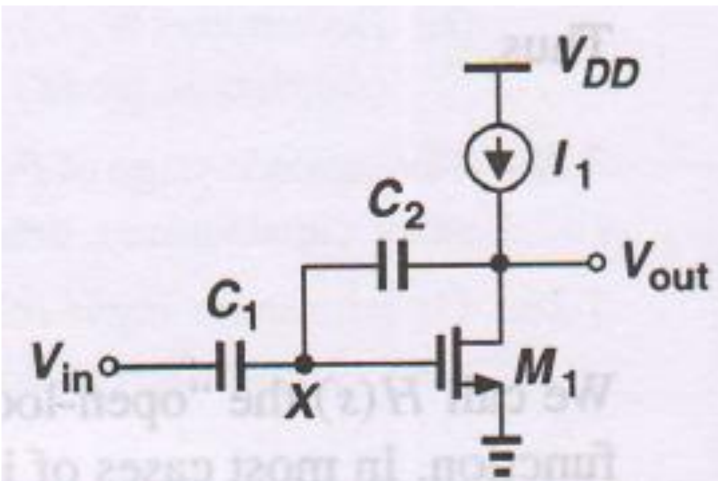
Lecture – 21

Date: 09.11.2015

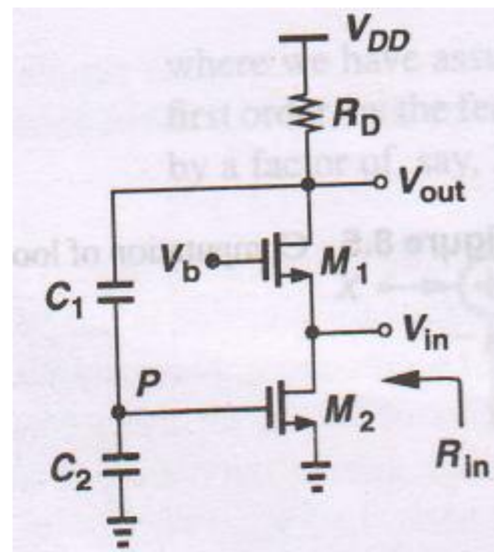
- Review Lecture 20
- Feedback Topologies

Quiz – 8

Q1: Calculate Loop Gain of the following network. [0.75 marks]

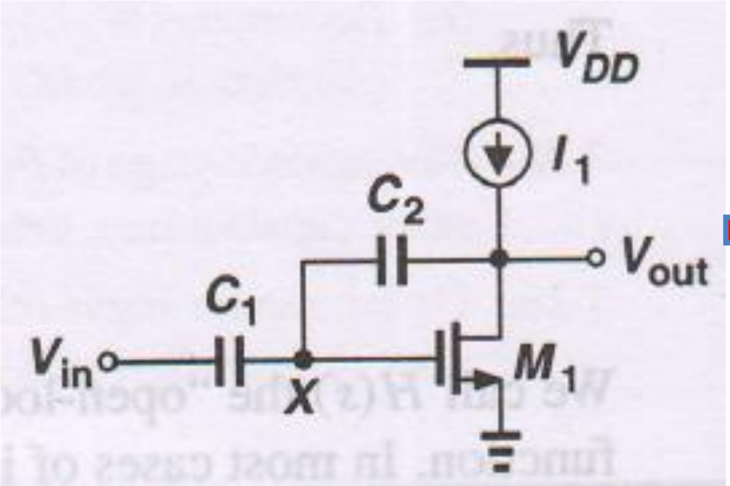


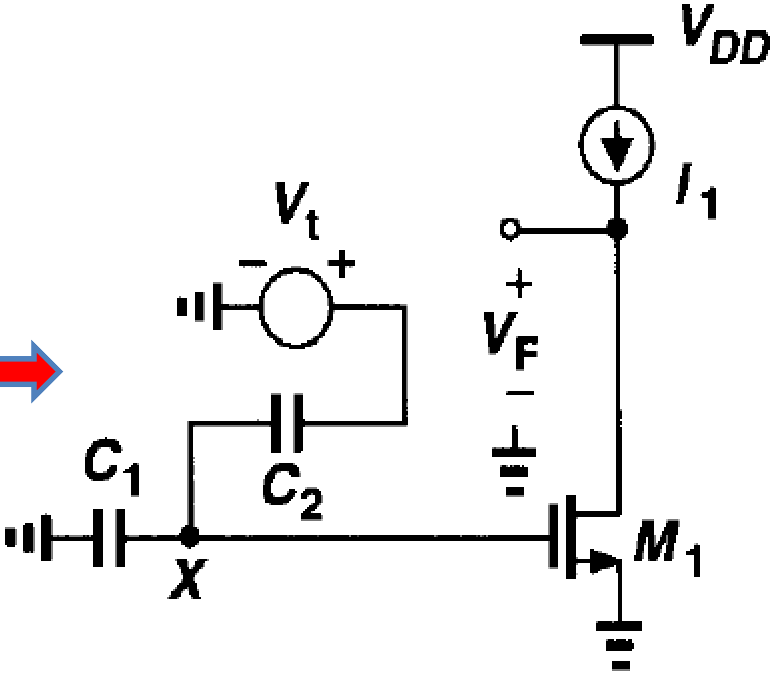
Q2: Determine the closed loop input impedance ($R_{in,closed}$) of the following network. Also identify the four elements of the feedback. [1.75 marks]



Quiz – 8: Soln

Soln-1: Loop gain calculation

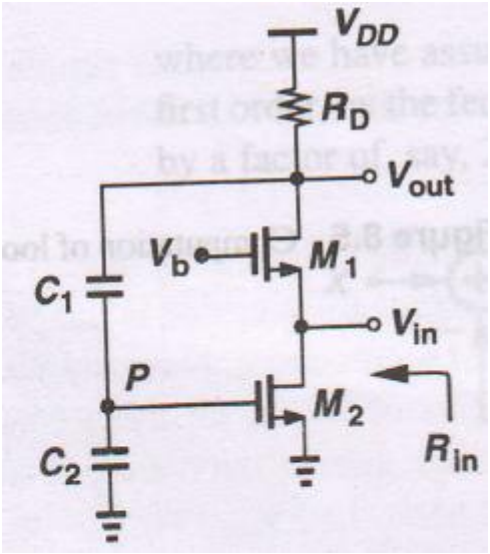




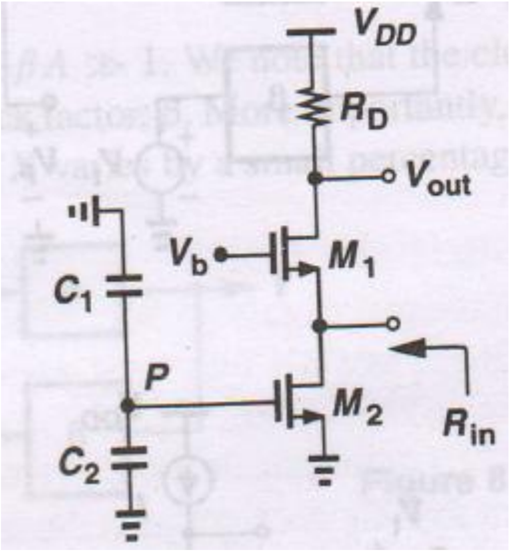
$$\therefore \frac{V_F}{V_t} = -\frac{C_2}{C_1 + C_2} g_{m1} r_{o1}$$

Quiz – 8: Soln

Soln-2:



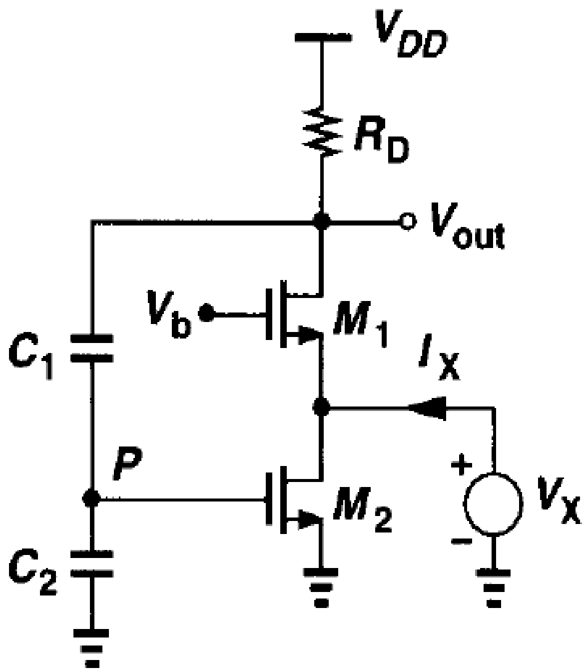
Break the loop at the output node



$$R_{in,open} = \frac{1}{g_{m1} + g_{mb1}}$$

Quiz – 8: Soln

Soln-2 contd:



$$\frac{V_X}{I_X} = R_{in,closed} = \frac{1}{g_{m1} + g_{mb1}} \frac{1}{1 + g_{m2} R_D \dfrac{X_{C1}}{X_{C1} + X_{C2}}}$$

$$R_{in,closed} = R_{in,open} \frac{1}{1 + g_{m2} R_D \dfrac{X_{C1}}{X_{C1} + X_{C2}}}$$

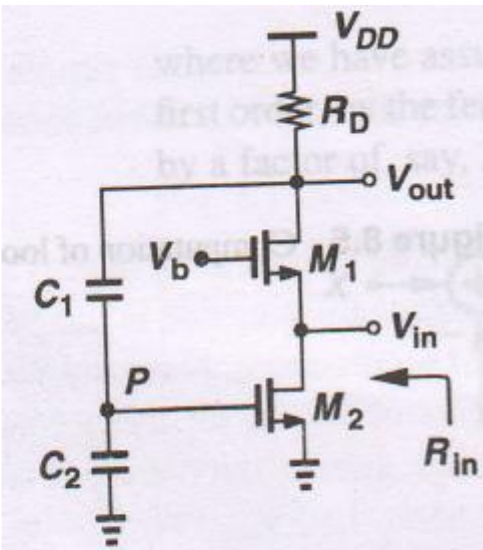
Loop Gain: $g_{m2} R_D \dfrac{X_{C1}}{X_{C1} + X_{C2}}$

Feedback reduces the input impedance in this instance → quite useful circuit topology

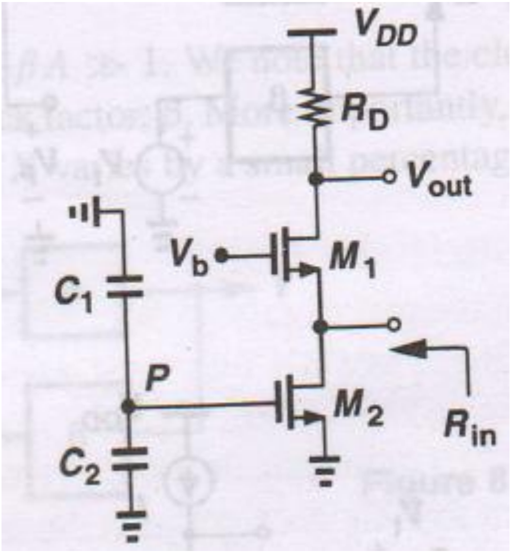
Four Elements of Feedback: feed-forward amplifier consists of M_1 and R_D, the output is sensed by C_1 and C_2, the feedback network comprise of C_1, C_2, and M_2, subtraction occurs in current domain at the input

Review – Lecture 20

Input Impedance Modification



Open-loop input impedance

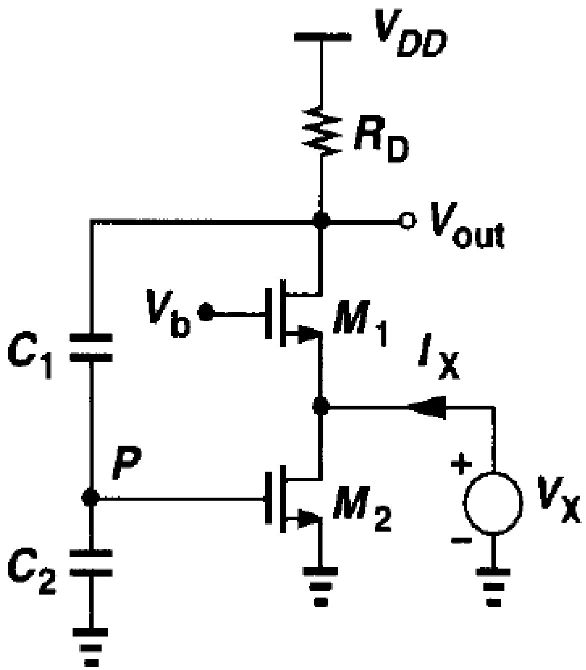


$$R_{in,open} = \frac{1}{g_{m1} + g_{mb1}}$$

CG stage (M_1) → capacitive divider senses V_{out} and applies it to gate of current source (M_2) → M_2 returns a current feedback signal to the input of M_1

Assumption: no channel-length modulation present

Review – Lecture 20



$$\frac{V_X}{I_X} = R_{in,closed} = \frac{1}{g_{m1}+g_{mb1}}\frac{1}{1+g_{m2}R_D\frac{X_{C1}}{X_{C1}+X_{C2}}}$$

$$R_{in,closed} = R_{in,open}\frac{1}{1+g_{m2}R_D\frac{X_{C1}}{X_{C1}+X_{C2}}}$$

Loop Gain: $g_{m2}R_D\frac{X_{C1}}{X_{C1}+X_{C2}}$

Feedback reduces the input impedance in this instance → quite useful circuit topology

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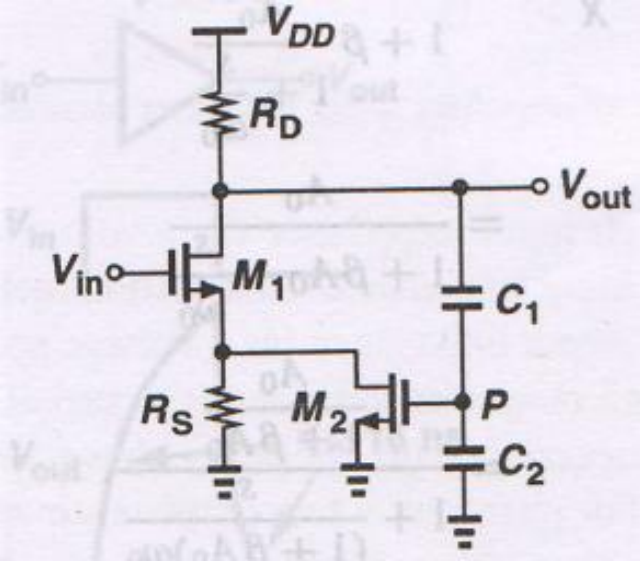
Review – Lecture 20

Output Impedance Modification



$$R_{out,open} = R_D$$

$$R_{out,closed} = \frac{R_D}{1+\frac{g_{m2}R_S\left(g_{m1}+g_{mb1}\right)R_D}{\left(g_{m1}+g_{mb1}\right)R_S}\frac{X_{C1}}{X_{C1}+X_{C2}}}$$

Loop Gain

Can you identify if this is a positive feedback or negative feedback circuit? Why?

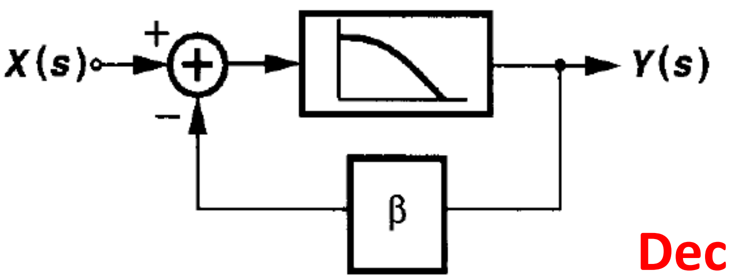
Review – Lecture 20

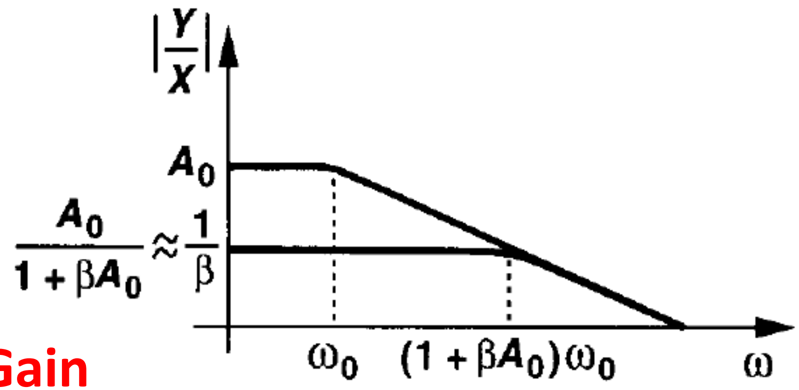
Bandwidth Modification

One pole transfer function:

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

One pole transfer function of a closed-loop system:





Decreased Gain

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

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

Constant GBW

High pole frequency

↔ Increased Bandwidth

Review – Lecture 20

Types of Amplifiers

Type: Based on the type of parameters (current or voltage) they sense at the input and the type of parameters (current or voltage) they produce at the output

- Amplifier sensing voltage at the input: exhibit high input impedance (as a voltmeter)
- Amplifier sensing current at the input: exhibit low input impedance (as an ammeter)
- Amplifier sensing voltage at the output: exhibit low output impedance (as a voltage source)
- Amplifier sensing current at the output: exhibit high output impedance (as a current source)

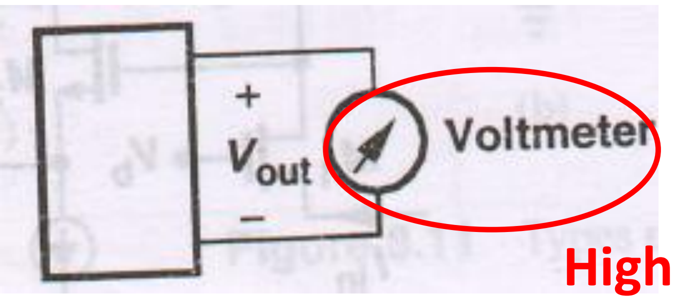
Review – Lecture 20

Sense and Return Mechanism

- Placing a circuit in the feedback requires sensing the output signal and then returning a fraction to the input
- Voltage and Current as input and output quantities provide 4 different possibilities for feedback circuit (sense and return circuit)
- Voltage-Voltage: both the input and output of the feedback circuit is voltage
- Voltage-Current: input of feedback is voltage and output is current
- Current-Voltage: input of feedback is current and output is voltage
- Current-Current: both the input and output of feedback circuit is current

Review – Lecture 20

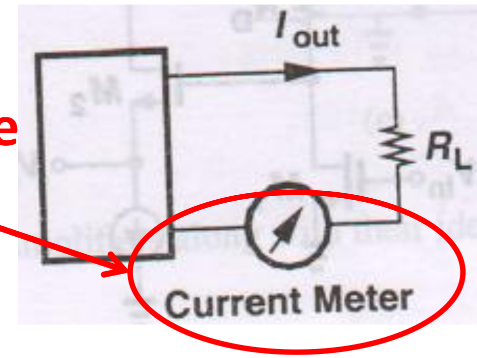
To sense a voltage:



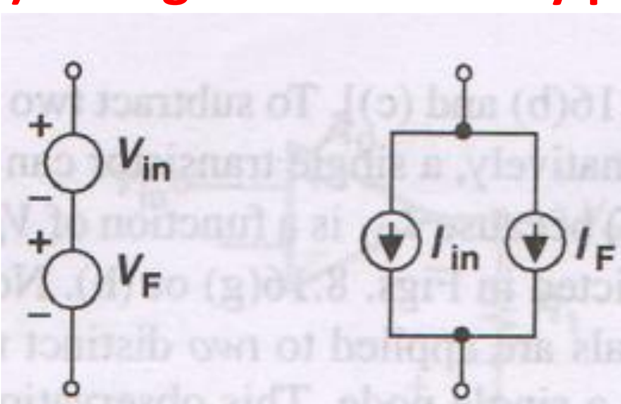
High Impedance

To sense a current:

Low Impedance



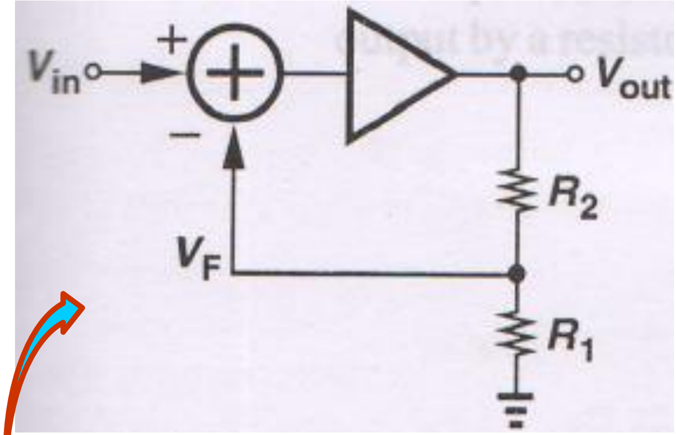
- The addition/subtraction at the input can be done in current or voltage domain: (a) currents are added by placing them in parallel; (b) voltages are added by placing them in series



The sense and return mechanism ideally do not affect the operation of feed-forward amplifier → in practical circuits they do introduce loading effects

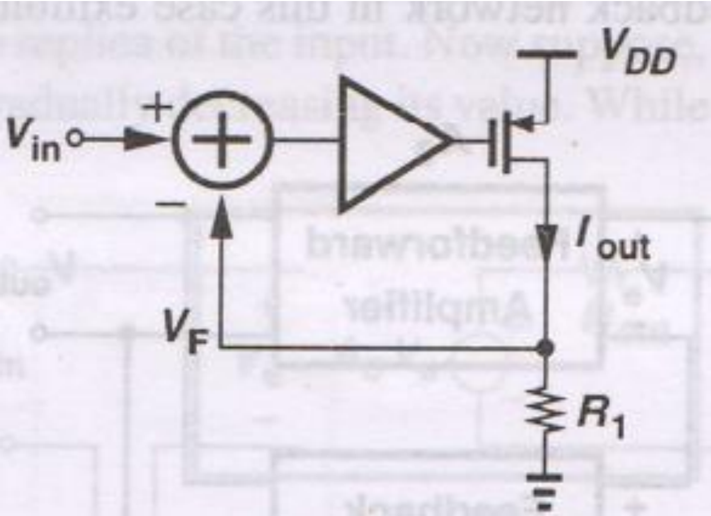
Review – Lecture 20

Practical Implementations of Sensing:

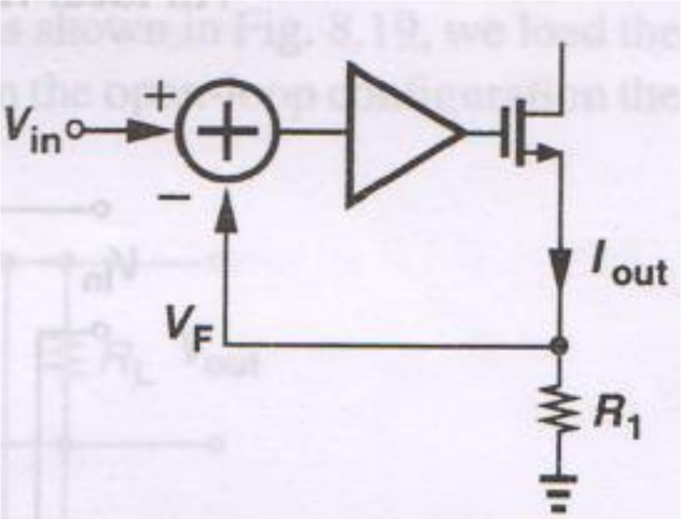


Voltage Sensing

A voltage can be sensed by a resistive (or capacitive) divider in parallel with the port



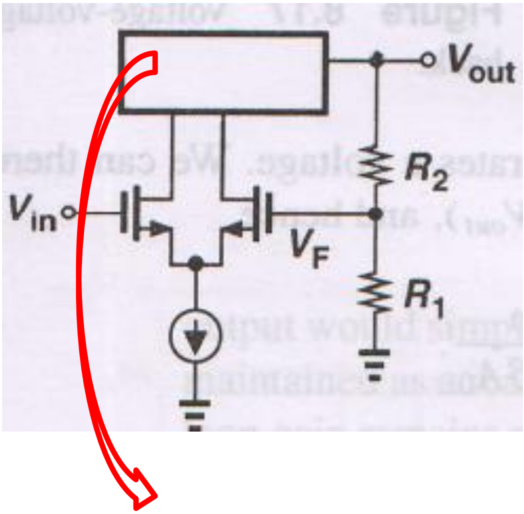
Current Sensing



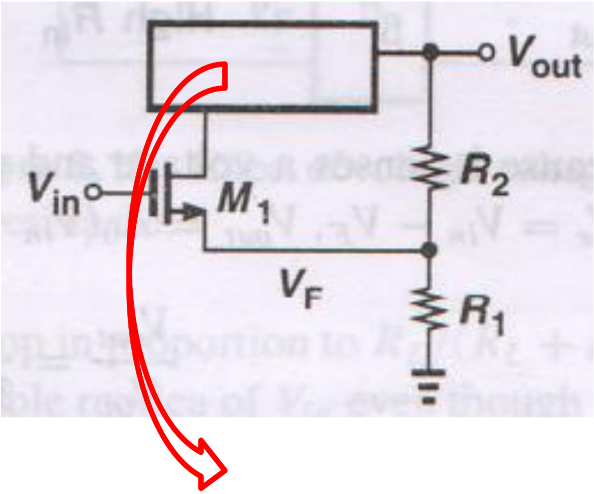
Current Sensing

Review – Lecture 20

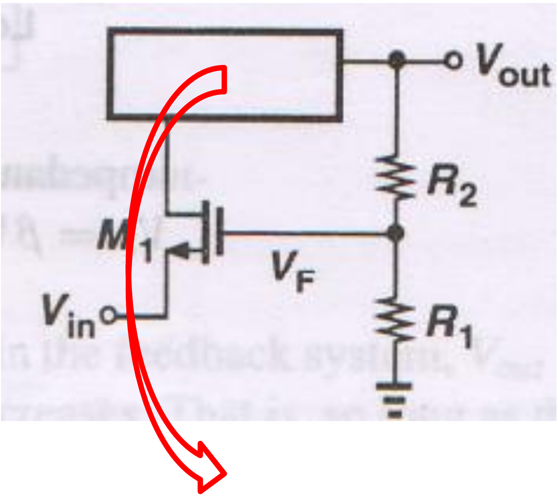
Practical Implementations of Voltage Subtraction:



Provides the amplified version of difference between V_{in} and the portion of V_{out}



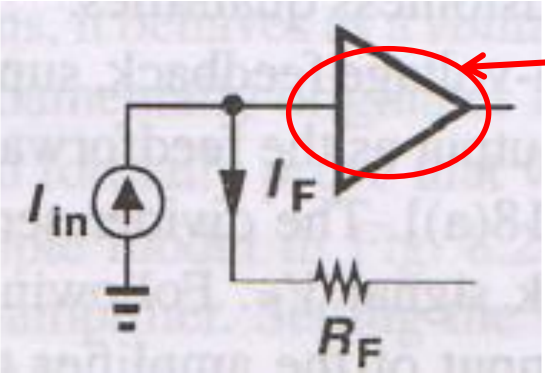
This CS stage provides output in terms of voltage difference V_{in} - V_F



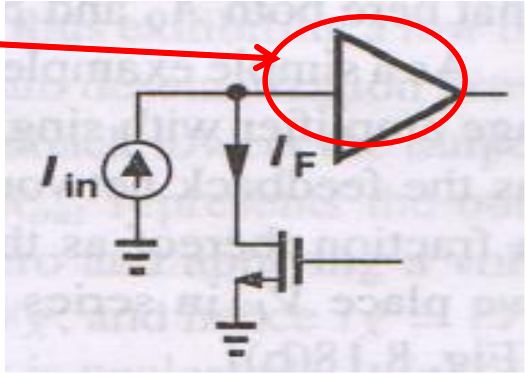
This CG stage provides output in terms of voltage difference V_{in} - V_F

Review – Lecture 20

Practical Implementations of Current Subtraction:



Feed-forward Amplifier



Important: voltage subtraction happens when they are applied to two distinct nodes whereas current subtraction happens when they are applied to a single node → a precursor to feedback topologies

Feedback Topologies

- **Voltage-Voltage Feedback (also called Shunt-Series Feedback):** both the input and output of the feedback circuit is voltage
- **Voltage-Current Feedback (also called Shunt-Shunt Feedback):** input of feedback is voltage and output is current
- **Current-Voltage (also called Series-Series Feedback):** input of feedback is current and output is voltage
- **Current-Current (also called Series-Shunt Feedback):** both the input and output of feedback circuit is current

Feedback Topologies (contd.)

Voltage – Voltage Feedback

Sensed Quantity is Voltage

Returned Quantity is Voltage

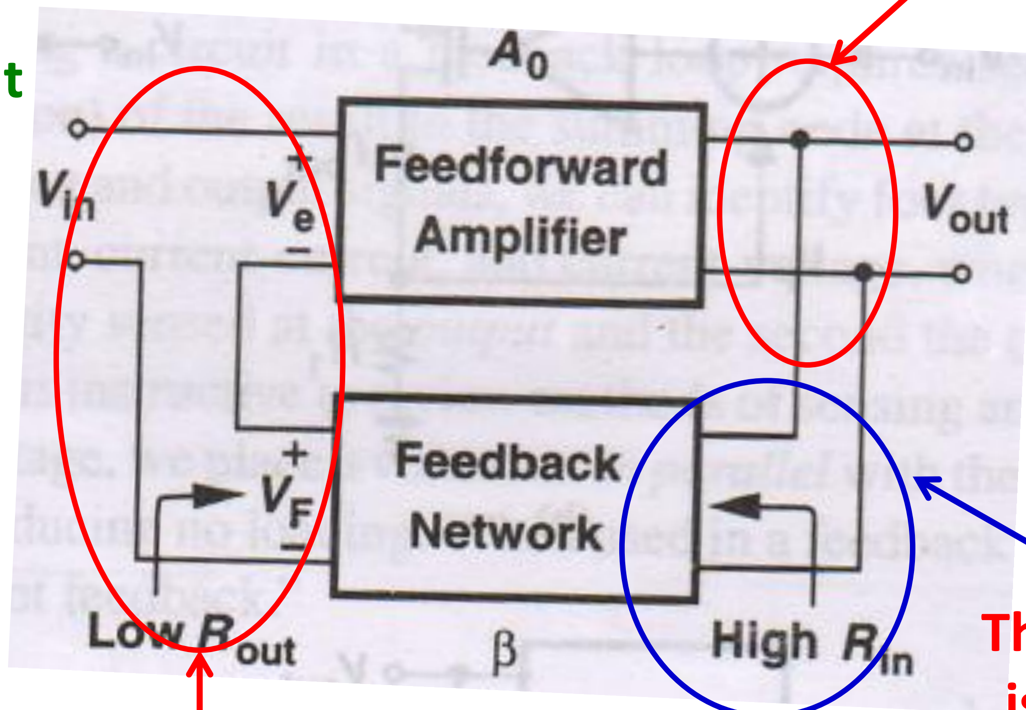
Voltmeter Type Characteristics

Should be added/subtracted in series

Voltage-Voltage Feedback

Voltmeter Type Connection → Parallel Sensing

Increased Input Impedance

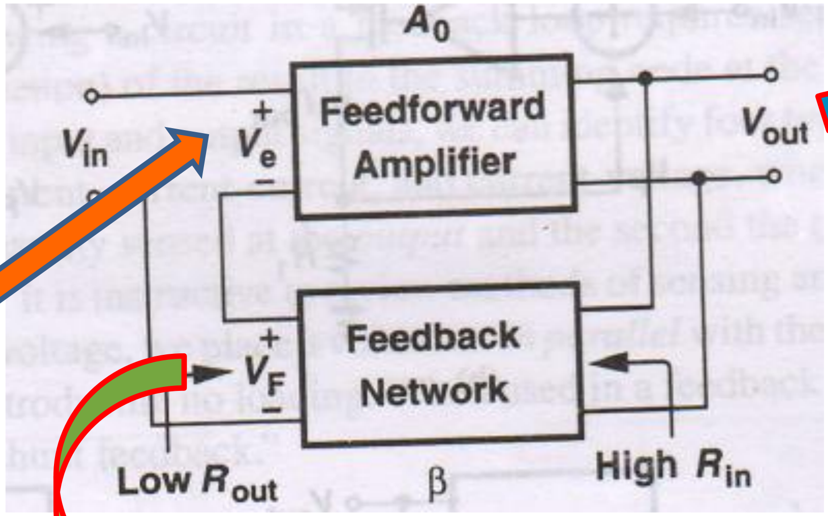


Reduced Output Impedance

This high impedance is in parallel to the feedforward amplifier

Subtracted in series

Voltage-Voltage Feedback (contd.)



$$V_e = V_{in} - V_F$$

$$V_F = \beta V_{out}$$

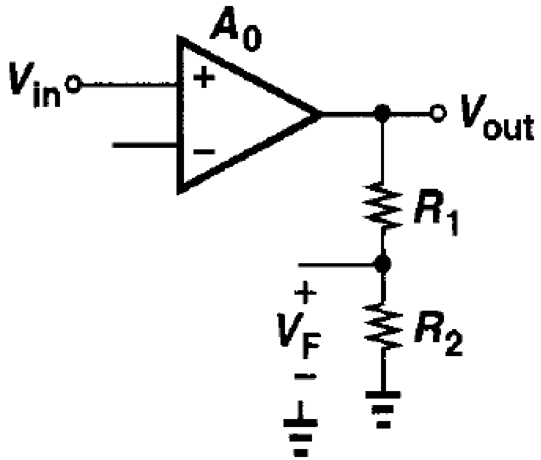
$$V_{out} = A_0 V_e = A_0 \left(V_{in} - \beta V_{out} \right)$$

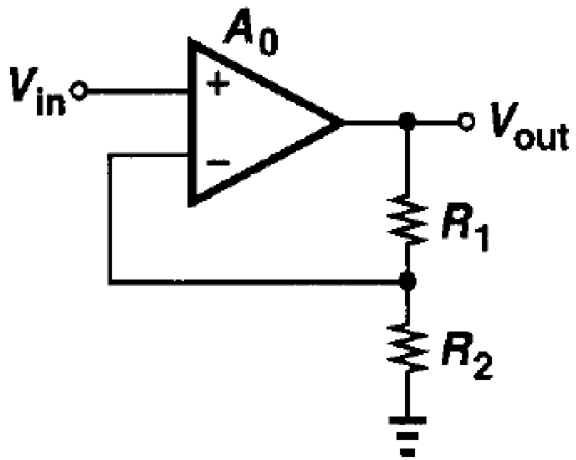
$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{A_0}{1+\beta A_0}$$

Closed loop gain → modified gain → smaller !!!

Voltage-Voltage Feedback (contd.)

Example: Voltage-Voltage Feedback





For voltage sensing – parallel to the output node of this differential input but single ended output amplifier

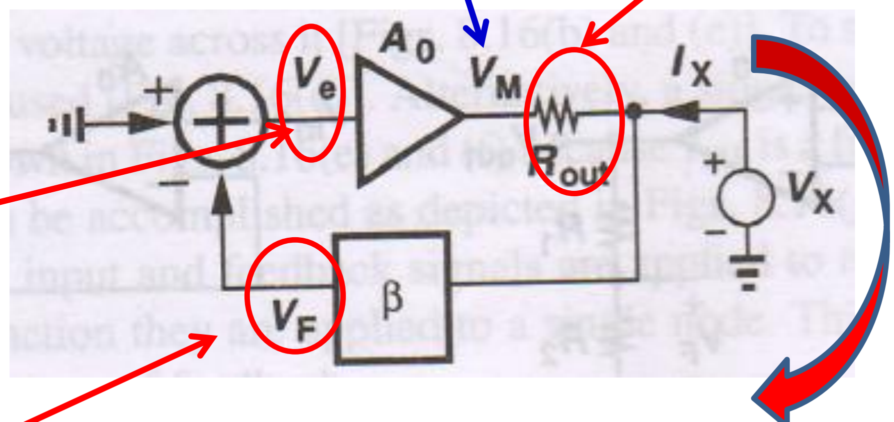
The voltage signal from feedback network is fed to the other input node of the differential amplifier

Voltage-Voltage Feedback (contd.)

Output Impedance

$$V_M = A_0 V_e = -A_0 \beta V_X$$

Open-Loop Output Impedance



$$V_e = -V_F = -\beta V_X$$

$$V_F = \beta V_X$$

$$I_X = \frac{\left[V_X - (-A_0 \beta V_X)\right]}{R_{out}}$$

$$\Rightarrow R_{out,closed} = \frac{V_X}{I_X} = \frac{R_{out}}{1 + A_0 \beta}$$

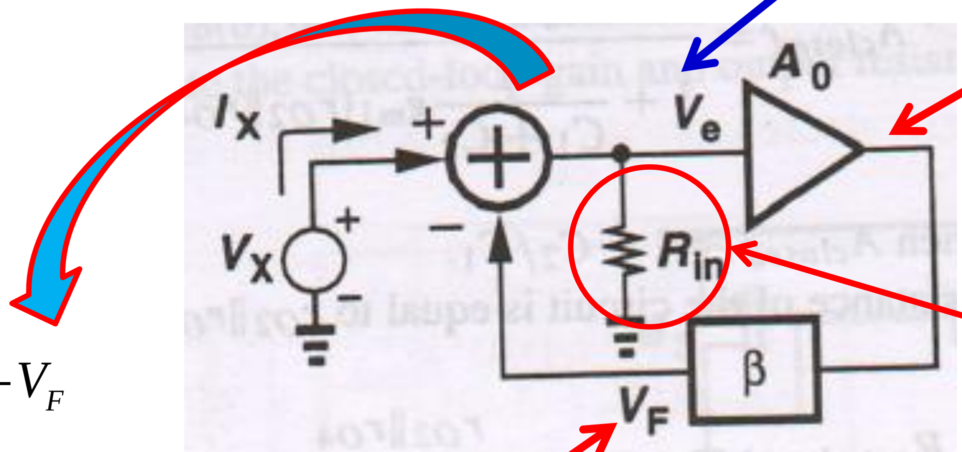
Reduced Closed-Loop Output Impedance

Voltage-Voltage Feedback (contd.)

Input Impedance

$V_e = I_X R_{in}$

$A_0 I_X R_{in}$



$V_e = V_X - V_F$

Open-Loop Input Impedance

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

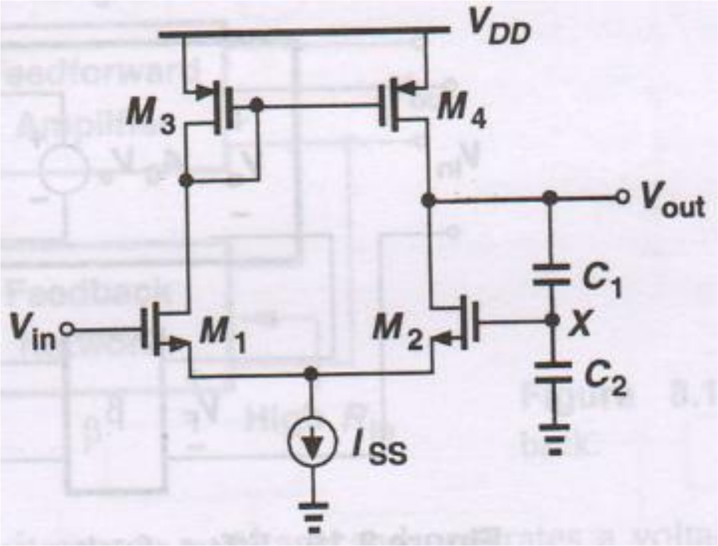
$$\Rightarrow V_e = V_X - V_F = V_X - \beta A_0 I_X R_{in} = I_X R_{in}$$

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

Increased Input Impedance

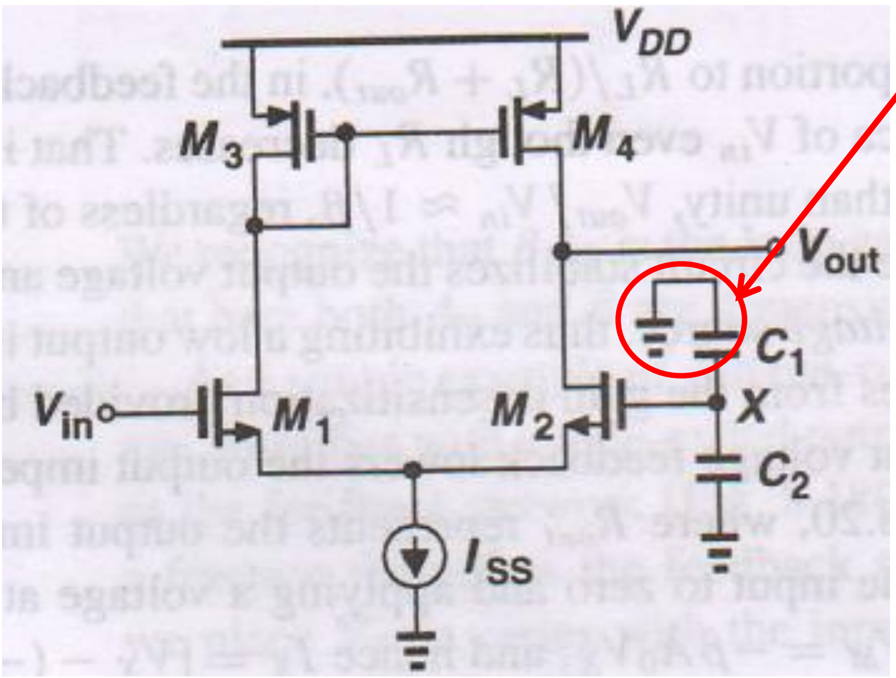
Voltage-Voltage Feedback (contd.)

Example: calculate gain and output impedance of the following circuit



Voltage-Voltage Feedback (contd.)

Step-1: determine open-loop voltage gain



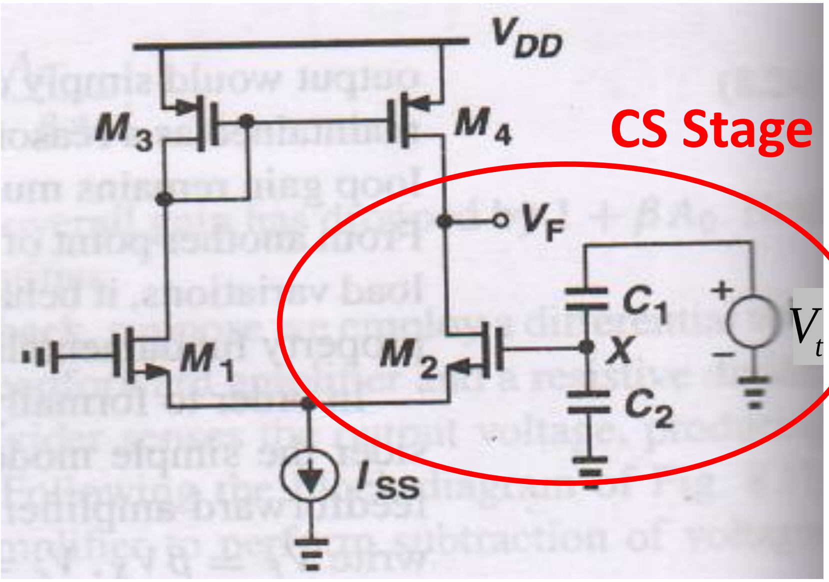
Grounding ensures there is no voltage feedback

Open-loop gain is:

$$A_0 = g_{m1}\left(r_{o2} \,||\, r_{o4}\right)$$

Voltage-Voltage Feedback (contd.)

Step-2: determine the loop gain



$$V_F = -V_t \frac{C_1}{C_1 + C_2} g_{m1} (r_{o2} \| r_{o4})$$

Drain Current

Output impedance

Therefore,

$$\beta A_0 = \frac{C_1}{C_1 + C_2} g_{m1} (r_{o2} \| r_{o4})$$

$$\Rightarrow A_{closed} = \frac{A_0}{1 + \beta A_0} = \frac{g_{m1}(r_{o2} \| r_{o4})}{1 + \frac{C_1}{C_1 + C_2} g_{m1}(r_{o2} \| r_{o4})}$$

Voltage-Voltage Feedback (contd.)

- **For βA_0>>1,**

$$A_{closed} \simeq \frac{g_{m1}\left(r_{o2} \parallel r_{o4}\right)}{\frac{C_1}{C_1+C_2} g_{m1}\left(r_{o2} \parallel r_{o4}\right)} = 1 + \frac{C_2}{C_1}$$

- **The closed-loop output impedance,**

$$R_{out,closed} = \frac{R_{out,open}}{1+\beta A_0} = \frac{\left(r_{o2} \parallel r_{o4}\right)}{1 + \frac{C_1}{C_1+C_2} g_{m1}\left(r_{o2} \parallel r_{o4}\right)}$$

- **For βA_0>>1,**

$$R_{out,closed} \simeq \left(1 + \frac{C_2}{C_1}\right)\frac{1}{g_{m1}}$$

Relatively Smaller Value