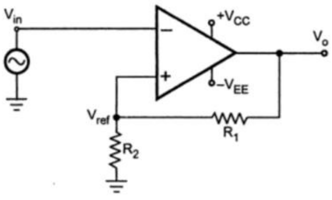
CMR
INSTITUTE OF
TECHNOLOGY

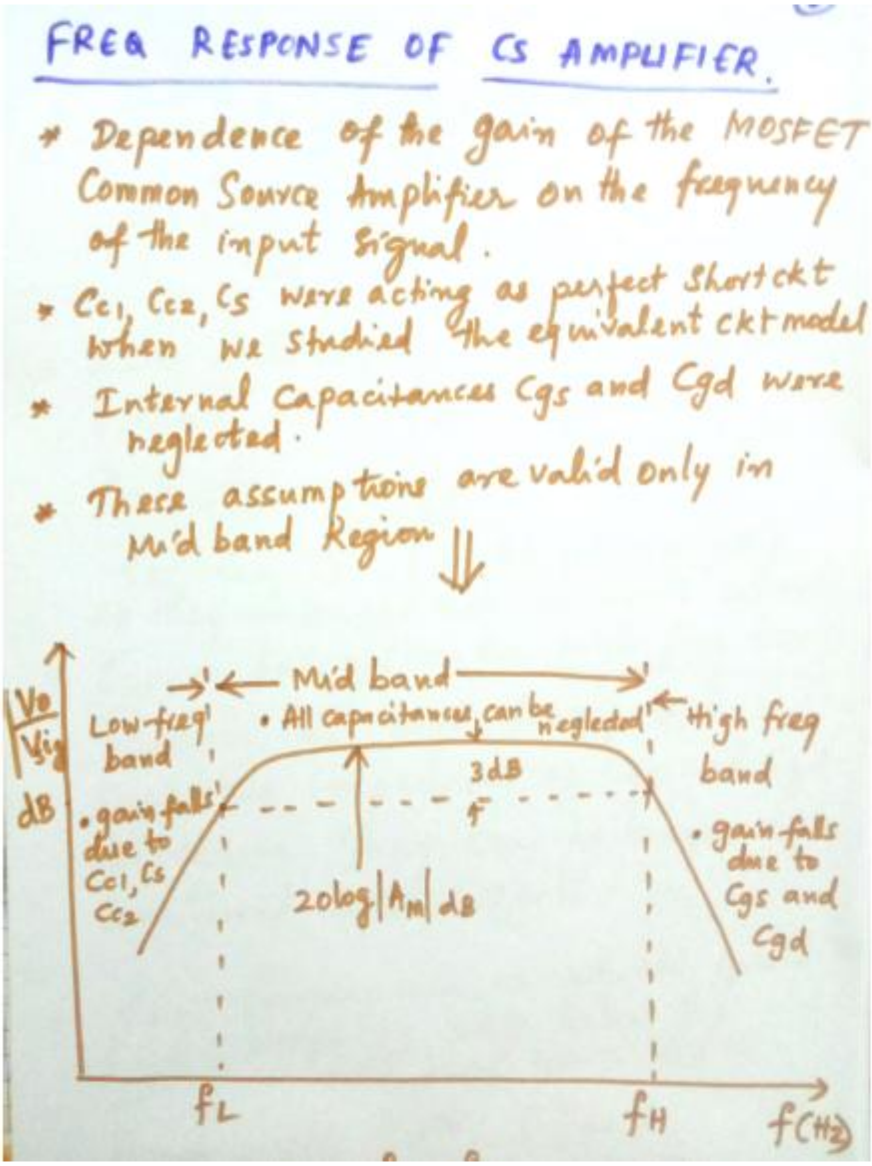
USN | | | | | | | | | | |

Internal Assesment Test - II

Sub:	Analog Circuits							Code:	18EC42
Date:	03/ 08/ 2022	Duration:	90 mins	Max Marks:	50	Sem /Sec :	4th/A,B,C, D	Branch :	ECE
Answer Any FIVE FULL Questions									

		Marks	OBE	
			CO	RBT
1.	Draw and explain the complete frequency response of a common source amplifier. Derive the expression for its lower cut-off frequency.	[10]	CO2	L3
2.	With the help of neat circuit diagram and small signal equivalent model explain the working of FET based RC Phase shift Oscillator. Also explain how three RC pair can be used to in the feedback to achieve 180 degree phase shift.	[10]	CO3	L3
3.	Find the midband gain AM , and the upper 3-dB frequency fH of a CS amplifier fed with a signal source having an internal resistance Rsig = 100 kΩ. Theamplifier has RG = 4.7MΩ, RD = RL = 15 kΩ, , gm=1mA/V, ro=150kΩ , Cgs=1pFand Cgd=0.4pF	[10]	CO2	L3
4.	Explain the internal capacitances of a MOSFET. For the n-channel MOSFET in saturation with tox=10nm, L=1μm, W=10μm, LOV=0.05 μm, Csbo = Cdbo = 10fF, VO=0.6V, VSB=1V and VDS=2V. Given dielectric used is SiO2. Calculate i)COX ii)COV iii)Cgs iv)Cgd v)Csb vi)Cdb	[10]	CO2	L3
5.	With relevant circuit diagrams and equatuions explain the following a) Colpitts Oscillator b) Crystal Oscillator.	[10]	CO2	L3
6.	Draw the circuit of nonoinverting amplifier and derive the expressions for a) Exact gain b)Ideal gain c)Input Resistance d) Bandwidth.	[10]	CO2	L2
7.	With a neat circuit diagram explain the opamp based non - inverting Summing amplifier, scaling amplifier and averaging circuit with relevant expressions for the output.	[10]	CO3	L3
8.	Draw the circuit and waveforms for an inverting Schmitt Trigger usingopamp, with relevant expressions.For an inverting Schmitt Trigger circuit R2 = 1KΩ ; R1 = 3KΩ and Vin=10Vp-pp sine wave. The saturation voltages are ± 14V. i) Determine the threshold voltages Vut and Vlt.  ii) Find the value of Hysteresis voltage Vhy.	[10]	CO2	L3

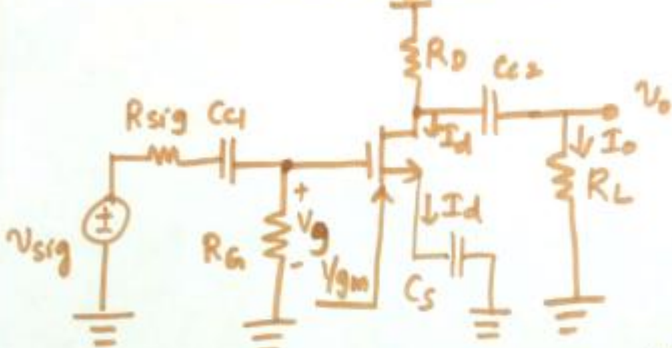
Question 1 - Draw and explain the complete frequency response of a common source amplifier. Derive the expression for its lower cut-off frequency.



FREQ RESPONSE OF CS AMPLIFIER.

* Dependence of the gain of the MOSFET Common Source Amplifier on the frequency of the input signal.
* C_{c1}, C_{c2}, C_s were acting as perfect short ckt when we studied the equivalent ckt model
* Internal capacitances C_{gs} and C_{gd} were neglected.
* These assumptions are valid only in Mid band Region ⇓

Low-frequency Response (4.9.3)



To find the low-freq Response, V_{DD} and V_{SS} voltage sources are short circuited, current source I is open circuited. The coupling capacitors and bypass capacitor is taken into consideration. For simplicity r_o is neglected (it has minor effect also)

$$V_g = V_{sig} \cdot \frac{R_G}{R_{sig} + \frac{1}{sC_{c1}} + R_G}.$$

In low freq Response, we need to consider the effect of 3 capacitors. All of them affect the Low frequency Response.

There will be three break frequencies represented as:-

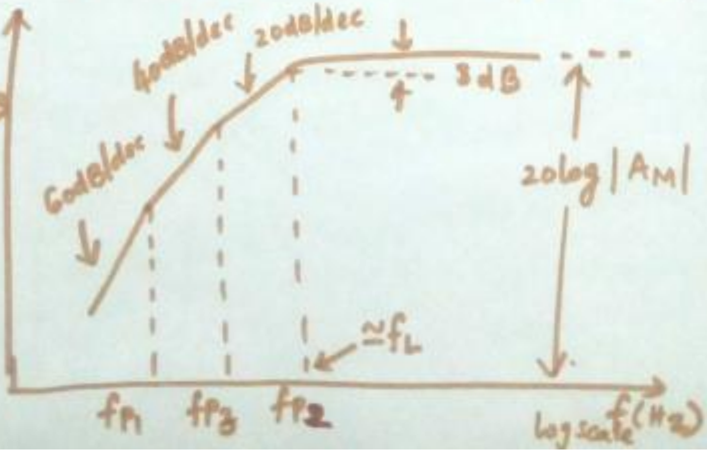
$$\omega_{P_1} = \frac{1}{C_{C1}(R_G + R_{sig})}$$

$$\omega_{P_2} = \frac{g_m}{C_S}$$

$$\omega_{P_3} = \frac{1}{C_{C2}(R_D + R_L)}$$

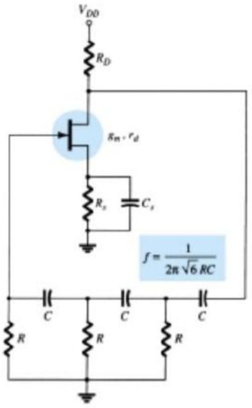
Over all low-frequency transfer function is given by

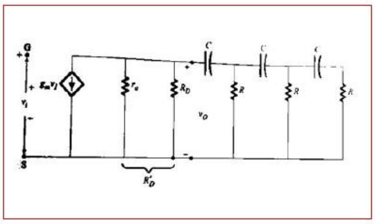
$$\frac{V_o}{V_{sig}} = -\left[\frac{R_G}{R_G + R_{sig}}\right]\left(g_m R_D \| R_L\right)\left(\frac{s}{s+\omega_{P_1}}\right)\left(\frac{s}{s+\omega_{P_2}}\right)\left(\frac{s}{s+\omega_{P_3}}\right)$$



Question 2 - With the help of neat circuit diagram and small signal equivalent model explain the working of FET based RC Phase shift Oscillator. Also explain how three RC pair can be used to in the feedback to achieve 180 degree phase shift.

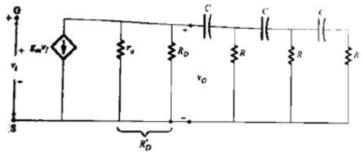
FET Based RC Phase Shift Oscillator





Small Signal Equivalent

$$j\omega = S; capactive\ reactance\ is\ \frac{1}{SC}$$

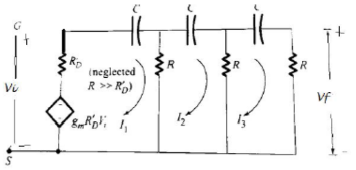


KVL $$-I_2R + I_1\left(R + \frac{1}{SC}\right) = -g_m R_D{}' V_i$$

$$-I_1R + I_2\left(2R + \frac{1}{SC}\right) - I_3R = 0; j\omega = S$$

$$-I_2R + I_3\left(2R + \frac{1}{SC}\right) = 0$$

$$V_f = I_3R$$



Loop gain

$$A\beta = \frac{V_f}{V_i} = \frac{-g_m R_D{}'}{(1-5\alpha^2) + j(\alpha^3 - 6\alpha)}\ ;where\ \alpha = \frac{1}{\omega RC}$$

Loop gain

$$A\beta = \frac{V_f}{V_i} = \frac{-g_m R_D{}'}{(1-5\alpha^2) + j(\alpha^3 - 6\alpha)}\ ;where\ \alpha = \frac{1}{\omega RC}$$

Loop gain is real

$$\alpha^3 - 6\alpha = 0 \xrightarrow{yields} \alpha^2 = 6$$

$$\frac{1}{(\omega RC)^2} = 6$$

$$(2\pi f_o RC)^2 = \frac{1}{6}; f_o = \frac{1}{2\pi RC\sqrt{6}}$$

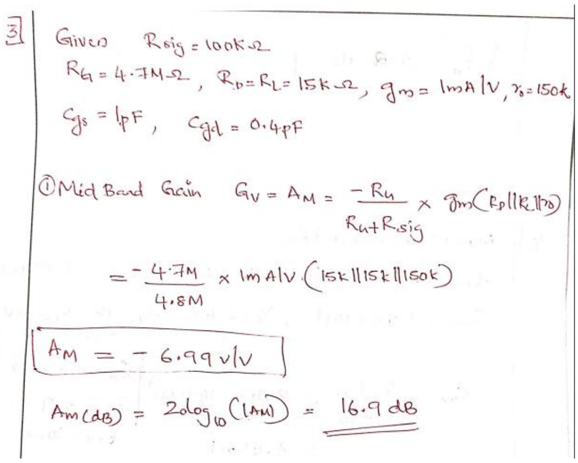
$$A\beta = \frac{V_f}{V_i} = \frac{-g_m R_D{}'}{(1-5\alpha^2)} = \frac{g_m R_D{}'}{29}$$

For sustained oscillation

$$|A\beta| > 1;\ |A| = g_m R_D{}' > 29\ and\ \beta = \frac{1}{29}$$

Question 3 - Find the midband gain AM , and the upper 3-dB frequency fH of a CS amplifier

fed with a signal source having an internal resistance Rsig = 100 kΩ. Theamplifier has RG = 4.7MΩ, RD = RL = 15 kΩ, , gm=1mA/V, ro=150kΩ , Cgs=1pFand Cgd=0.4pF


3

Given $R_{sig} = 100k\Omega$

$R_G = 4.7M\Omega$, $R_D = R_L = 15k\Omega$, $g_m = 1mA/V$, $r_o = 150k$

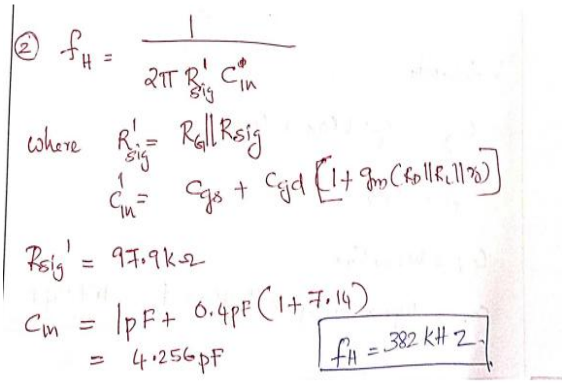
$C_{gs} = 1pF$, $C_{gd} = 0.4pF$

① Mid Band Gain $G_v = A_M = \frac{-R_{in}}{R_{in}+R_{sig}} \times g_m(R_D \| R_L \| r_o)$

$= \frac{-4.7M}{4.8M} \times 1mA/V \, (15k \| 15k \| 150k)$

$\boxed{A_M = -6.99 \, v/v}$

$A_M(dB) = 20\log_{10}(|A_M|) = \underline{\underline{16.9 \, dB}}$


② $f_H = \frac{1}{2\pi R'_{sig} C_{in}}$

where $R'_{sig} = R_G \| R_{sig}$

$C'_{in} = C_{gs} + C_{gd}\left[1 + g_m(R_D \| R_L \| r_o)\right]$

$R_{sig}' = 97.9k\Omega$

$C_{in} = 1pF + 0.4pF(1 + 7.14)$

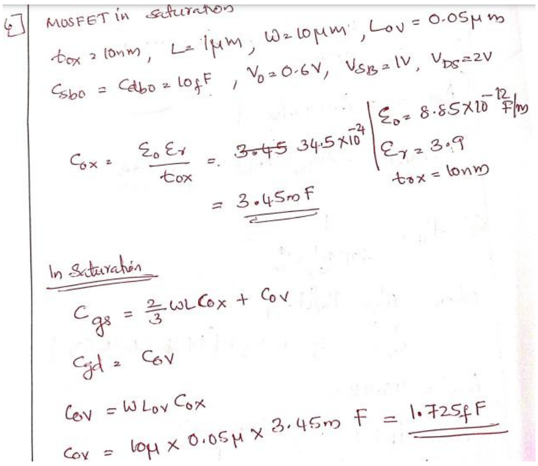
$= 4.256pF$

$\boxed{f_H = 382 \, KHz}$

Question 4 -

Explain the internal capacitances of a MOSFET.

For the n-channel MOSFET in saturation with tox=10nm, L=1µm, W=10µm, LOV=0.05 µm, Csbo = Cdbo = 10fF, VO=0.6V, VSB=1V and VDS=2V. Given dielectric used is SiO2. Calculate i)COX ii)COV iii)Cgs iv)Cgd v)Csb vi)Cdb


4

MOSFET in saturation

$t_{ox} = 10nm$, $L = 1\mu m$, $W = 10\mu m$, $L_{ov} = 0.05\mu m$

$C_{sbo} = C_{dbo} = 10fF$, $V_0 = 0.6V$, $V_{SB} = 1V$, $V_{DS} = 2V$

$C_{ox} = \frac{\varepsilon_0 \varepsilon_r}{t_{ox}} = ~~3.45~~ \; 34.5 \times 10^{-4}$

$\varepsilon_0 = 8.85 \times 10^{-12} F/m$

$\varepsilon_r = 3.9$

$t_{ox} = 10nm$

$= \underline{\underline{3.45mF}}$

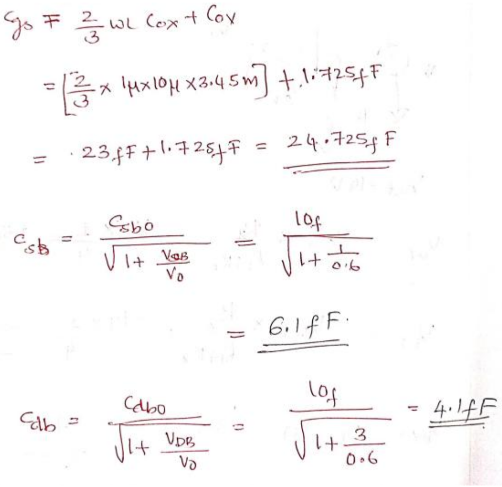
In Saturation

$C_{gs} = \frac{2}{3} WLC_{ox} + C_{ov}$

$C_{gd} = C_{ov}$

$C_{ov} = W L_{ov} C_{ox}$

$C_{ov} = 10\mu \times 0.05\mu \times 3.45m \, F = \underline{\underline{1.725fF}}$


$C_{gs} = \frac{2}{3} WL C_{ox} + C_{ov}$

$= \left[\frac{2}{3} \times 1\mu \times 10\mu \times 3.45m\right] + 1.725fF$

$= 23fF + 1.725fF = \underline{\underline{24.725fF}}$

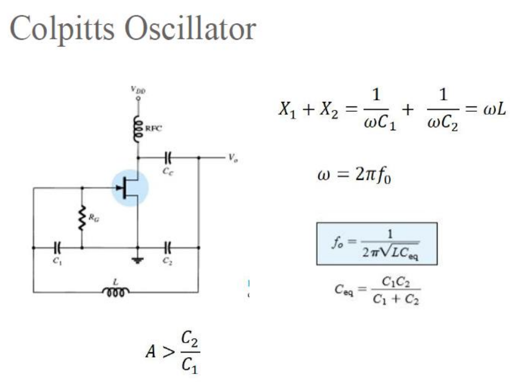
$C_{sb} = \frac{C_{sbo}}{\sqrt{1 + \frac{V_{SB}}{V_0}}} = \frac{10f}{\sqrt{1 + \frac{1}{0.6}}}$

$= \underline{\underline{6.1fF}}$

$C_{db} = \frac{C_{dbo}}{\sqrt{1 + \frac{V_{DB}}{V_0}}} = \frac{10f}{\sqrt{1 + \frac{3}{0.6}}} = \underline{\underline{4.1fF}}$

Question 5- With relevant circuit diagrams and equatuions explain the following

a) Colpitts Oscillator b) Crystal Oscillator.



Colpitts Oscillator

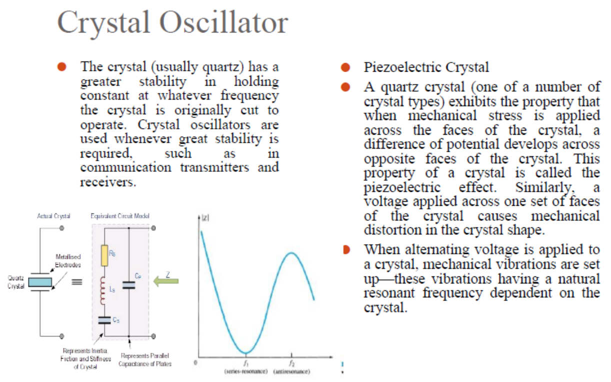
$$X_1 + X_2 = \frac{1}{\omega C_1} + \frac{1}{\omega C_2} = \omega L$$

$$\omega = 2\pi f_0$$

$$\boxed{f_o = \frac{1}{2\pi\sqrt{LC_{eq}}}}$$

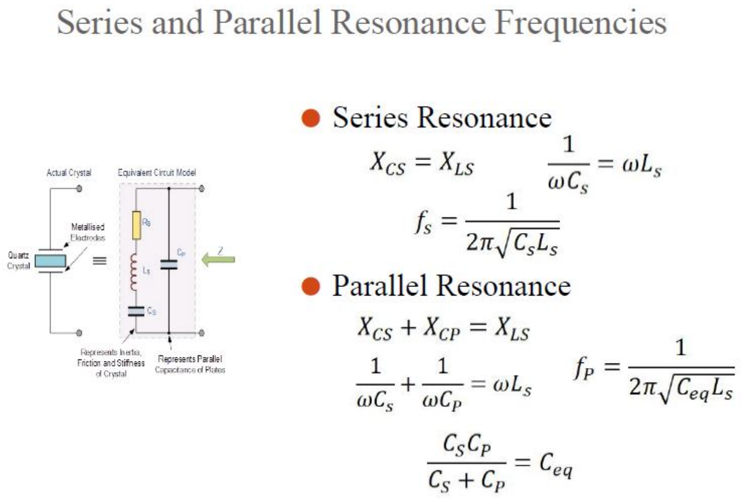
$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

$$A > \frac{C_2}{C_1}$$



Crystal Oscillator

- The crystal (usually quartz) has a greater stability in holding constant at whatever frequency the crystal is originally cut to operate. Crystal oscillators are used whenever great stability is required, such as in communication transmitters and receivers.
- Piezoelectric Crystal
- A quartz crystal (one of a number of crystal types) exhibits the property that when mechanical stress is applied across the faces of the crystal, a difference of potential develops across opposite faces of the crystal. This property of a crystal is called the piezoelectric effect. Similarly, a voltage applied across one set of faces of the crystal causes mechanical distortion in the crystal shape.
- When alternating voltage is applied to a crystal, mechanical vibrations are set up—these vibrations having a natural resonant frequency dependent on the crystal.



Series and Parallel Resonance Frequencies

- Series Resonance

$$X_{CS} = X_{LS} \qquad \frac{1}{\omega C_s} = \omega L_s$$

$$f_s = \frac{1}{2\pi\sqrt{C_s L_s}}$$

- Parallel Resonance

$$X_{CS} + X_{CP} = X_{LS}$$

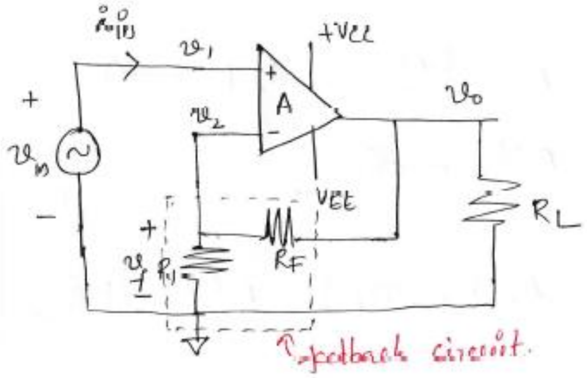
$$\frac{1}{\omega C_s} + \frac{1}{\omega C_P} = \omega L_s \qquad f_P = \frac{1}{2\pi\sqrt{C_{eq} L_s}}$$

$$\frac{C_S C_P}{C_S + C_P} = C_{eq}$$

Question 6 - Draw the circuit of nonoinverting amplifier and derive the expressions for

a) Exact gain b)Ideal gain c)Input Resistance d) Bandwidth.

Non inverting Amplifier with feedback [Voltage Series feedback Amplifier]



A] Closed loop Voltage Gain (A_F)

Recall $A_F = \frac{v_0}{v_{id}}$

and $v_0 = A(v_1 - v_2) = A v_{id}$ —①

$v_f = B v_0$ —②

from ① and ②

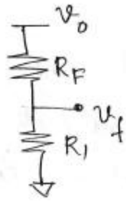
$$v_0 = A(v_{in} - v_f) = A(v_{in} - Bv_0)$$

On rearranging

$$(1+AB)v_0 = A v_{in}$$

$$\boxed{A_F = \frac{v_0}{v_{in}} = \frac{A}{1+AB}} \quad —③$$

from the ckt



$$v_f = \frac{v_0 \times R_1}{R_1 + R_F}$$

$$\boxed{B = \frac{v_f}{v_0} = \frac{R_1}{R_1+R_F}}$$

Substituting value of B in ③

$$\boxed{A_F = \frac{A}{1+\frac{AR_1}{R_1+R_F}} = \frac{A(R_1+R_F)}{R_1+R_F+AR_1}} \quad —④$$

Note: In ideal case $A \ggg$. thus if ideal op-amp is considered

$$1 + \frac{AR_1}{R_1+R_F} \simeq \frac{AR_1}{R_1+R_F} \quad \text{OR}$$

$$R_1 + R_F + AR_1 \simeq AR_1$$

thus eqn ④ becomes under ideal can.

$$\boxed{A_F = \frac{A(R_1+R_F)}{AR_1} = 1 + \frac{R_F}{R_1}} \quad —— ⑤$$

closed loop Voltage gain A_F

Exact

$$A_F = \frac{A(R_1+R_F)}{R_1+R_F+AR_1}$$

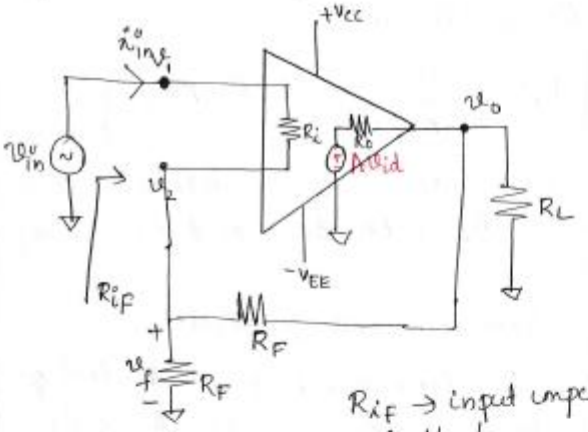
Ideal

$$\boxed{A_F = 1 + \frac{R_F}{R_1}}$$

Note: Gain of the feedback amplifier is decided by ratio of R_F and R_1. All components must be kept below 1MΩ so that the external circuitry won't affect op amp internal circuit.

B] Input Resistance

Consider the amplifier ckt with the op-amp replaced with its equivalent model



R_{if} → input impedence with feedback

from the ckt

$$R_{if} = \frac{v_{in}}{i_{in}} \quad —— ⑥$$

$$i_{in} = \frac{v_1 - v_2}{R_i} = \frac{v_{in} - v_f}{R_i} \quad —— ⑦$$

Recall $\Rightarrow v_{in} - v_f = \frac{v_0}{A}$

and $v_0 = A_F v_{in}$

$$v_{in} - v_f = \frac{A_F v_{in}}{A} = \frac{\frac{A}{1+AB} v_{in}}{A} = \frac{v_{in}}{1+AB}$$

substitute this in ⑦

$$i_{in} = \frac{v_{in}}{R_i(1+AB)}$$

and ⑥ yeilds

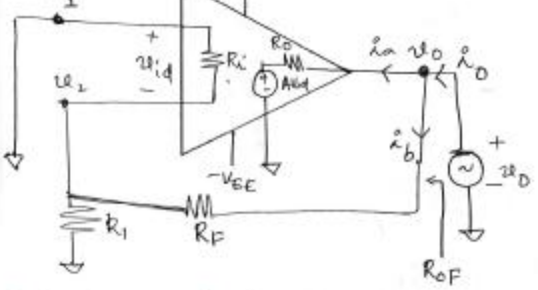
$$\boxed{R_{iF} = \frac{v_{in}}{i_{in}} = R_i(1+AB)}$$

<u>Note:</u> Input impedance of op-amp with feedback is improved by $(1+AB)$ times of that of an open loop op-amp circuit.

C] Output Resistance with feedback

output impedance can be found by looking back into the feedback amplifier from the output terminal.

① Replace input side by its thevinine equivalent ⇒ replace v_{in} with internal impedance, idally zero.



② Apply an external voltage v_o, which force a current i_o

Let i_a be the current through R_o, and i_b through

$$\left[R_F + (R_i \| R_1)\right]$$

since $R_F + (R_1 \| R_i) \ggg R_o$; $i_b \lll i_a$

$$\boxed{i_o = i_a + i_b \cong i_a}$$

$$\boxed{R_{OF} = \frac{v_o}{i_o}}$$

writing KVL

$$v_o - i_o R_o - A v_{id} = 0$$

$$v_o - i_o R_o + A v_f = 0$$

$$v_o - i_o R_o + AB v_o = 0$$

$$(1+AB) v_o = i_o R_o$$

$$\boxed{R_{OF} = \frac{v_o}{i_o} = \frac{R_o}{1+AB}}$$

Note: Output impedence has substantially improved by a factor $\frac{1}{1+AB}$ with feedback.

Question 7 - With a neat circuit diagram explain the opamp based non - inverting Summing amplifier, scaling amplifier and averaging circuit with relevant expressions for the output.

Non-Inverting Configuration.

Refer the circuit diagram in Fig 4.2, where the input voltages are connected at non-inverting terminals.

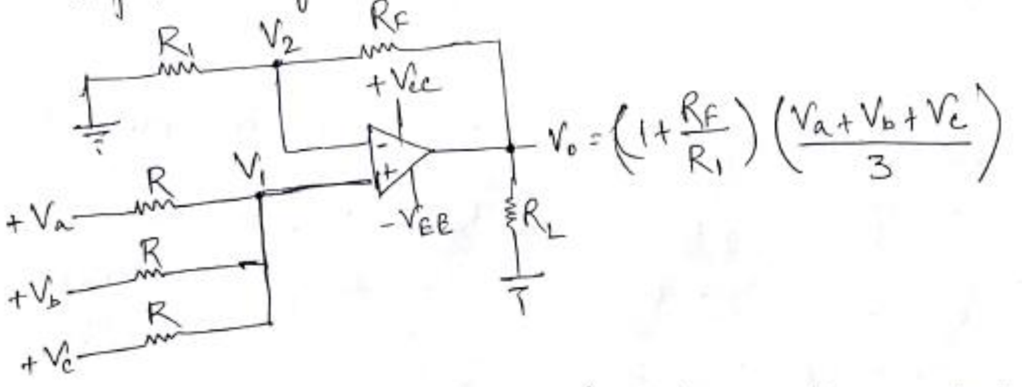


Fig 4.2: Non-inverting configuration with 3 inputs

Voltage at V_1 due to only $V_a = \frac{R/2}{R+R/2} V_a$.

" " V_1 " " " $V_b = \frac{R/2}{R+R/2} V_b$.

" " " due " " $V_c = \frac{R/2}{R+R/2} V_c$.

Hence using Superposition theorem, the total voltage ~~at~~ [illegible] ~~non~~ V_1 at non-inverting terminal is

$$V_1 = \frac{R/2}{R+R/2} V_a + \frac{R/2}{R+R/2} V_b + \frac{R/2}{R+R/2} V_c .$$

$$\Rightarrow V_1 = \frac{V_a}{3} + \frac{V_b}{3} + \frac{V_c}{3}$$

$$\Rightarrow V_1 = \frac{V_a + V_b + V_c}{3} \qquad \text{—(8)}$$

Therefor the output voltage can be given as.

$$V_o = \left(1 + \frac{R_F}{R_1}\right) V_1$$

$$\boxed{V_o = \left(1 + \frac{R_F}{R_1}\right)\left(\frac{V_a + V_b + V_c}{3}\right)} \quad \text{—(9)}$$

(a) Summing Amplifier (Non-inverting configuration)

After analysing Eq(9), one can conclude that is the gain of the circuit in Fig. 4.2 is chosen such that

$$1 + \frac{R_F}{R_1} = 3$$

Then Eqn 9, becomes.

$$V_0 = 3\left(\frac{V_A + V_B + V_C}{3}\right)$$

$$\Rightarrow \boxed{V_0 = V_A + V_B + V_C} \quad \text{——} ⑩$$

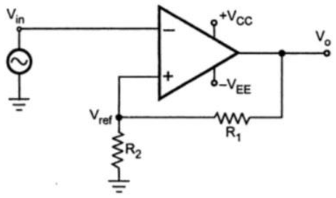
The output voltage is sum of all three input voltages. Hence it is called a non-inverting summing amplifier.

(b) Averaging Amplifier (non-inverting configuration)

~~Fo~~ From Eq. 9, it is clear that output voltage is equal to all input voltages multiplied by gain of the circuit $\left(1+\frac{R_F}{R_1}\right)$, hence the name as averaging amplifier.

Question 8 - Draw the circuit and waveforms for an inverting Schmitt Trigger usingopamp, with relevant expressions.For an inverting Schmitt Trigger circuit R2 = 1KΩ ; R1 = 3KΩ and Vin=10Vp-pp sine wave. The saturation voltages are ± 14V.

i) Determine the threshold voltages Vut and Vlt.



ii) Find the value of Hysteresis voltage Vhy.

SCHMITT TRIGGER

Need for Schmitt Trigger.

In some applications, the input Vin may be slowly changing waveform i.e low frequency channel. Hence in the presence of noise ~~around~~ at around 0V, Vo may fluctuate quickly from one saturation voltage to another. This problem can be cured by the use of regenerative or positive feedback that causes the output Vo to change faster and eliminate any false output transitions due to noise signals at the input. This arrangement give rise to Schmitt Trigger Circuit.

Schmitt Trigger:

- Fig 4.6 shows an inverting comparator with positive feedback, known as Schmitt Trigger, which converts an irregular-shaped waveform to square wave or pulse.
- The input voltage V_{in} triggers the output V_o everytime it exceeds certain voltage levels called the upper threshold voltage V_{ut} and lower threshold voltage V_{lt}

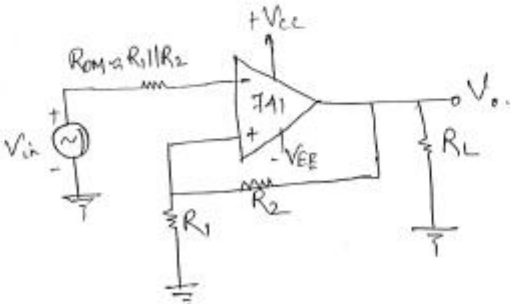


Fig 4.6.a:- Schmitt Trigger.

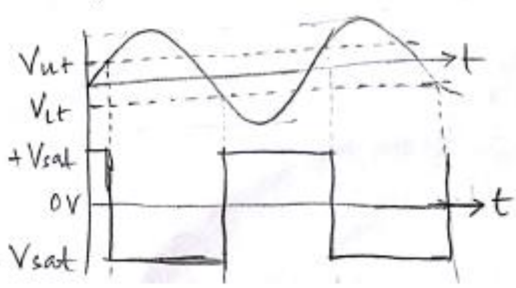


Fig 4.6.b:- Input/Output Waveform of Schmitt Trigger

- From circuit diagram in Fig 4.6.a, using voltage divider rule across R_1 & R_2, V_{ut} is given as.

$$\boxed{V_{ut} = \frac{R_1}{R_1+R_2}\left(+V_{sat}\right)} \quad —1.$$

- Similarly when $V_o = -V_{sat}$, the V_{lt} is given as

$$\boxed{V_{lt} = \frac{R_1}{R_1+R_2}\left(-V_{sat}\right)} \quad —2$$

- Thus if threshold voltages V_{ut} & V_{lt} are made larger than the input noise voltages, the positive feedback will eliminate the false output transitions.
- $R_{om} = R_1 \| R_2$ is used to minimize offset problem.
- Hysteresis in Schmitt Trigger:-

The comparator with positive feedback is said to exhibit hysteresis, a dead band condition. This is when the input of the comparator exceeds V_{ut}, its output switches from $+V_{sat}$ to $-V_{sat}$ and ~~and~~ again comes back to $+V_{sat}$ when the input V_{in} goes below V_{lt} (Refer Fig 4.6.b)

• Therefore it is obvious, the hysteresis voltage is equal to difference of V_{ut} & V_{lt} i.e.

$$V_{hy} = V_{ut} - V_{lt}$$
$$= \frac{R_1}{R_1+R_2}\left[+V_{sat} - (-V_{sat})\right]$$

$$\boxed{V_{hy} = 2 \cdot \frac{R_1}{R_1+R_2} \cdot V_{sat}} \quad — 3$$

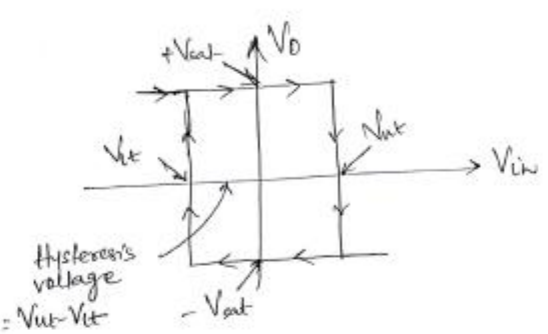
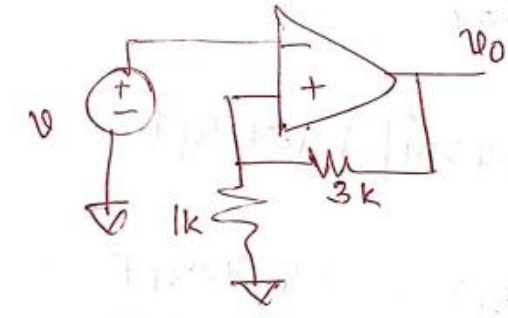


Fig 4.6.c: Hysteresis Voltage

8] Schmitt



$V_{sat} = 14\,V$

$$V_{UT} = V_{sat} \times \frac{R_2}{R_1+R_2} = 14 \times \frac{1}{4} = \underline{\underline{+3.5\,V}}$$

$$V_{LT} = -V_{sat} \times \frac{R_2}{R_1+R_2} = -14 \times \frac{1}{4} = \underline{\underline{-3.5\,V}}$$