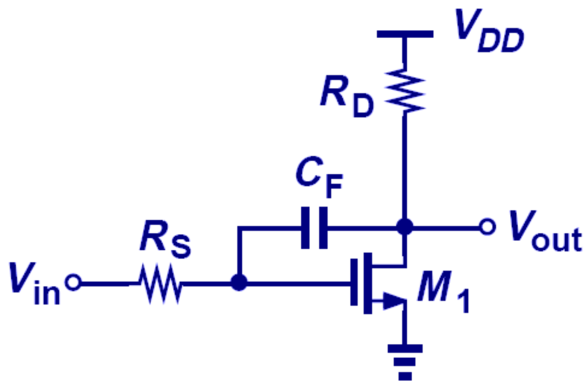
Lecture-20 Date: 05.11.2015

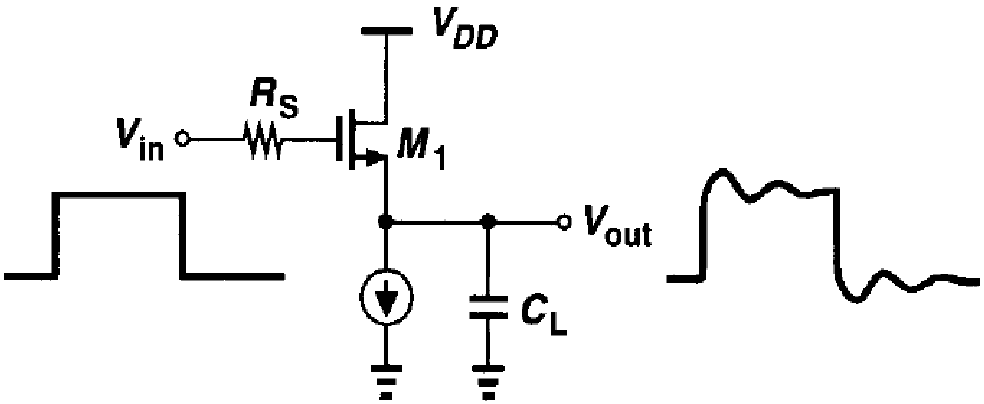
- Quiz-7
- Feedback

Quiz – 7

1. **What is transit frequency of a MOSFET? What is its significance? [0.50 marks]**
2. **At high frequencies, the frequency response of this amplifier doesn't decay with the usual rule of -20bB/decade? Give justifications. [1.0 marks]**



3. **What leads to the ringing problem in this amplifier? What could be the solutions to overcome this? [1.0 marks]**



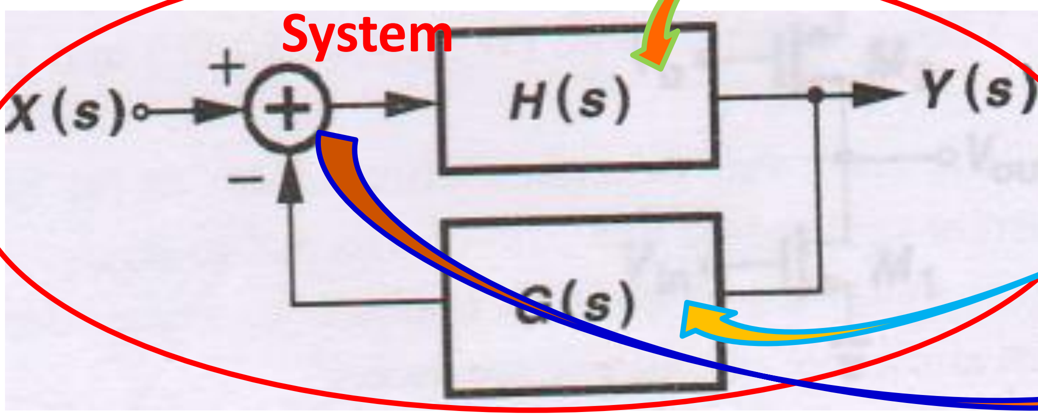
Feedback

General Considerations:

Feedforward Network

Feedback Network

Negative Feedback System



Subtraction at this node makes this system negative feedback

$$Y(s) = H(s)\left[X(s) - G(s)Y(s)\right]$$

Generic Equation

Open Loop Transfer Function

Error Signal or Compensation Signal

Feedback (contd.)

$$Y(s) = H(s)\left[X(s) - G(s)Y(s)\right] \Rightarrow \frac{Y(s)}{X(s)} = \frac{H(s)}{1+G(s)H(s)}$$

Closed Loop Transfer Function: $\frac{Y(s)}{X(s)}$

Open-Loop Transfer Function: $H(s)$

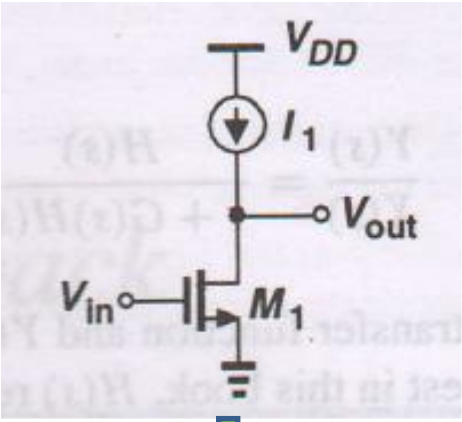
In our discussion: H(s) represents an amplifier and G(s) is a frequency-independent quantity representing the feedback network

Elements of Feedback System:

- The feed forward amplifier [H(s)]
- A means of sensing the output
- The feedback network [G(s)]
- A means of generating the feedback error [X(s) – G(s)Y(s)]

Properties of Feedback Circuits

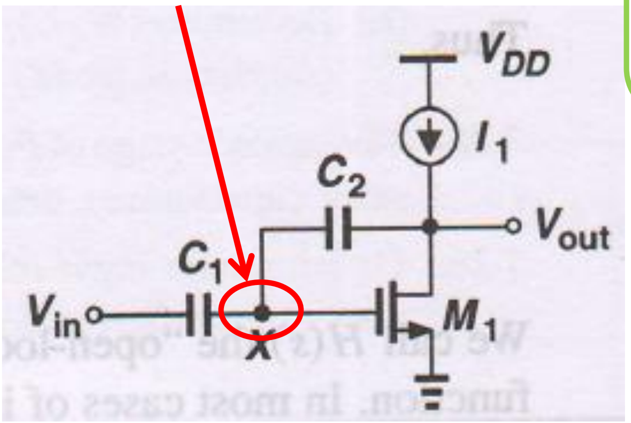
Gain Desensitization



$$\frac{V_{out}}{V_{in}} = -g_{m1} r_{o1}$$

Dependent on process parameters, temperature, bias etc.

Node generating error term



$$\frac{V_{out}}{V_{in}} = -\frac{1}{\left(1+\frac{1}{g_{m1} r_{o1}}\right)\frac{C_2}{C_1} + \frac{1}{g_{m1} r_{o1}}}$$

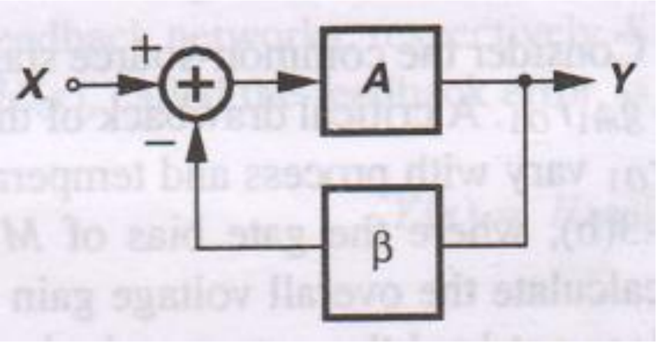
For large $g_{m1} r_{o1}$

$$\frac{V_{out}}{V_{in}} \cong -\frac{C_1}{C_2}$$

The closed-loop gain is much less sensitive to device parameters

Feedback makes gain of this CS stage independent of process and temperature

Properties of Feedback Circuits (contd.)



$$\frac{Y}{X} = \frac{A}{1+A\beta} = \frac{1}{\beta}\frac{1}{\left(1+\frac{1}{A\beta}\right)}$$

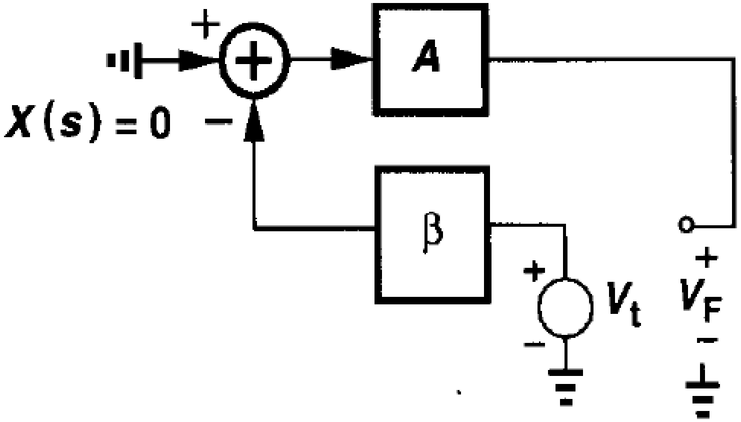
$$\frac{Y}{X} \cong \frac{1}{\beta}\left(1-\frac{1}{A\beta}\right)$$

The impact of variations in A on the closed loop gain is insignificant

- The quantity βA (loop gain) is critical for any feedback system → higher the βA, less sensitive is the closed loop gain to the variations of A
- Accuracy of the closed loop gain improves by maximizing either A or β
- β increases → closed loop gain decreases → means a trade-off exist between precision and the closed loop gain

Properties of Feedback Circuits (contd.)

Loop Gain Calculation

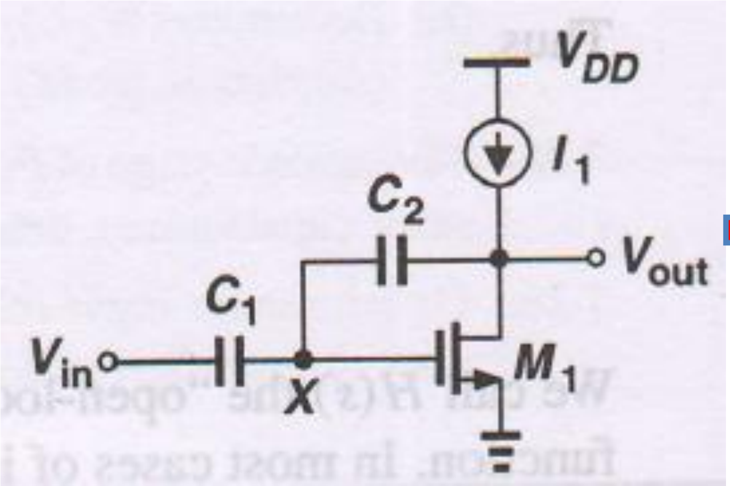


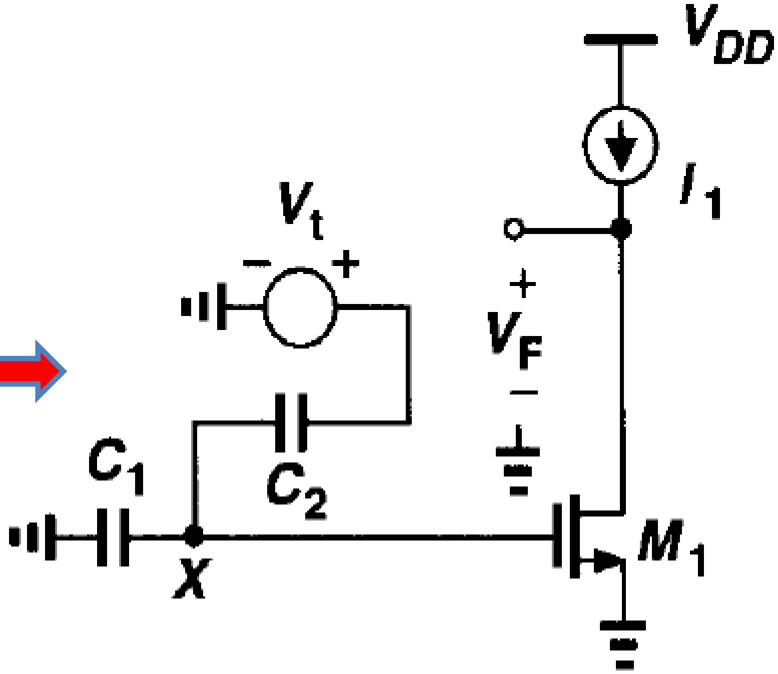
- Set the main input to zero
- Break the loop at some point
- Inject a test signal 'while maintaining the direction and polarity'
- Follow the signal around the loop and obtain the expression/value

$$V_t \beta (-1) A = V_F \quad \Rightarrow \quad \therefore \frac{V_F}{V_t} = -\beta A$$

Example – 1

Calculate Loop Gain:

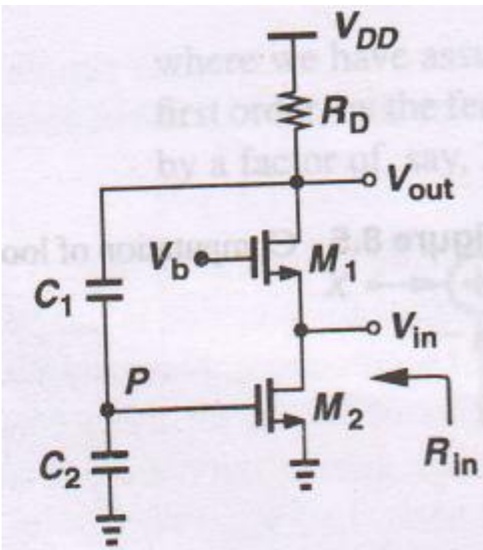




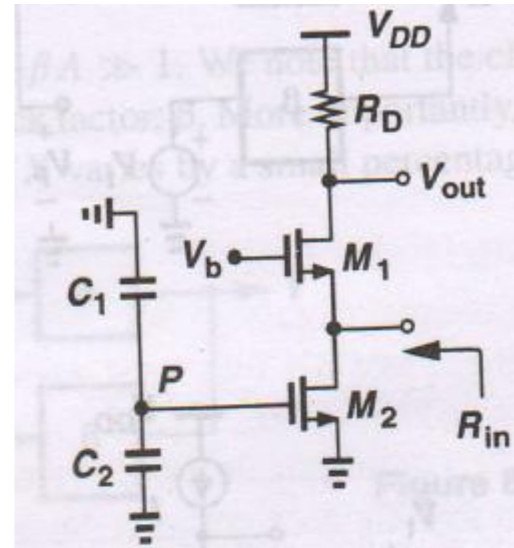
$$\therefore \frac{V_F}{V_t} = -\frac{C_2}{C_1 + C_2} g_{m1} r_{o1}$$

Properties of Feedback Circuits (contd.)

Input Impedance Modification



Lets check input impedance with and without feedback

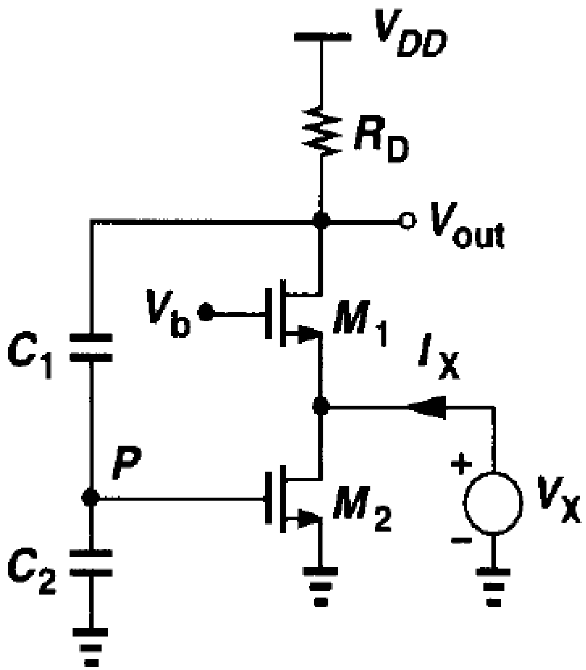


CG stage (M_1) → capacitive divider senses V_{out} and applies it to gate of current source (M_2) → M_2 returns a current feedback signal to the input of M_1

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

Assumption: no channel-length modulation present

Properties of Feedback Circuits (contd.)



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

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

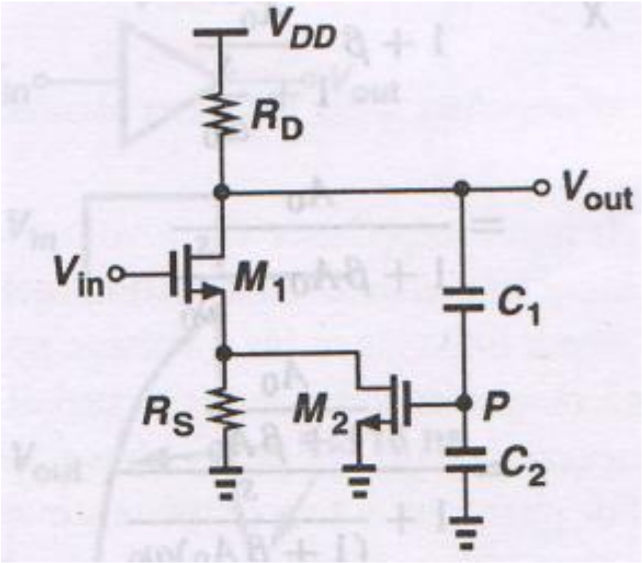
Loop Gain

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

Properties of Feedback Circuits (contd.)

Output Impedance Modification



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

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

Loop Gain

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

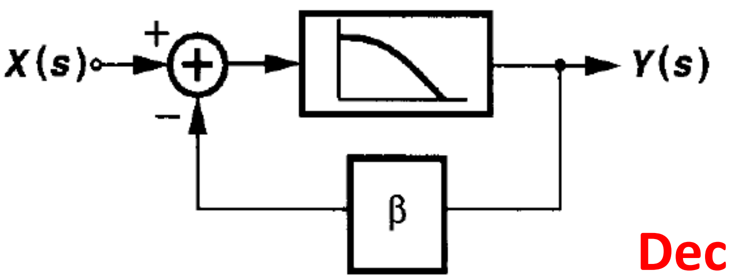
Properties of Feedback Circuits (contd.)

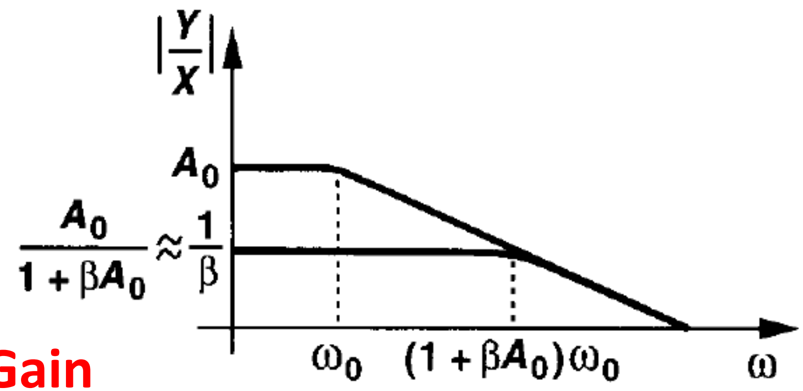
Bandwidth Modification

One pole transfer function:

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

One pole transfer function of a closed-loop system:





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

Decreased Gain

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

Constant GBW

High pole frequency

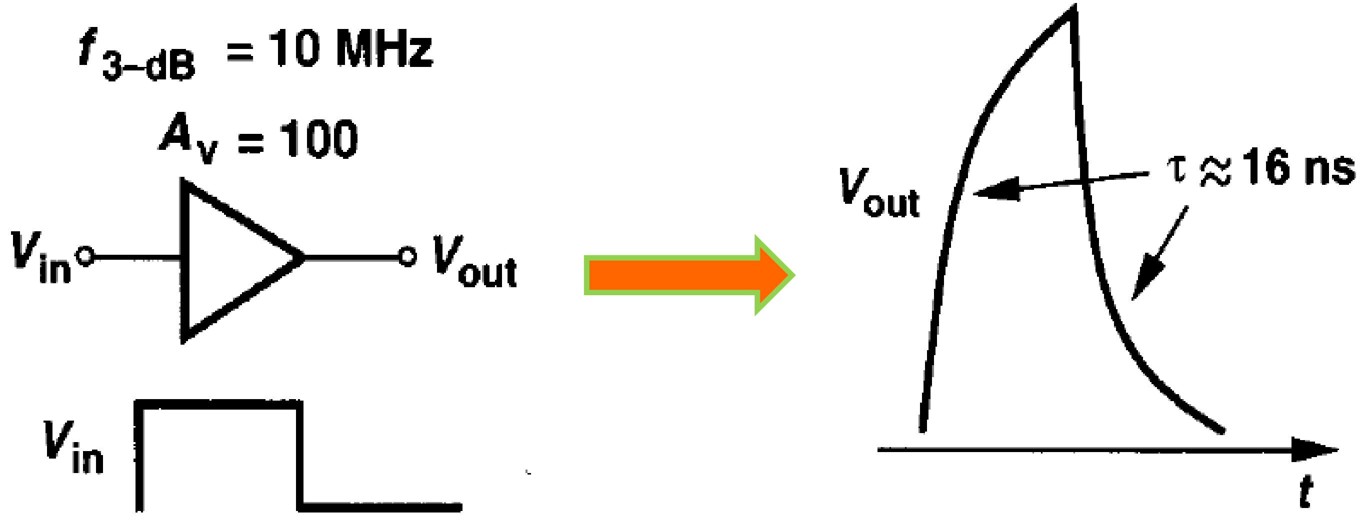
↔ Increased Bandwidth

Properties of Feedback Circuits (contd.)

Bandwidth Modification

GBW of a single pole system doesn't change with feedback. But how to improve the speed of the system with high gain?

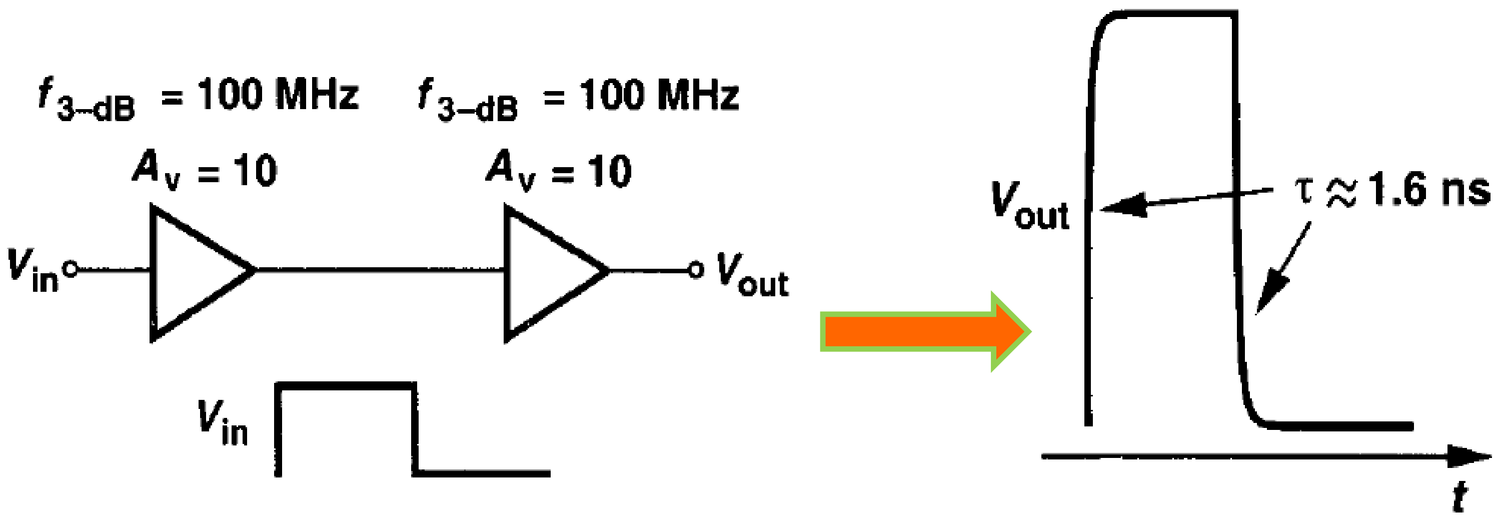
Suppose we need to amplify a 20 MHz square wave by a factor of 100 and maximum bandwidth but we only have single pole amplifier with an open-loop gain of 100 and 3-dB bandwidth of 10 MHz.



Properties of Feedback Circuits (contd.)

Bandwidth Modification

Apply feedback in such a way that the gain and bandwidth are modified to 10 and 100 MHz. Then use two stage amplification to achieve the desired.



Types of Amplifiers

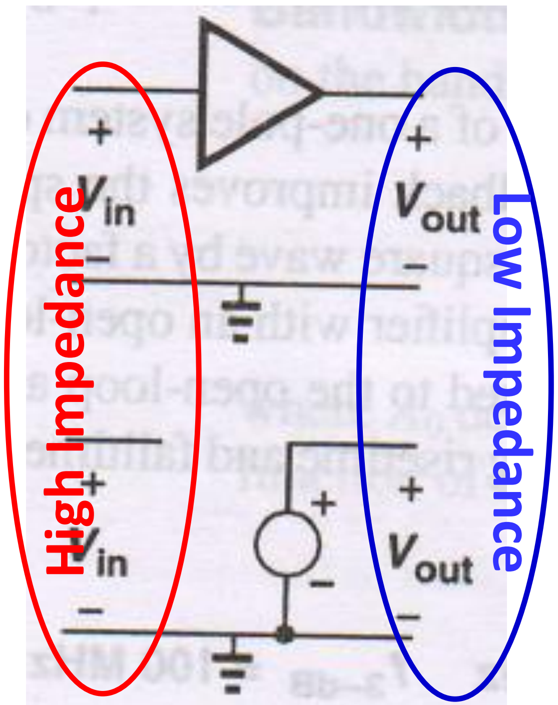
Type: Based on the type of parameters (current or voltage) they sense at the input and the type of parameters (current or voltage) they produce at the output

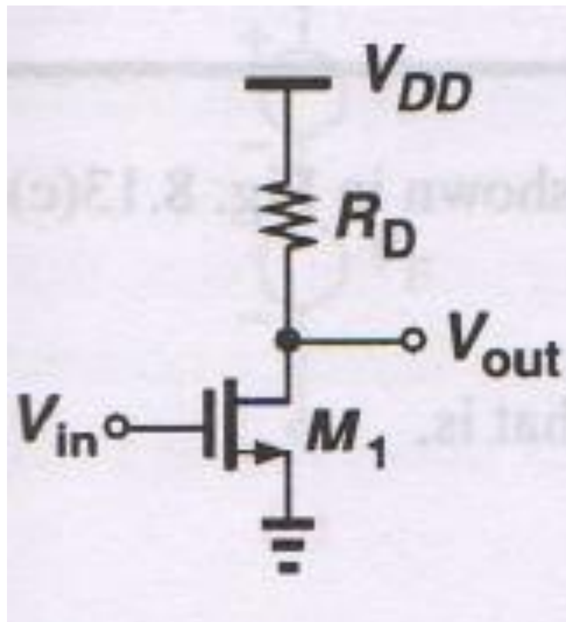
- **Amplifier sensing voltage at the input: exhibit high input impedance (as a voltmeter)**
- **Amplifier sensing current at the input: exhibit low input impedance (as an ammeter)**
- **Amplifier sensing voltage at the output: exhibit low output impedance (as a voltage source)**
- **Amplifier sensing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

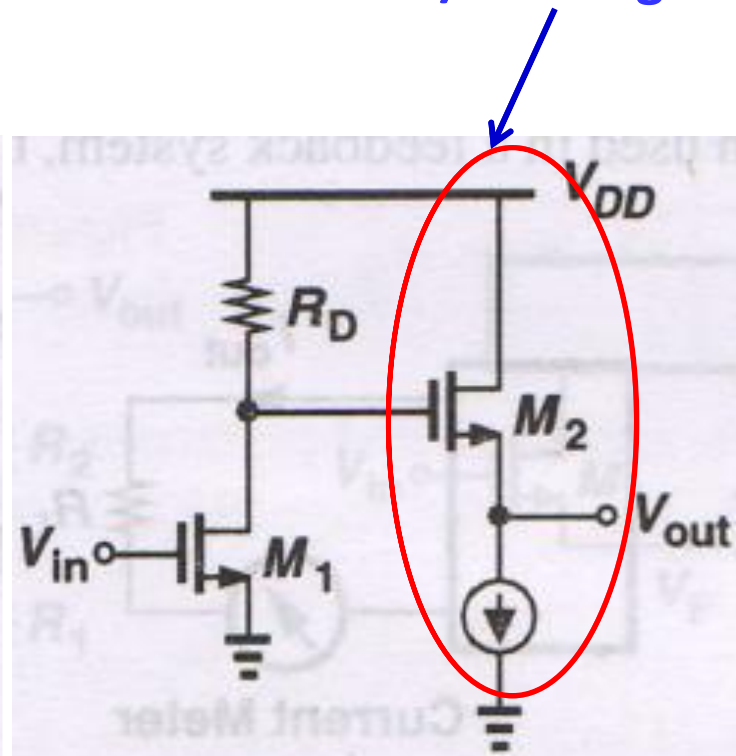
Types of Amplifiers (contd.)

Voltage Amplifier

Buffer / CD Stage







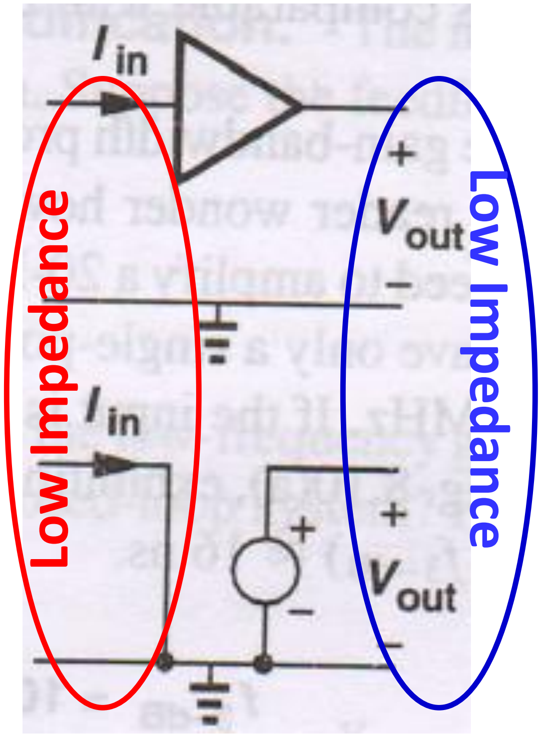
CS Amplifier

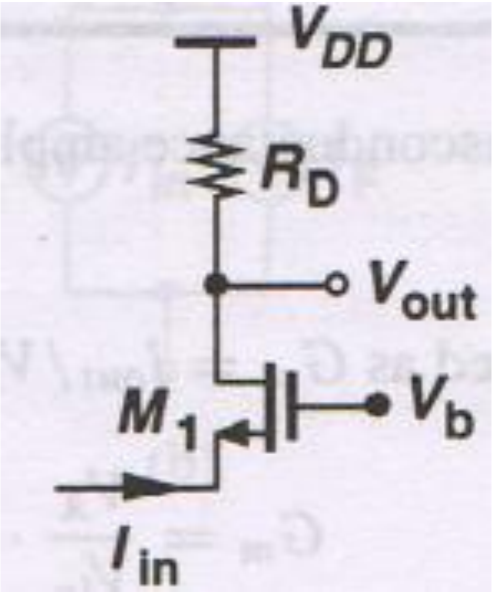
CS Amplifier with a buffer

Possess Relatively
High Output
Impedance

Types of Amplifiers (contd.)

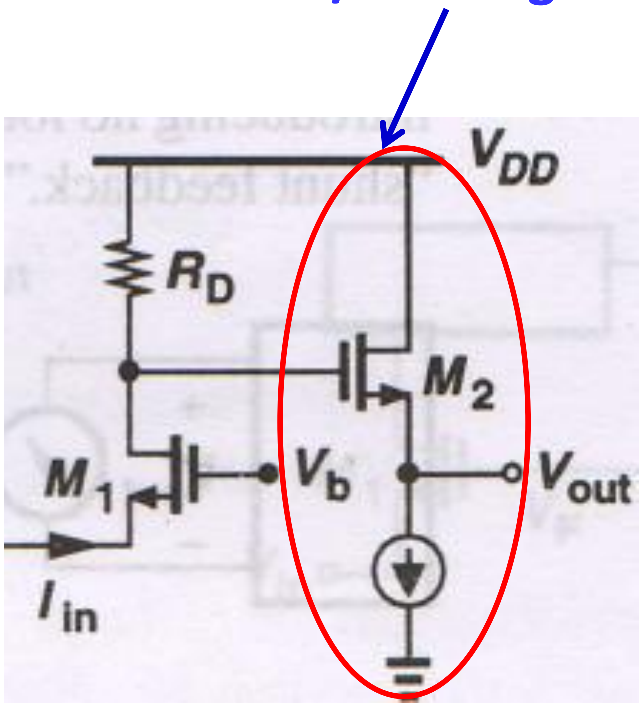
Transimpedance Amplifier





CG Amplifier

Buffer / CD Stage

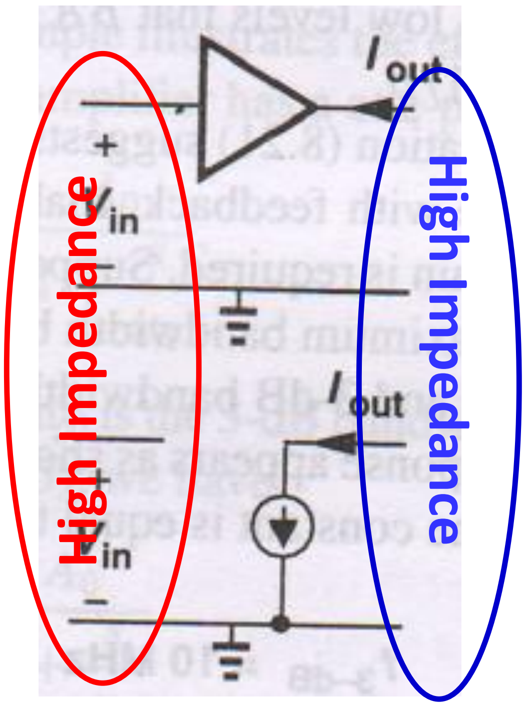


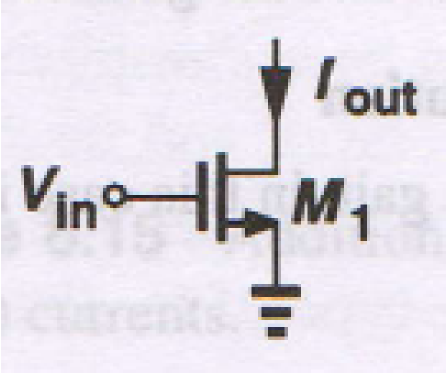
CG Amplifier with a buffer

Possess Relatively High
Output Impedance

Types of Amplifiers (contd.)

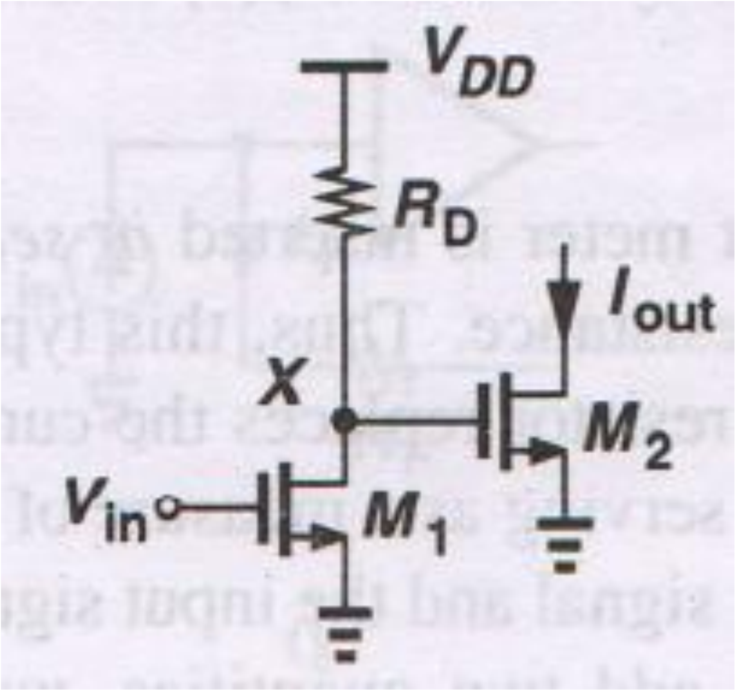
Transconductance Amplifier





CS Stage

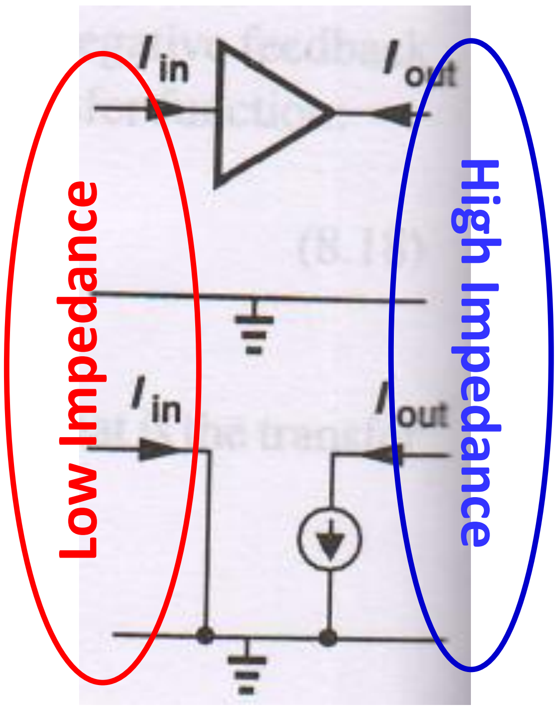
Less control on input impedance

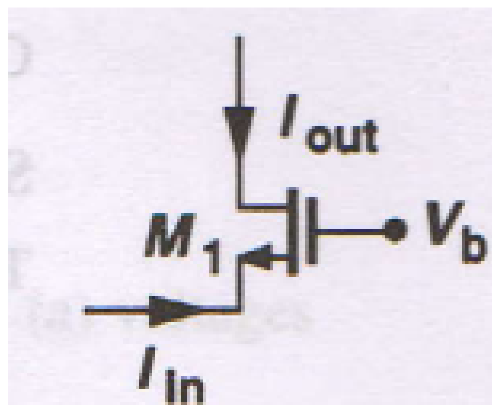


CS Stage with CS Amplifier at the input

Types of Amplifiers (contd.)

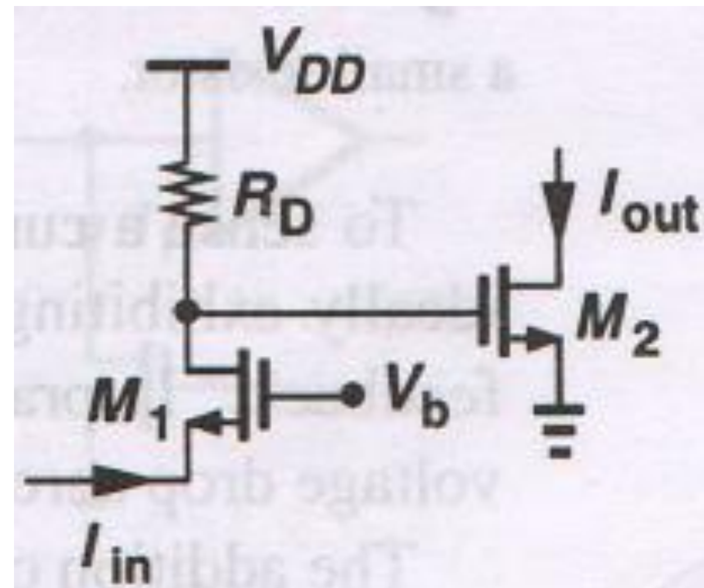
Current Amplifier





CG Stage

Less control on input impedance



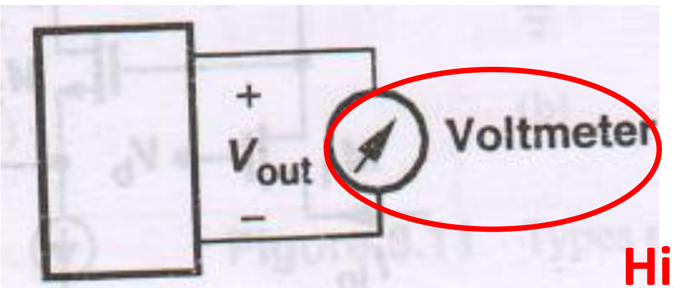
CG Stage with CG Amplifier at the input

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

Sense and Return Mechanism (contd.)

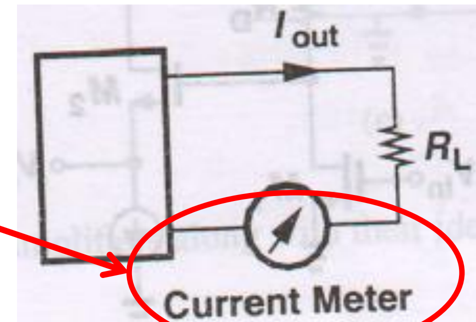
To sense a voltage:



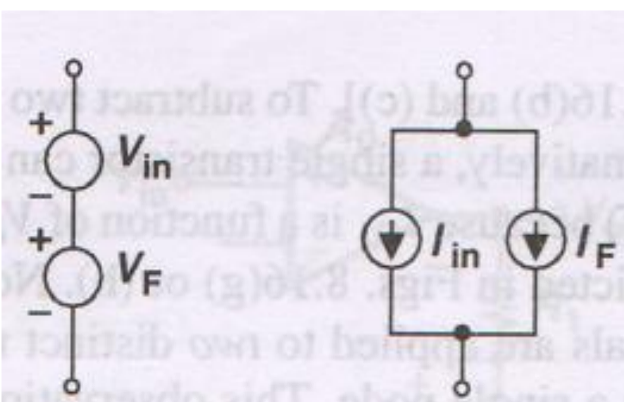
High Input Impedance

To sense a current:

Low Input Impedance



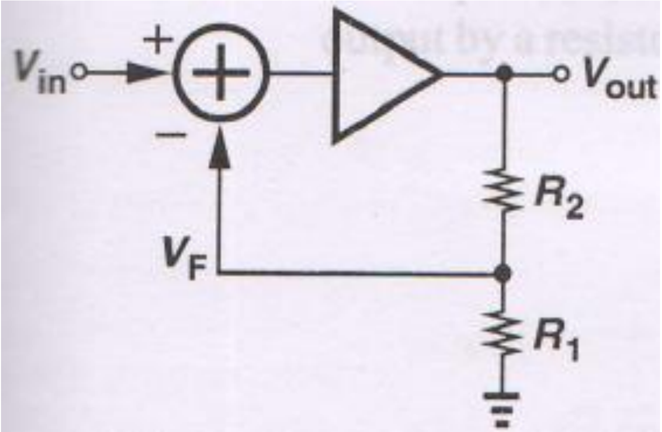
- **The addition/subtraction at the input can be done in current or voltage domain: (a) currents are added by placing them in parallel; (b) voltages are added by placing them in series**



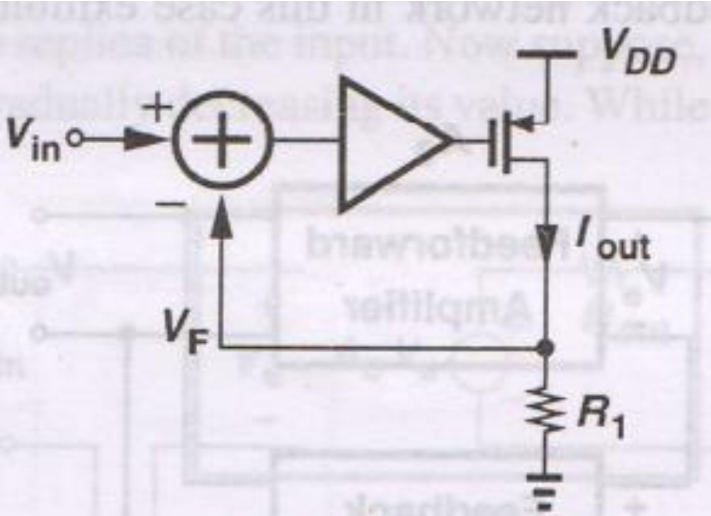
The sense and return mechanism ideally do not affect the operation of feed-forward amplifier → in practical circuits they do introduce loading effects

Sense and Return Mechanism (contd.)

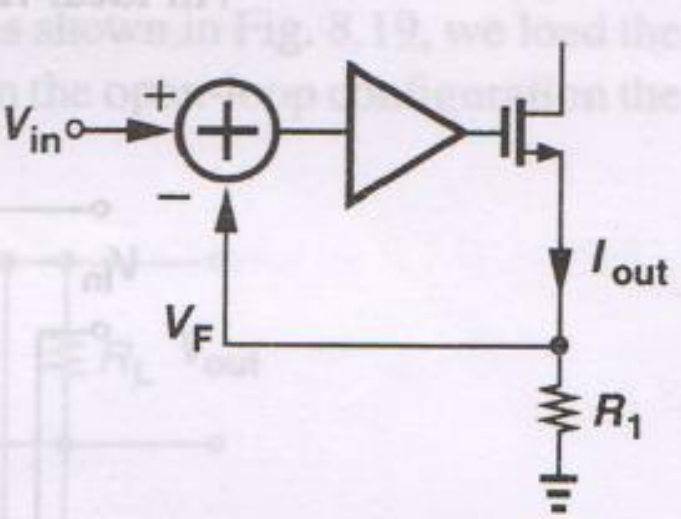
Practical Implementations of Sensing:



Voltage Sensing



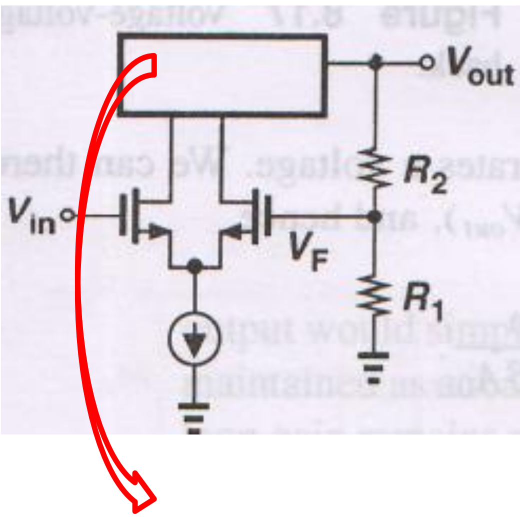
Current Sensing



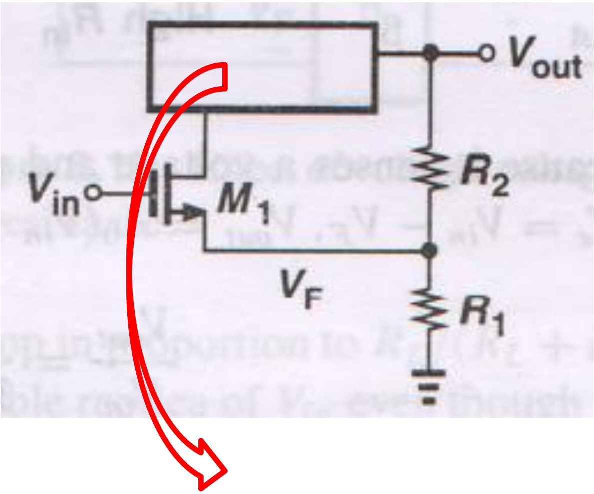
Current Sensing

Sense and Return Mechanism (contd.)

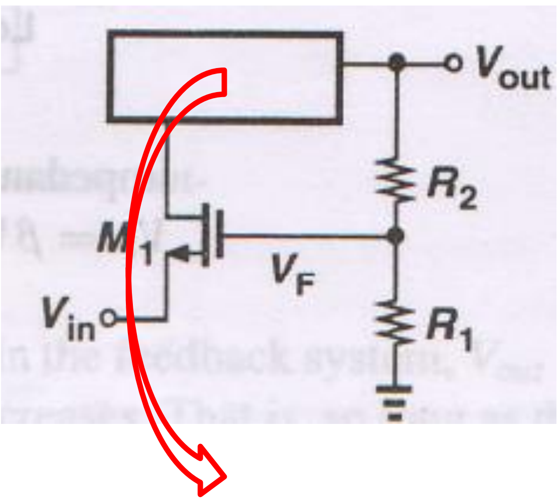
Practical Implementations of Voltage Subtraction:



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



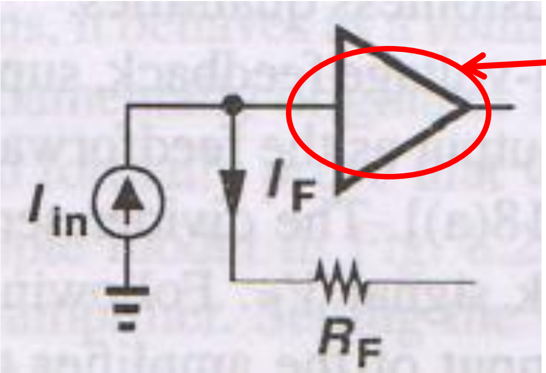
This CS stage provides output in terms of voltage difference V_{in} - V_F



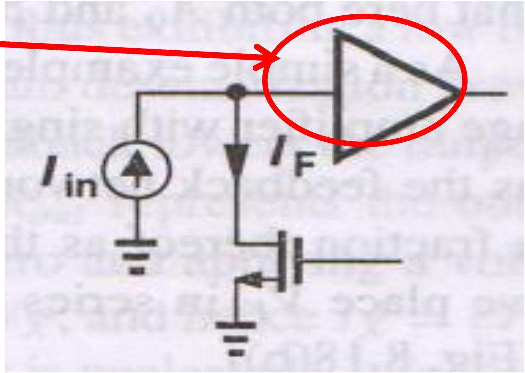
This CG stage provides output in terms of voltage difference V_{in} - V_F

Sense and Return Mechanism (contd.)

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