} = \frac{1}{g_{m1}} \cdot \frac{1}{1 + \frac{g_{m2} R_{D1} R_{D2}}{R_F}}$$

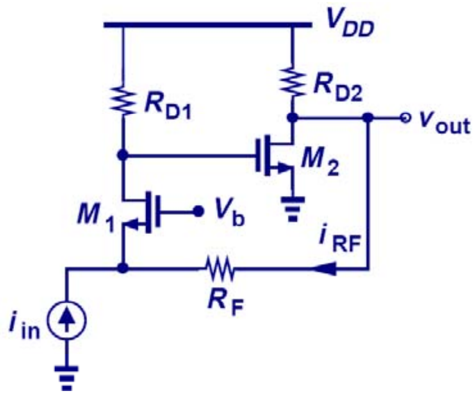
Output Impedance of a V-C Feedback



$$\frac{V_X}{I_X} = \frac{R_{out}}{1 + R_0 K}$$

- A better voltage source.

Example: V-C Feedback Output Impedance



$$R_{out,closed} = \frac{R_{D2}}{1 + \frac{g_{m2} R_{D1} R_{D2}}{R_F}}$$

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What next

- Feedback contd..