

Chapter 12

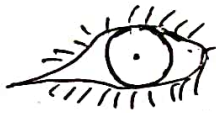
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Today's lect.

- Introduction to feedback
- General feedback system
- Closed loop transfer function

Example of Negative feedback:

Eye



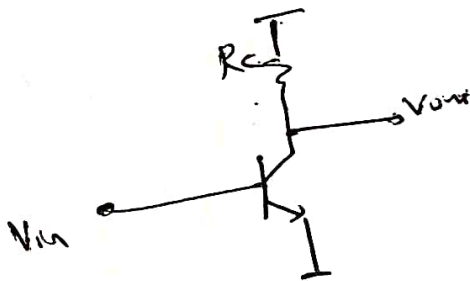
pupil shrinks when we go to a bright room

Ear



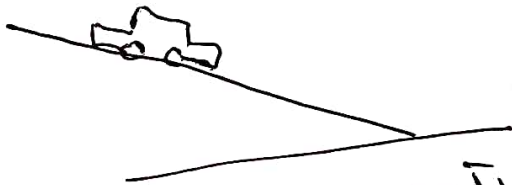
Ear: control the level of sound.

* Why negative feedback?

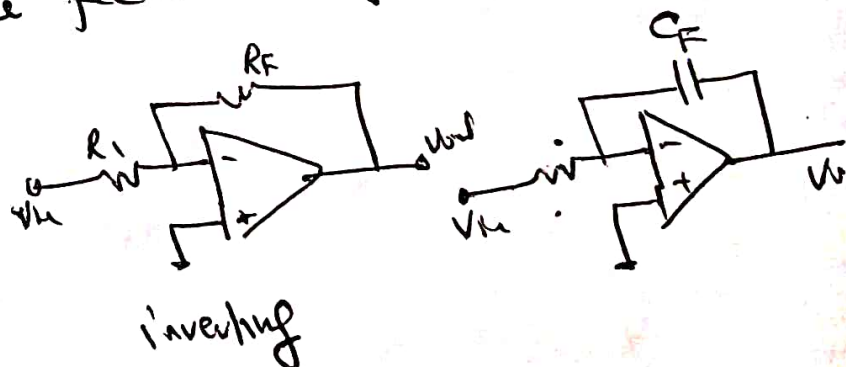
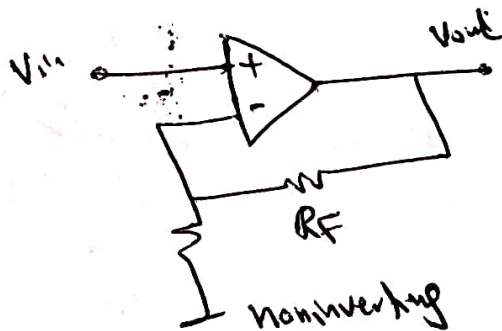


$V_A = \infty$ $A_v = -g_m R_c$
The problem is that that gain is not fixed (not accurate)
ex: $A_v = 4.00$

without feedback, we have poorly controlled circuit

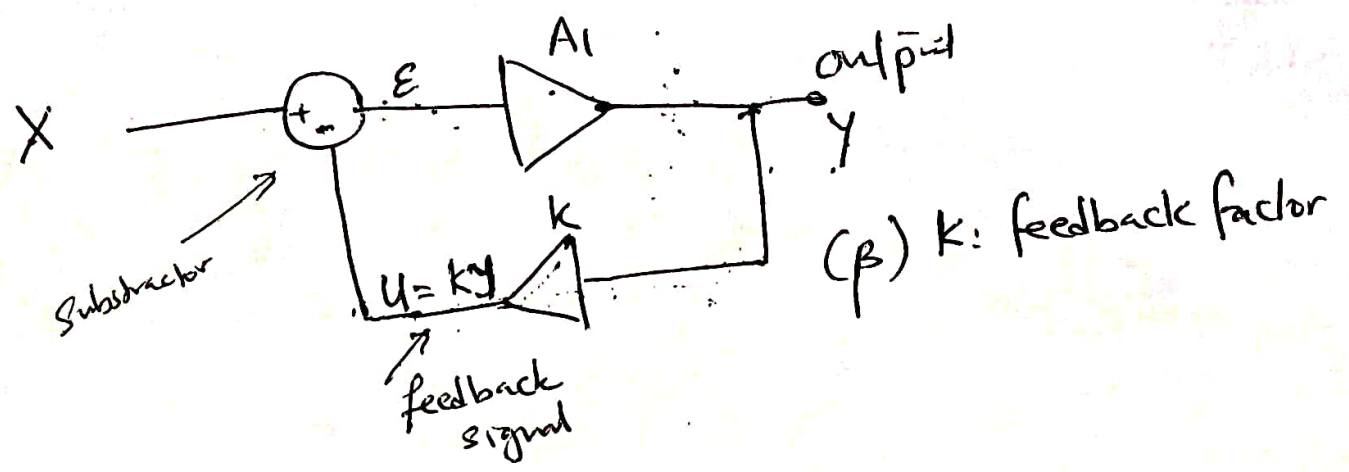


* We have seen negative feedback before:



General Negative feedback system

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error signal

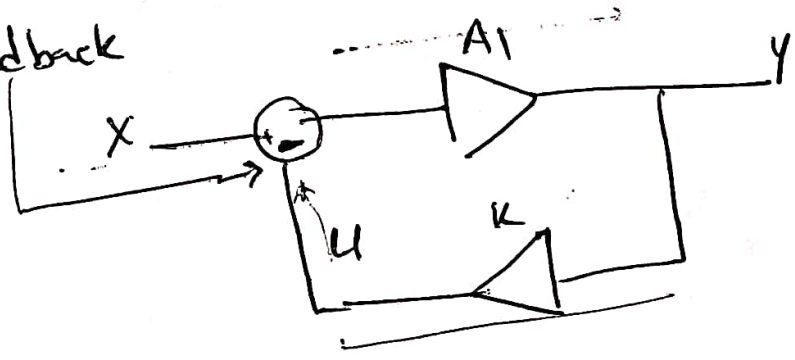
$$E = X - U = X - KY$$

* The feedback system consists of 4 components.

- 1) A_1 : feedforward system
- 2) Sensing mechanism
- 3) feedback Network
- 4) Subtractor.

Notes:- 1) - Negative feedback

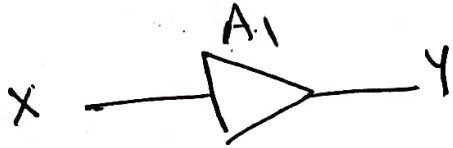
2) - Direction of signal flow



3) error signal
 $E = X - U$

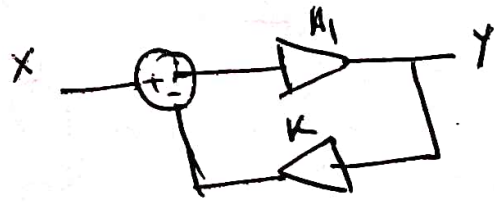
E : must be minimize
why and How?

4) if $K=0$



system is called
open loop system.

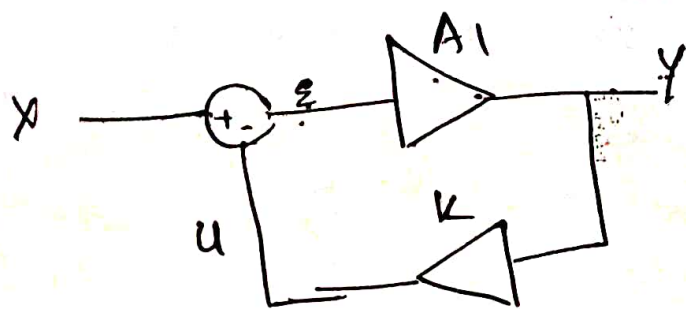
$K \neq 0$



$\Rightarrow$ system is called
closed loop system.

Transfer function of closed loop system

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$$U = KY$$

$$\varepsilon = X - U$$

$$= X - KY$$

$$Y = A_1 \varepsilon$$

$$Y = A_1 [X - KY]$$

$$= A_1 X - A_1 KY$$

$$Y[1 + KA_1] = A_1 X$$

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

A_1 : open loop gain

$\frac{A_1}{1 + KA_1}$: closed loop gain.

Both (K, A_1) are positive

- ⇒ The closed loop gain is less than the open loop gain
- ⇒ Why, we reduce the gain? Answer Later.
- ⇒ How we can implement the subtractor? Answer later
- ⇒ What is the purpose of feedback network?

Quiz: Determine the error signal in term of input X

$$\varepsilon = X - U = X - KY = X - K \frac{A_1}{1 + KA_1} X$$

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

To minimize ε , we have to maximize KA_1

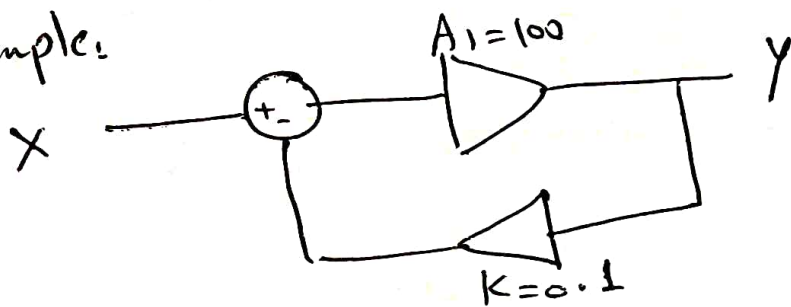
Observations:

-4-

1) If ε is minimize. then $X-U$ becomes small.
 $\Rightarrow X=U \Rightarrow$ the output is copy of the input

$\Rightarrow$ That means the feedback system is a good copy of the input.

Example:



find Y/X

$$\frac{Y}{X} = \frac{A_1}{1 + KA_1} = \frac{100}{1 + 0.1 \times 100} = 9.09$$

Ex: What happens if A_1 drops to 50.

$$\frac{Y}{X} = \frac{50}{1 + 0.1 \times 50} = \frac{50}{6} = 8.33$$

Even though the open loop gain is changed by a factor of 2 $\Rightarrow$ the closed loop gain changes by only 10%.

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

$$\text{If } KA_1 \gg 1 \Rightarrow \frac{Y}{X} = \frac{1}{K}$$

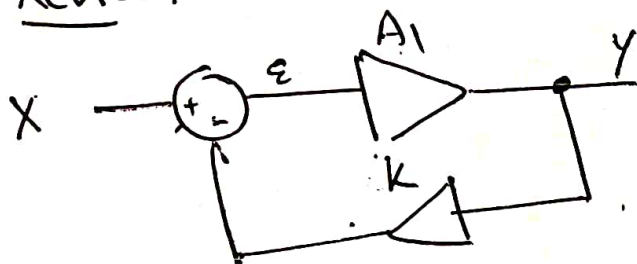
that means the closed loop gain is relatively indep of the open loop gain

$\Rightarrow$ We should try to maximize KA_1

Today's lect.

- Example to determine closed loop gain
- Loop gain Calculation
- Properties of Negative feedback

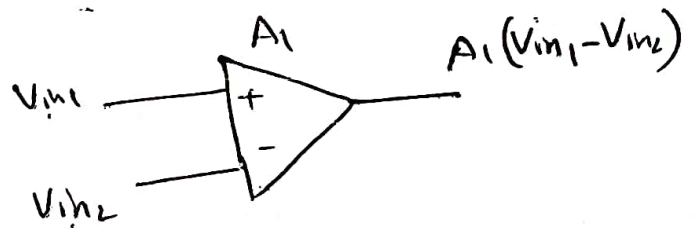
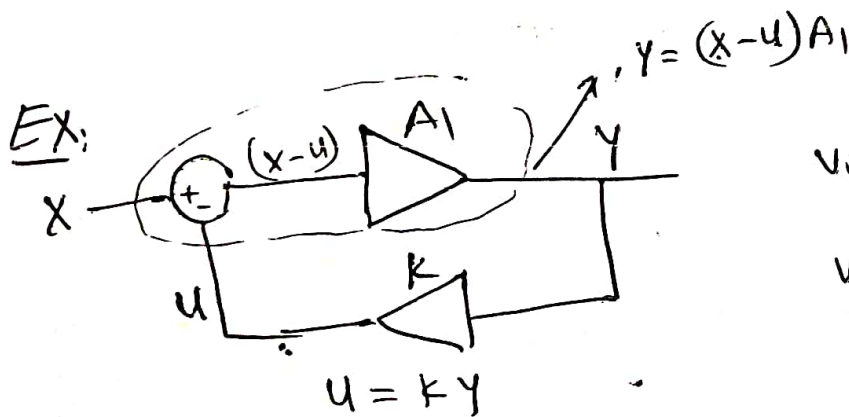
Review:



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

for $KA_1 \gg 1 \Rightarrow \frac{Y}{X} = \frac{1}{K}$

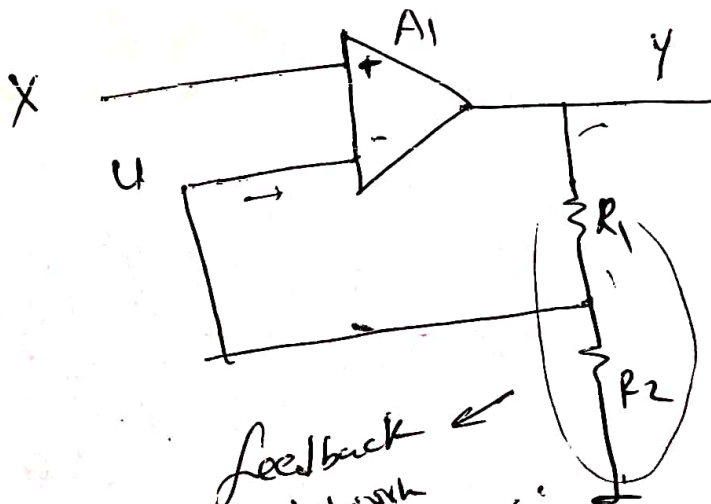
To have a closed loop gain ≥ 1
K is usually chosen to be ≤ 1



Noninverting amplifier

$$U = \frac{R_2}{R_1 + R_2} Y$$

$$K = \frac{R_2}{R_1 + R_2}$$



Feedback Network
Creating of K by using voltage divider

Closed loop gain

$$\frac{Y}{X} = \frac{A_1}{1 + KA_1} = \frac{A_1}{1 + \frac{R_2}{R_1 + R_2} A_1}$$

In a well designed Negative feedback system
 $KA_1 \gg 1$

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

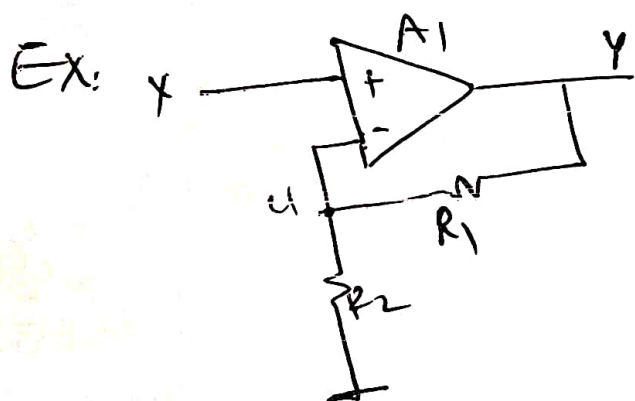
$$\Rightarrow \frac{Y}{X} = \frac{1}{\frac{R_2}{R_2 + R_1}} = \boxed{1 + \frac{R_1}{R_2}}$$

Even R_1 and R_2 vary with temp $\Rightarrow (1 + \frac{R_1}{R_2})$ is accurated.

Loop gain: (KA_1)

in a well designed Negative feedback system the loop gain $KA_1 \gg 1$

$\Rightarrow$ closed loop gain $\cong \frac{1}{K}$

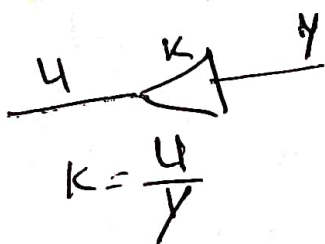


find the loop gain in the noninverting circuit

Loop gain = KA_1

$$K = \frac{U}{Y}, \quad U = \frac{R_2}{R_1 + R_2} Y$$

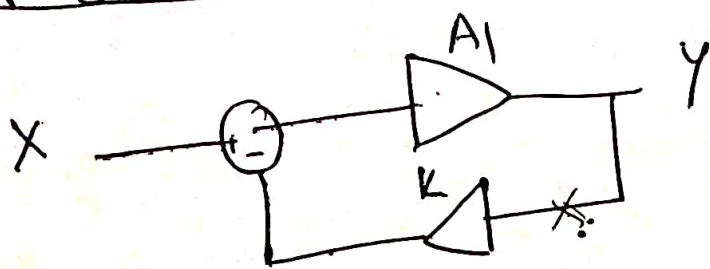
$$\frac{U}{Y} = K = \frac{R_2}{R_1 + R_2}$$



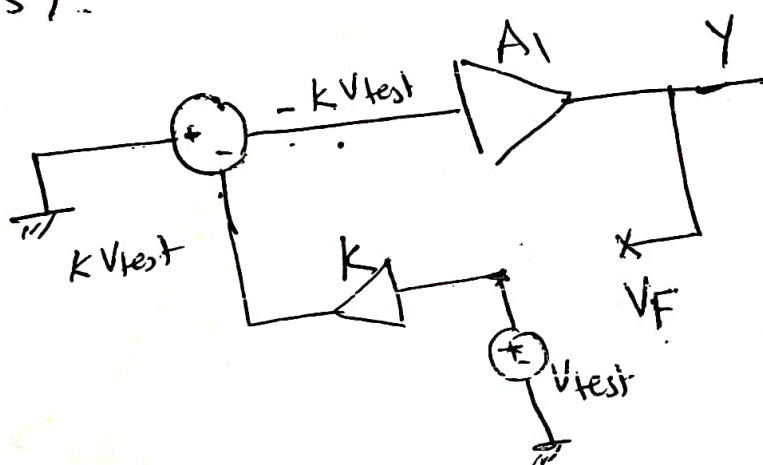
$$\Rightarrow KA_1 = A_1 \times \left[\frac{R_2}{R_1 + R_2} \right]$$

Loop gain Calculation:

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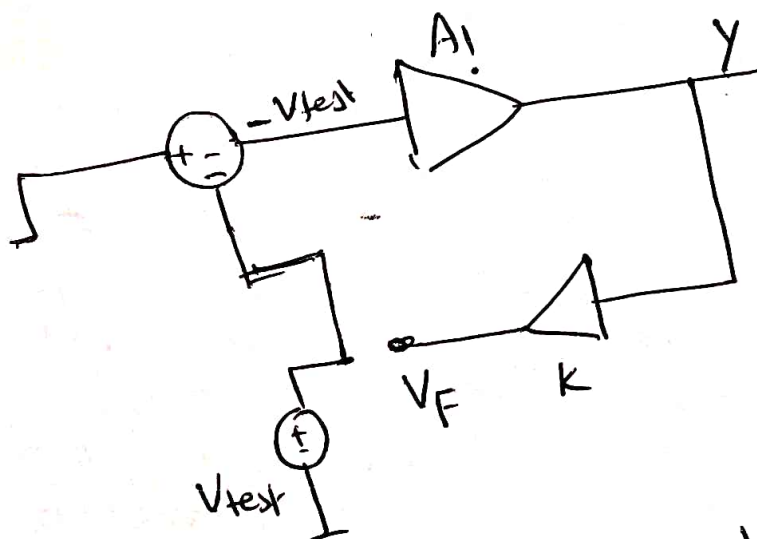
- 1) Set the input ($X=0$)
- 2) Break the feedback path
- 3) Apply V_{test} at the break point
- 4) The node where to break is called V_F
- 5) The loop gain is determined as $= -\frac{V_F}{V_{test}}$



$$Y = V_F = -K V_{test}$$

$$\boxed{-\frac{V_F}{V_{test}} = K A_1}$$

Ex.



$$Y = -A_1 V_{test}$$

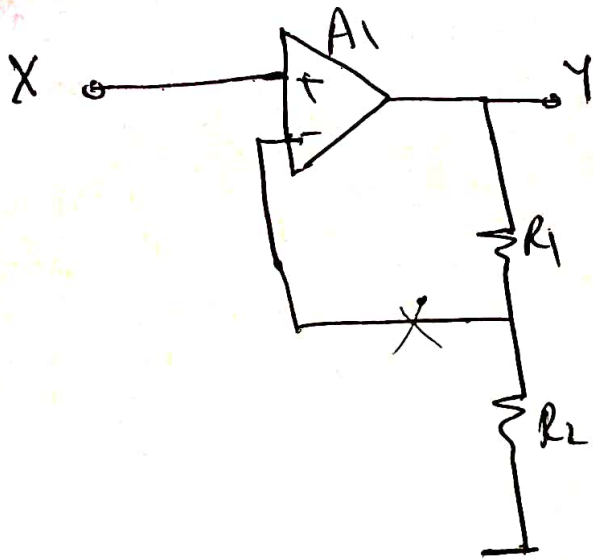
$$V_F = K Y$$

$$= -K A_1 V_{test}$$

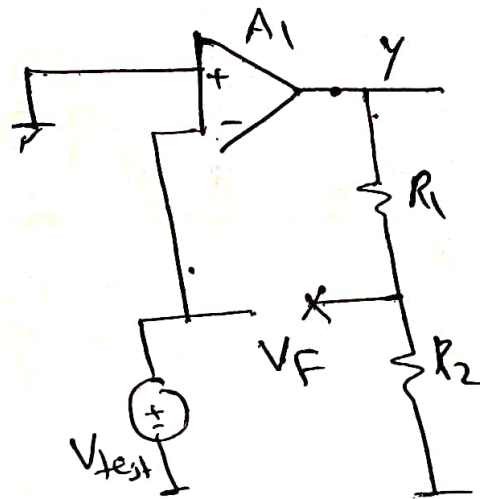
$$\boxed{K A_1 = -\frac{V_F}{V_{test}}}$$

* We can break the circuit any where in the feedback path.

Example,



Find the loop gain
(KA_1)

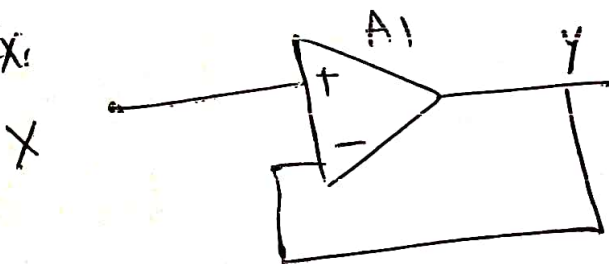


$$Y = -A_1 V_{test}$$

$$V_F = \frac{R_2}{R_1 + R_2} Y = \frac{R_2}{R_1 + R_2} (-A_1 V_{test})$$

$$\Rightarrow -\frac{V_F}{V_{test}} = \underbrace{(A_1)}_{A_1} \underbrace{\left(\frac{R_2}{R_1 + R_2}\right)}_K$$

Ex:

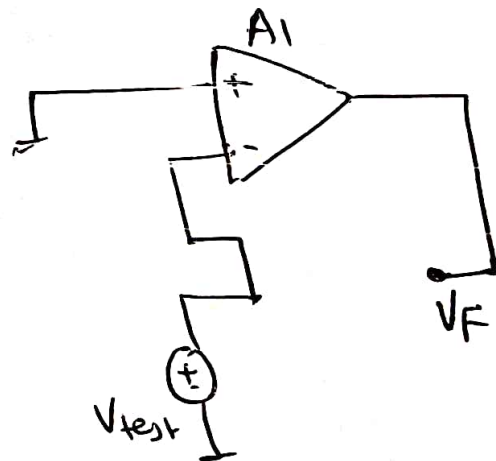


$$V_F = -A_1(V_{test})$$

$$-\frac{V_F}{V_{test}} = A_1$$

$$\text{loop gain} = KA_1 = A_1$$

$$\Rightarrow K = 1$$

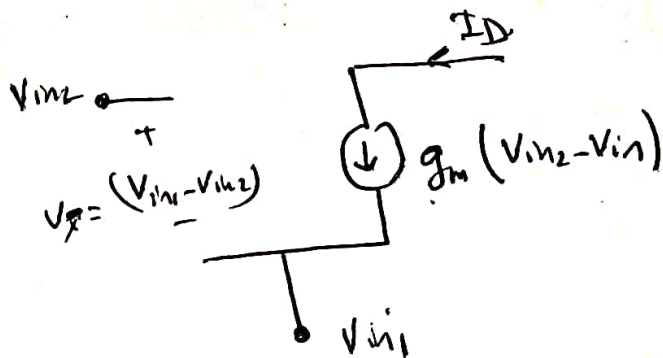
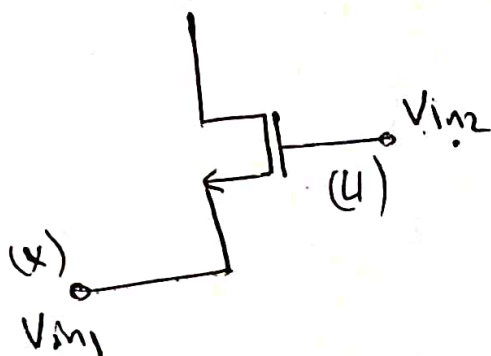
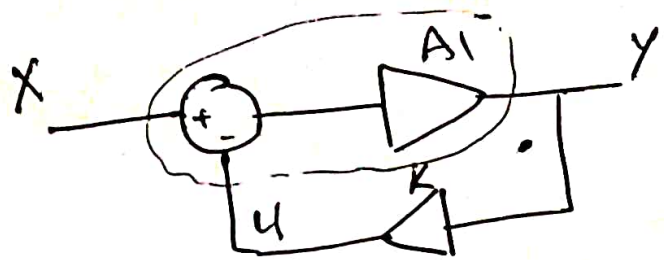


Example

Replacing a device that has two inputs and one output

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$$Y = A_1 (X - U)$$



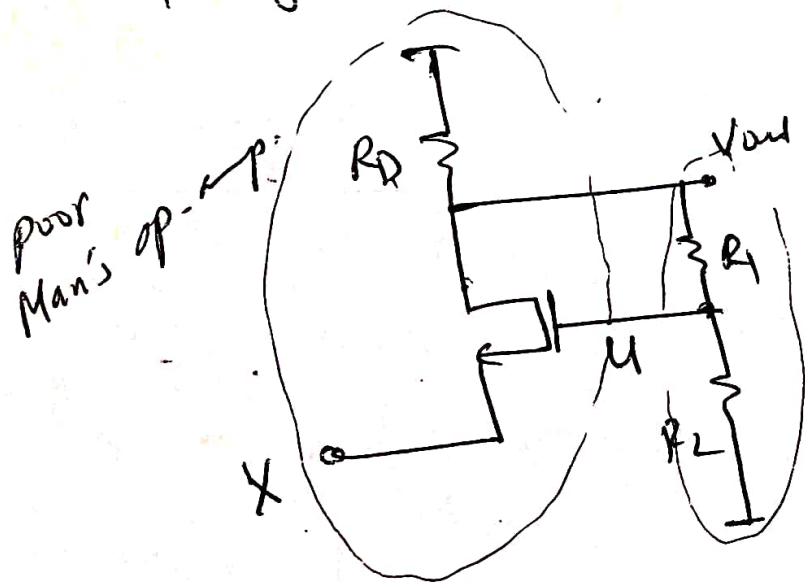
$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{gs} - V_{th})^2$$

$$= \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{in2} - V_{in1} - V_{th})^2$$

for small signal

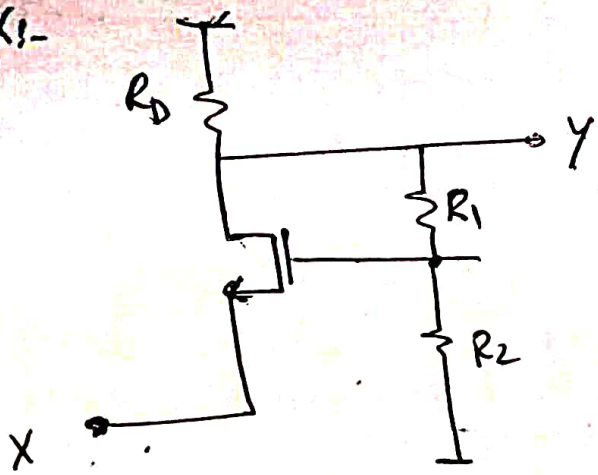
$$I_D = g_m (V_{gs}) = g_m [V_{in2} - V_{in1}]$$

To generate voltage $\Rightarrow$ pass I_D through R_D



k-created by using voltage divider

Ex:-



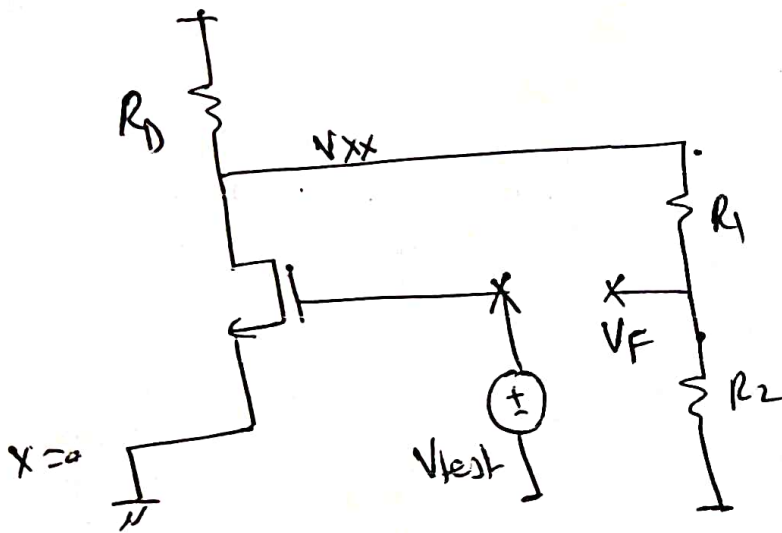
find $\frac{Y}{X} = \frac{A_1}{1 + KA_1}$:-10-

Assume (R_1, R_2) is very large.

A_1 : ~~open~~ gain of common gate

$A_1 = g_m R_D$

To find loop gain $KA_1 \left(-\frac{V_F}{V_{test}} \right)$



$V_{xx} = -g_m R_D V_{test}$

$V_F = \frac{R_2}{R_1 + R_2} V_{xx}$

$V_F = -g_m R_D \frac{R_2}{R_1 + R_2} V_{test}$

$\Rightarrow -\frac{V_F}{V_{test}} = \underbrace{+ g_m R_D}_{A_1} \underbrace{\left(\frac{R_2}{R_1 + R_2} \right)}_K$

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

Properties of Negative feedback

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$$\frac{Y}{X} = \frac{A_1}{1 + KA_1} \approx \frac{1}{K} \quad KA_1 \gg 1$$

1) Gain desensitization

$\frac{Y}{X}$ is less sensitive to temp / supply than A_1 is.

2) Bandwidth Extension.

greater bandwidth for closed loop system than open loop system

3) Modification of input / output impedance.

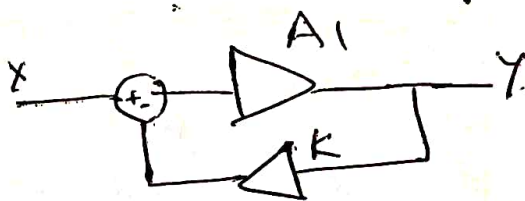
4) higher linearity.

Today's lect.

- Properties of Negative feedback.
- Prerequisites for Analysis of Feedback.

Properties of Negative feedback.

1) Gain desensitization:



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

$$\text{if } KA_1 \gg 1 \Rightarrow \frac{Y}{X} = \frac{1}{K}$$

A_1 : open gain (A_1 changes due to various factor) such as (temp, supply, frequency, loading)

$\Rightarrow$ The closed loop gain doesn't change as much.

2) Bandwidth Extension:

for open loop gain

$$A_1(s) = \frac{A_0}{1 + s/\omega_{p0}}$$

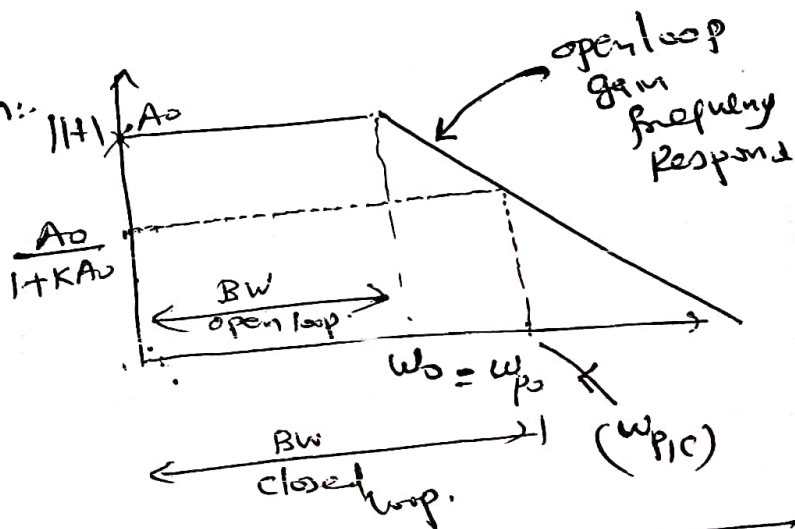
for single pole.

for closed loop gain

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

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

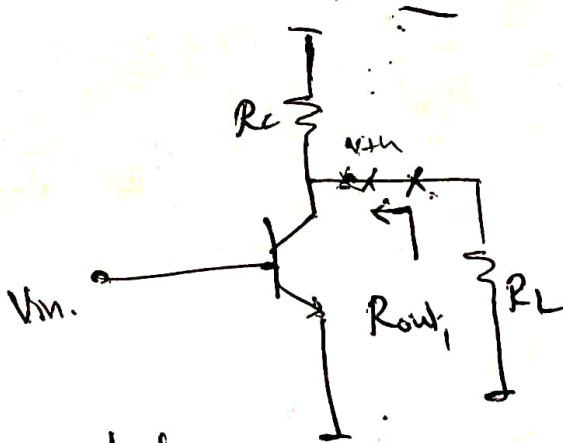
$$= \frac{\frac{A_0}{1 + KA_0}}{1 + \frac{s}{\omega_0(1 + KA_0)}} = \frac{\frac{A_0}{1 + KA_0}}{1 + \frac{s}{\omega_{p,c}}}$$



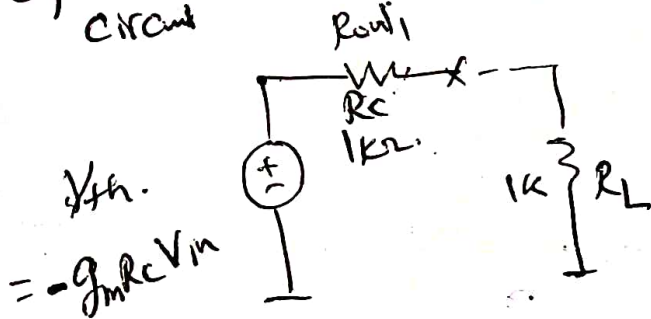
3) Modification of Input/output impedance

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without feedback

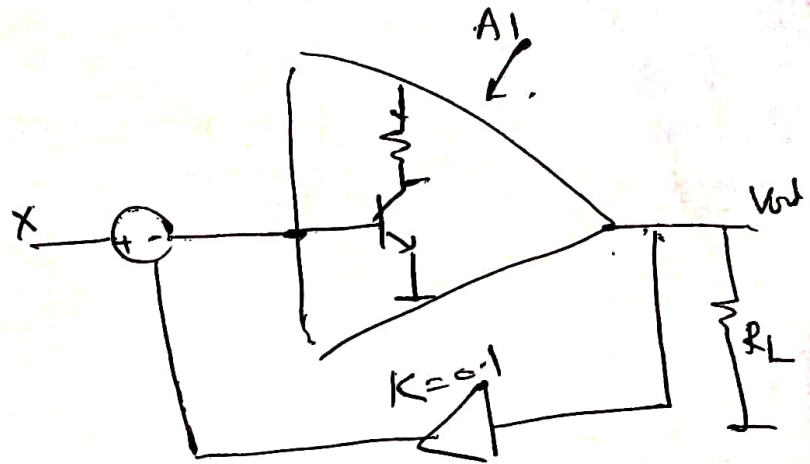


Equivalent circuit



A_v is drop by a factor of 2

with feedback



$$A_1 = -50 \text{ without load}$$

$$A_1 = -25$$

closed loop gain without R_L

$$A_{v0} = \frac{A_v}{1 + K A_v} = \frac{-50}{1 + 5} = -8.33$$

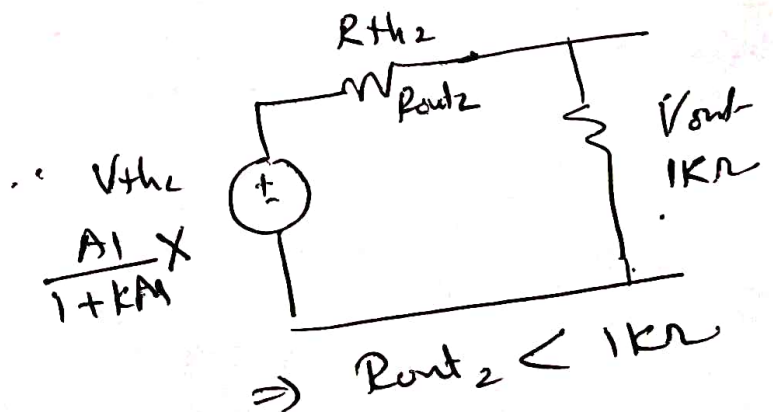
with R_L

$$A_v = \frac{-25}{1 + 2.5} \approx -7.22$$

The closed loop gain is drop by a factor of less than 1V.

$$\underline{R_{out2} < R_{out1}}$$

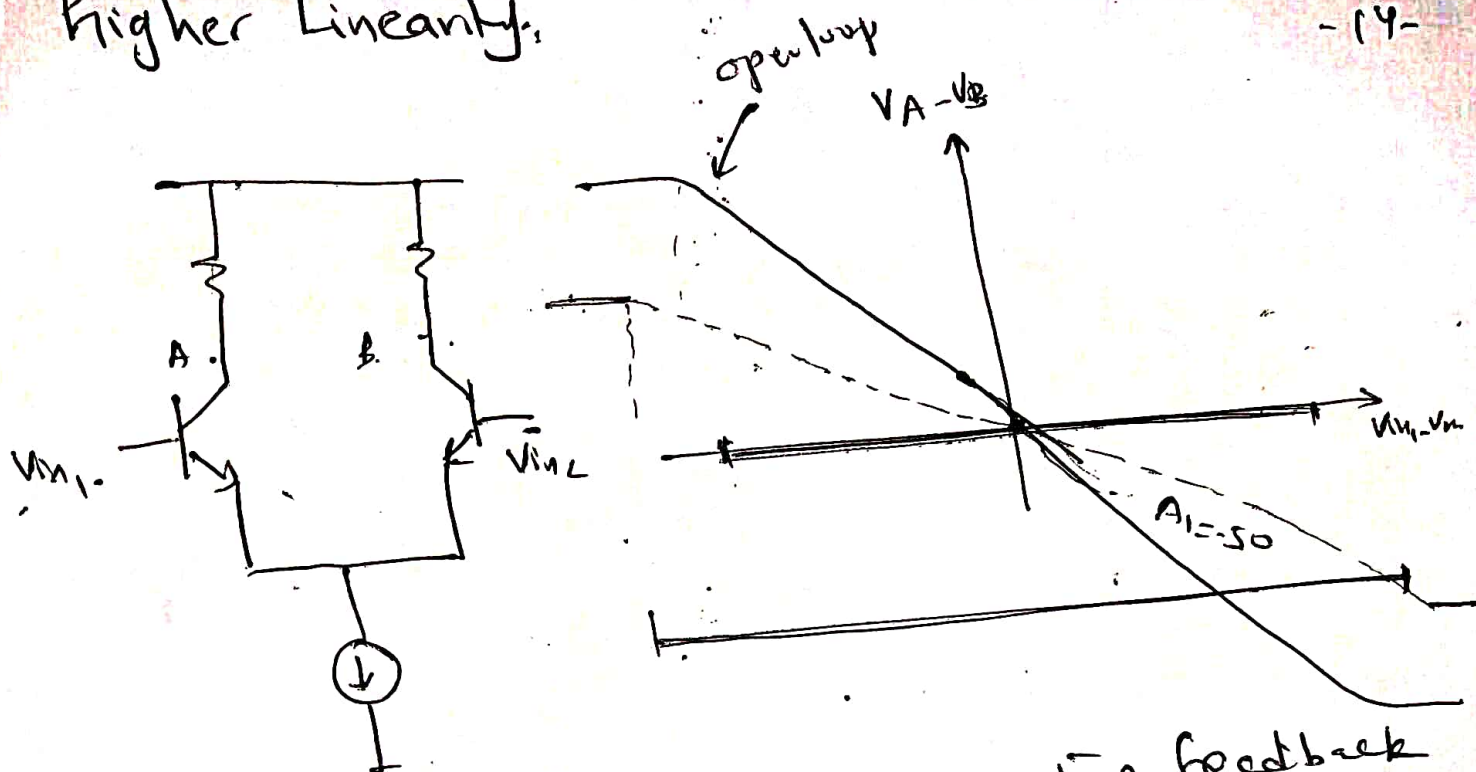
⇒ negative feedback system modifies the output resistance of the circuit



$$\Rightarrow R_{out2} < 1k\Omega$$

a) Higher Linearity:

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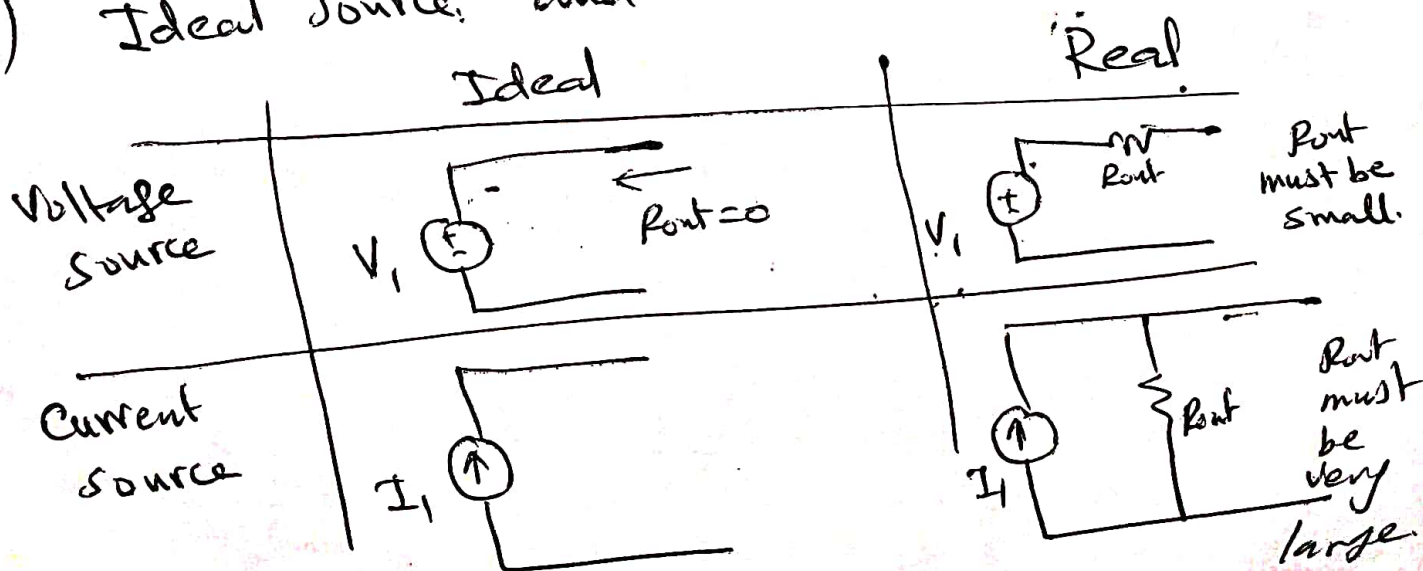


higher linearity when using negative feedback
the gain is reduced $\Rightarrow$ the slope become
less $\Rightarrow$ so that the range of the (V_{in1}, V_{in2})
becomes more than before)

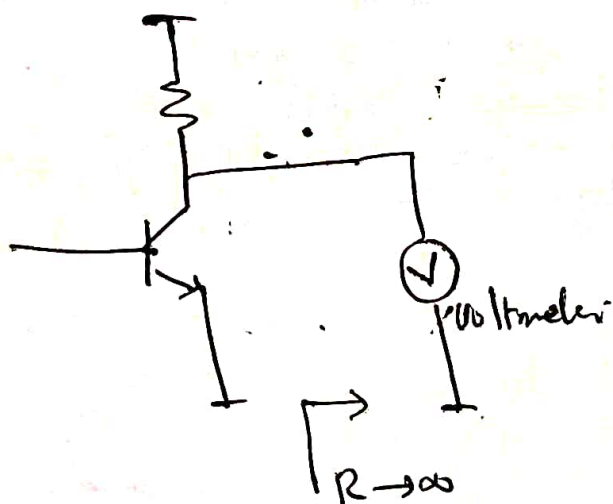
Prerequisites for Analysis of feedback:

few Quick Notes:

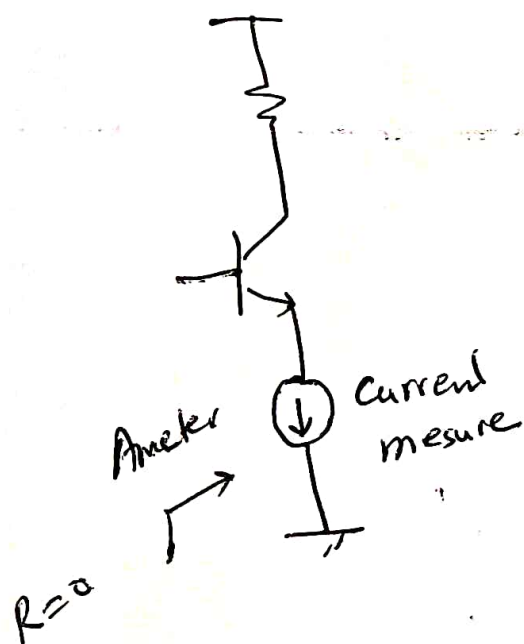
1) Ideal Source, and Real source



How to measure a voltage and current :- 15

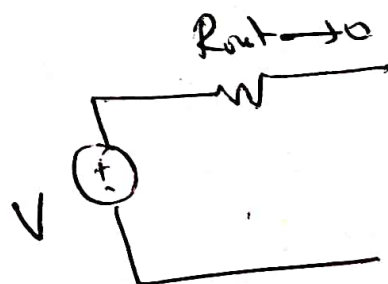


In order to measure a voltage, the voltmeter must have high impedance

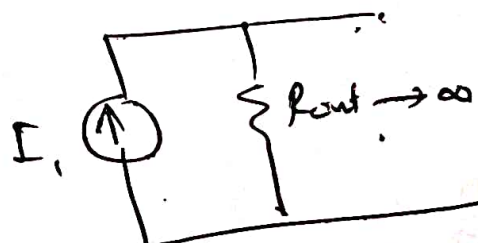


To measure the Current the impedance of Ammeter must be Low.

Review: 1) Good Voltage source



2) Good Current source



Today's lect

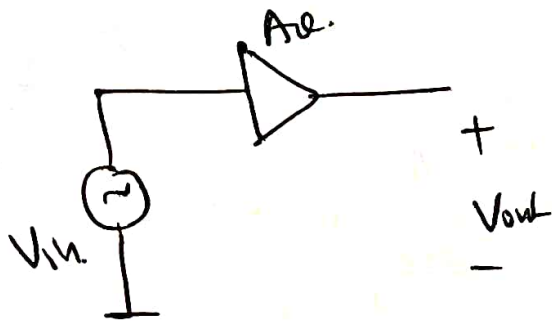
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- Types of Amplifiers

- Sense and Return mechanisms

Types of Amplifiers

1)



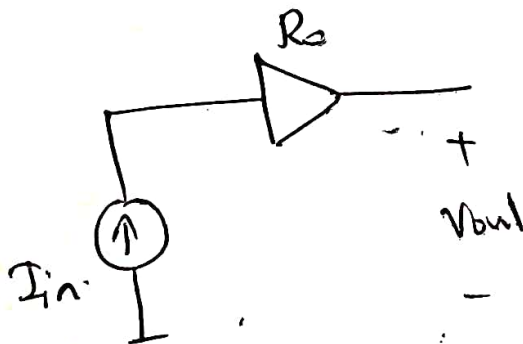
Input $\rightarrow$ voltage

output $\rightarrow$ voltage

$$A_v = \frac{V_{out}}{V_{in}}$$

Voltage amplifier.

2)



input: Current

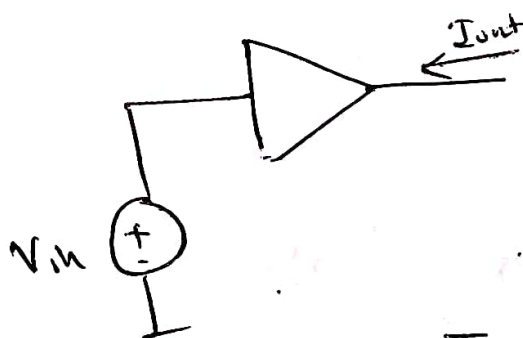
output: voltage

$$A_v = \frac{V_{out}}{I_{in}} = R_o$$

Transimpedance amplifier.

$$R_o = \frac{V_{out}}{I_{in}} (\Omega)$$

3)



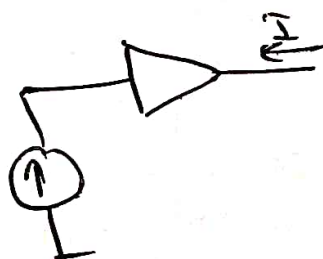
Input $\rightarrow$ voltage

output $\rightarrow$ current

$$g_m = \frac{I_{out}}{V_{in}} (\text{A/V}) \text{ Siemens}$$

Transconductance Amplifier.

4)



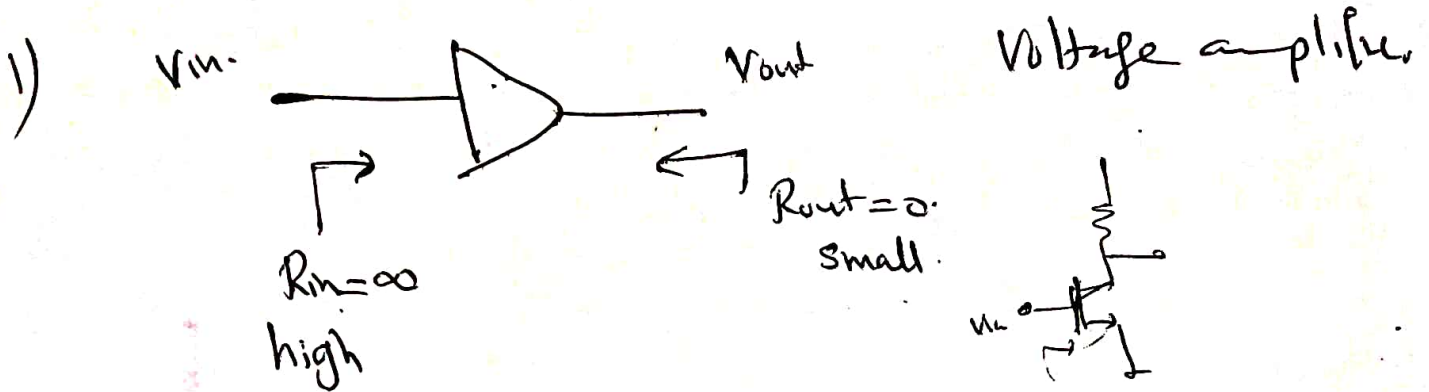
input $\rightarrow$ current

output $\rightarrow$ current

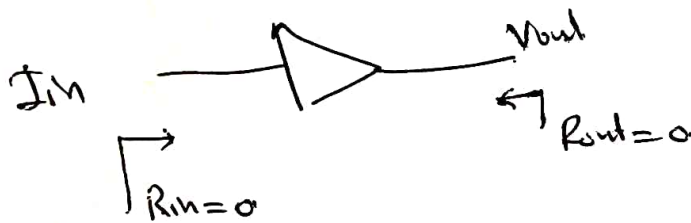
$$A_I = \frac{I_{out}}{I_{in}} : \text{Current gain.}$$

Input and Output Impedance of four Amplifier topologies

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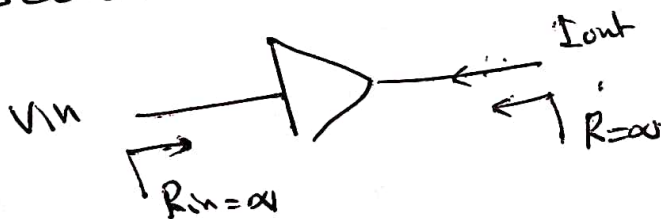
2) Transimpedance Amplifier



Input Impedance

Input	~~Input~~	~~Output~~
I	$R = 0$	
V	$R = \infty$	

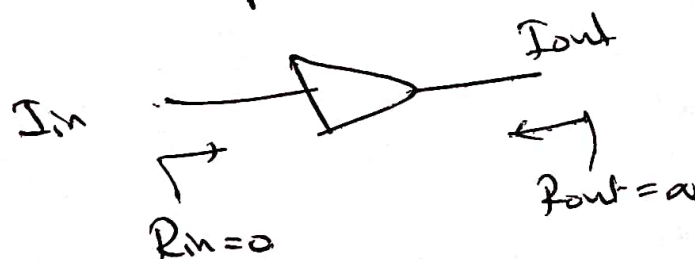
3) Transconductance



Output

I	$R \rightarrow \infty$
V	$R \rightarrow 0$

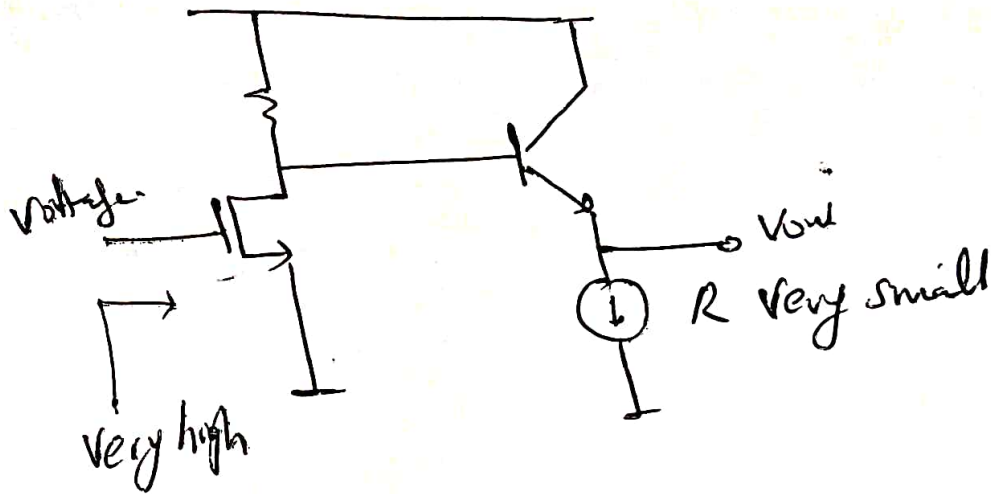
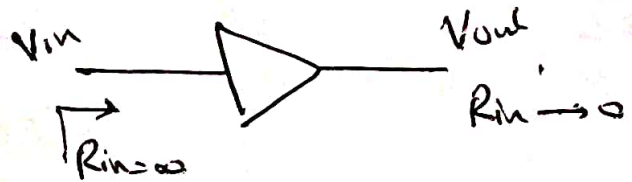
4) Current Amplifier



Examples of Amplifier Implementations.

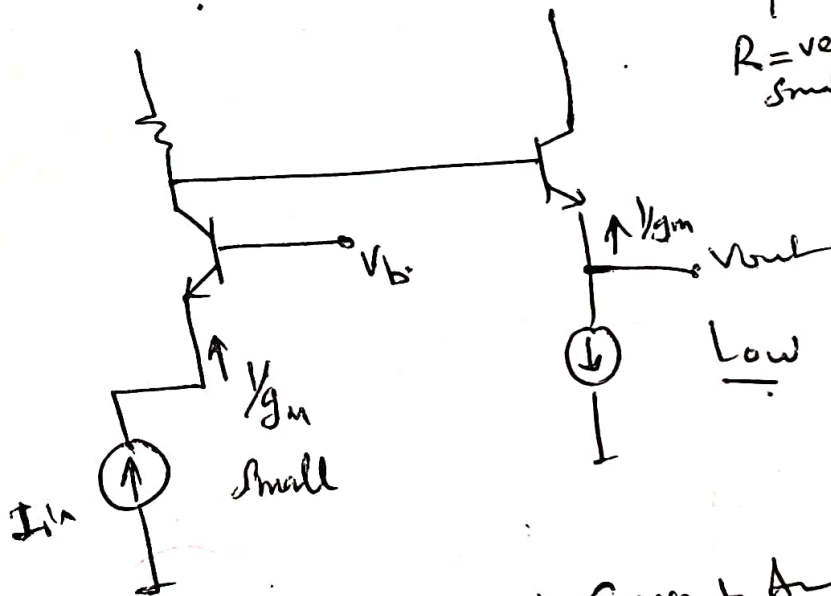
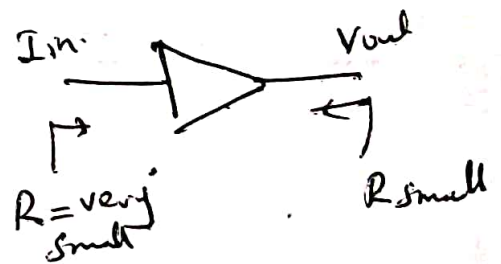
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1) Voltage Amplifier

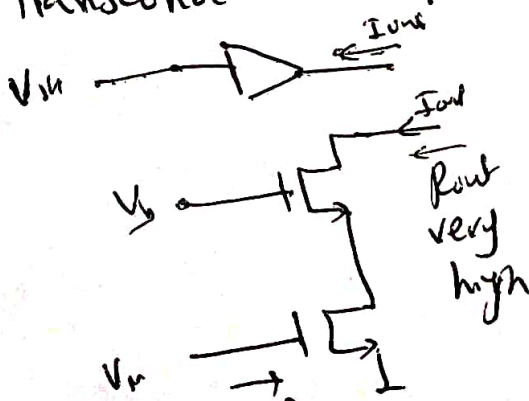


2)

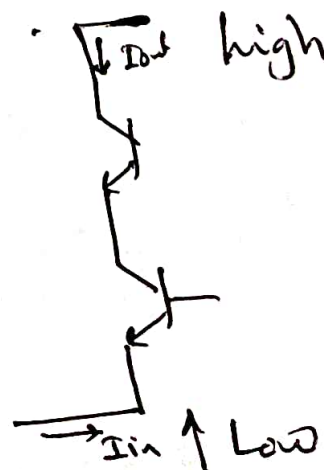
Transimpedance Amplifier



3) Transconductance Amplifier



4) Current Amplifier

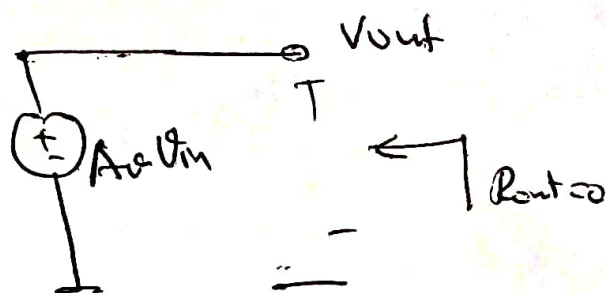
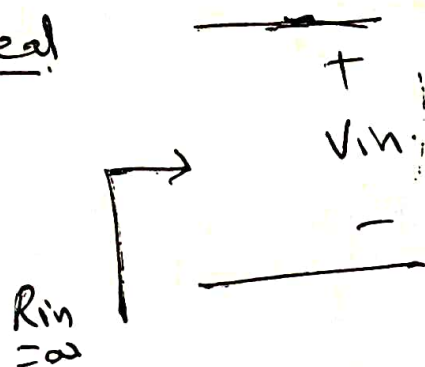


Models of Four Amplifier Topologies

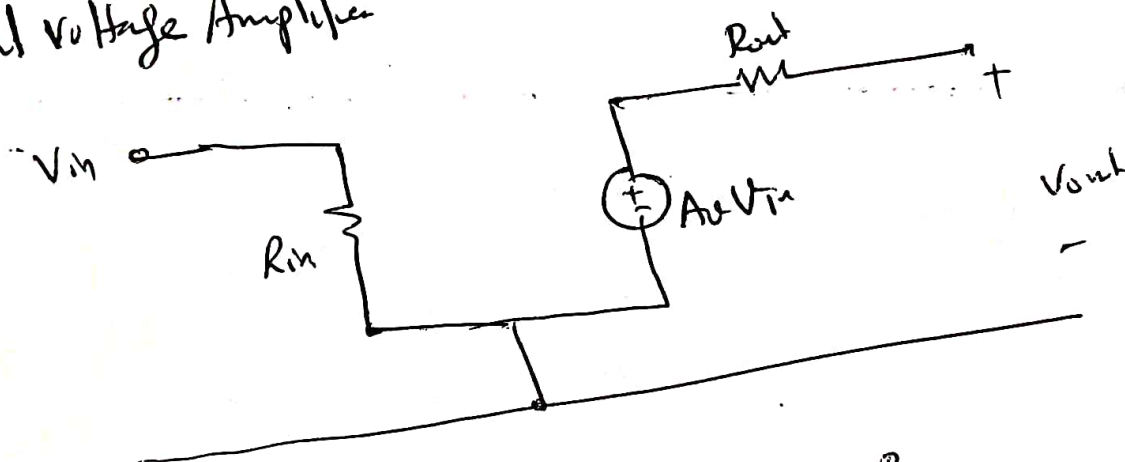
49-

1) Voltage Amplifier

ideal

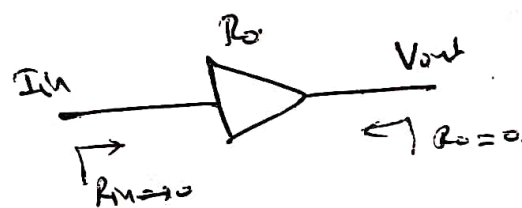
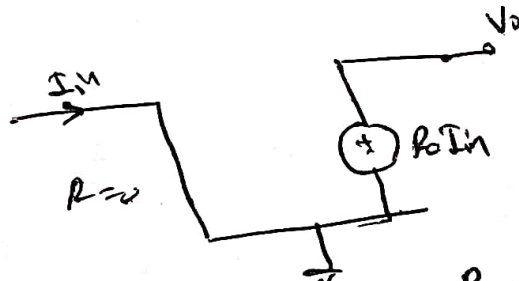


Actual voltage Amplifier

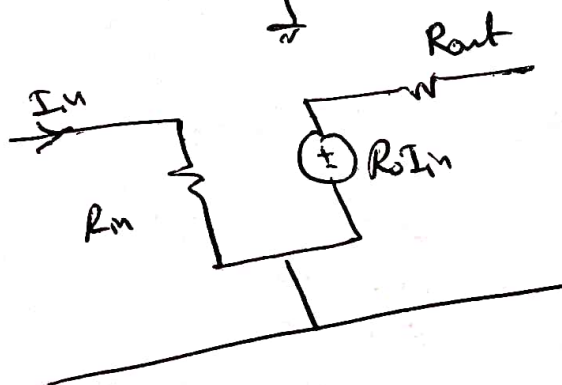


2) Transimpedance Amplifier

ideal

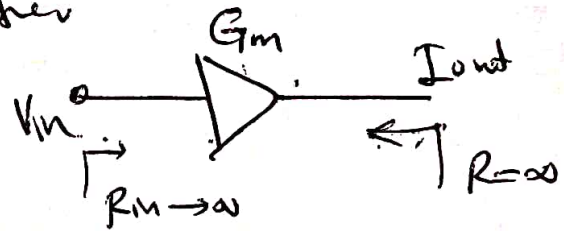


actual

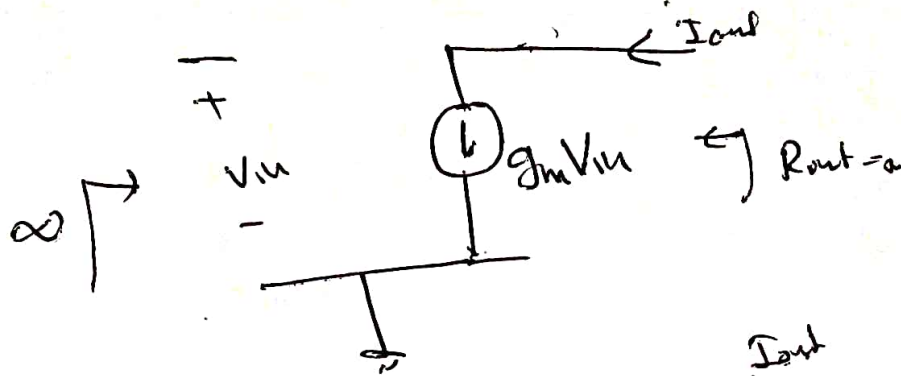


Transconductance Amplifier

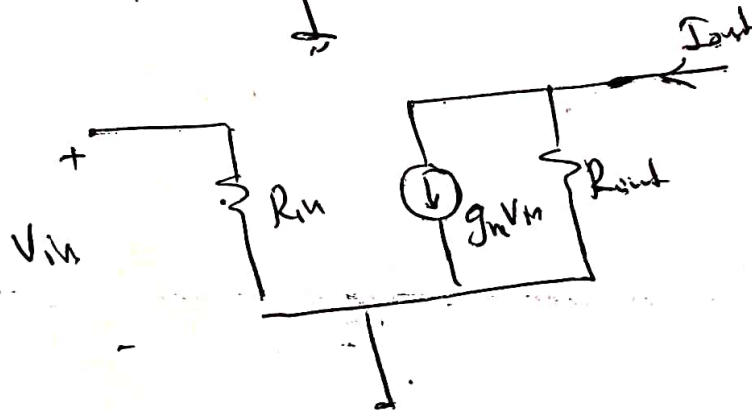
-20-



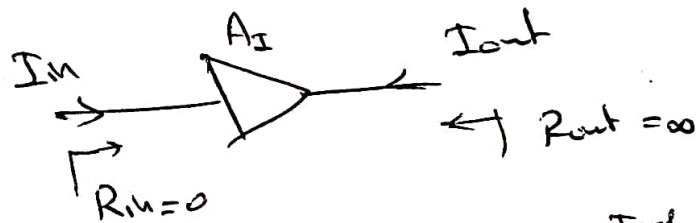
ideal



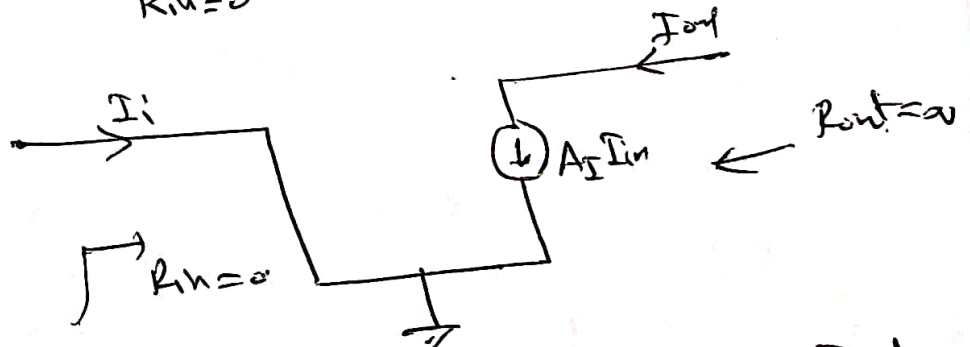
Real



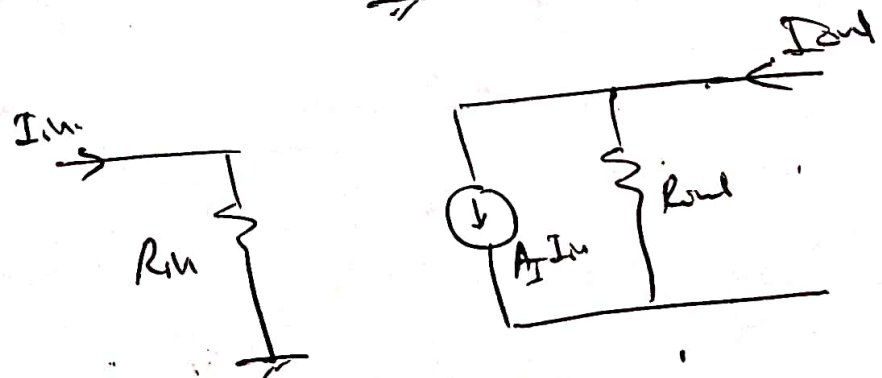
Current gain



ideal



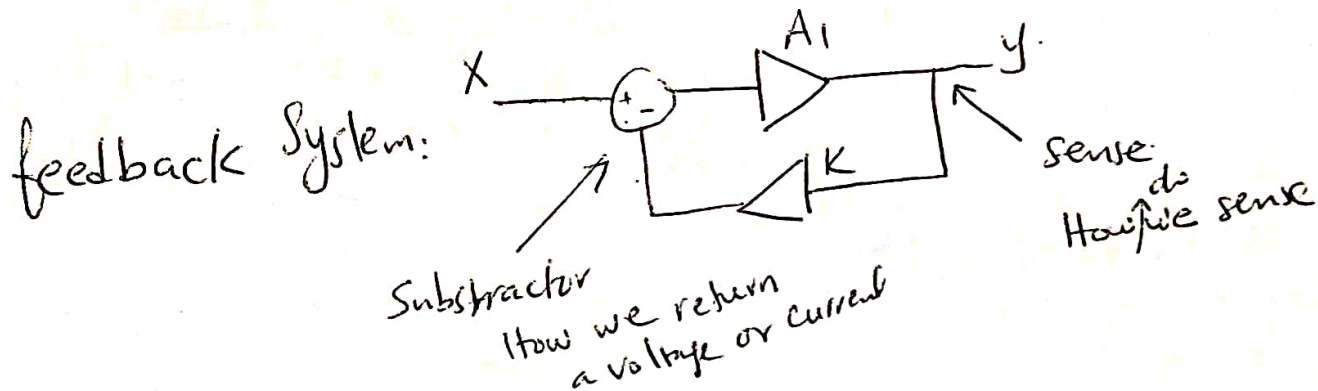
Real



Today's lect.

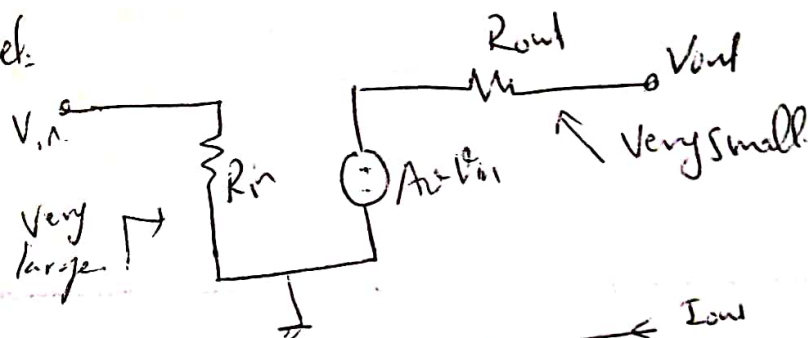
(21)

- Sense and Return Mechanisms
- Feedback Circuit Examples.

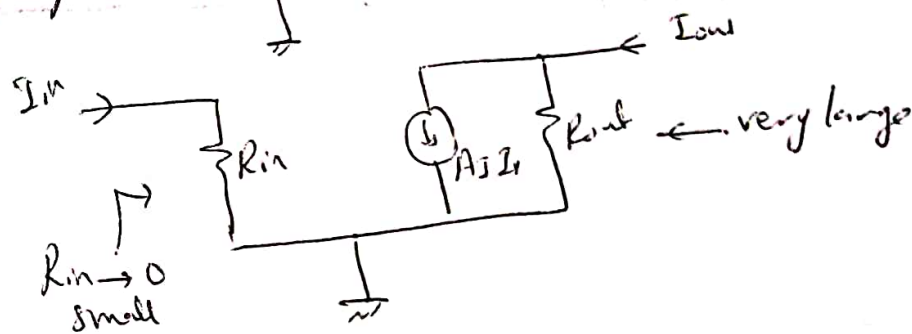


Amplifier Model:

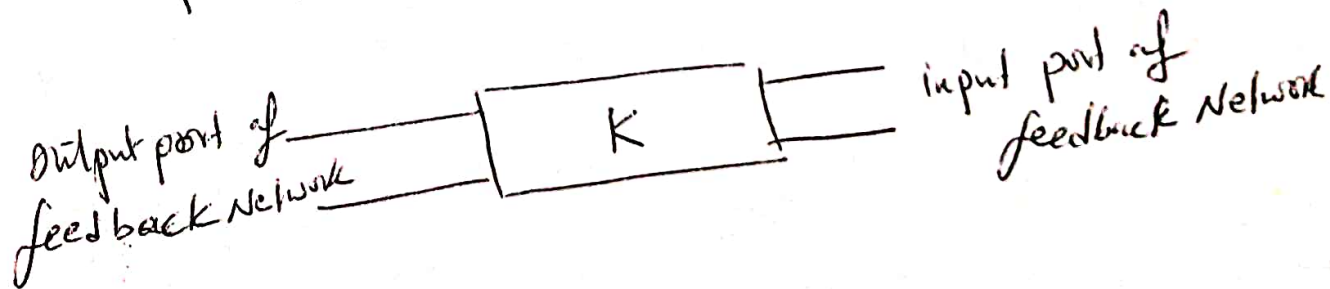
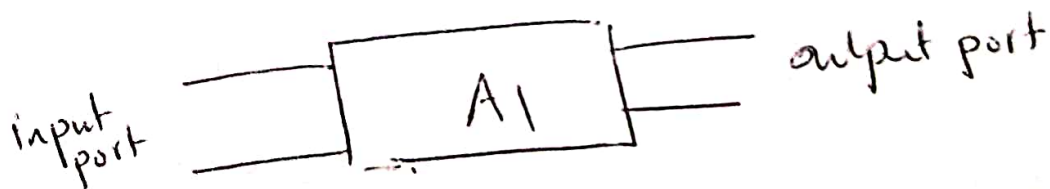
V-V



I-I

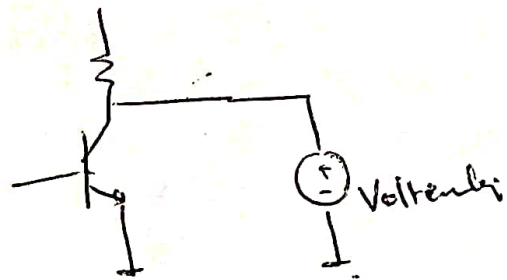


Alternative feedback system:



Mechanism of sensing:- (Sense the output y) (22)

Voltage:- we connect voltmeter in parallel

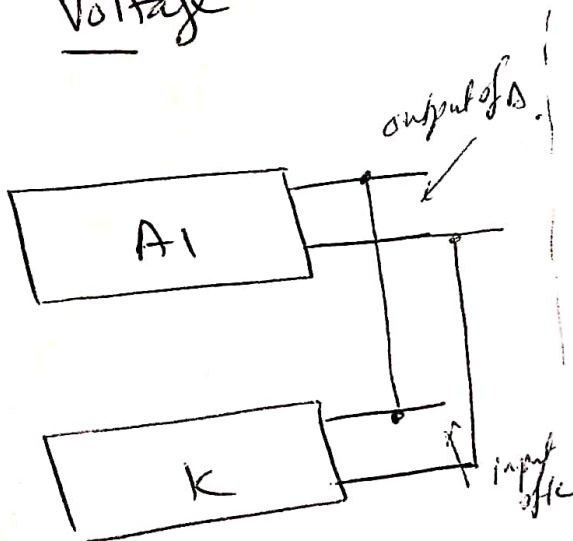


Current



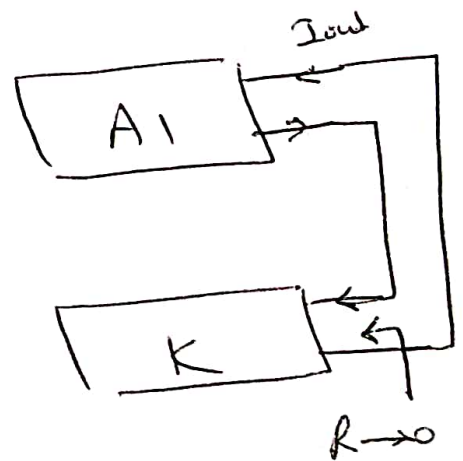
To measure current
we connect the ammeter in
series.

Voltage



The output of A₁ is connected
in parallel with the
input port of K

Current

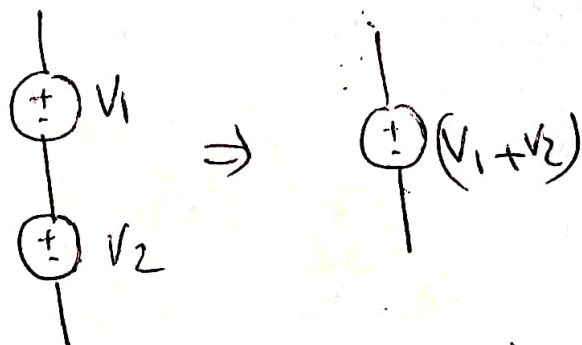
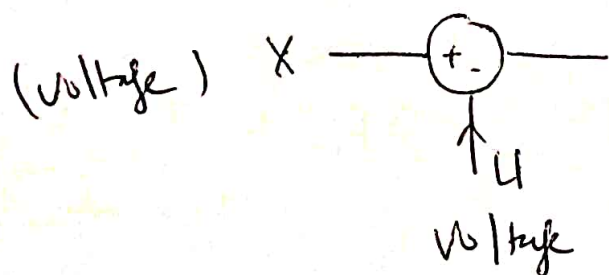


The output of A₁ is
connected in series
with the input
port of K

Return Mechanism:-

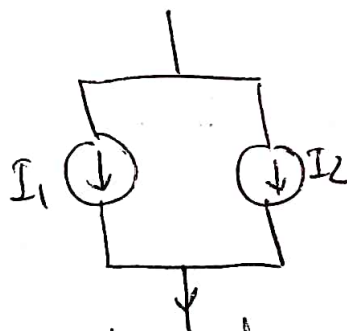
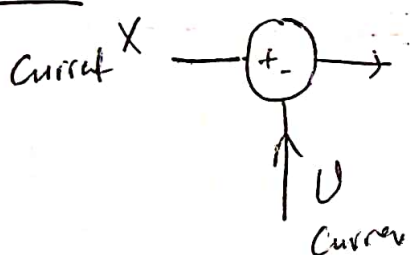
(23)

* How to subtract two voltage or two current



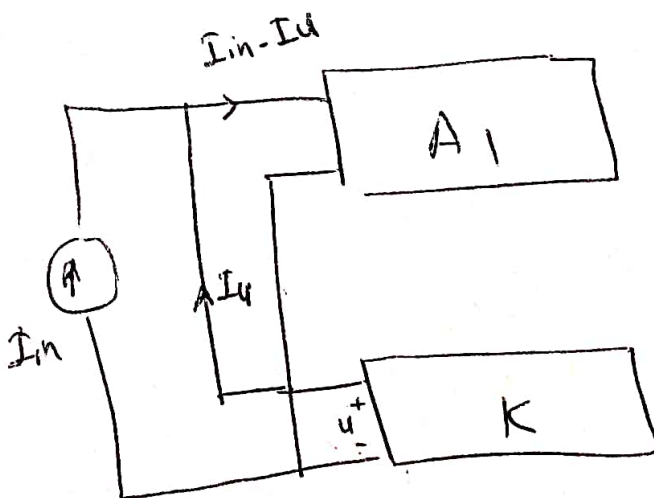
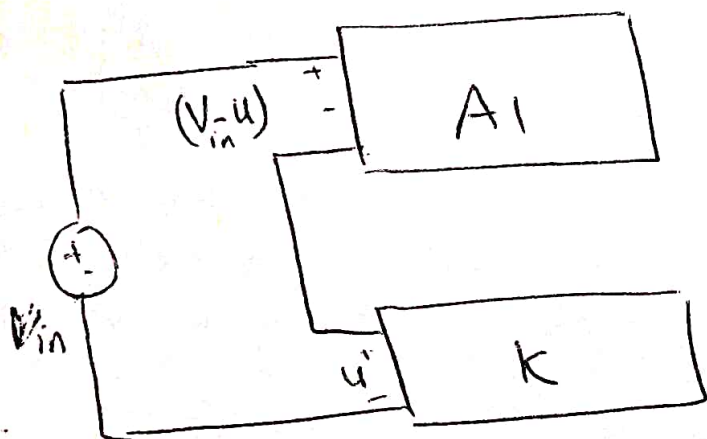
To add two voltage they have to be in series

Current

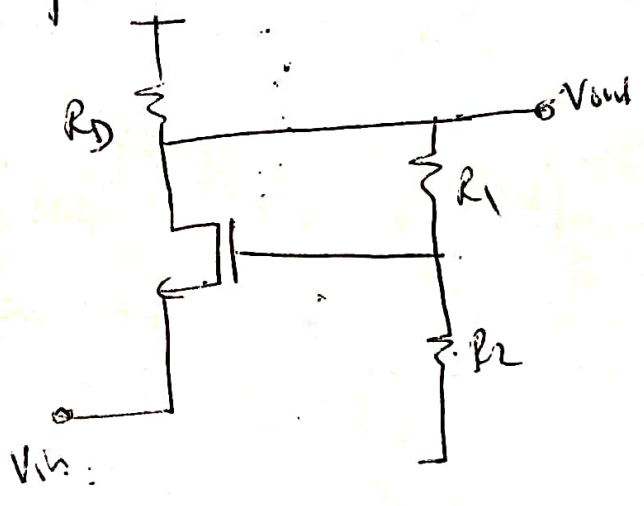


To add two current they have to be in parallel

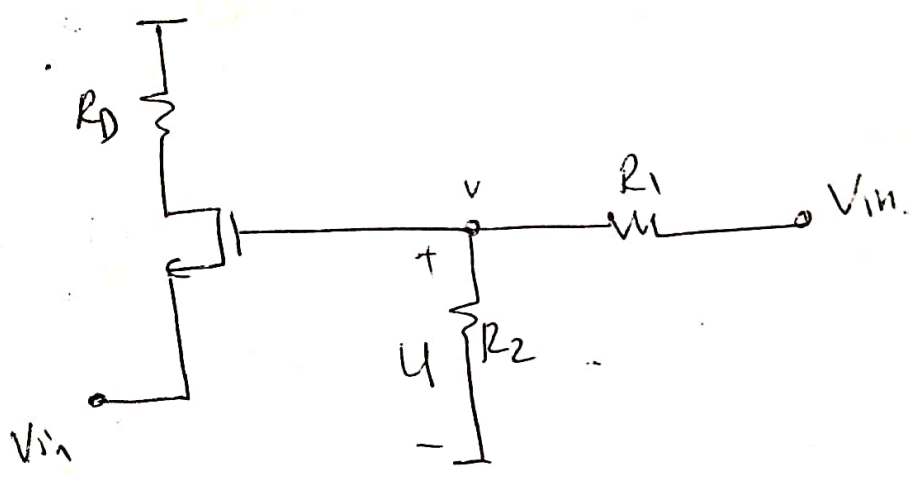
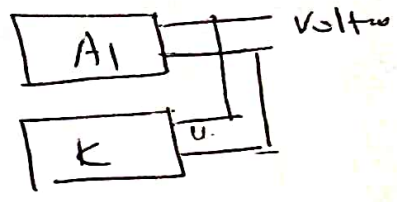
voltage



Example.

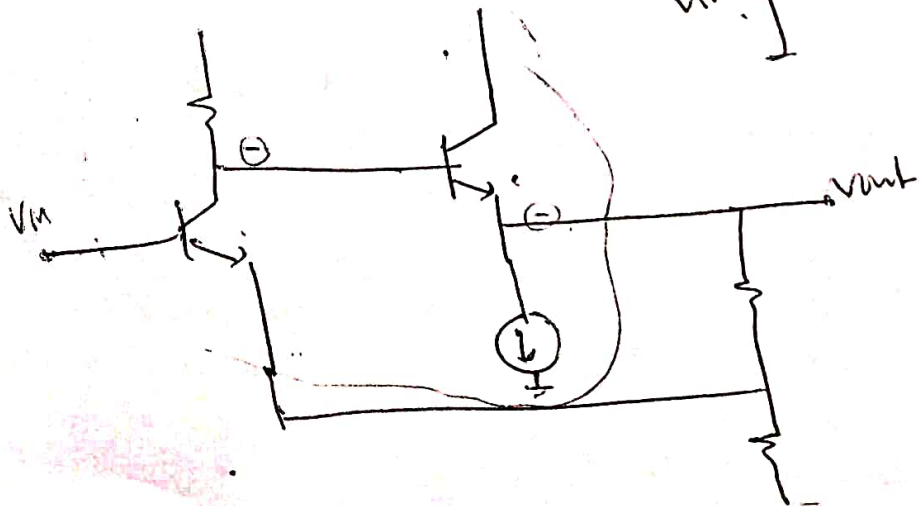
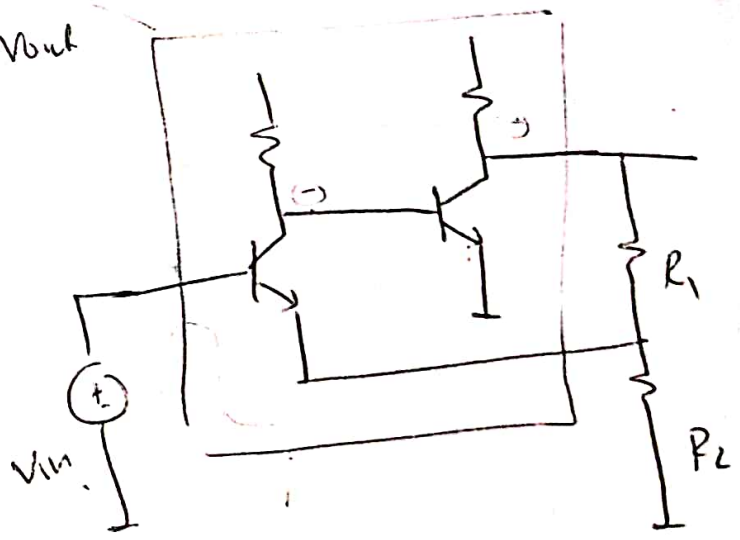
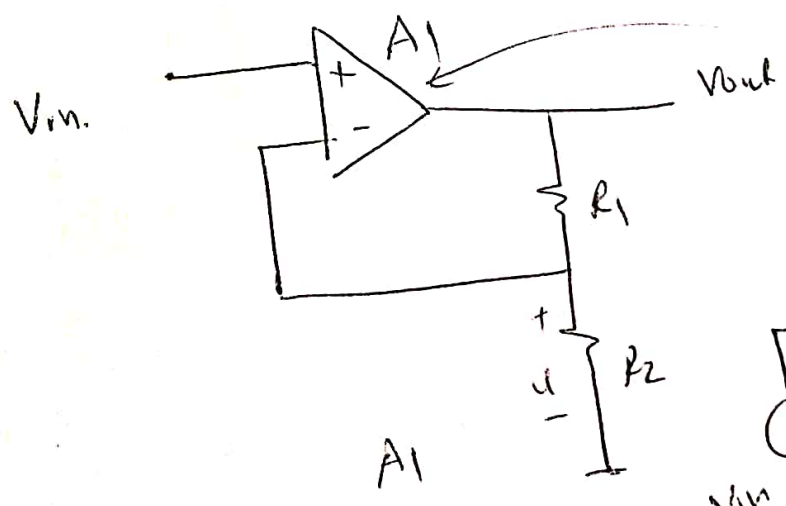


assume R_1, R_2 very large.



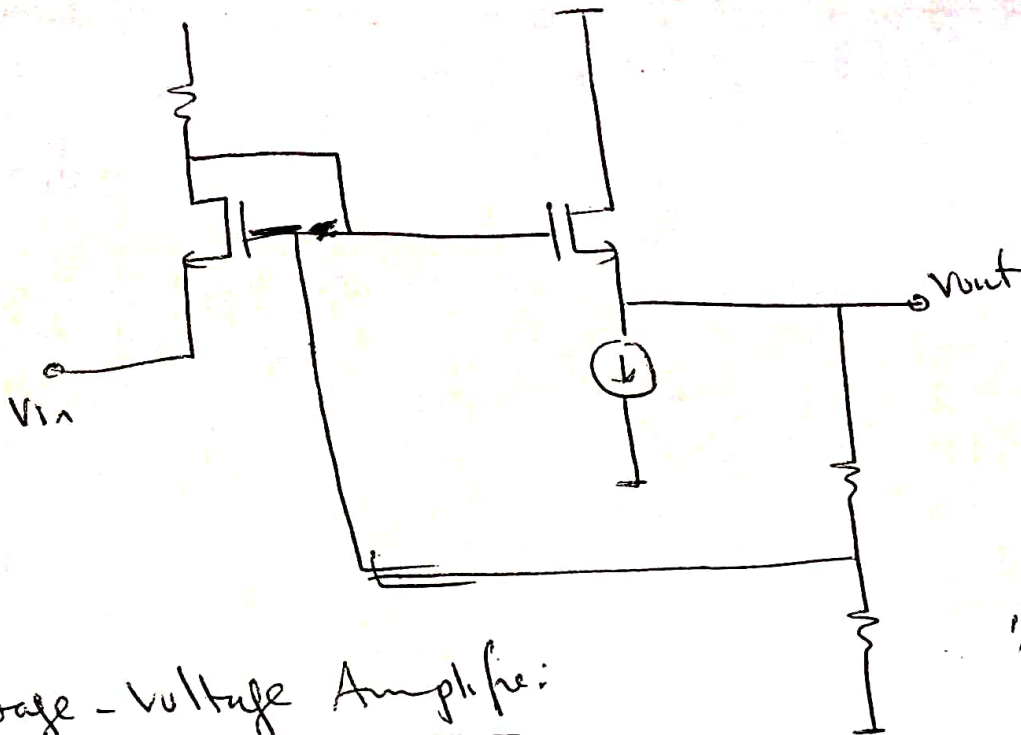
Voltage - Voltage

Ex.



Quiz

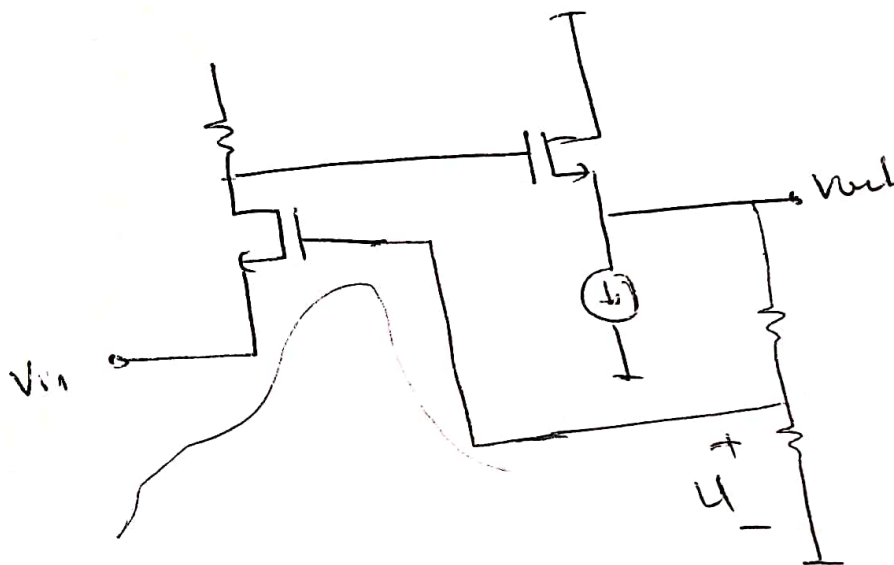
25



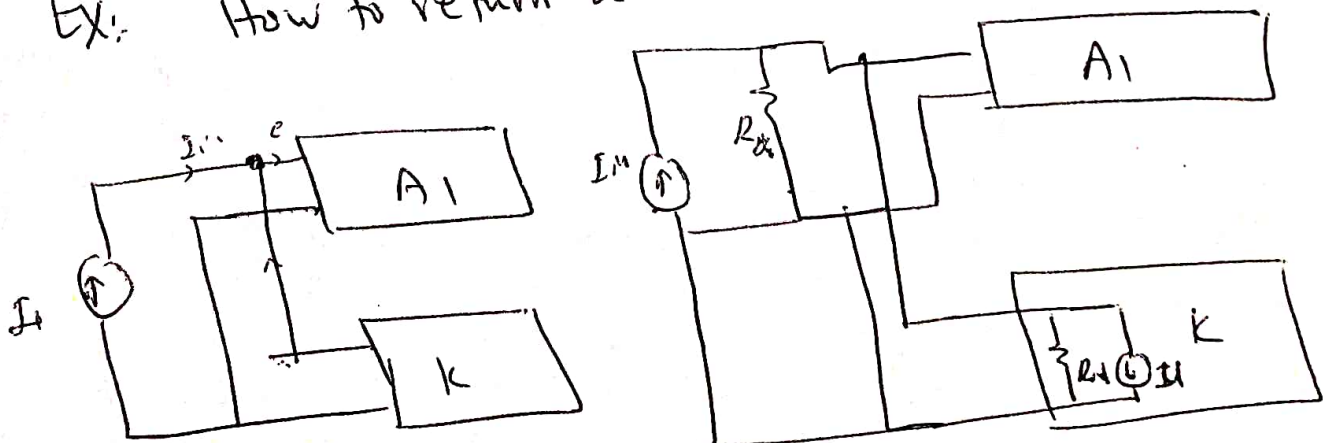
Voltage - voltage Amplifier:

Output senses

- 1) show the main Amplifier
- 2) the feedback

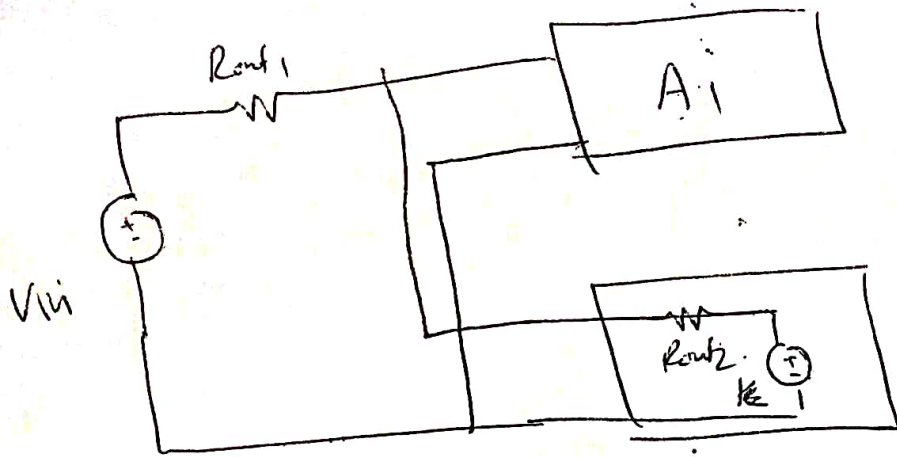


Ex: How to return a current

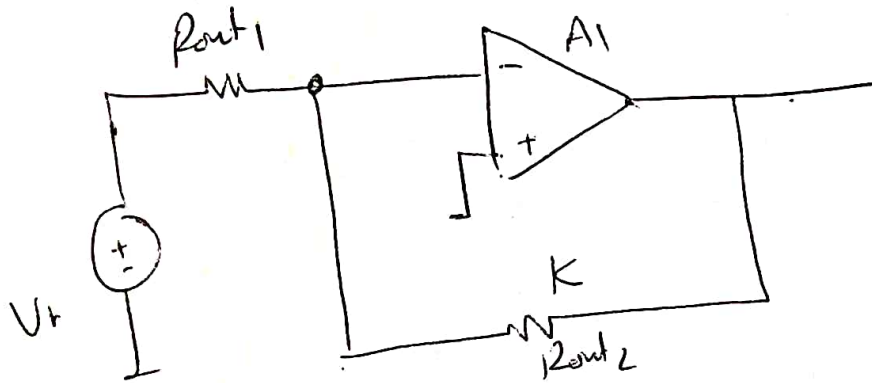


Using Thev: equi

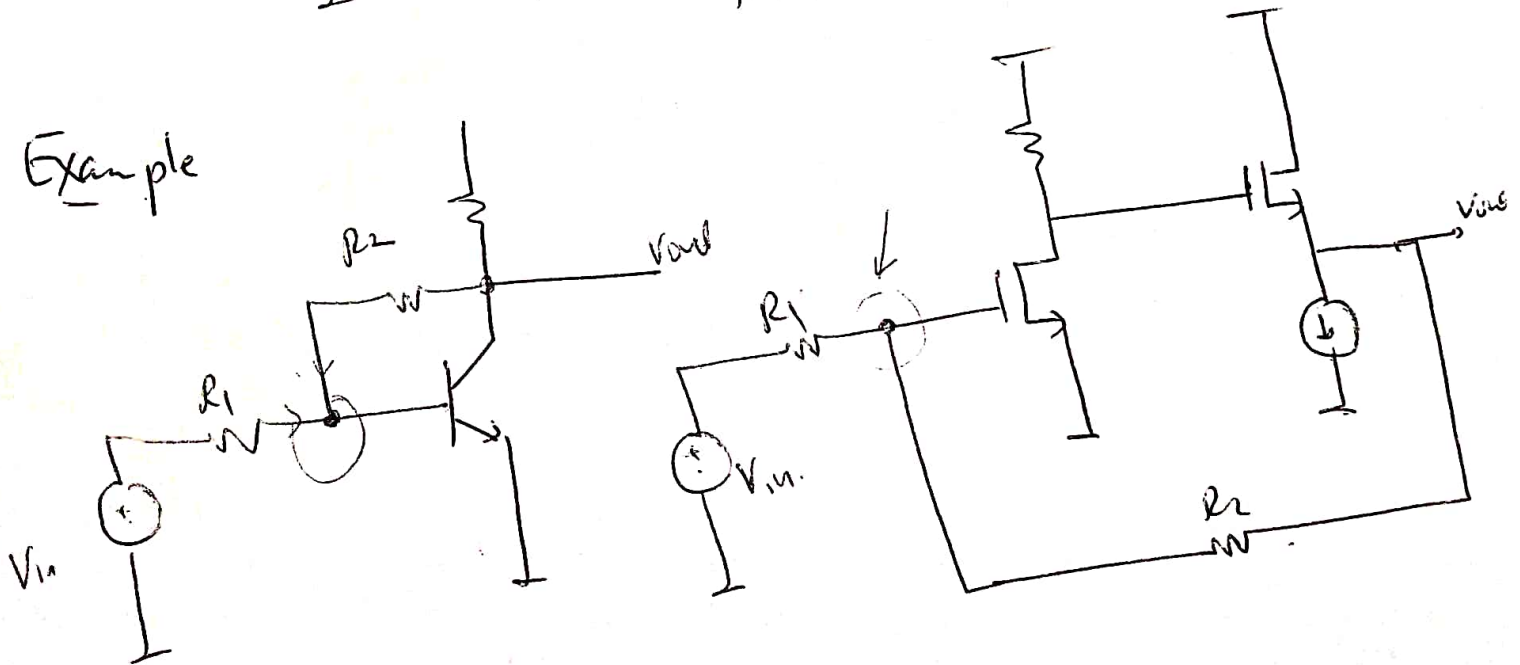
26



Ex:



Example



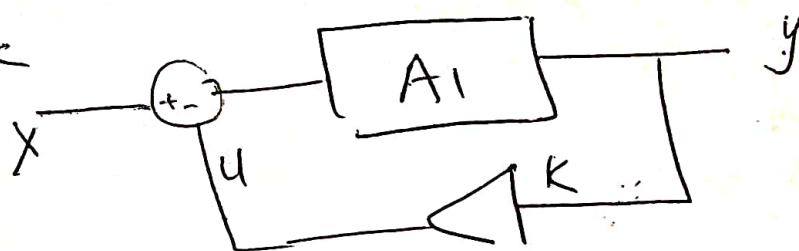
return input current
output voltage

Today's lect

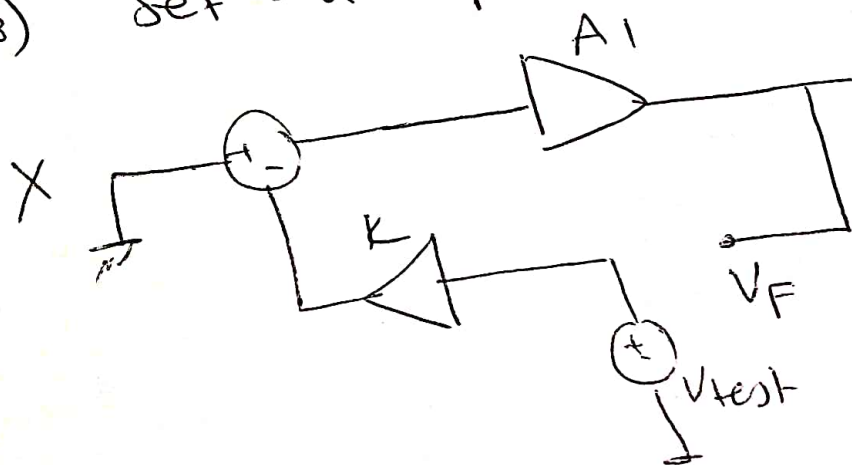
(27)

- Sign of feedback;
- Four feedback topologies;
- Analysis of feedback topologies

Sign of feedback

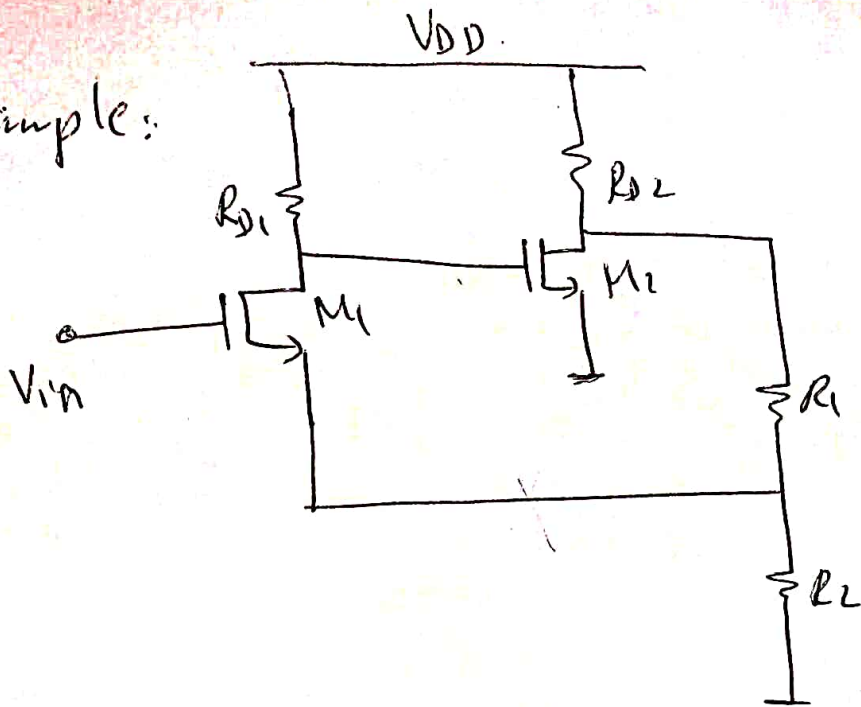


- 1) Break the feedback loop
- 2) Apply V_{test}
- 3) Set all dep source to zero.



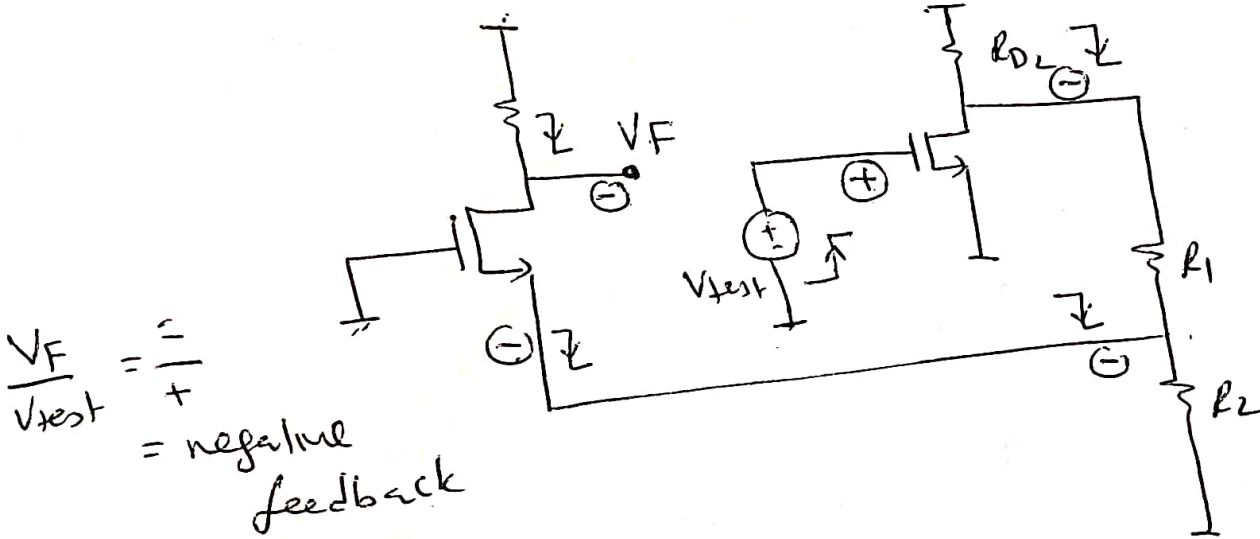
If $\frac{V_F}{V_{test}} < 0 \Rightarrow$ feedback is negative

Example:



Find the sign of feedback

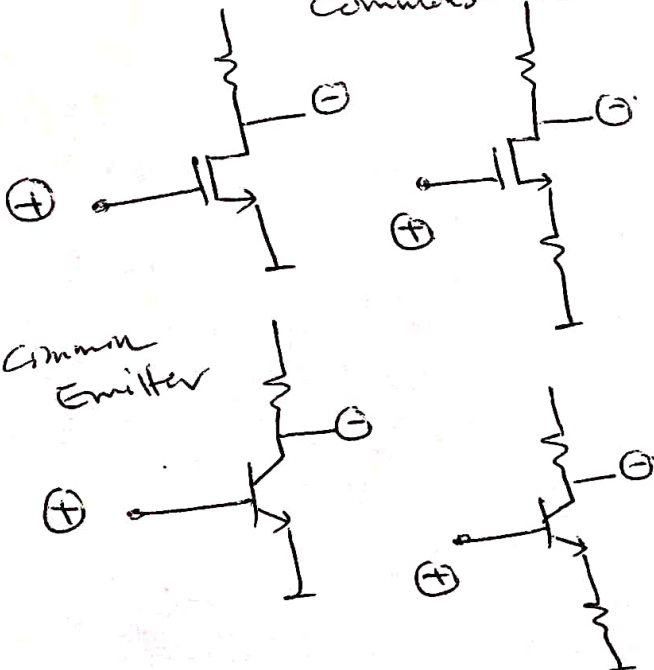
- 1) $V_{in} = 0$
- 2) Break at the gate of M_2



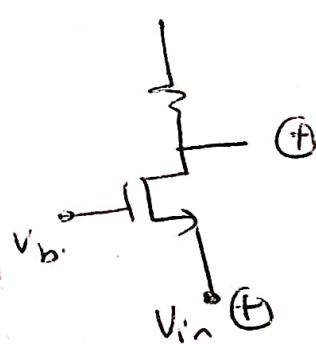
* Common Source

$A_v = (-)$

Common Source



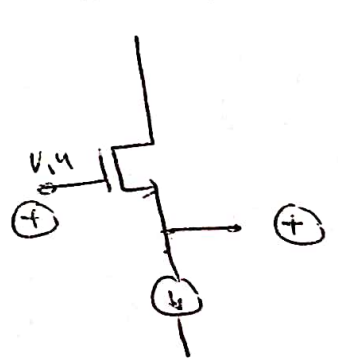
Common Gate



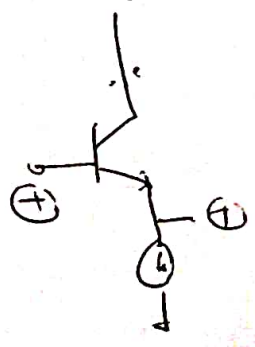
Common Base



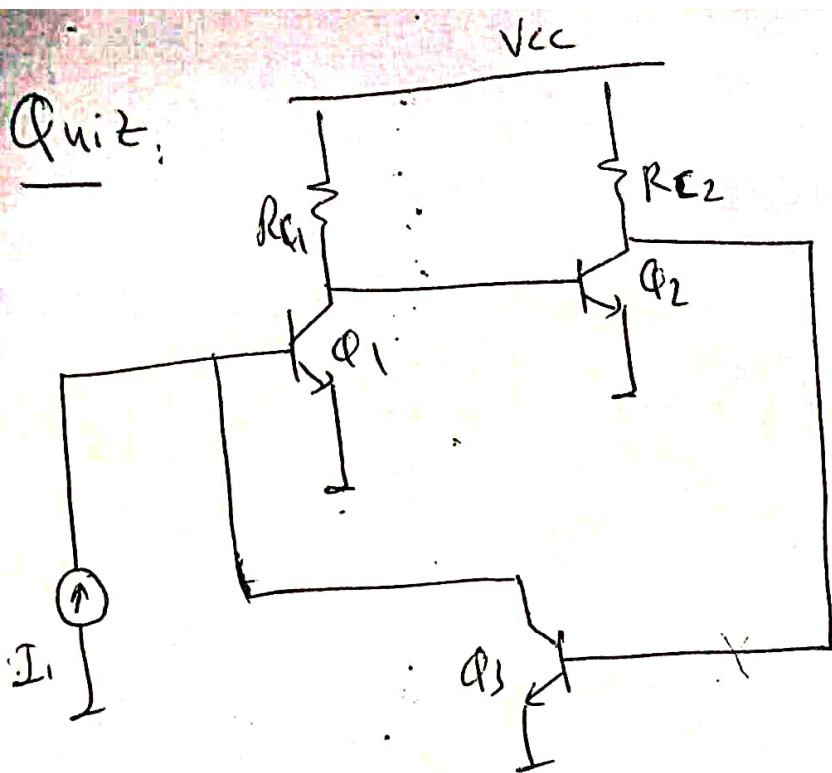
Source follower



Emitter follower

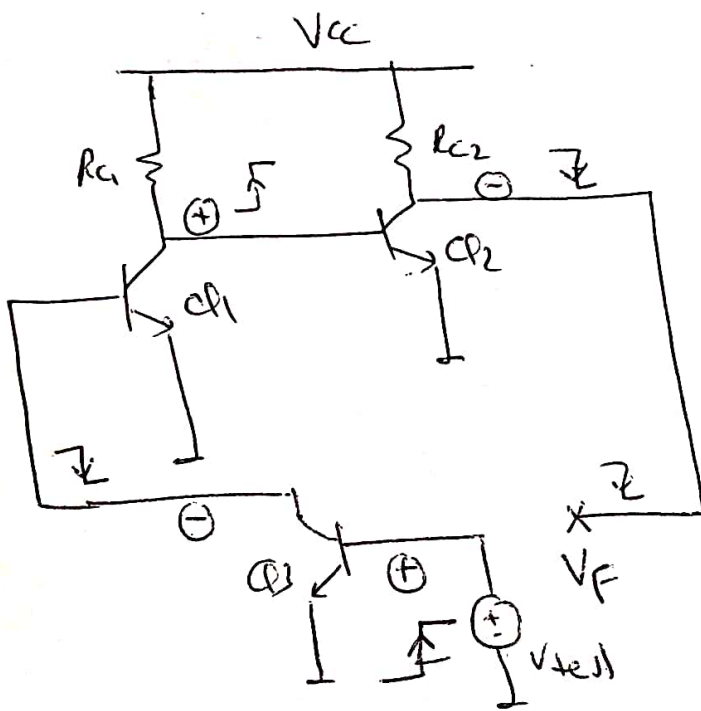
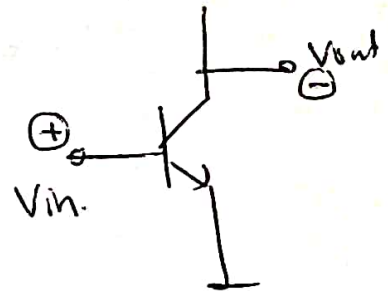


Quiz:



Find the sign of feedback.

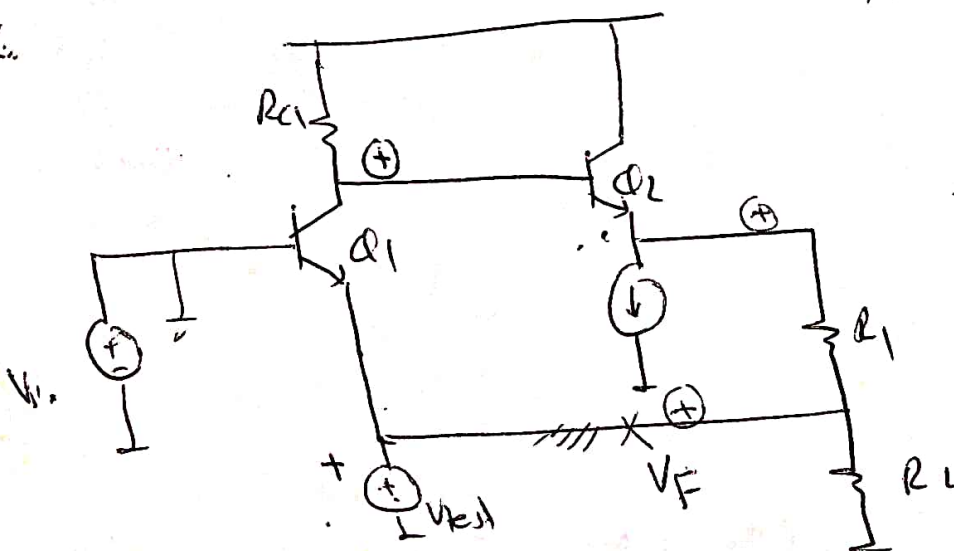
all (Q_1, Q_2, Q_3) are in Common Emitter Configuration



$$\frac{V_F}{V_{test}} = \frac{-}{+}$$

⇒ negative feedback

Ex.



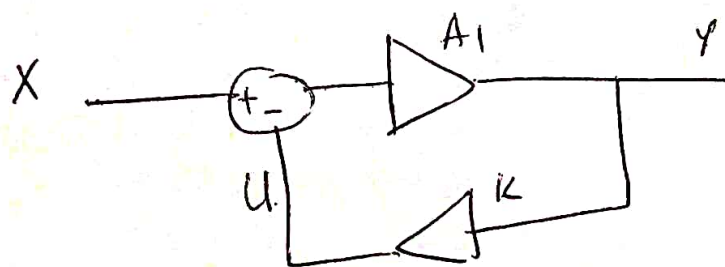
Find the sign of FB.

$$\frac{V_F}{V_{test}} = \frac{+}{+}$$

positive feedback

Four feedback topologies

(30)



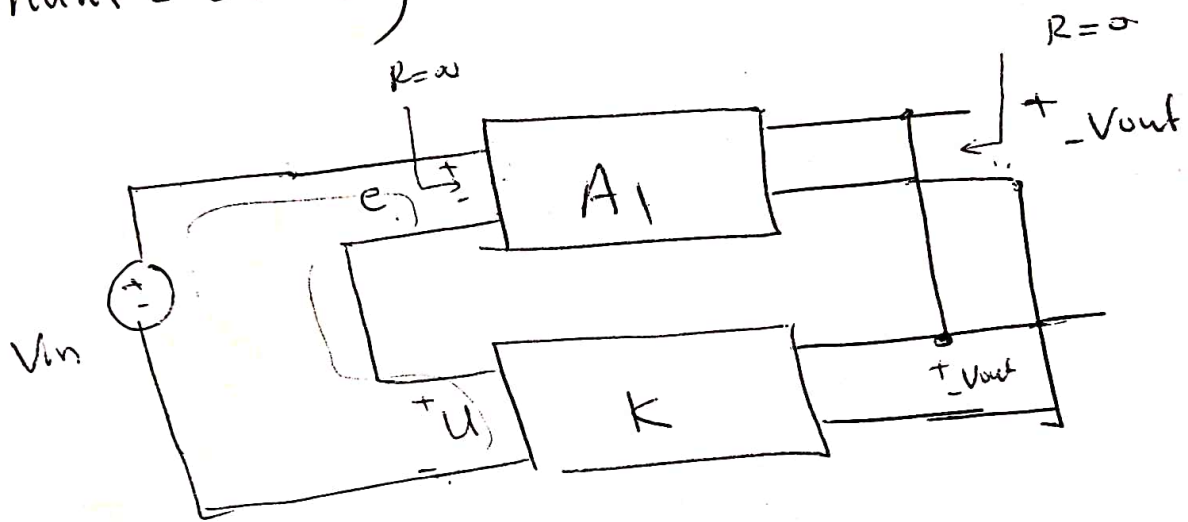
Input X	output Y	Return U	Feedback Topologies
V	V	V	Output - input Voltage - voltage ~~feedback~~ shunt - series feedback
I	V	I	Voltage - Current feedback ampl. shunt - shunt feedback
V	I	V	Current - Voltage feedback series - series "
I	I	I	Current - current feedback series - shunt feedb.

Analysis of feedback Amplifier:

(31)

- find the closed loop gain
- find the closed loop input impedance
- find the closed loop output impedance

**** Voltage - voltage feedback :**
(Shunt - series)



1) Closed loop gain $\left(\frac{V_{out}}{V_{in}} \right)$

$$U = K V_{out}$$

$$e = V_{in} - U = V_{in} - K V_{out}$$

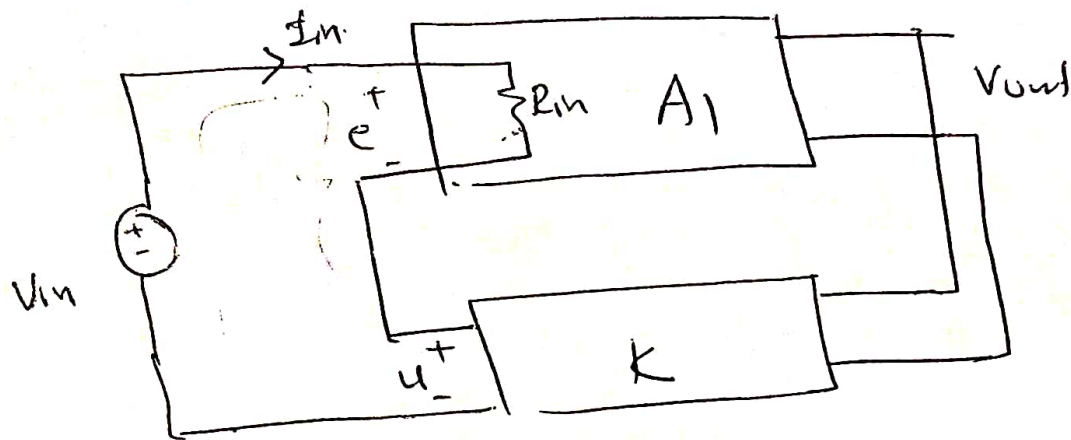
$$V_{out} = e A_1 = (V_{in} - K V_{out}) A_1$$

$$V_{out} [1 + K A_1] = V_{in} A_1$$

$$\boxed{\frac{V_{out}}{V_{in}} = \frac{A_1}{1 + K A_1}}$$

closed loop gain.

Finding the input impedance of the closed loop ⁽³²⁾



$$R_{in\text{ closed}} = \frac{V_{in}}{I_{in}}$$

R_{in} : input imp of open loop

$$V_{out} = e A_1 = R_{in} I_{in} A_1$$

$$U = K V_{out} = K [R_{in} I_{in} A_1]$$

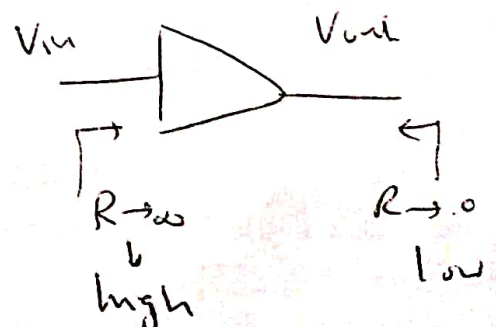
KVL:

$$V_{in} = e + U$$

$$= R_{in} I_{in} + K R_{in} I_{in} A_1$$

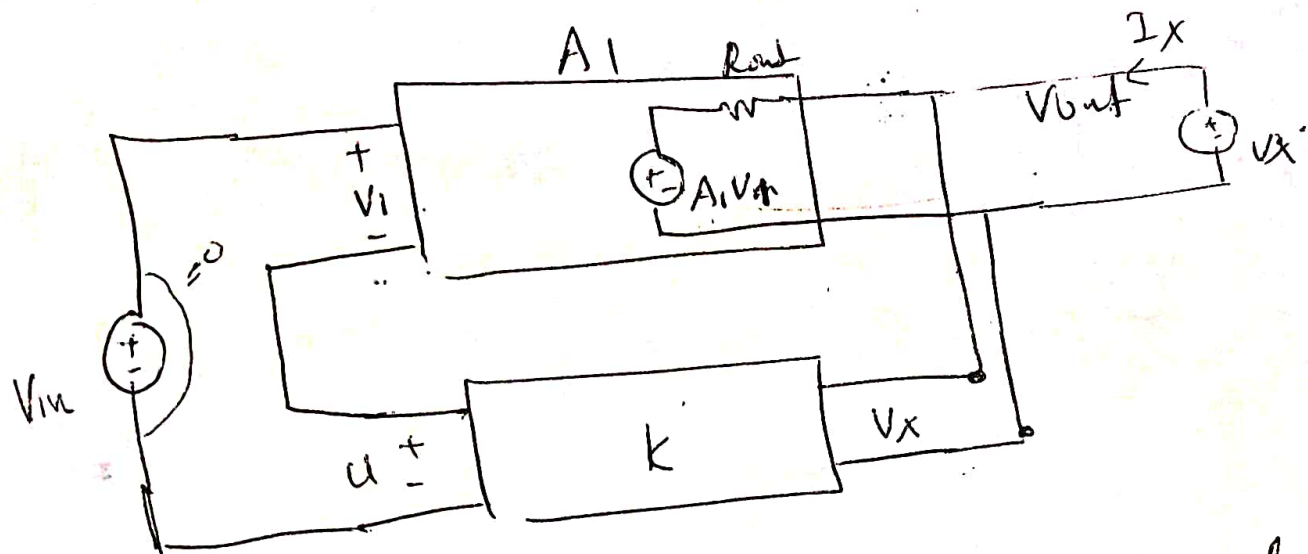
$$= I_{in} [R_{in} (1 + K A_1)]$$

$$\boxed{\frac{V_{in}}{I_{in}} = R_{in} (1 + K A_1)}$$



Closed loop output impedance.

(32)



R_{out} : output impedance open loop

$$R_{out} = \frac{V_x}{I_x} \Big|_{V_{in}=0}$$

$$U = V_x k$$

$$V_1 \neq U = 0 \Rightarrow V_1 = -U = -V_x k$$

KVL @ output loop:

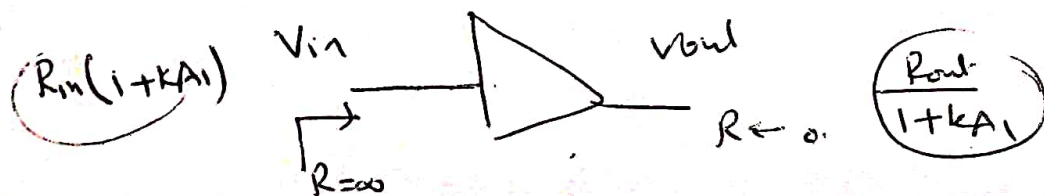
$$-A_1 V_1 - I_x R_{out} + V_x = 0$$

$$+ A_1 V_x k - I_x R_{out} + V_x = 0$$

$$I_x R_{out} = V_x [1 + k A_1]$$

Closed loop output impedance

$$R_{out} = \frac{V_x}{I_x} = \frac{R_{out}}{1 + k A_1}$$

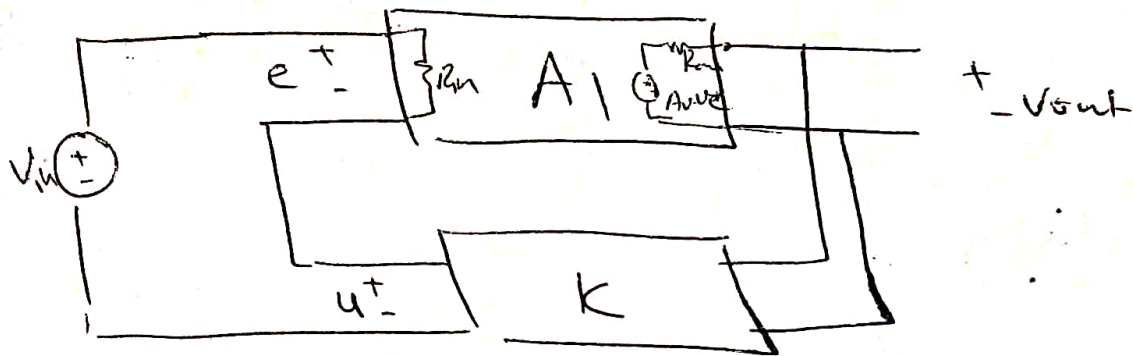


today's lect.

(34)

Examples of voltage-voltage feedback

Review: voltage-voltage feedback
Shunt-series



- closed loop parameter

$$\frac{V_{out}}{V_{in}} = A_{cl}$$

$$\frac{V_{out}}{V_{in}} = \frac{A_1}{1 + K A_1}$$

open loop parameter

A_1 : open loop gain

R_{in} : input resistance

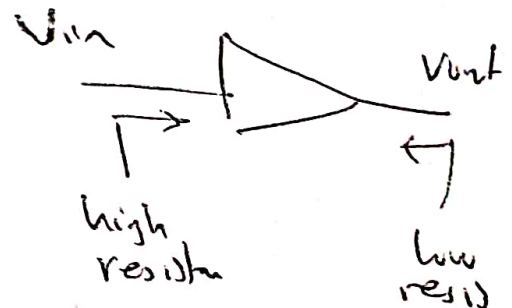
R_{out} : output resistance

- closed loop input impedance

$$R_{in, closed} = R_{in}(1 + K A_1)$$

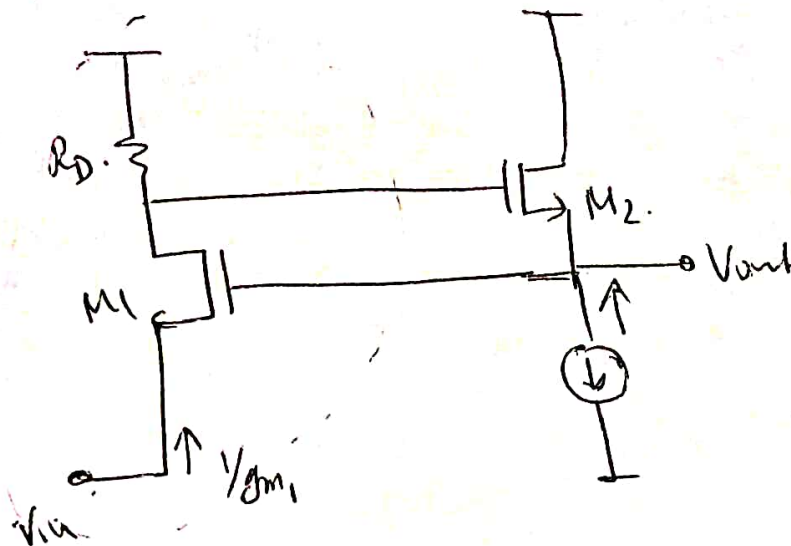
- closed loop output impedance

$$R_{out, closed} = \frac{R_{out}}{1 + K A_1}$$



Example

-35-



Find the closed loop input and output impedance

$$K = 1$$

$$(1 + K A_1) = 1 + g_{m1} R_D$$

Common gate
 $A_1 = g_{m1} R_D$

* Closed loop input impedance

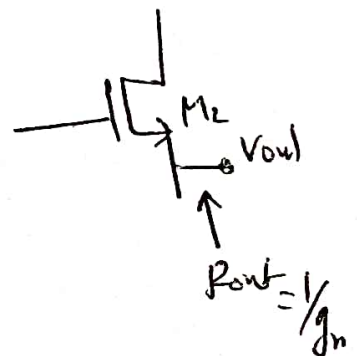
$$R_{in,cl} = R_{in}(1 + K A_1) = \frac{1}{g_{m1}}(1 + K A_1)$$

$$= \frac{1}{g_{m1}}(1 + g_{m1} R_D)$$

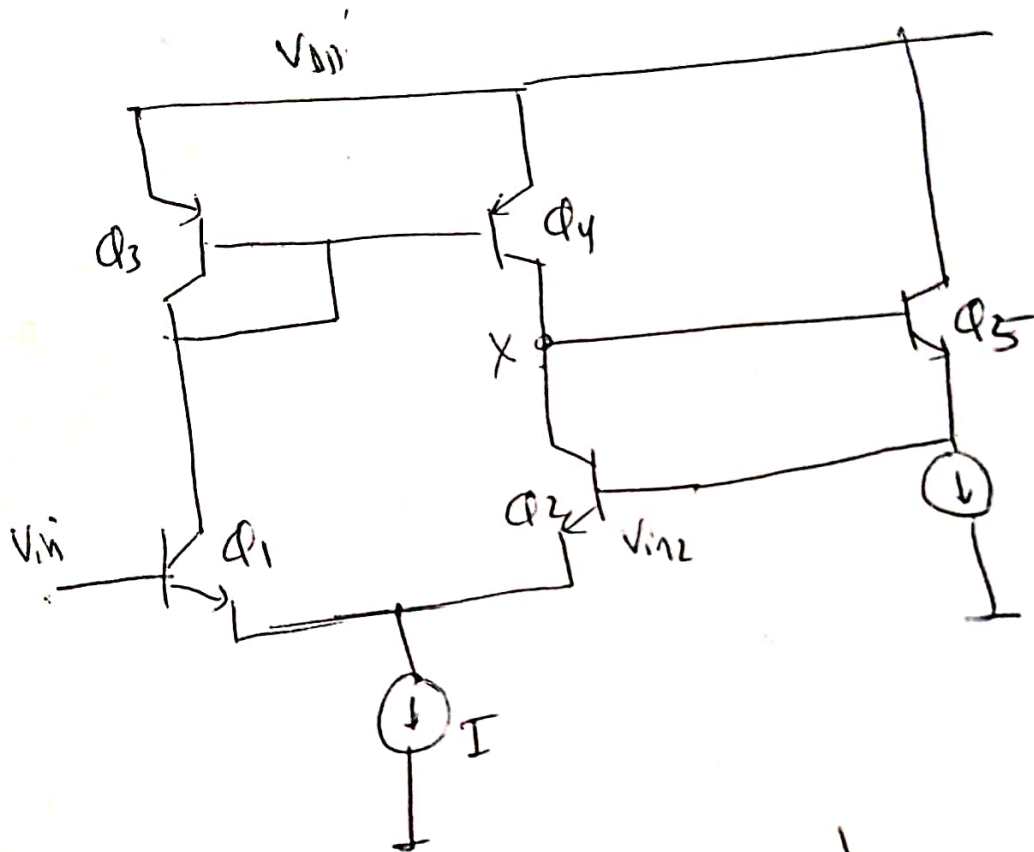
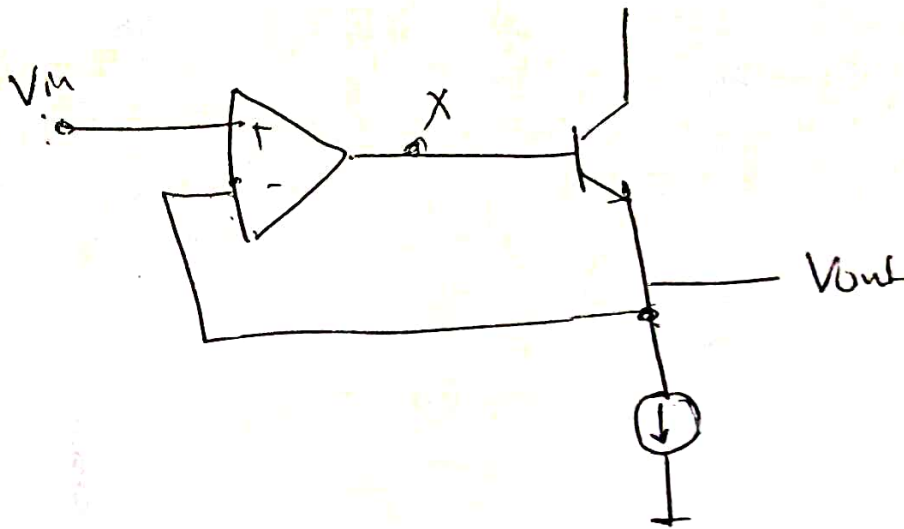
* Closed loop output impedance

$$R_{out,cl} = \frac{R_{out}}{1 + K A_1}$$

$$= \frac{1/g_{m2}}{1 + g_{m1} R_D}$$

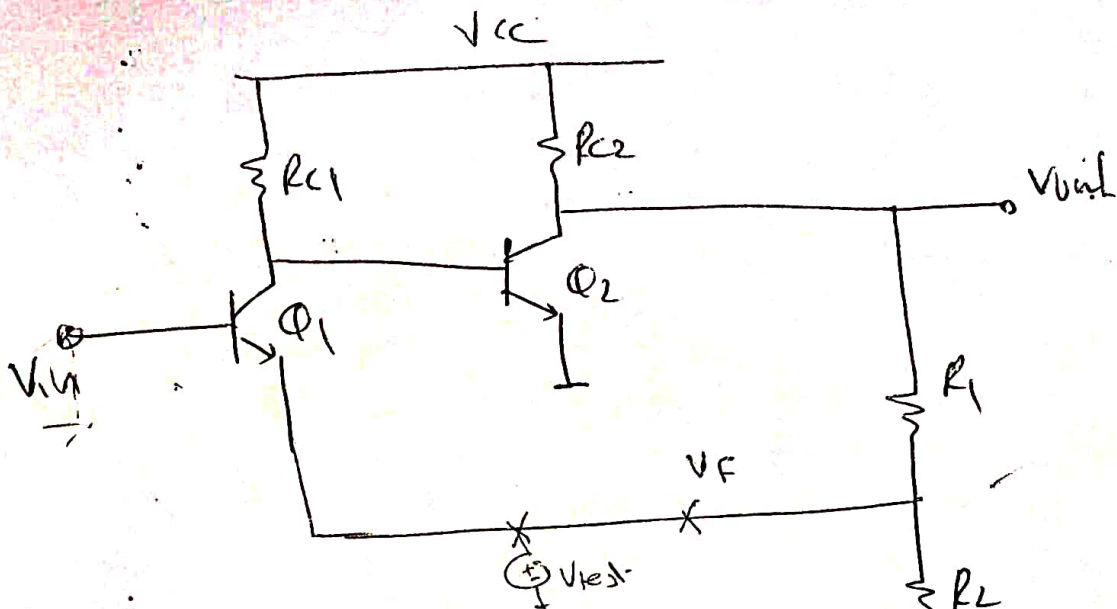


Example: - How do implement the op-amp in previous example



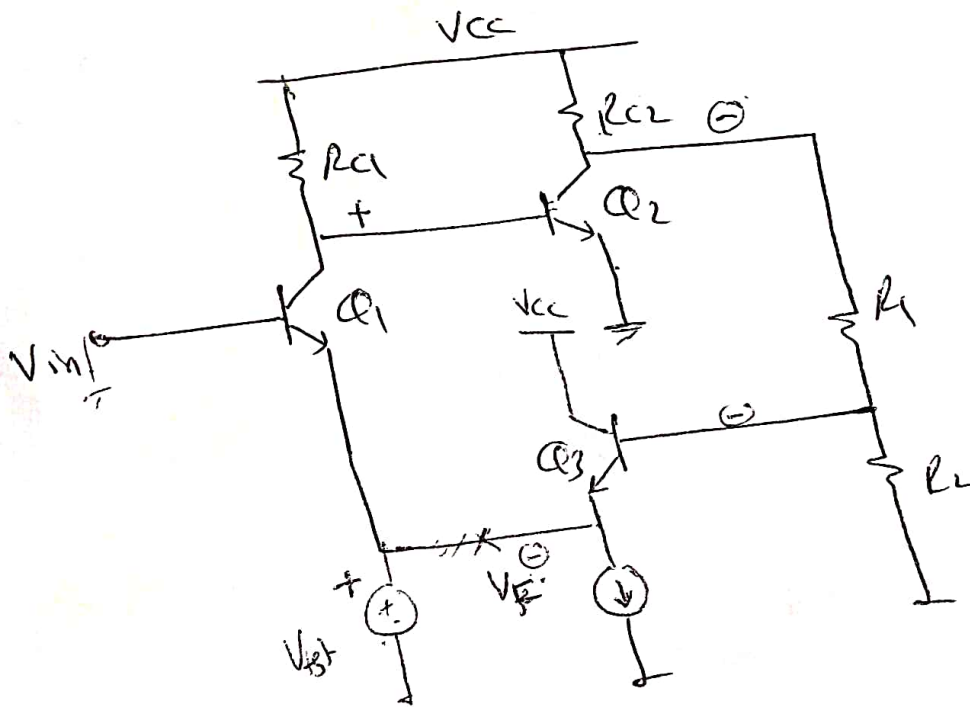
$$A_{00} = g_{m_{N1}} (r_{o_{NMOS}} \parallel r_{o_{PMOS}})$$

Example: Can we use a transistor in the feedback network
 ? yes



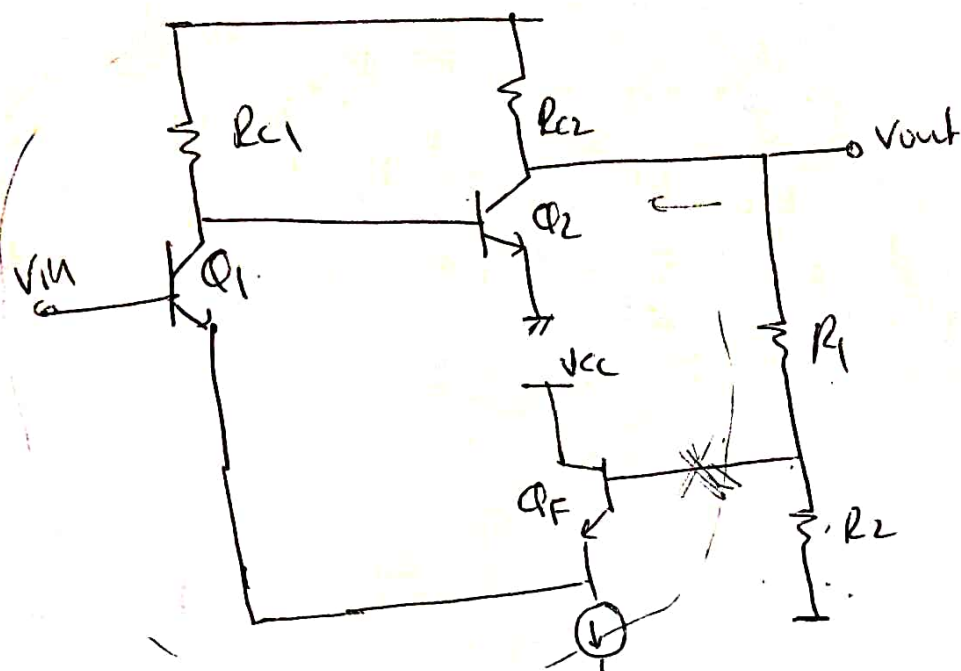
Type: Voltage-voltage
Shunt-series feedback.

$R_1 + R_2$
very large.

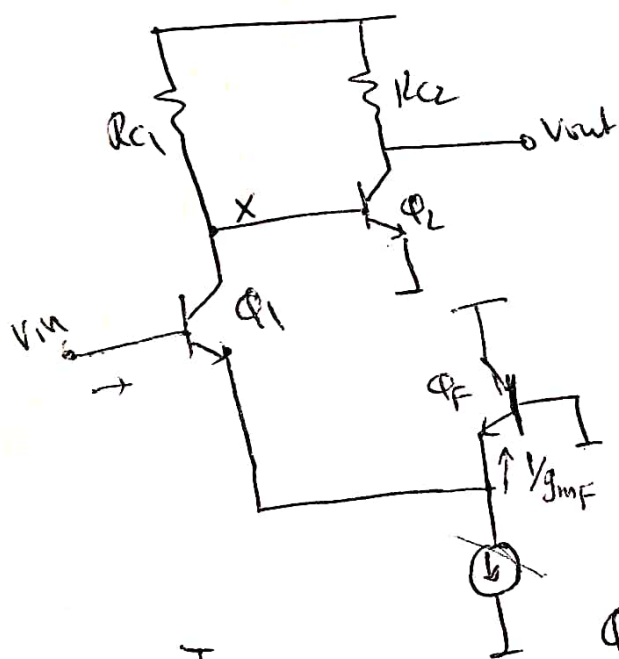


Example;

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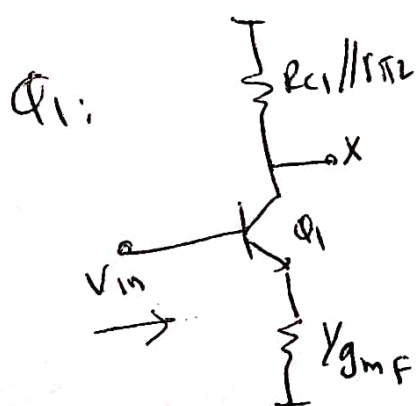


1) Find the open loop gain, R_{in} , R_{out}



$$\frac{V_{out}}{V_{in}};$$

$$= \frac{V_x}{V_{in}} \times \frac{V_{out}}{V_x}$$



Q_1 : acts as CE with degeneration

$$\frac{V_x}{V_{in}} = \frac{-(R_{c1} \parallel R_{E2})}{\frac{1}{g_{m1}} + \frac{1}{g_{mF}}}$$

Q_2 is acting as CE:

$$\frac{V_{out}}{V_x} = -g_{m2} R_{c2} \parallel (R_1 + R_2)$$

$$\frac{V_{out}}{V_{in}} = - \frac{(R_{C1} \parallel r_{\pi 2})}{\frac{1}{g_{m1}} + \frac{1}{g_{mF}}} \times -g_{m2} R_{C2} \parallel (R_1 + R_2) \quad \text{very large}$$

$$= - \frac{(R_{C1} \parallel r_{\pi 2})}{\frac{1}{g_{m1}} + \frac{1}{g_{mF}}} \times -g_{m2} R_{C2}$$

$$\text{If } g_{m1} = g_{mF} = g_{m1}$$

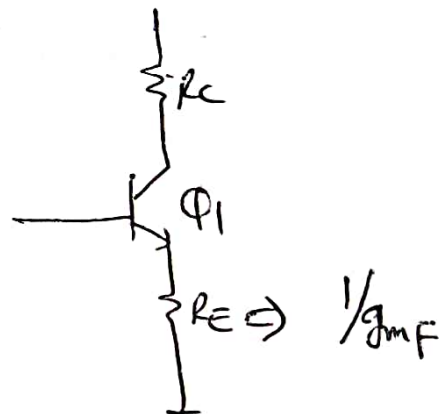
$$A_{vo} = \frac{V_{out}}{V_{in}} = \frac{g_{m1}}{2} (R_{C1} \parallel r_{\pi 2}) g_{m2} R_{C2}$$

Open loop input impedance

$$R_{in} = r_{\pi 1} + (\beta + 1) R_E$$

$$= r_{\pi 1} + (\beta + 1) \frac{1}{g_{mF}}$$

$$= r_{\pi 1} + \frac{\beta}{g_{mF}} = r_{\pi 1} + r_{\pi 1} = 2r_{\pi 1}$$



Open loop output impedance

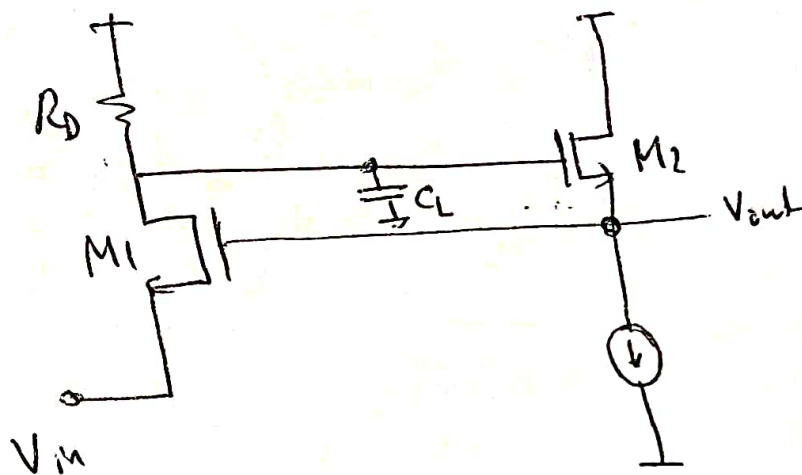
$$R_{out} = R_{C2} \parallel (R_1 + R_2) \quad \text{very large}$$

$$\approx R_{C2}$$

Closed loop parameter	$K = \frac{R_2}{R_1 + R_2}$	$R_{in, closed} = R_{in} (1 + K A_{vo})$
$A_{closed} = \frac{A_{vo}}{1 + K A_{vo}}$		$R_{out, closed} = \frac{R_{out}}{1 + K A_{vo}}$

Example: Unity gain buffer

-40-

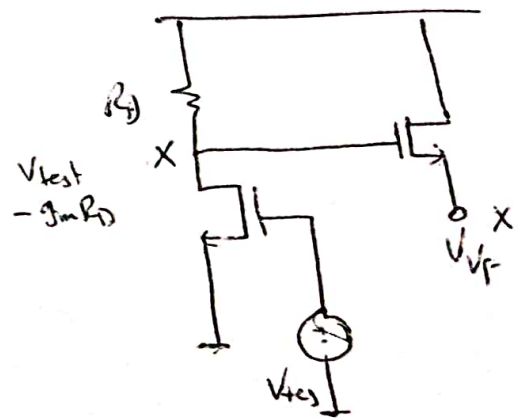
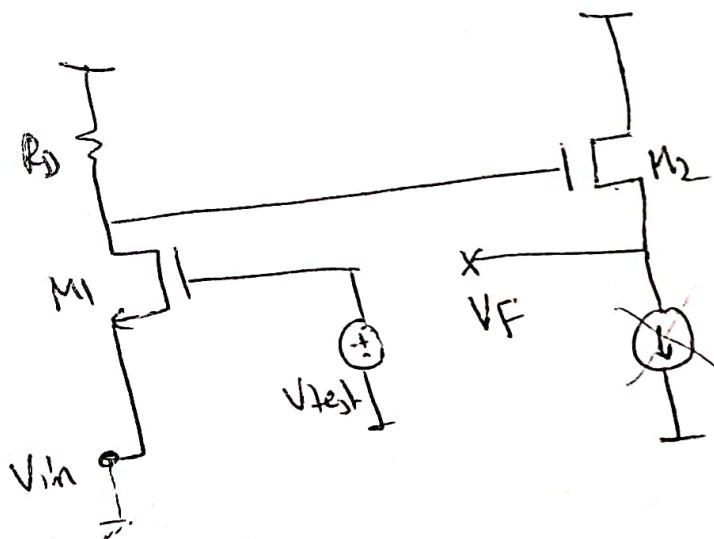


Find the closed loop BW of the circuit

$$\text{Closed loop BW} = \text{open loop BW} \times (1 + \text{Loop gain})$$

$$\text{Open loop BW} = \omega_p = \frac{1}{R_D C_L}$$

To find the loop gain: $= -\frac{V_F}{V_{\text{test}}}$



$$\frac{V_F}{V_X} = 1$$

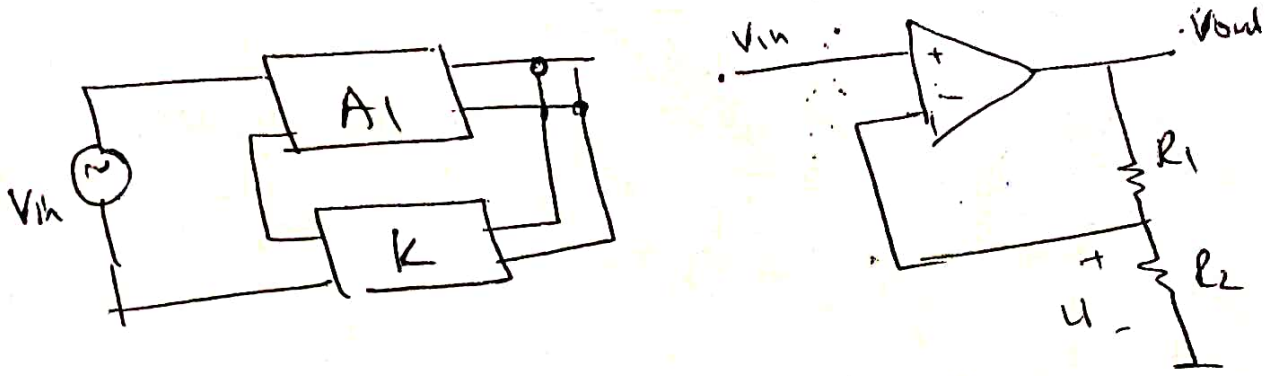
$$\frac{-V_F}{V_{\text{test}}} = g_{m1} R_D = K_{A1}$$

Closed loop BW

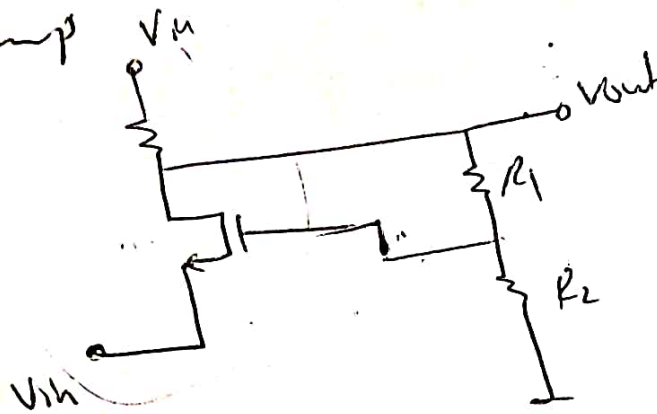
$$= \frac{1}{R_D C_L} (1 + g_{m1} R_D) \approx \frac{g_{m1}}{C_L}$$

$$\frac{V_F}{V_{\text{test}}} = 1$$

Summary of voltage-voltage feedback circuit 41-

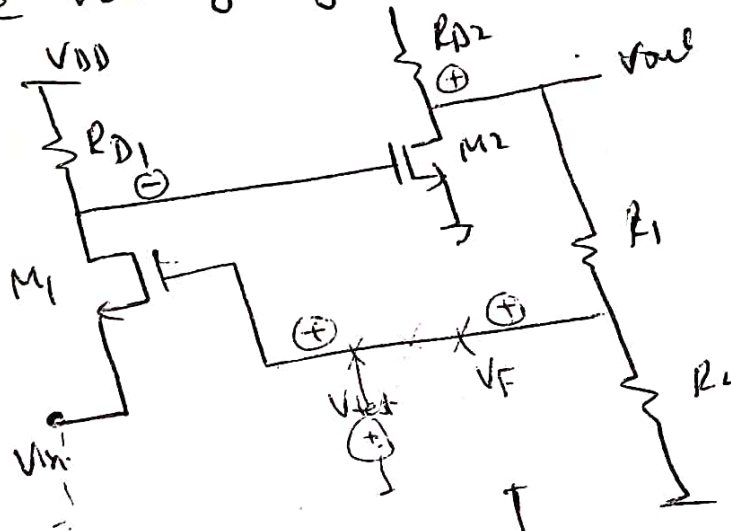


Build op-amp

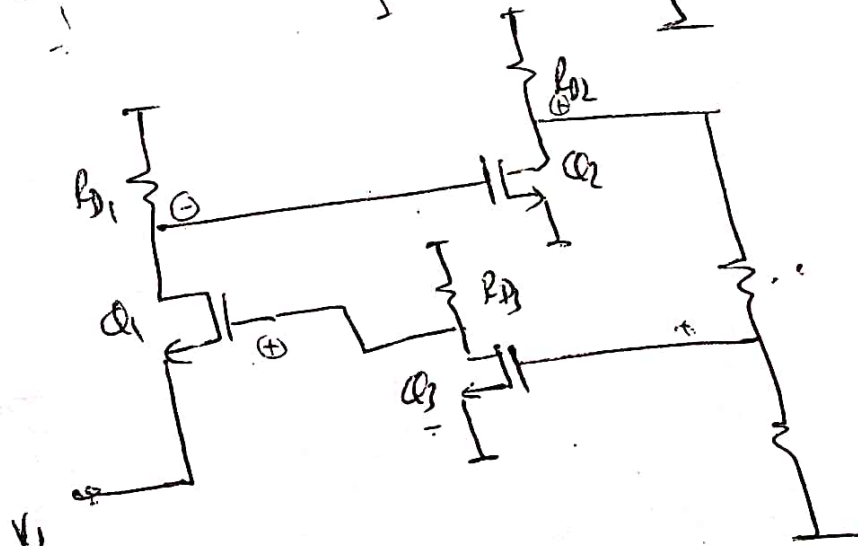


To have more voltage gain

Positive feedback
unwanted



Negative feedback

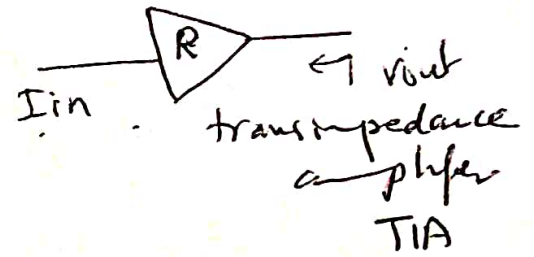


Today's lect

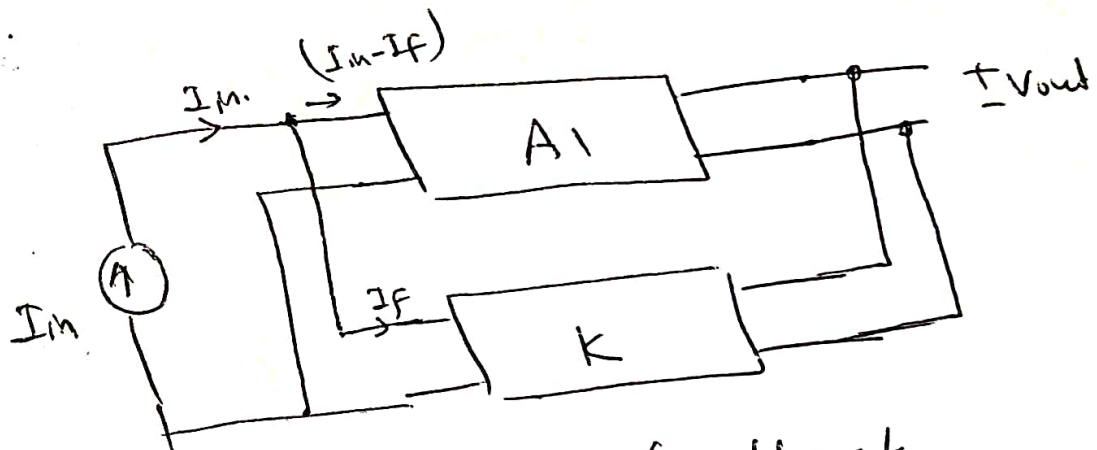
42-

- Voltage - Current feedback
- Shunt - Shunt feedback

- Examples:



Voltage - current feedback



Analysis of voltage current feedback

Quiz: Does the unit of K have to be $\frac{1}{\text{unit } A_1}$

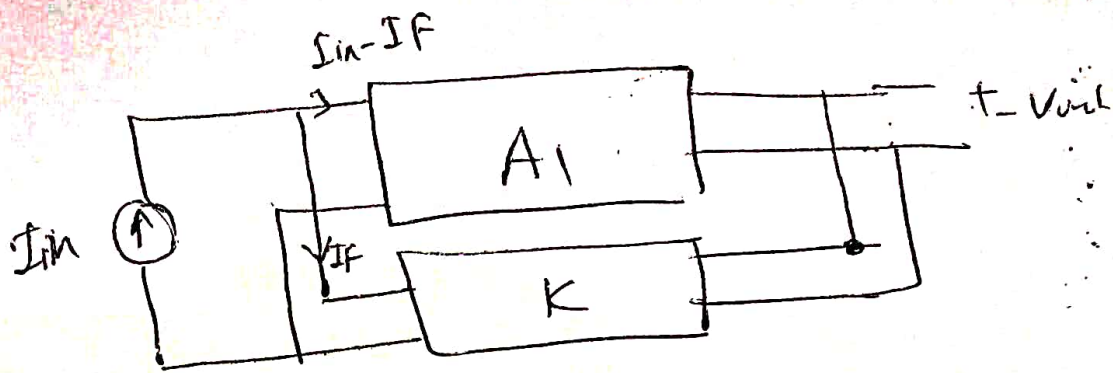
Unit A: $\frac{V_{out}}{I_{in}} = R (\Omega)$

Unit K: $\frac{I_F}{V_{out}} = \frac{1}{R} (1/\Omega)$

the answer yes:

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

$\Rightarrow$ So, be sure that KA_1 has no unit



$$I_F = K V_{out}$$

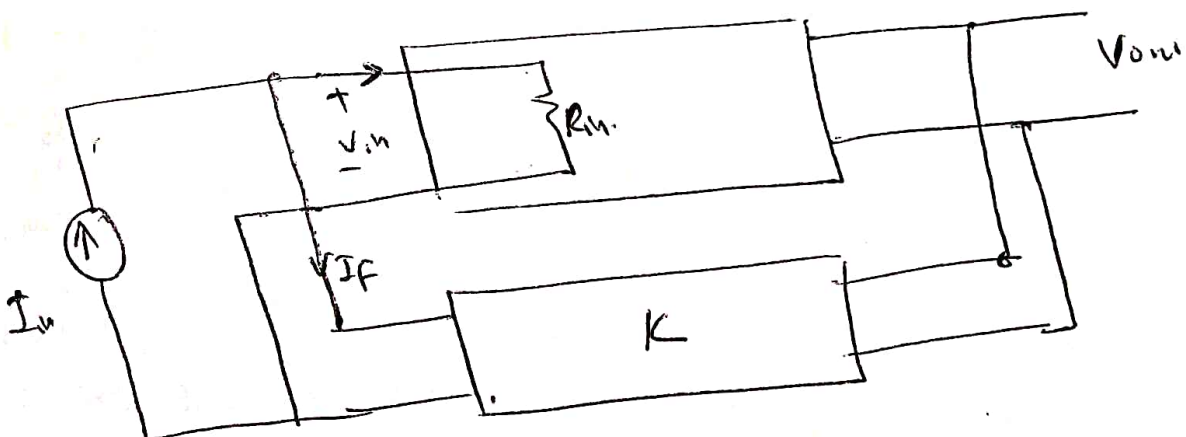
$$V_{out} = A_1 [I_{in} - I_F] = A_1 [I_{in} - K V_{out}]$$

$$V_{out} = A_1 I_{in} - V_{out} A_1 K$$

$$V_{out} [1 + K A_1] = A_1 I_{in}$$

$$R_{open} \otimes = \frac{V_{out}}{I_{in}} = \frac{A_1}{1 + K A_1} \Rightarrow \text{closed loop gain}$$

Closed loop input Impedance



$$V_{out} = \frac{V_{in}}{R_{in}} \times R_o(\text{gain}) \quad \text{KVL:}$$

$$V_{in} = R_{in} (I_{in} - I_F) = R_{in} (I_{in} - K \frac{V_{in}}{R_{in}} R_o)$$

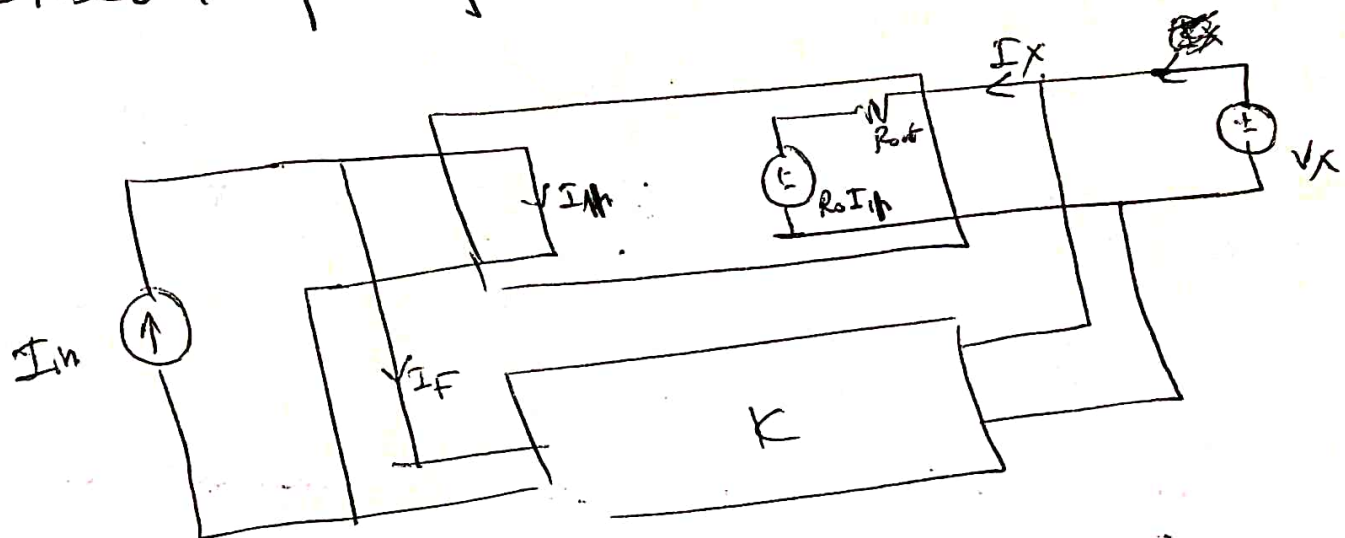
$$\left(\frac{V_{in}}{I_{in}} = \frac{R_{in}}{1 - K R_o} \right) \quad \text{open loop gain}$$

Notes:

Return current $\rightarrow$ Reducing R_{in}

Return voltage $\rightarrow$ increasing R_{in}

Closed loop output impedance



$$R_{out} = \frac{V_X}{I_X} \Big|_{I_{in}=0} \Rightarrow I_{in} = 0$$

$$I_F = K V_X$$

$$I_1 = -K V_X$$

KVL: $V_X + R_{out} I_X = 0$

$$I_X = \frac{V_X - R_0 I_1}{R_{out}}$$

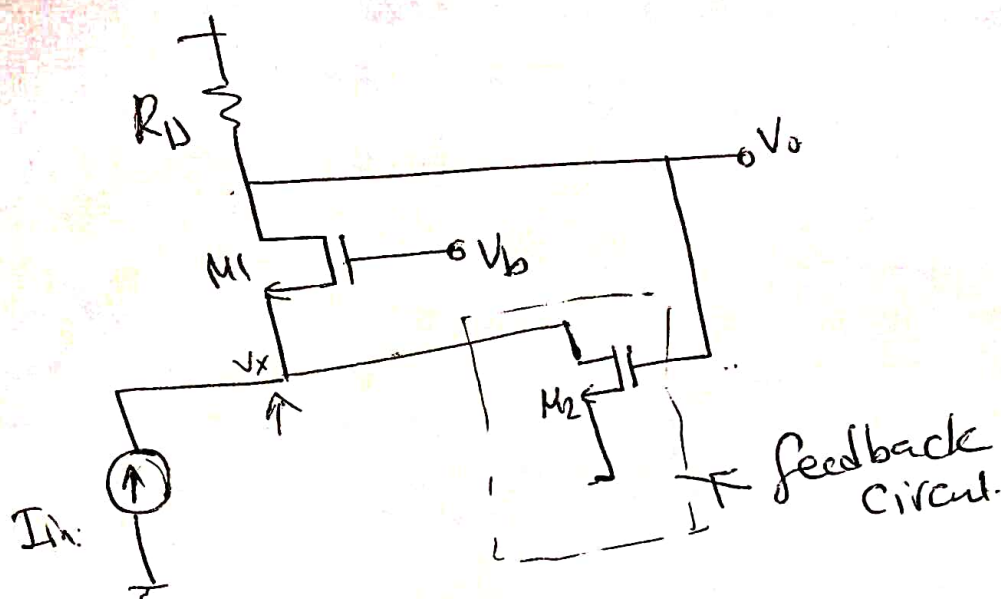
$$I_X = \frac{V_X + K V_X R_0}{R_{out}} = \frac{V_X (1 + K R_0)}{R_{out}}$$

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

$\downarrow$ open-loop gain

Note: sensing of voltage $\Rightarrow$ Reducing R_{out}
 sensing of current $\Rightarrow$ increasing R_{out}

Ex: How do we return current to the input -45-



- Open loop gain R_D $\frac{V_o}{I_{in}} = \frac{g_{m1} R_D}{1}$

$$V_o = R_D I_{in} \Rightarrow \frac{V_o}{I_{in}} = R_D = R_o$$

- R_{in} open loop $\frac{1}{g_{m1}}$

- R_{out} open loop R_D

Closed loop parameter:

$$K = g_{m2} / A = R_D = R_o$$

$$R_{o \text{ closed loop}} = \frac{R_o}{1 + K R_o} = \frac{R_D}{1 + g_{m2} R_D}$$

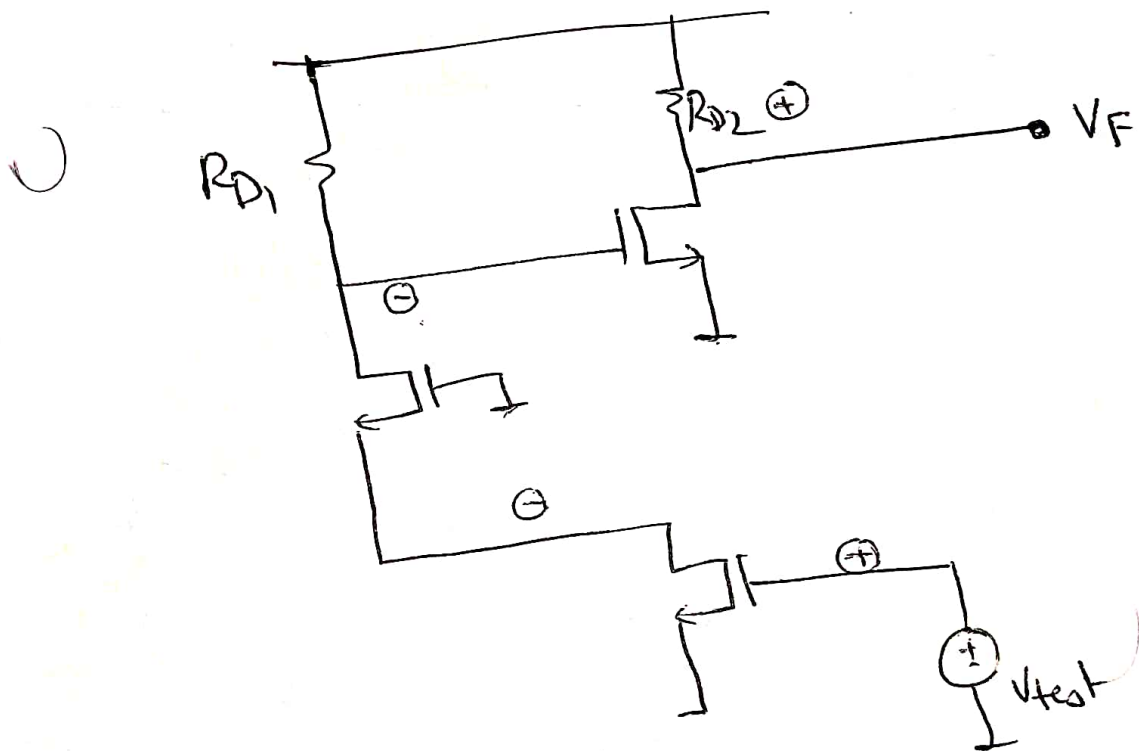
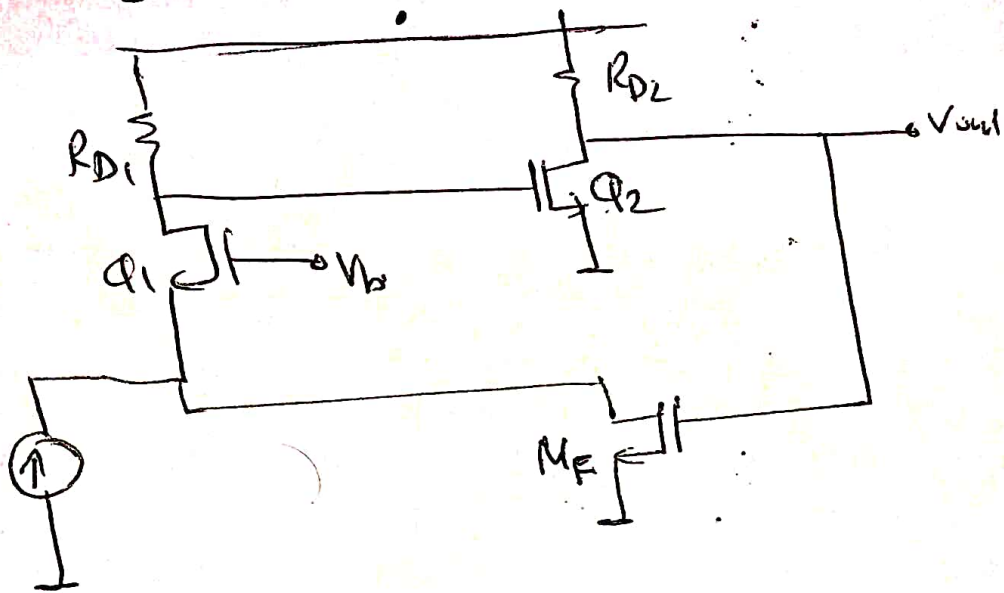
$$\text{Closed loop input impedance} = \frac{R_{in}}{1 + K R_o} = \frac{1/g_{m1}}{1 + g_{m2} R_D}$$

Closed loop output impedance

$$= \frac{R_{out}}{1 + K A_1} = \frac{R_D}{1 + g_{m2} R_D}$$

Improving the gain

-46-



$$\frac{V_F}{V_{test}} = \frac{+}{+} = \oplus$$

positive feedback.

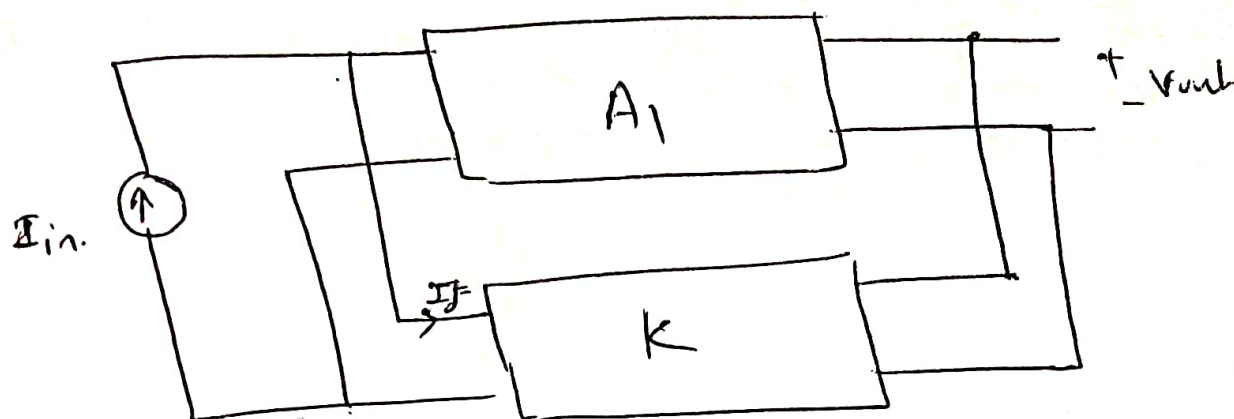
⇒ We have problem of negative feedback

Today's lect.

48.

- Examples of voltage-current feedback
- Current-current feedback

Review: Voltage-current feedback
shunt-shunt



$\frac{V_{out}}{I_{in}}$: closed loop gain = $\frac{A_1}{1 + KA_1}$ where $A_1 = R_o$

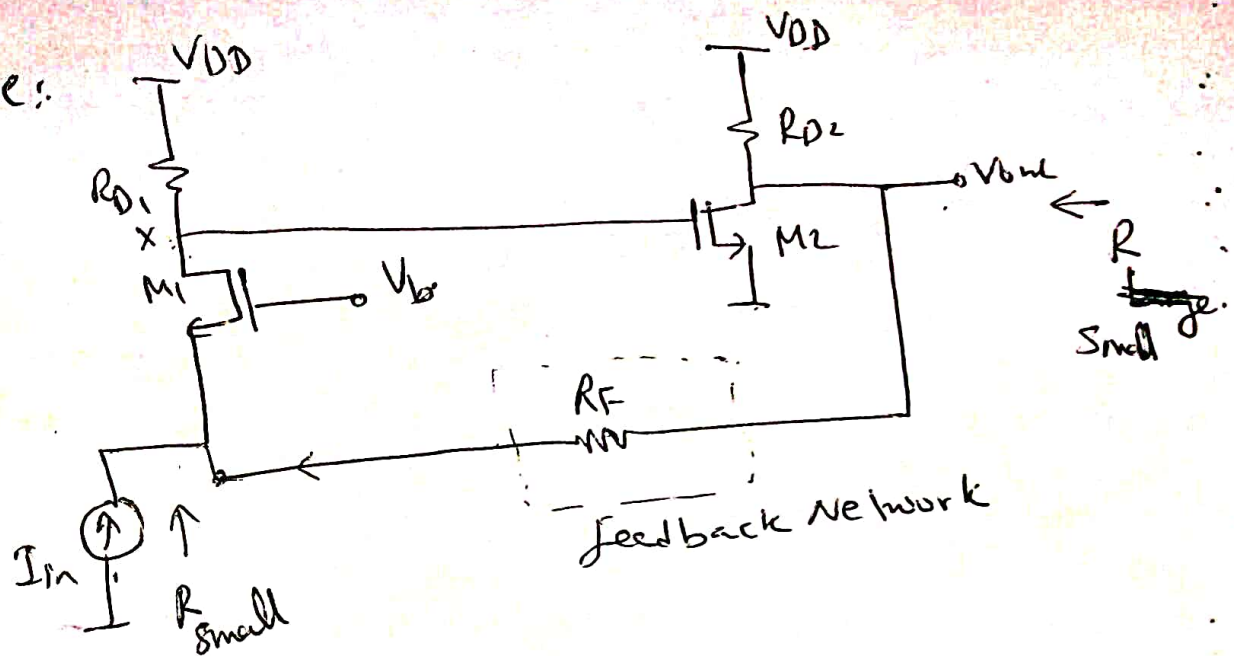
$R_{in,cl} = \frac{R_{in}}{1 + KA_1}$

$R_{out,cl} = \frac{R_{out}}{1 + KA_1}$

Return :- $\left\{ \begin{array}{l} \text{current} \rightarrow \text{Reducing } R_{in} \rightarrow R_{in,cl} = \frac{R_{in}}{1 + KA_1} \\ \text{voltage} \rightarrow \text{increasing } R_{in} \rightarrow R_{in,cl} = \frac{R_{in}(1 + KA_1)}{1} \end{array} \right.$

Sensing $\left\{ \begin{array}{l} \text{voltage} \rightarrow \text{Reducing } R_{out,cl} = \frac{R_{out}}{1 + KA_1} \\ \text{current} \rightarrow ?? \end{array} \right.$

Example:



Observation : 1) A Good TIA has low input impedance
2) " " " has Large output impedance

$$I_F = \frac{V_{out} - V_{in}}{R_F} = \frac{V_{out}}{R_F} - \left(\frac{V_{in}}{R_F} \right) \times \text{input small resist}$$

$$I_F \approx \frac{V_{out}}{R_F}$$

- Determine the open loop parameters (gain, R_{in} , R_{out})
- Determine the closed loop parameters (closed loop gain, closed loop input impedance, closed loop output impedance)

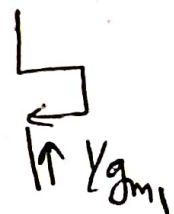
* Open Loop parameter :-

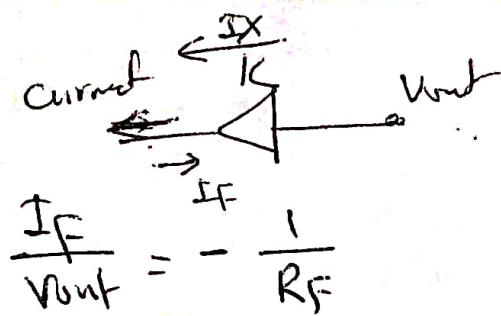
$$\text{Gain} = \frac{V_{out}}{I_{in}} = \frac{V_{out}}{V_X} \times \frac{V_X}{I_{in}}$$

$$= -g_{m1} R_{D1} \times (R_D)$$

$$\text{Input Impedance } R_{in} = 1/g_{m1}$$

$$\text{Output Impedance } R_{out} = R_{D2}$$





$$\frac{I_F}{V_{out}} = -\frac{1}{R_F}$$

$$I_F = \frac{V_{out}}{R_F}$$

$$I_X = -I_F = -\frac{V_{out}}{R_F}$$

$$\boxed{\frac{I_F}{V_{out}} = -\frac{1}{R_F}}$$

$$KA_1 = -\frac{1}{R_F} \times (-g_{m1} R_{D2} R_{D1}) = \frac{g_{m1} R_{D1} R_{D2}}{R_F}$$

Closed loop parameter:

$$\text{Closed loop gain} = \frac{A_1}{1 + KA_1} = \frac{-g_{m1} R_{D2} R_{D1}}{1 + \frac{g_{m1} R_{D1} R_{D2}}{R_F}}$$

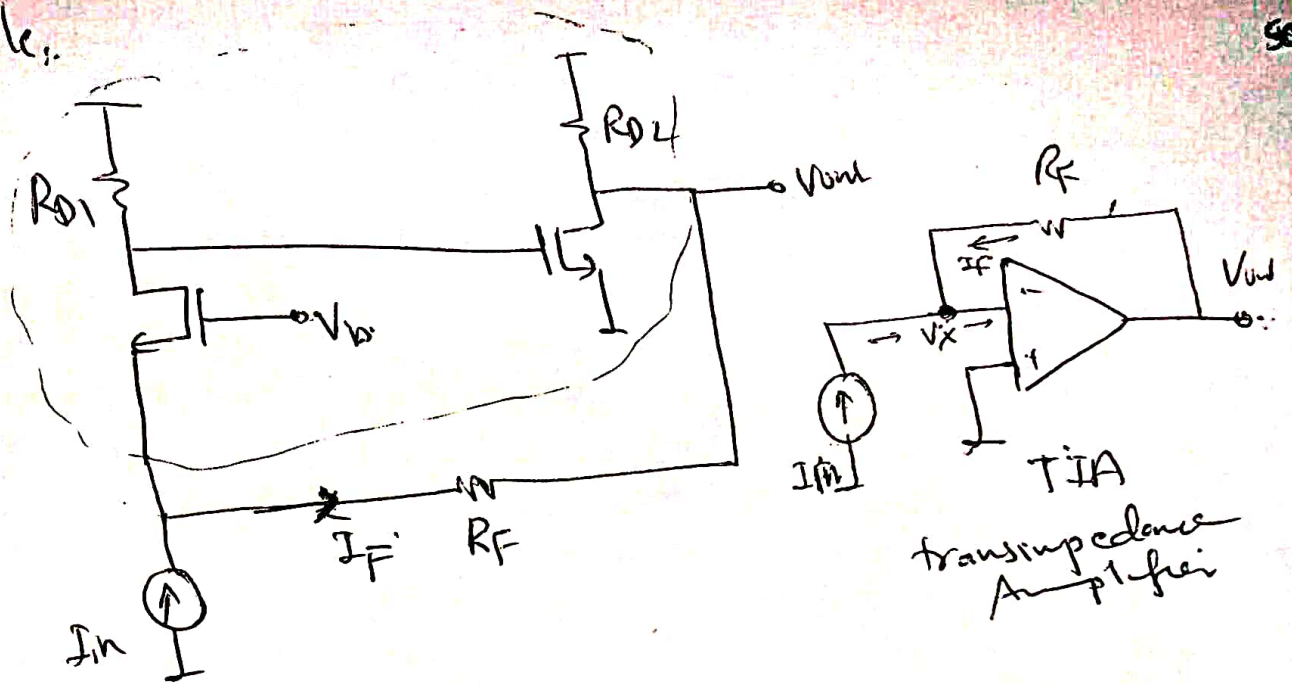
Closed loop input impedance

$$R_{in,cl} = \frac{R_{in}}{1 + KA_1} = \frac{\frac{1}{g_{m1}}}{1 + \frac{g_{m1} R_{D1} R_{D2}}{R_F}}$$

Closed loop output impedance.

$$R_{out,cl} = \frac{R_{out}}{1 + KA_1} = \frac{R_{D2}}{1 + \frac{g_{m1} R_{D1} R_{D2}}{R_F}}$$

Example:

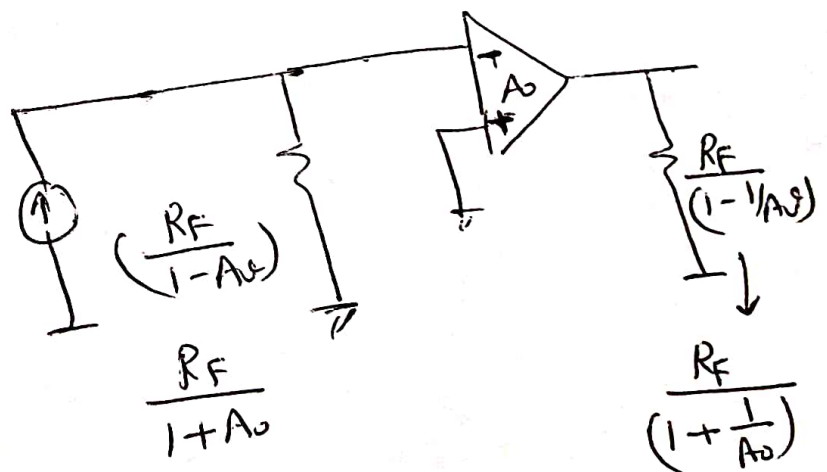


Closed loop parameter:

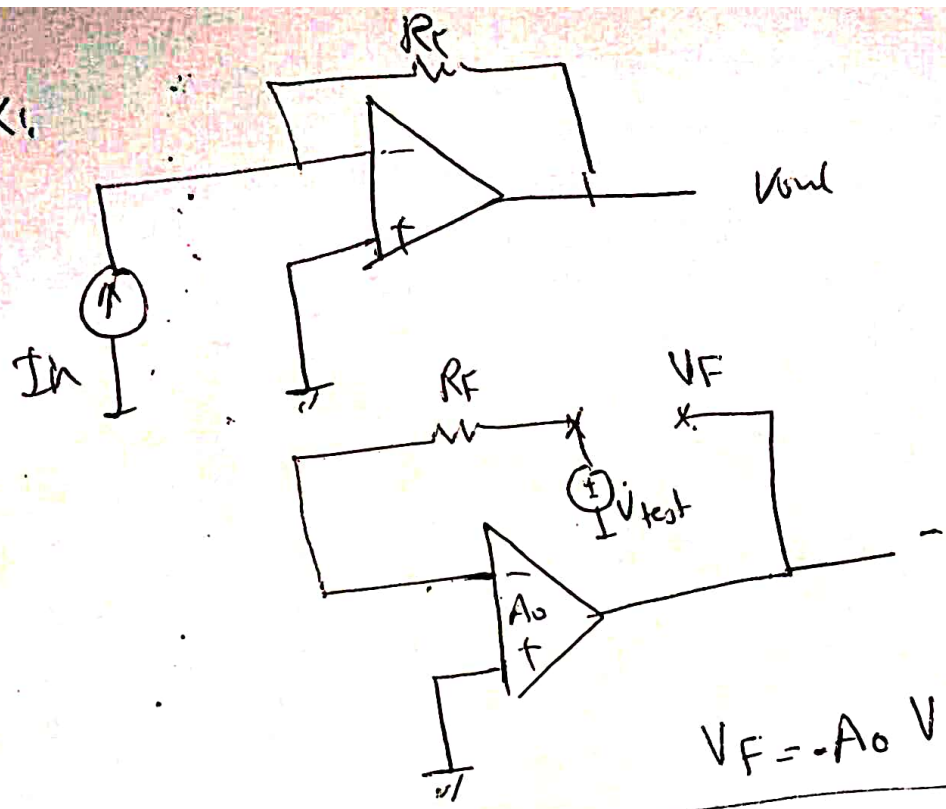
$$I_F = \frac{V_{out} - V_X}{R_F} = \frac{V_{out}}{R_F}$$

$$I_F + I_{in} = 0 \Rightarrow I_{in} = -I_F = -\frac{V_{out}}{R_F}$$

$$\frac{I_{out}}{V_{out}} = -\frac{1}{R_F}$$



Ex:



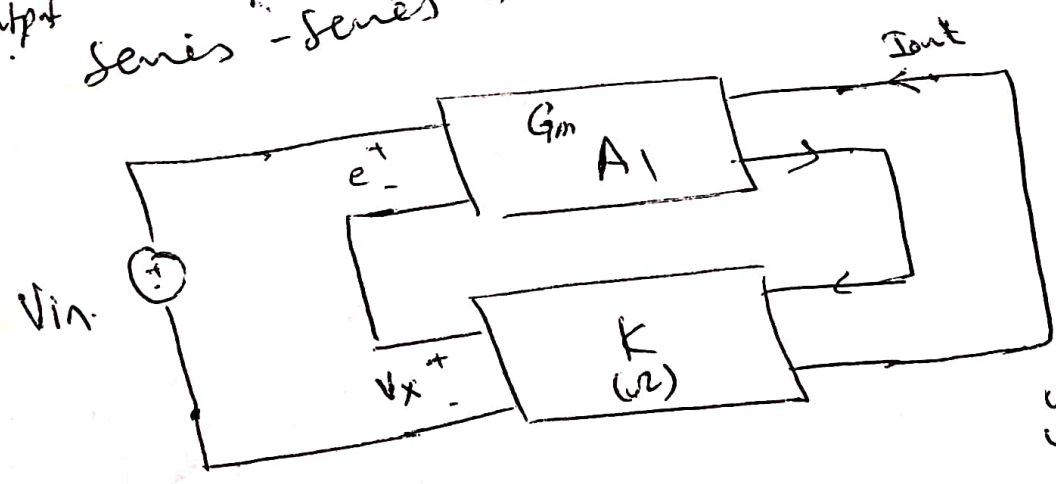
find the loop gain

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

$$V_F = -A_o V_{test}$$

$$\frac{-V_F}{V_{test}} = A_o \quad \text{loop gain}$$

* Current-Voltage feedback (transconductance amp).
 ↓ output ↓ input
 series-series "



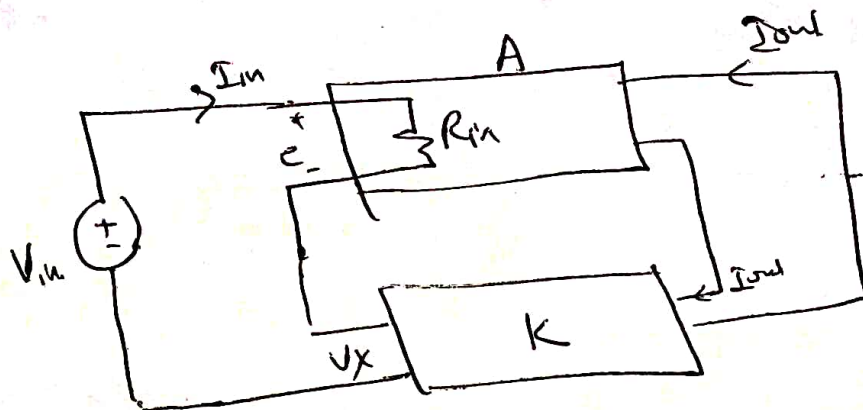
unit of $K = \Omega$
 unit of $A_1 = G_m$
 $KA_1 = \Omega \times \frac{1}{\Omega} = 1$

closed loop gain: ..
 $V_x = K I_{out} \quad , \quad e = V_{in} - K I_{out}$

$$\frac{I_{out}}{V_{in}} = \frac{A_1}{1 + KA_1} = \frac{G_m}{1 + K G_m}$$

$$I_{out} = e A_1 = (V_{in} - K I_{out}) A_1$$

Closed loop input impedance



$$I_{out} = e \times R_{in} \cdot A$$

$$= (I_{in} R_{in}) A$$

$$V_x = I_{out} K = (I_{in} R_{in} A) K$$

$$V_{in} = e + V_x$$

$$= R_{in} I_{in} + I_{in} R_{in} K A$$

$$= I_{in} [R_{in} (1 + K A)]$$

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

Closed loop output impedance

$$\boxed{R_{out_{cl}} = R_{out} (1 + K A)}$$

Sensing

Voltage $\rightarrow R_{out_{cl}} = \frac{R_{out}}{1 + K A}$

Current $\rightarrow R_{out_{cl}} = R_{out} (1 + K A)$

Returning

Voltage $\rightarrow R_{in} = R_{in} (1 + K A)$

Current $\rightarrow R_{in} = \frac{R_{in}}{1 + K A}$

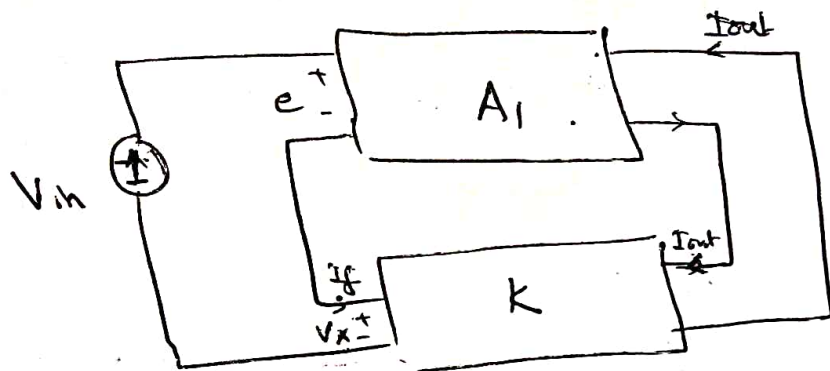
Today's lect.

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- Current voltage feedback
- Current - current feedback:

Review:

- Current - voltage feedback



output : Current
input : Voltage.

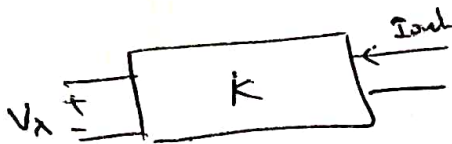
Sensing : current
series (~~parallel~~)
~~shunt~~

Returning : voltage
(series)

Units :-



$$A_1 = \frac{I_{out}}{e} = \frac{A}{V} = G_m \text{ (transconductance)} \quad \left(\frac{1}{R} = \frac{1}{\Omega} \right)$$



$$K = \frac{V_x}{I_{out}} = \frac{V}{A} = R = (\Omega)$$

$$KA_1 = \frac{1}{\Omega} \times \frac{1}{\Omega} = 1 \text{ without unit.}$$

closed loop parameter

$$\left. \frac{I_{out}}{V_{in}} \right|_{cl} = \frac{G_m}{1 + KG_m}$$

$$R_{in,cl} = R_{in} (1 + G_m K)$$

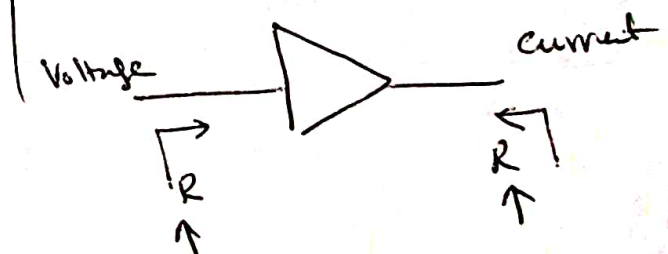
$$R_{out,cl} = R_{out} (1 + KG_m)$$

Open loop parameter

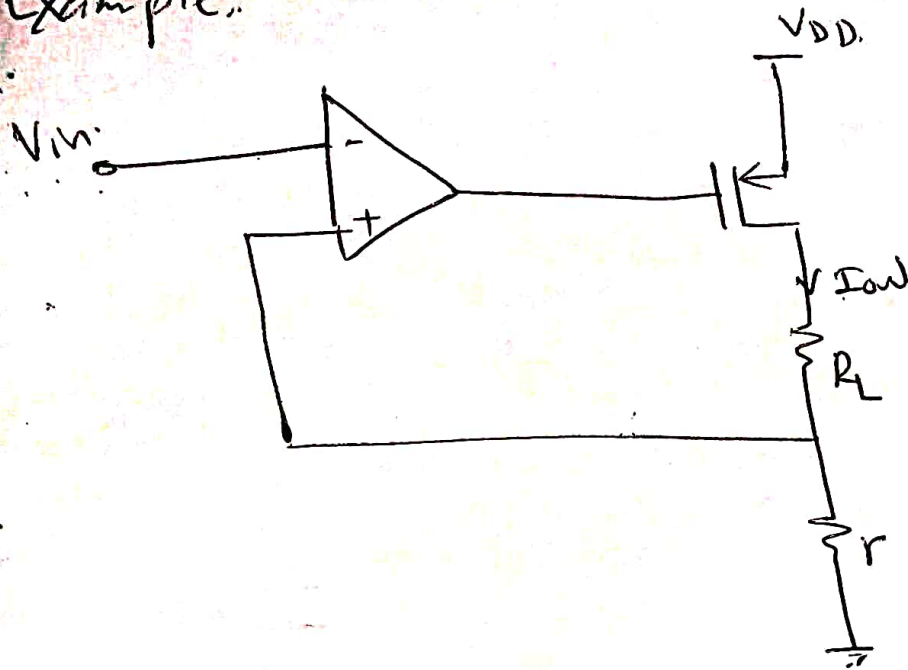
$$A_1 = G_m$$

R_{in}

R_{out}



Example:



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Current-voltage feedb.

- Sensing:
current $\rightarrow$ series.

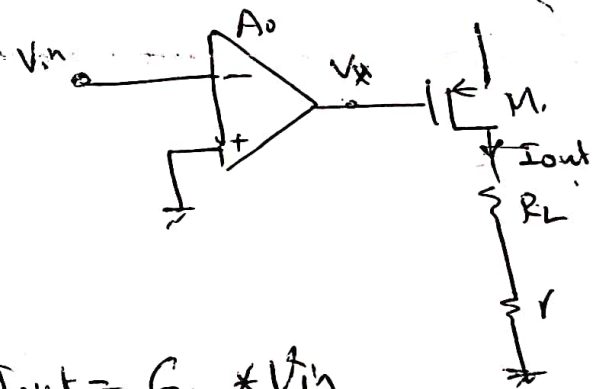
- Returning
voltage - series

** Series-series

* Open loop parameters :-

$$V_x = A_o [o - V_{in}]$$

$$= -A_o V_{in}$$



MOS: $\frac{I_{out}}{V_{in}} = G_m \Rightarrow I_{out} = G_m \times V_{in}$

$$\Rightarrow I_{out} = G_m V_x$$

$$= G_m (-A_o V_{in})$$

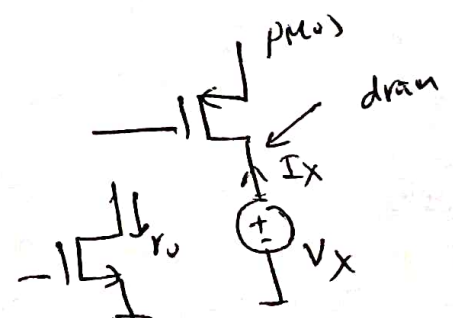
$$= -g_m A_o V_{in}$$

$$\Rightarrow \boxed{\frac{I_{out}}{V_{in}} = -g_m A_o = G_m}$$

open loop gain

to find open loop $R_{out} = \frac{V_x}{I_x} = r_o$

$$R_{in} = \infty$$

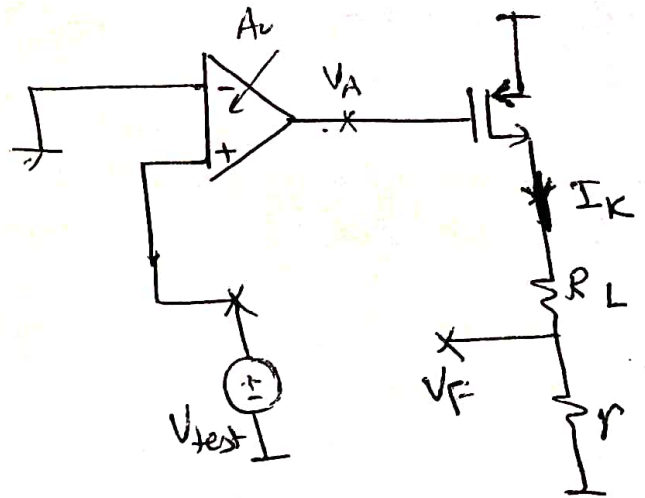


* Closed loop parameters.

* loop gain: $KA_1 = KG_m$

To find loop gain:

- all indep source $\rightarrow$ shorted
- break the feedback loop
- V_F , apply V_{test}



* loop gain $= -\frac{V_{test}}{V_F}$

$$V_A = A_0 [V_{test} - 0] = A_0 V_{test}$$

$$I_K = g_m V_A = -g_m A_0 V_{test}$$

$$V_F = -g_m A_0 V_{test} r$$

$$-\frac{V_F}{V_{test}} = g_m A_0 r = KA_1 = KG_m$$

← Loop gain.

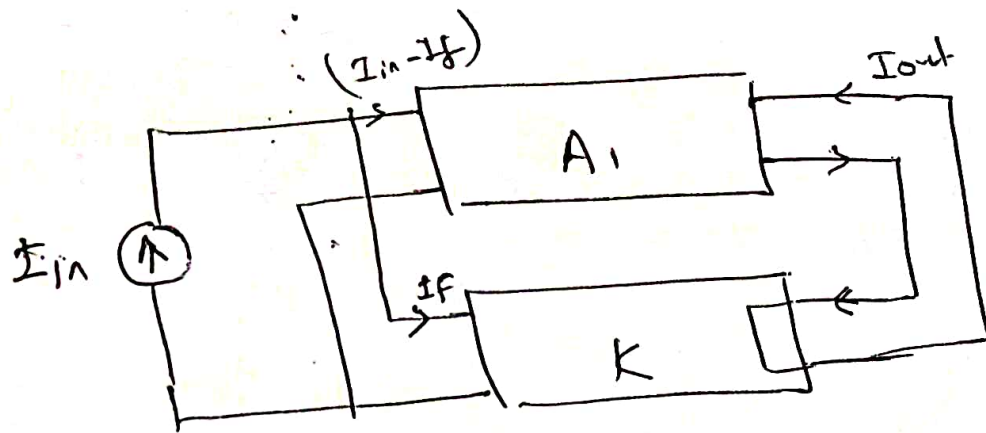
$$\text{Closed loop gain} = \frac{G_m}{1 + KG_m} = \frac{-g_m A_0}{1 + g_m A_0 r}$$

Closed loop output impedance

$$R_{out_{cl}} = R_{out} (1 + KG_m) = r_o (1 + g_m A_0 r)$$

Current - Current Feedback:

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Closed loop gain $\frac{I_{out}}{I_{in}}_{cl} = \frac{A_1}{1 + K A_1}$

unit: $A_1 = \frac{I_{out}}{I_{in} - I_F} = A/A = A_I$



$K = \frac{I_F}{I_{out}} = A_I$

Gain closed loop = $\frac{A_I}{1 + K A_I}$

Sensing: (output section):

$\Rightarrow$ current $\Rightarrow$ high resistance

$R_{out,cl} = R_{out} (1 + K A_I) = R_{out} (1 + K A_I)$

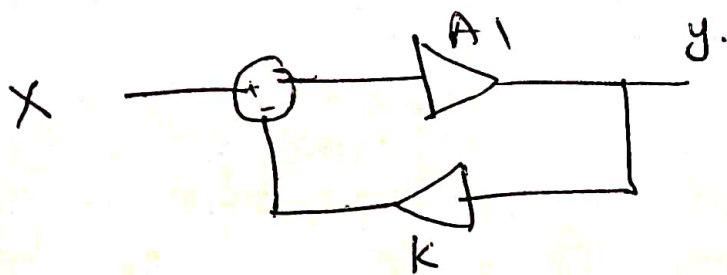
Returning: (input section):

$\Rightarrow$ current $\Rightarrow$ low resistance

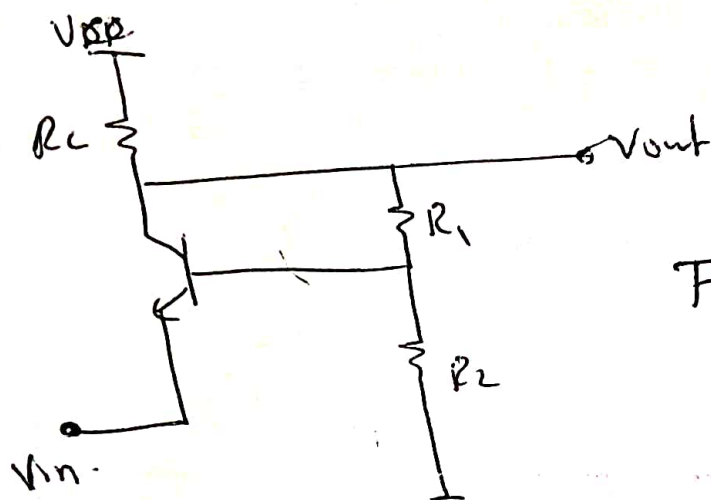
$R_{in,cl} = \frac{R_{in}}{1 + K A_I}$

Problem of loading in feedback circuit.

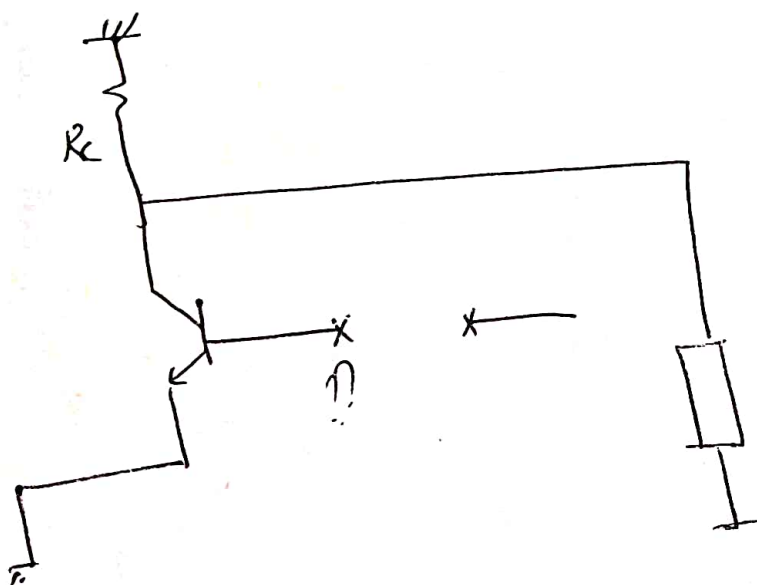
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Ex:



Find open loop gain



Find A_o
 R_{out}