FEEDBACK AMPLIFIERS AND OSCILLATORS

Feedback

→ Powerful technique that finds wide application in analog circuits

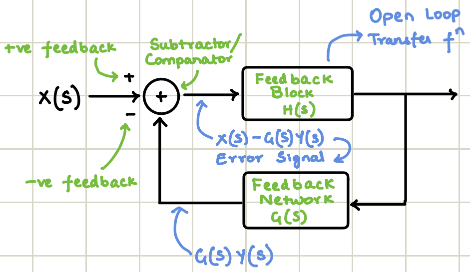
→ 2 Types

i) Positive Feedback → Building Oscillators

ii) Negative Feedback → Allows high-precision signal processing

General Considerations

→



→ Output of $G(s) = G(s)\,Y(s)$

Input to $H(s) = X(s) - G(s)Y(s)$ (Feedback Error)

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

$$= H(s)X(s) - H(s)G(s)Y(s)$$

$$Y(s) + H(s)G(s)Y(s) = H(s)X(s)$$

$$\boxed{\frac{Y(s)}{X(s)} = \frac{H(s)}{1 + H(s)G(s)}}$$ ← Closed Loop Transfer Function

$H(s)$ ← Open Loop Transfer Function

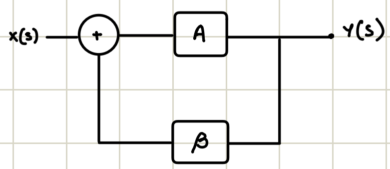
→ Components of Feed back Amplifier

1) Feed Forward Block (Amplifier) $H(s)$

2) Sense Mechanism

3) Feedback Network (Resistors) (Frequency Independant Quantity) $G(s)$

4) Comparator



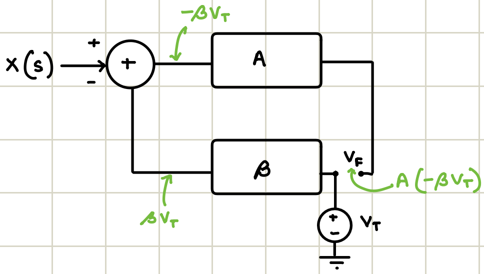
$$\boxed{\frac{Y(s)}{X(s)} = \frac{A}{1+A\beta}}$$

$-A\beta$: Loop Gain

$$= \frac{1}{\beta}\left(1 - \frac{1}{\beta A}\right)$$

Calculation of Loop Gain

→



1) Open the feedback loop
2) Apply a test signal
3) Short the input to zero

Loop Gain ⇒ $V_F = -A\beta V_T$

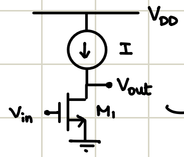
$\frac{V_F}{V_T} = -A\beta =$ Loop Gain

Properties of Feedback System

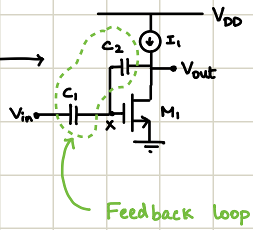
1) Gain Desensitization

→ We know $A_V = -g_m r_{o_1}$

and critical drawback of this circuit is the poor definition of gain because g_{m_1} & r_{o_1} vary with process & temperature



Reconfigured ckt with feedback



The current through C_1 = current through C_2

this is because gate cannot draw any current then

$(V_{out} - V_x) C_2 s = (V_x - V_{in}) C_1 s$

$V_{out} C_2 s - V_x C_2 s = V_x C_1 s - V_{in} C_1 s$

$V_{out} C_2 s = V_x (C_1 + C_2) s - V_{in} C_1 s$

also $\frac{V_{out}}{V_x} = -g_m r_{o_1} \Rightarrow V_x = \frac{V_{out}}{g_m r_{o_1}}$

then finally, $\frac{V_{out}}{V_{in}} = \frac{-1}{\left(1 + \frac{1}{g_m r_{o_1}}\right)\frac{C_2}{C_1} + \frac{1}{g_m r_{o_1}}}$

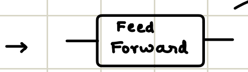
and if $g_m r_{o_1} >> 1$, $\frac{V_{out}}{V_{in}} = \frac{-1}{\frac{C_2}{C_1} + 0} = \frac{-C_1}{C_2}$

which means gain can be controlled with higher accuracy,

and if C_1 & C_2 are made of same material, then temperature & process variations don't change $\frac{C_1}{C_2}$

→ This shows closed loop is less sensitive to device parameters than open loop, hence 'desensitization'

2) Bandwidth Modification

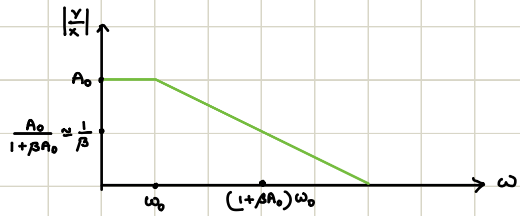
→ 

A_0 (Amplifier) → One pole

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

A_0 → low frequency gain

ω_0 → 3 dB Bandwidth



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

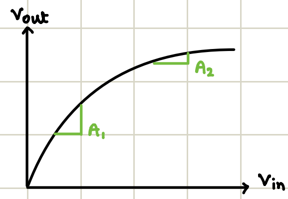
$$= \frac{A_0}{1 + \frac{s}{\omega_0} + \beta A_0}$$

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

⇒ When −ve feedback is given, bandwidth increases by large amount

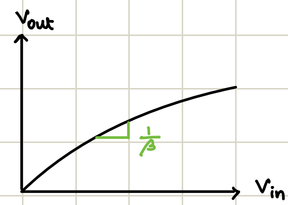
3) Non-Linearity Reduction

→ A non-linear characteristic is the one that departs from straight line (slope varies)



Gain of open loop varies from A_1 to A_2

$$r_{open} = \frac{A_2}{A_1} = \frac{A_1 - \Delta A}{A_1} = 1 - \frac{\Delta A}{A_1}$$



With feedback (closed loop), amplifier exhibits less gain variation

Hence, higher linearity

$$r_{closed} = \frac{\frac{A_2}{1+\beta A_2}}{\frac{A_1}{1+\beta A_1}} = \frac{\frac{\beta A_1 + 1}{\beta A_1}}{\frac{\beta A_2 + 1}{\beta A_2}} = \frac{1 + \frac{1}{\beta A_1}}{1 + \frac{1}{\beta A_2}}$$

$$r_{closed} \simeq 1 - \frac{\frac{1}{\beta A_1} - \frac{1}{\beta A_2}}{1 + \frac{1}{\beta A_2}}$$

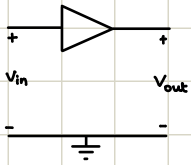
$$\simeq 1 - \frac{A_1 - A_2}{1 + \beta A_2} \cdot \frac{1}{A_1}$$

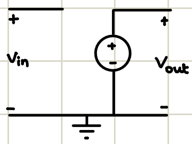
$$\simeq 1 - \frac{\Delta A}{A_1(1+\beta A_2)}$$

Types of Amplifiers

→ 4 Types :

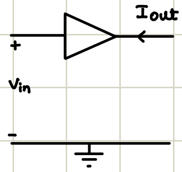
i) Voltage Amplifier

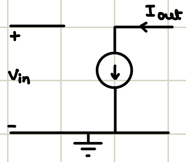




ex: CS Resistive Load

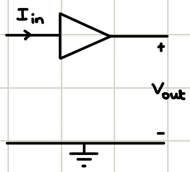
iii) Transconductance Amplifier

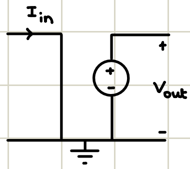




ex: CS Transistor

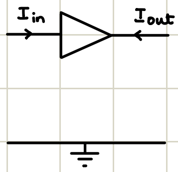
ii) Transimpedance Amplifier

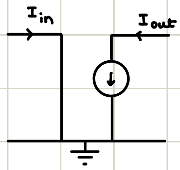




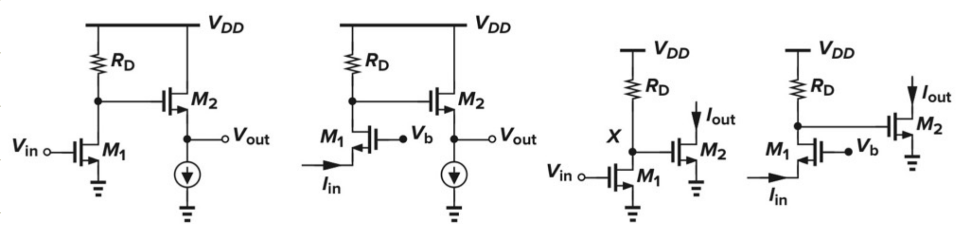
ex: CS Stage

iv) Current Amplifier





ex: CG stage

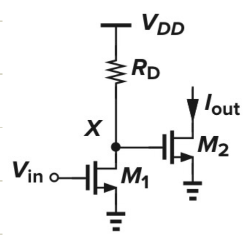


(a) (b) (c) (d)

→ 4 Types of amplifiers with improved performance

Q. Calculate gain of transconductance amplifier in the following diagram

A.
$$G_m = \frac{I_{out}}{V_{in}}$$

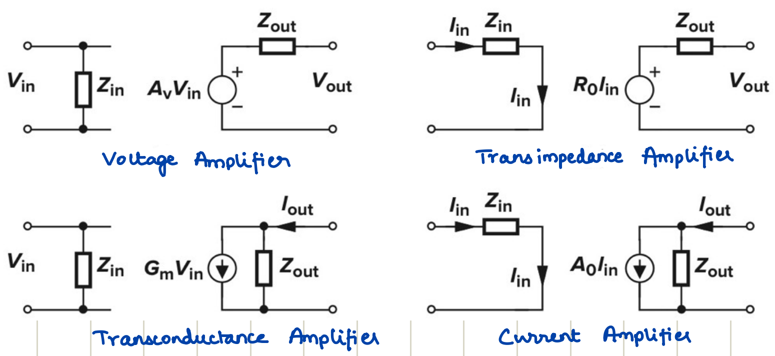


$$= \frac{V_x}{V_{in}} \cdot \frac{I_{out}}{V_x}$$

$$= -g_{m_1}(r_{o_1} \,||\, R_D) \cdot g_{m_2}$$

Q. Construct the 4 amplifiers if they were non-ideal

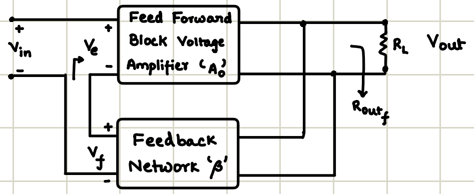
A.



Feedback Topologies

→ Voltage - voltage Feedback (Series - Shunt Feedback)

→



V_e : Error Voltage

V_f : Output Voltage

(Feedback n/w connected in $\parallel^{el}$ with output & in series with input)

↳ ideal v-v feedback exhibits ∞ input impedance, finite output impedance

→ $A_o = \dfrac{V_{out}}{V_e}$ = Voltage gain w/o Feedback

$A_f = \dfrac{V_{out}}{V_{in}}$ = Voltage gain w Feedback

→ Should be a series connection b/w V_{in} and FFBG & FB N/W

$V_f = \beta V_{out}$

Apply KVL to entire input Loop

$V_{in} - V_e - V_f = 0$

$V_e = V_{in} - V_f$

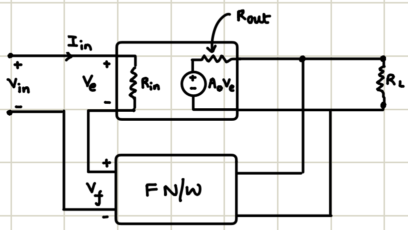
$= V_{in} - \beta V_{out}$

$V_{out} = A_o \cdot V_e$

$= A_o (V_{in} - \beta V_{out})$

$(A_o B + 1) V_{out} = A_o V_{in}$

$\boxed{\dfrac{V_{out}}{V_{in}} = \dfrac{A_o}{A_o B + 1} = A_{of}}$ ↳ Closed Loop Transfer Function



→ R_{out_f} ⇒ $V_e = I_{in} R_{in}$

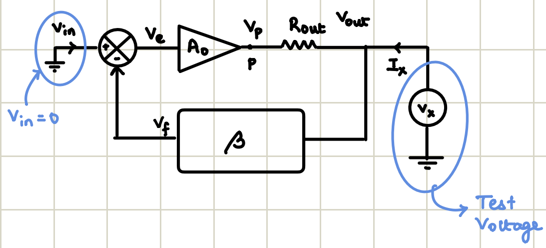
$V_{out} = A_o V_e = A_o I_{in} R_{in}$

$V_f = \beta V_{out} = \beta A_o I_{in} R_{in}$

$V_e = V_{in} - V_f = V_{in} - \beta A_o I_{in} R_{in}$

$R_{in} I_{in} = V_{in} - \beta A_o I_{in} R_{in} \Rightarrow I_{in} R_{in} (1 + \beta A_o) = V_{in}$

$\boxed{\dfrac{V_{in}}{I_{in}} = R_{in}(1 + \beta A_o)}$



→ R_{in_f} ⇒ $V_p = A_o V_e$

$V_e = V_{in} - V_f = 0 - V_f = -V_f$

$V_p = -A_o V_f$

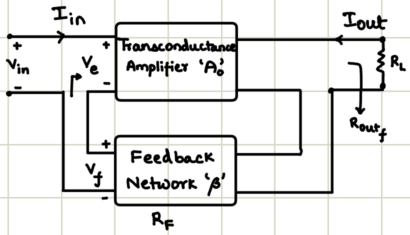
$= -A_o \beta x$

$\dfrac{V_x - V_p}{R_{out}} = I_x$

$I_x = \dfrac{V_x + A_o \beta V_x}{R_{out}} = \dfrac{V_x}{R_{out}} (1 + A_o \beta)$

$\boxed{\dfrac{V_x}{I_x} = \dfrac{R_{out}}{1 + A_o \beta}}$

→ Current - Voltage Feedback (Series - Series Feedback)

→ 

$G_{mf} = \dfrac{I_{out}}{V_{in}}$ gain ω feedback

$G_m = \dfrac{I_{out}}{V_e}$ gain w/o feedback

→ $V_f = R_F \cdot I_{out}$

$V_{in} - V_e - V_f = 0$

$V_e = V_{in} - V_f$

$\quad = V_{in} - R_F\, I_{out}$

$I_{out} = G_m V_e$

$\quad = G_m (V_{in} - R_F I_{out}) \Rightarrow I_{out}(1 + G_m R_F) = G_m V_{in}$

$\boxed{\dfrac{I_{out}}{V_{in}} = \dfrac{G_m}{1 + R_F G_m}}$

Entire Transconductance is going to drop by (1+ loop gain)

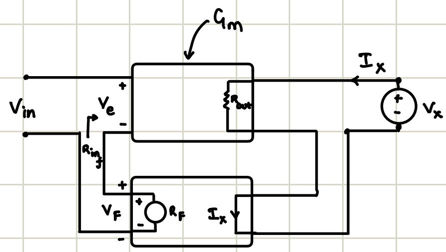
→ $R_{out_f} \Rightarrow$

$V_F = I_x R_F$

$\dfrac{V_x}{R_{out}} = I_x + G_m R_F I_x$

$\dfrac{V_x}{R_{out}} = I_x(1 + G_m R_F)$

$\boxed{\dfrac{V_x}{I_x} = R_{out}(1 + G_m R_F)}$



→ $R_{in_f} \Rightarrow$

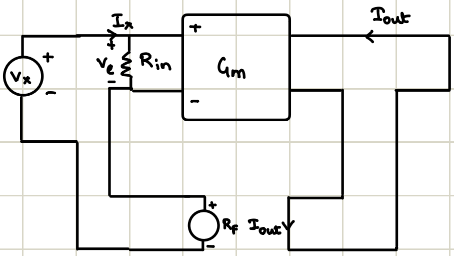
$I_{out} = G_m R_{in} I_x$

$V_e = V_x - I_x R_{in} G_m R_F$

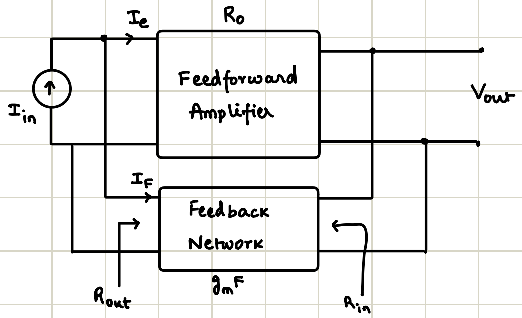
$V_e = R_{in} I_x$

$V_x = I_x R_{in}(1 + G_m R_F)$

$\boxed{\dfrac{V_x}{I_x} = R_{in}(1 + G_m R_F)}$



→ Voltage Current Feedback (Shunt - Shunt Feedback)

→ 

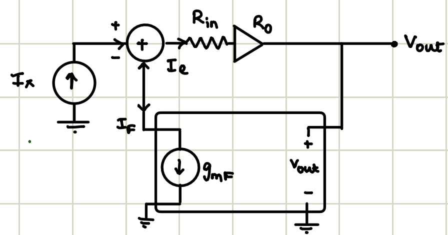
→ $I_F = g_{mF} V_{out}$

$I_e = I_{in} - I_F$

$$V_{out} = R_o I_e = R_o \left(I_{in} - g_{mF} V_{out} \right)$$

$$V_{out} \left(1 + g_{mF} R_o \right) = I_{in} R_o$$

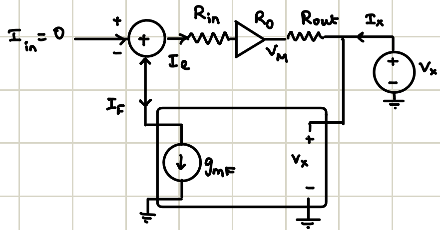
$$\boxed{\frac{V_{out}}{I_{in}} = \frac{R_o}{1 + g_{mF} R_o}}$$



→ $R_{in_f} \Rightarrow I_F = I_x - \frac{V_x}{R_{in}}$

$$\left(\frac{V_x}{R_{in}} \right) R_o g_{mF} = I_F \Rightarrow \left(\frac{V_x}{R_{in}} \right) \left(1 + R_o g_{mF} \right) = I_x$$

$$\boxed{\frac{V_x}{I_x} = \frac{R_{in}}{1 + g_{mF} R_o}}$$



→ $R_{out_f} \Rightarrow$

$I_F = V_x g_{mF}$

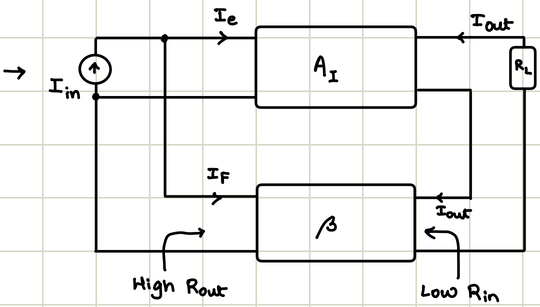
$I_e = -I_F$

$V_M = -R_o g_{mF} V_x$

$$I_x = \frac{V_x - V_M}{R_{out}} = \frac{V_x + R_o g_{mF} V_x}{R_{out}}$$

$$\boxed{\frac{V_x}{I_x} = \frac{R_{out}}{(1 + R_o g_{mF})}}$$

→ Current - Current Feedback (Shunt - Series Feedback)



→ Input of Feedback network is ammeter (ideally a resistance & current should flow through it)

$$I_{in} = I_e + I_f$$

$$A_{I_f} = \frac{I_{out}}{I_{in}} \Rightarrow \text{Closed Loop Transfer } f^n$$

$$I_F = \beta I_{out}$$

$$I_{out} = A_I \cdot I_e$$

$$I_{out} = A_I (I_{in} - \beta I_{out})$$

$$\boxed{\frac{I_{out}}{I_{in}} = \frac{A_I}{1 + A_I \beta}}$$

→ $$\boxed{R_{out_f} = R_{out}(1 + A_I B)}$$

$$\boxed{R_{in_f} = \frac{R_{in}}{1 + A_I B}}$$

Summary!

Type	Gain	Input Impedance	Output Impedance
Voltage - Voltage Feedback	$\frac{V_{out}}{V_{in}} = \frac{A_0}{1+\beta A_0}$	$\frac{V_x}{I_x} = R_{in}(1+\beta A_0)$	$\frac{V_x}{I_x} = \frac{R_{out}}{1+\beta A_0}$
Current - Voltage Feedback	$\frac{I_{out}}{V_{in}} = \frac{G_m}{1+G_m R_F}$	$\frac{V_x}{I_x} = R_{in}(1+G_m R_F)$	$\frac{V_x}{I_x} = R_{out}(1+G_m R_F)$
Voltage - Current Feedback	$\frac{V_{out}}{I_{in}} = \frac{R_0}{1+g_{mF} R_0}$	$\frac{V_x}{I_x} = \frac{R_{in}}{1+g_{mF} R_0}$	$\frac{V_x}{I_x} = \frac{R_{out}}{1+g_{mF} R_0}$
Current - Current Feedback	$\frac{I_{out}}{I_{in}} = \frac{A_I}{1+\beta A_I}$	$\frac{V_x}{I_x} = \frac{R_{in}}{1+\beta A_I}$	$\frac{V_x}{I_x} = R_{out}(1+\beta A_I)$

Oscillators

→ An amplifier senses a signal & reproduces it as output with some gain
But an oscillator GENERATES a signal, typically periodic in the form of voltage

→ Consider feed back system $\frac{Y(s)}{X(s)} = \frac{H(s)}{1+H(s)}$

If amplifier experiences phase shift at high frequencies, feedback becomes +ve
or if $H(j\omega_0) = -1$, closed-loop gain approaches ∞ at ω_0
Which means circuit amplifies its own noise components at ω_0 indefinitely

→ For oscillation to begin, loop gain should be ≥ 1
This can be seen by following the signal around the loop over many cycles & expressing amplitude of subtractor's output as GP

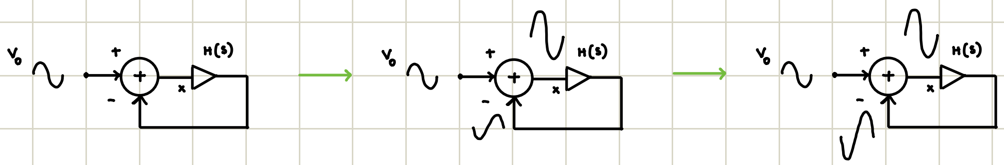
$$V_x = V_0 + |H(j\omega_0)|V_0 + |H(j\omega_0)|^2 V_0 + |H(j\omega_0)|^3 V_0 + \dots$$

If $|H(j\omega_0)| > 1 \Rightarrow$ GP diverges
but if $|H(j\omega_0)| < 1 \Rightarrow V_x = \frac{V_0}{1-|H(j\omega_0)|} < \infty$

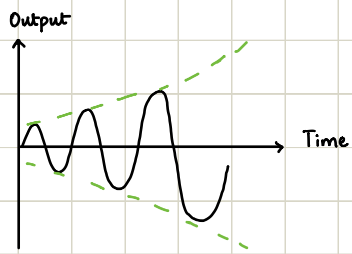
→ For a circuit to oscillate at ω_0, negative-feedback circuit must satisfy 2 conditions
they are called Barkhausen Criteria

$|H(j\omega)| \geq 1$

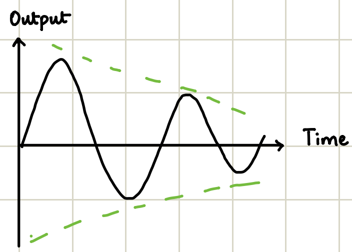
$\angle H(j\omega) = 180^\circ$ or total phase shift $= 0^\circ$ or 360°



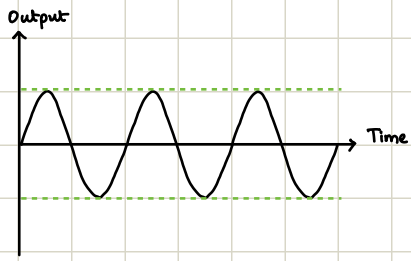
→ When $|A\beta| > 1 \Rightarrow$ Growing Type Oscillations



When $|A\beta| < 1 \Rightarrow$ Decaying Oscillations



When $|A\beta| = 1 \Rightarrow$ Sustained Oscillations



→ LC Oscillators

→ Various Topologies and Applications

→

Oscillator Topology	Cross-Coupled Oscillator	Crystal Oscillator
Implementation	Integrated	Discrete or Integrated
Typical Frequency Range	Upto 100 GHz	Upto 100 MHz
Application	Wireless Transceivers	Precise Reference

→ LC Oscillator use Inductors & Capacitors to define oscillation frequency

→ Advantages :

i) Faster than ring oscillators

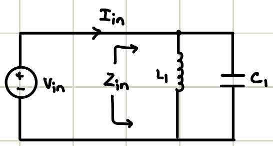
ii) Exhibit less noise

Disadvantages :

i) Difficult to design

ii) Occupy larger chip area than ring oscillators

→ Consider ideal parallel LC Tank Circuit



$$Z_1(s) = L_1 s \parallel \frac{1}{C_1 s} = \frac{\frac{L_1 s}{C_1 s}}{L_1 s + \frac{1}{C_1 s}} = \frac{L_1 s}{L_1 C_1 s^2 + 1}$$

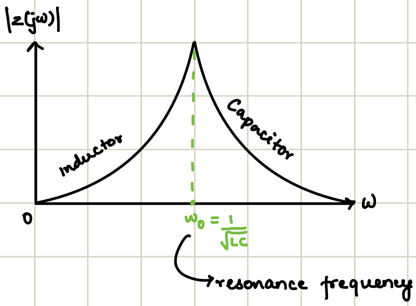
$$Z_1(j\omega) = \frac{j\omega L}{1 - L_1 C_1 \omega^2}$$

→ $|Z_1(j\omega)| = \infty$ at $\omega_1 = \frac{1}{\sqrt{L_1 C_1}}$

At $\omega = \omega_1$, inductor & capacitor exhibit equal & opposite impedances, cancelling each other yielding an open circuit

At $\omega < \omega_1$, low frequency, $\angle j\omega = 90°$

At $\omega > \omega_1$, high frequency, $\angle j\omega = -90°$



→ But in practise, impedance of parallel LC Tank doesn't go to ∞ because

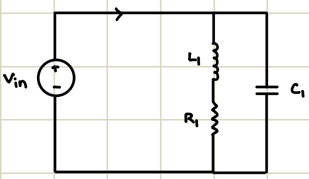
The wire that forms the inductor has finite resistance

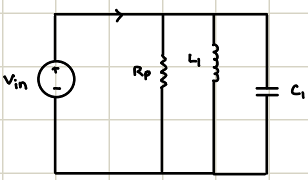
When L_1 carries current, its wire resistance R_1 heats up & dissipates energy which forces V_{in} to replenish energy & hence $Z_1 < \infty$ even at resonance

→ It is called Lossy Tank to indicate loss of energy

Lossy Tank

→ The LC Tank is replaced by





→ For LC Oscillators analysis, we use the model with parallel resistance R_p.

Both the models aren't equal for all frequencies

At $\omega \simeq 0$, in 1st model, $Z_2 = R_1$ (L_1 is short circuit, C_1 is open)

in 2nd model, $Z_2 = 0$

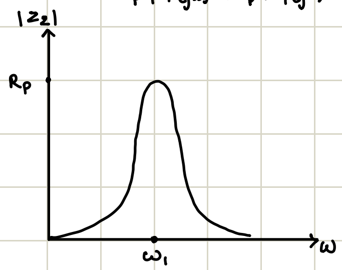
Only at a narrow range they are equal $\left(R_p = \frac{L_1^2 \omega^2}{R_1} \right)$

→ For plotting magnitude & phase of $z_2(s)$ as a function of frequency,

$$z_2(s) = R_p \,||\, L_1 s \,||\, \frac{1}{C_1 s}$$

$$= \frac{R_p L_1 s}{C_1 s \left(R_p L_1 s + \frac{R_p}{C_1 s} + \frac{L_1 s}{C_1 s} \right)} = \frac{R_p L_1 s}{R_p L_1 C_1 s^2 + R_p + L_1 s}$$

$$z_2(j\omega) = \frac{R_p L_1 (j\omega)}{R_p L_1 C_1 (j\omega)^2 + R_p + L_1 (j\omega)} = \frac{j R_p L_1 \omega}{j L_1 \omega + R_p (1 - L_1 C_1 \omega^2)}$$



At $\omega_1 = \frac{1}{\sqrt{L_1 C_1}}$, $z_2(j\omega_1) = R_p$

At high freq, $z_2 = jL_1\omega$

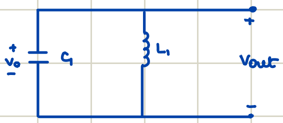
low freq, $z_2 = \frac{1}{jC_1\omega}$

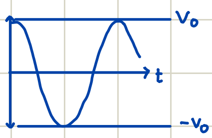
Q. If we apply initial voltage V_0 across capacitor in an isolated $||^{el}$ tank, study the behaviour of circuit in time domain if tank is ideal or lossy

A. For an ideal circuit, capacitor begins to discharge through inductor

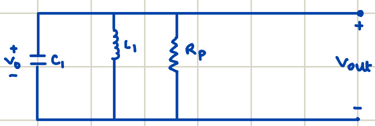
When $V_{out} = 0$, only L_1 carries energy in the form of a current

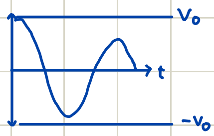
Current charges C_1 towards $-V_0$ & transfer of energy b/w C_1 & L_1 oscillates indefinitely





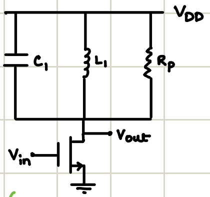
For lossy tank, non-zero output voltage causes current flow through R_p & hence energy gets dissipated, and tank loses energy every cycle producing oscillatory output

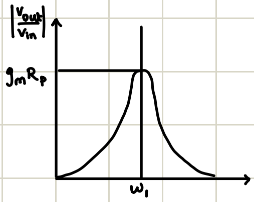


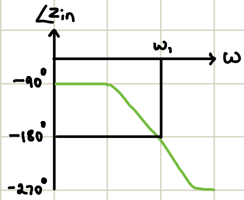


Cross - Coupled Oscillator

→ Consider CS stage using $\parallel^{el}$ LC Tank as its load







CS with Tank Load

$$\frac{V_{out}}{V_{in}} = -g_m Z_2(s)$$

$$Z_2(s) = R_p \parallel (L_1 s) \parallel \frac{1}{C_1 s}$$

Angle of $\frac{V_{out}}{V_{in}}$ obtained by shifting Z_2 by 180° (up or down) to account for -ve sign in $-g_m Z_2(s)$

→ CS stage oscillation if input & output tied

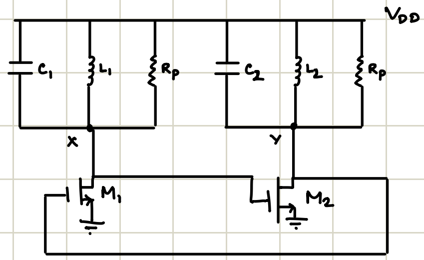
→ For it to oscillate, total phase shift around the loop must reach 360° at finite frequency which isn't possible with one stage circuit

→ To fix this, we can add one more CS stage in loop

→ Both stages will give 360° (180° each) shift which is possible at $\omega = \omega_1$

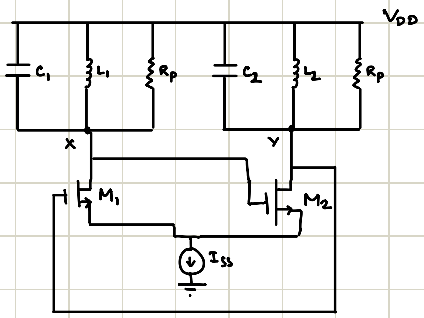
→ Single stage has $A_v = g_m R_p$ at ω_1

then, Barkhausen's loop gain $= (g_m R_p)^2 \geq 1$



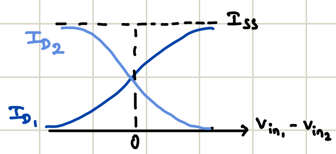
→ But the problem is that drain current of M_1 & M_2 vary with process, Supply voltage & temperature

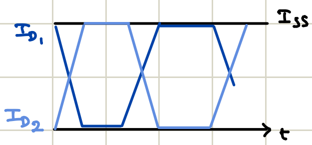
→ To fix this problem, gate of each device is tied to drain & add tail current source ensuring total bias current of M_1 & M_2 = I_{ss}



⇒ Most popular & robust LC oscillator used in integrated circuits

→ Drain currents of M_1 & M_2





Crystal Oscillators

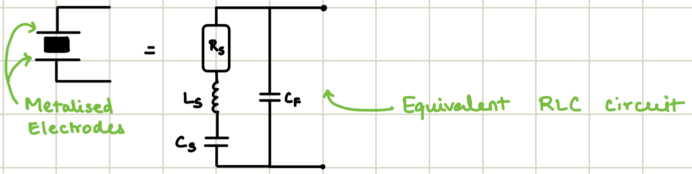
→ These oscillators don't provide precise output frequency (Temperature variations)

→ So we use crystal oscillators for high-precision

→ They use piezoelectric materials like quartz & it mechanically vibrates at certain frequency if subjected to voltage difference which is extremely stable with temperature

→ They have very low losses behaving like ideal tank

Symbol ⇒



→ Equivalent impedance of crystal has series resonance (Cs resonates with inductance)

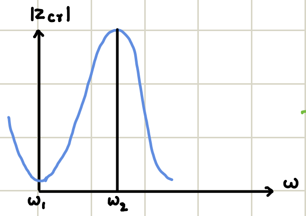
(Ls resonates at $\underbrace{\text{crystal operating freq}}_{\text{Crystal series freq } (f_s)}$)

There is another freq. point due to parallel resonance when L_s & C_s resonate with L_P

→ As freq ↑, at particular frequency, interaction b/w C_s & L_s creates series resonance at freq ω_1

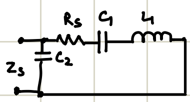
As freq ↑ above series resonance point, crystal behaves like inductor until it reaches ω_2 ($\parallel^{el}$ resonant freq)

interaction b/w L_s & C_p creates $\parallel^{el}$ tuned LC tank ckt



→ Impedance (at ω_1) $\simeq 0$ (L_1 resonates with C_1)

Impedance (at ω_2) = very high (L_1 & C_1 resonate with C_2)



→ For series resonance $\omega_1 = \dfrac{1}{\sqrt{L_1C_1}}$

→ Finding ω_2 in terms of circuit parameters (neglecting R_s)

$$Z_{cr}(j\omega) = Z_s(j\omega) \parallel \frac{1}{jC_2\omega} \simeq \frac{1 - L_1C_1\omega^2}{j\omega\,(C_1 + C_2 - L_1C_1C_2\omega^2)}$$

$$Z_{cr} \to \infty \quad \text{at} \quad \omega_2 = \frac{1}{\sqrt{\frac{L_1C_1C_2}{C_1+C_2}}} \simeq \frac{1}{\sqrt{L_1C_1}}$$

hence $C_1 \simeq \dfrac{C_1C_2}{C_1+C_2}$

$$\text{If} \quad C_2 >> C_1 \Rightarrow \frac{\omega_2}{\omega_1} = \sqrt{\frac{C_1+C_2}{C_2}} \simeq 1 + \frac{C_1}{2C_2}$$

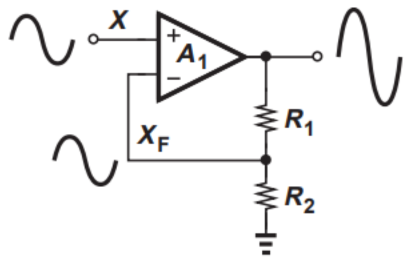
Thanks to

Prof. Anuros Thomas (RRC) for

guiding & teaching me ACD :)

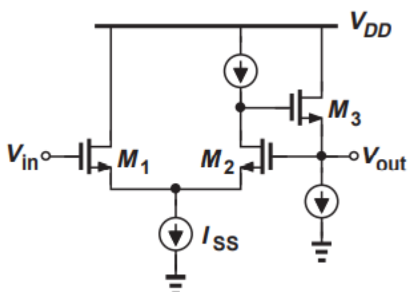
ACD Unit 4 – Numericals

1. In the circuit shown, the input is a sinusoid with a peak amplitude of 2 mV. If $A_1 = 500$ and $R_1/R_2 = 7$, determine the amplitude of the output waveform and the feedback waveform

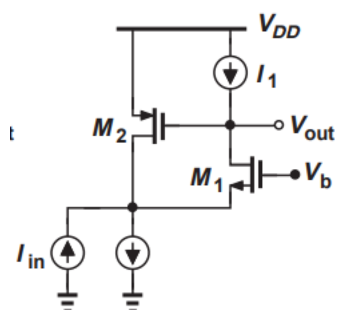


2. Identify the sense and return signals in each of the circuits shown and hence the type of feedback amplifier.

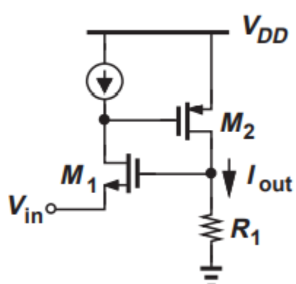
a.



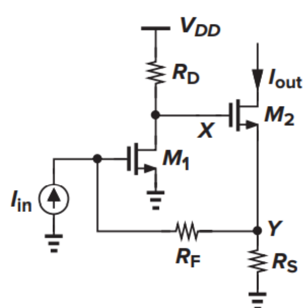
b.



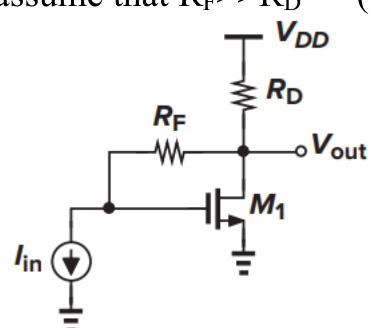
c.



d.



3. Calculate the input and output impedances of the circuit shown For simplicity, assume that $R_F >> R_D$ (Worked example 8.10)



4. Determine a) open and closed loop gain b) open and closed loop input impedance c) open and closed loop output impedance for the circuits shown, Assume $R_1+R_2 >> R_D$ in Fig. a and C1 and C2 are very small in Fig. b

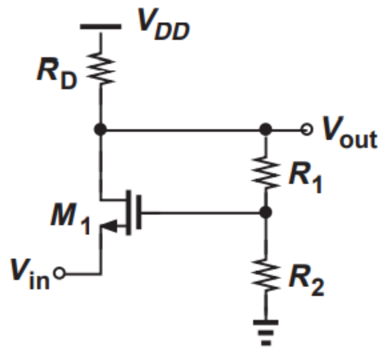


Fig. a

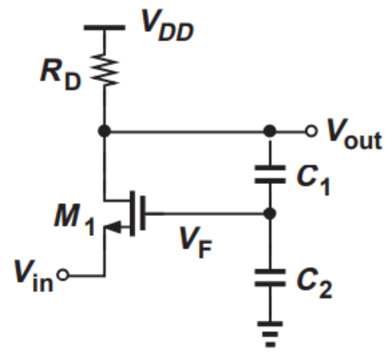
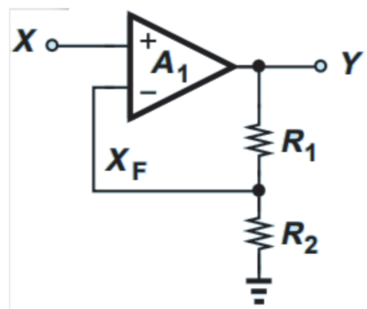
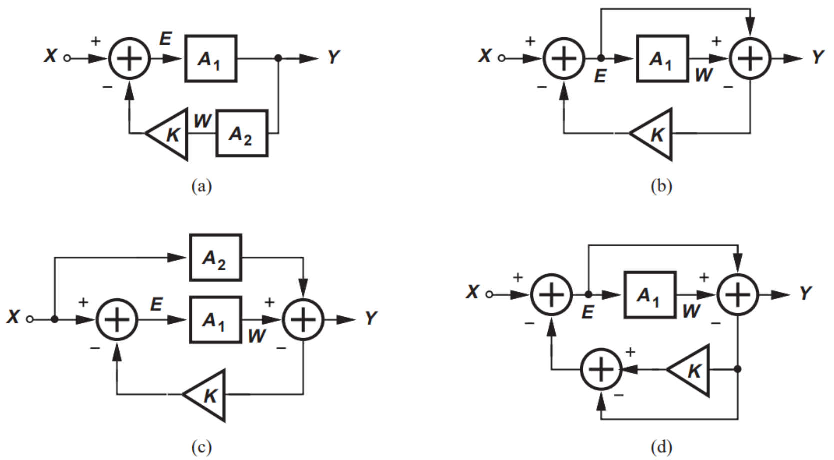


Fig. b

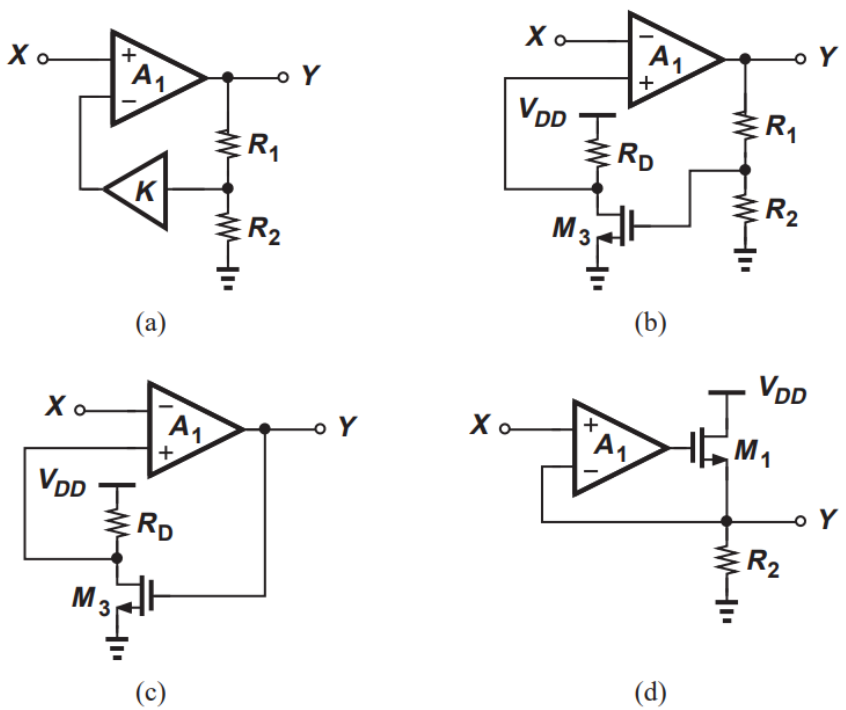
5. The circuit shown is designed for a nominal gain of 4. (a) Determine the actual gain if $A_1 = 1000$. (b) Determine the percentage change in the gain if A_1 drops to 500. (Worked example)



6. Determine the transfer function, Y/X, W/X and E/X for the systems shown in Fig.



7. Calculate the loop gain of the circuits illustrated in Fig. Assume the amp exhibits an open-loop gain of A1. Also, $\lambda = 0$.



Rekha.

ACD Unit 4 – Numericals

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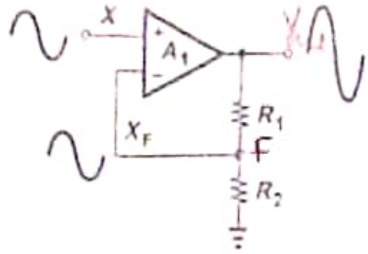


$\beta = \frac{V_f}{V_{out}} = \frac{R_2}{R_1+R_2} = \frac{1}{1+\frac{R_1}{R_2}} = \frac{1}{8}$

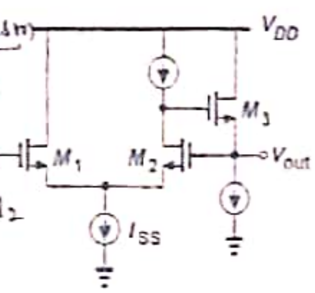
$V_{out} = \frac{A_1}{1+\beta A_1} V_{in} = 15.7 mV$

$V_F = \beta V_{out} = 1.96 mV$

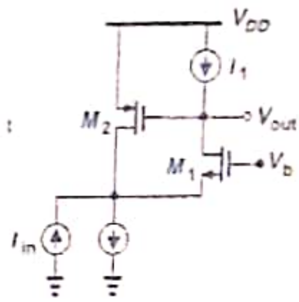
2. Identify the sense and return signals in each of the circuits shown and hence the type of feedback amplifier.

a.

Sense Mechanism
Current from M_3
Return Mechanism
Voltage to gate of M_2



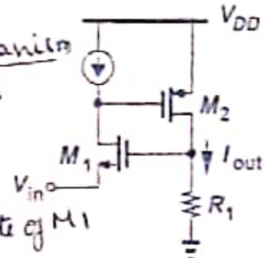
b.



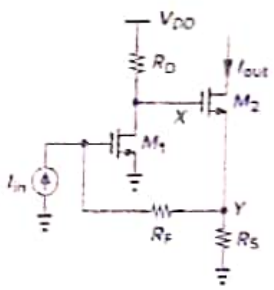
Sense Mechanism
Gate of M_2 voltage is sensed
Return - Current output of M_2

c.

Sense Mechanism
R_1, senses current
Return
voltage to gate of M1

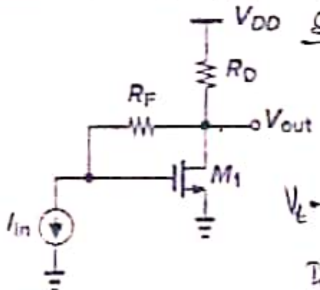


d.



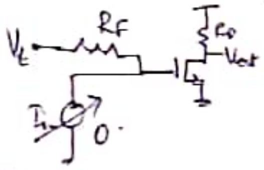
Senses current for M_2 and returns current

3. Calculate the input and output impedances of the circuit shown For simplicity, assume that $R_F >> R_D$ (Worked example 8.10)



Sol^n: R_F senses the output voltage and returns the current to the Input.

To find loop gain ⇒ break the loop as shown in fig below



Set $I_{in}=0$ and apply V_t at one end of loop & measure Vout

$\frac{V_{out}}{V_F} = -g_m R_D$

But since it is negative feedback loop gain will be $\boxed{g_m R_D = \beta A}$

Rin without feedback is R_F

$\boxed{R_{out} \text{ without fb} = R_D}$ $\boxed{R_{in_{OL}} = R_F}$

→ Ckt is sensing current ←
hence Rin must be high

$R_{in \text{ with fb}} = \frac{R_{in_{OL}}}{1+A\beta} = \frac{R_F}{1+g_m R_D}$

→ Ckt generated voltage hence Rout must be low

$R_{out_{CL}} = \frac{R_{out_{OL}}}{1+\beta A} = \frac{R_D}{1+g_m R_D}$

4. Determine a) open and closed loop gain b) open and closed loop input impedance c) open and closed loop output impedance for the circuits shown. Assume $R_1 + R_2 >> R_D$ in Fig. a and C1 and C2 are very small in Fig. b

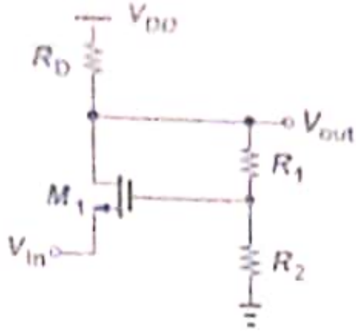


Fig. a

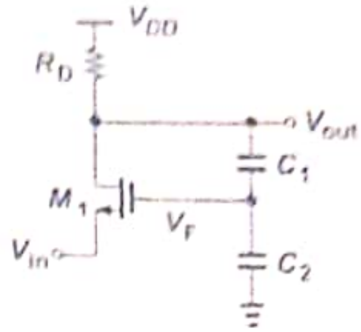
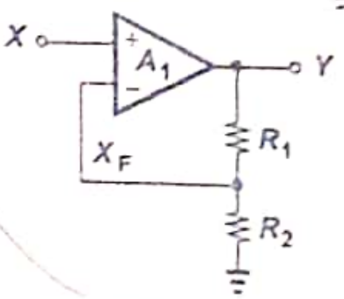


Fig. b

5. The circuit shown is designed for a nominal gain of 4. (a) Determine the actual gain if $A_1 = 1000$. (b) Determine the percentage change in the gain if A_1 drops to 500. (Worked example)



Solution

$$A_{CL} = \frac{A_1}{1+\beta A_1}$$

nominal gain = 4 = $\frac{Y}{X}$

$$\frac{Y}{X} \simeq \frac{A_1}{\beta A_1} \simeq \frac{1}{\beta}$$

$$4 \simeq 1/\beta \qquad \boxed{\beta = \frac{1}{4}}$$

Actual gain $= \frac{A_1}{1+\beta A_1} = \frac{1000}{1+\frac{1000}{4}} = 3.984$

When A_1 is drops to 500

Actual gain $= \frac{500}{1+\frac{1}{4}500} = 3.968$

$\boxed{0.4\%}$

a) Without feedback [open loop]

$$\frac{V_{out}}{V_{in}} = A_{OL} = g_m R_D$$

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

$$A_{CL} = \frac{A_{OL}}{1+\beta A_{OL}} = \frac{g_m R_D}{1+\frac{R_2}{R_1+R_2} g_m R_D}$$

gain with feedback [closed loop]

b) $R_{in_{OL}} = 1/g_m$

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

Since amp. senses voltage hence R_{in} must be high $\therefore \left(R_{in_{CL}} = R_{in OL}(1+A\beta)\right)$

(c) $R_{out_{OL}} = R_D$

$$R_{out_{CL}} = \frac{R_{out_{OL}}}{1+A\beta} = \frac{R_D}{1+\frac{R_2}{R_1+R_2} g_m R_D}$$

Here $\beta = \frac{C_1}{C_1+C_2}$

(a) $A_{OL} = g_m R_D$

$$A_{CL} = \frac{g_m R_D}{1+\frac{C_1}{C_1+C_2} g_m R_D}$$

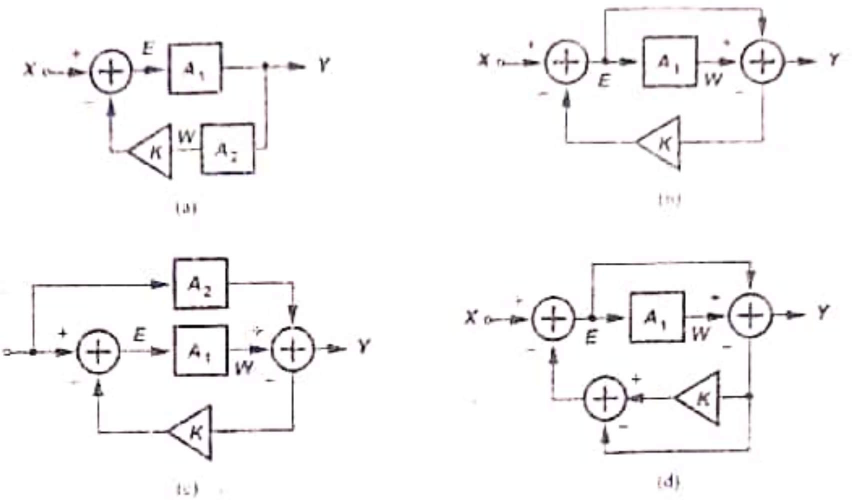
(b) $R_{in_{OL}} = 1/g_m$

$$R_{in_{CL}} = \frac{1}{g_m}\left(1+\frac{C_1 g_m R_D}{C_1+C_2}\right)$$

(c) $R_{out_{OL}} = R_D$

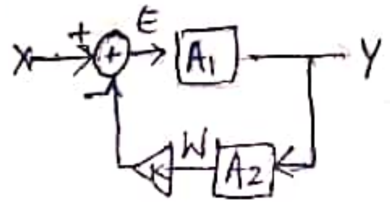
$$R_{out_{CL}} = \frac{R_D}{1+\frac{C_1}{C_1+C_2} g_m R_D}$$

6. Determine the transfer function, Y/X, W/X and E/X for the systems shown in Fig.



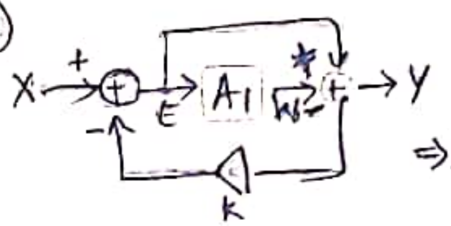
Transfer function Y/X

(a)



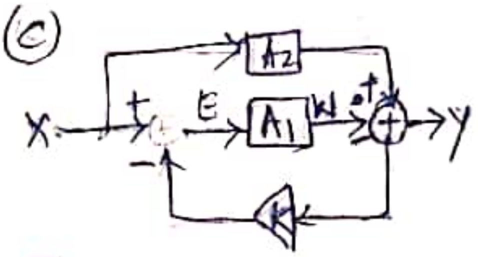
$$Y = A_1 E$$
$$= A_1[X - YA_2K]$$
$$\Rightarrow \frac{Y}{X} = \frac{A_1}{1+KA_1A_2}$$

(b)



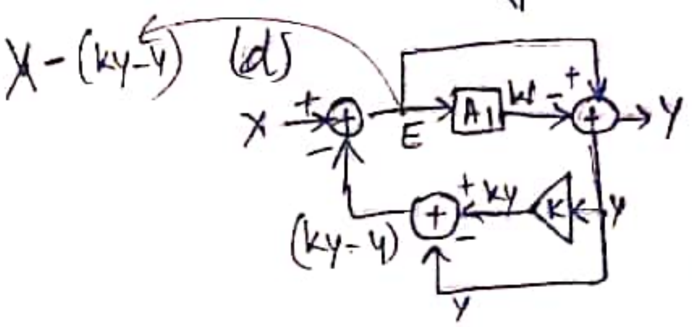
$$Y = E - A_1 W$$
$$= (X-KY) - A_1(X-KY)$$
$$\Rightarrow \frac{Y}{X} = \frac{1-A_1}{1+(1-A_1)K}$$

(c)



$$Y = XA_2 - W$$
$$= XA_2 - A_1(X - YK)$$
$$\Rightarrow \frac{Y}{X} = \frac{A_2 - A_1}{1 - A_1 Y}$$

(d)



$$Y = E - W$$
$$= [X - (KY - Y)] - A_1(X - (KY-Y))$$
$$\Rightarrow \frac{Y}{X} = \frac{(1-A_1)}{1+(K-1)(1-A_1)}$$

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Transfer function W/X

(a) $W = A_2 Y = A_2[(X - KW)A_1]$

$$\Rightarrow \frac{W}{X} = \frac{A_1 A_2}{1 + A_1 A_2 K}$$

(b) $W = A_1 \times E = A_1[X - YK]$

$$= A_1\left[X - K\left(\frac{W}{A_1} - W\right)\right]$$

$$\Rightarrow \frac{W}{X} = \frac{A_1}{1 + K(1 - A_1)}$$

$Y = E - W$

$E = \frac{W}{A_1}$

$Y = \left(\frac{W}{A_1} - W\right)$

(c) $W = A_1 E = A_1[X - (A_2 X - W)K]$

$$\Rightarrow \frac{W}{X} = \frac{A_1(1 - A_2 K)}{(1 - A_1 K)}$$

(d) $W = A_1 E = A_1\left[X - \left\{\left(\frac{W}{A_1} - W\right)K - \left(\frac{W}{A_1} - W\right)\right\}\right]$

$$\Rightarrow \frac{W}{X} = \frac{A_1}{1 + (K-1)(1 - A_1)}$$

Transfer function E/X

(a) $E = X - K A_2 A_1 E$

$$\Rightarrow \frac{E}{X} = \frac{1}{1 + K A_2 A_1}$$

(b) $E = X - K[E - A_1 E]$

$$\Rightarrow \frac{E}{X} = \frac{1}{1 + K(1 - A_1)}$$

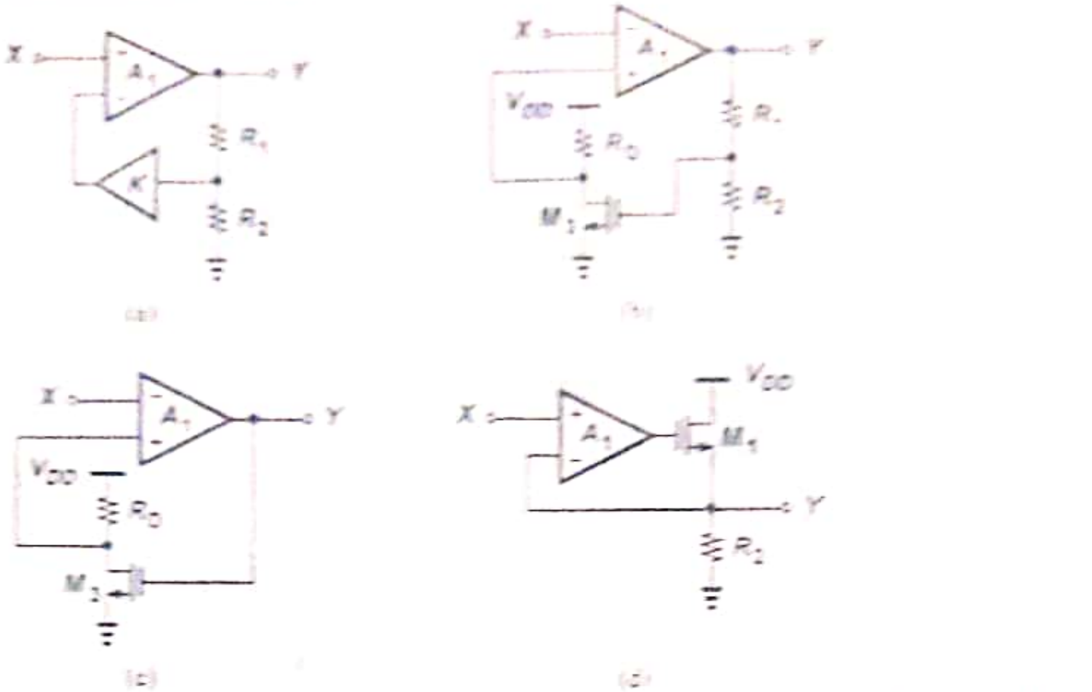
(c) $E = X - K[A_2 X - A_1 E]$

$$\Rightarrow \frac{E}{X} = \frac{1 - A_2 K}{1 - A_1 K}$$

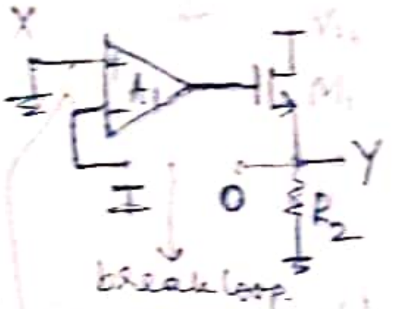
(d) $E = X - \{K[E - A_1 E] - [E - A_1 E]\}$

$$\Rightarrow \frac{E}{X} = \frac{1}{1 + (K-1)(1 - A_1)}$$

7. Calculate the loop gain of the circuits illustrated in Fig. Assume the op amp exhibits an open-loop gain of A1, but is otherwise ideal. Also, $\lambda = 0$.



(d)



$I \rightarrow$ Input of Loop

$O \rightarrow$ output of Loop

(X is grounded)

$V_E = [X - I]$

$$O = Y = (X - I)\, A_1 * \text{gain}_{M_1}$$

here $X = 0$

$$O = Y = -I \cdot \frac{g_{m1} R_2}{1 + g_{m1} R_2} \times A_1$$

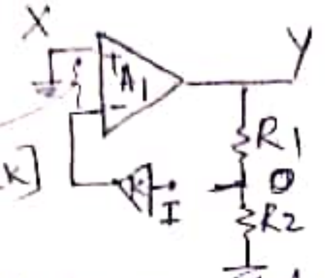
$$\Rightarrow -\frac{O}{I} = \text{Loop Gain } (-\text{ve tho})$$

$$= + A_1 \frac{g_{m1} R_2}{1 + g_{m1} R_2}$$

M_1 is source follower hence gain of M_1 amp. is $\dfrac{g_m R_2}{1 + g_m R_2}$

$I \rightarrow$ input of loop
$O \rightarrow$ output of loop

(a)



$V_E = [X - IK]$

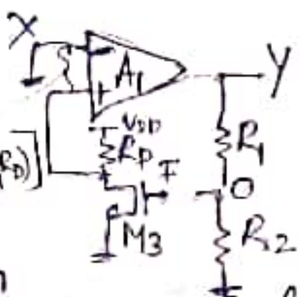
(X is grounded.
in loop-gain calculation)

$$O = Y\frac{R_2}{R_1+R_2} = (-IK)A_1\left(\frac{R_2}{R_1+R_2}\right)$$

$$-\frac{O}{I} = \text{Loop Gain} = +KA_1\left(\frac{R_2}{R_1+R_2}\right)$$

$\rightarrow Y = A_1 V_E = A_1\left[X - \text{gain of } M_3 \, I\right]$

(b)



$V_E = [X - I(-g_m R_D)]$

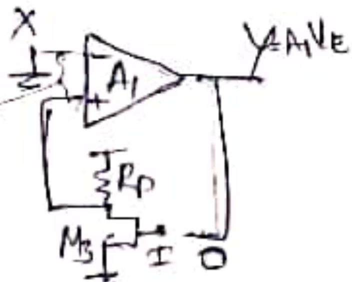
(X is grounded)

$$O = Y\left(\frac{R_2}{R_1+R_2}\right) = +I g_{m3} R_D A_1\left(\frac{R_2}{R_1+R_2}\right)$$

gain of M_3

$$\Rightarrow +\frac{O}{I} = \text{Loop Gain} = +g_{m3} R_D A_1\left(\frac{R_2}{R_1+R_2}\right)$$

(c)



$V_E = [X - I(-g_m R_D)]$

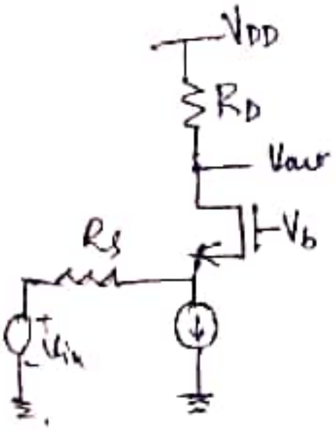
(X is grounded).

$O = Y = (O - I(-g_{m3}R_D)A_1)$

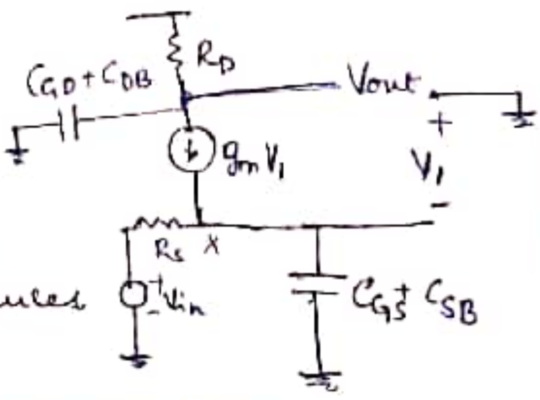
$$O = Y = +I g_{m3} R_D A_1$$

$$\Rightarrow \frac{O}{I} = \text{Loop gain} = +g_{m3} R_D A_1$$

(8) Compute the Transfer function of the Common-gate stage shown in fig. below, neglect channel-length modulation.



CG with parasitic capacitances



Worked example
Refer Text Book
6.5 example
page no. 179 & 180 in soft copy

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