Note:- Op-amp stands for operational amplifier which is a transistorised differential amplifier used for the amplification of difference between the two input voltages.

The five properties of op-amp are as followed:-

* Open loop gain:- Ideally the gain of the op-amp must be infinite as $V_0 = A_d V_d$ where A_d is differential or open loop gain & V_d is the difference voltage as gain will be infinite then it means $V_1 = V_2$ so that $V_d \to 0$

But ~~as~~ practically it is not infinite.

* Offset Voltage:- The presence of small output voltage even if both the inputs V_1 & V_2 are zero is called offset voltage.

Ideally the offset voltage must be zero.

But P

* CMRR:- It is the ability of the op-amp to reject the common mode signal as it creates noise & disturbances.

It is defined as the ratio of differential gain to common-mode gain

$$\boxed{CMRR = \left| \frac{A_d}{A_{cm}} \right|}$$

The CMRR of ideal op-amp must be infinite as A_d is infinite which tends the A_{cm} to be zero so that common mode gain will

CMR

* Slew rate :- Slew rate is defined as ratio of change in output voltage wrt time. It is actually the parameter which tells that the output changes simultaneously with inputs.

$$\boxed{S = \frac{dV_o}{dt}} \quad \text{or} \quad \boxed{S = 2\pi f V_m}$$

Ideally the slew rate should be infinite but practically it is not ∞.

* PSRR :- It is the ratio of change in output offset voltage wrt change in one of the supply voltages keeping one supply constant.

$$PSRR = \frac{\Delta V_{ios}}{\Delta V_{CC}}\bigg|_{V_{EE} = \text{constant}} \qquad PSRR = \frac{\Delta V_{ios}}{\Delta V_{EE}}\bigg|_{V_{CC} = \text{constant}}.$$

Ideally it should be zero.

* Infinite bandwidth :- Bandwidth is the range of frequency over which ~~it~~ the gain remains constant & ideally it should be infinite.

* Input impedance :- It is the impedance which is present at any one of the input terminal & ideally input impedance should be infinite.

Sol-30. Given it is voltage follower

So, $\beta = 1$

$A_{OL\,min} = 50,000$

$A_{OL\,max} = 2,00,000$

$Z_i = 2M\Omega$

$Z_o = 75\Omega$

So, Minimum input impedance with feedback

$$Z_{inf} = Z_{in}(1 + A_{OL\,min}\beta)$$

$$= 2M\Omega(1 + 50,000 \times 1)$$

$$= 1.000 \times 10^{11}\Omega$$

5

$$Z_{inf\,max} = Z_{in}(1 + A_{OL\,max}\beta)$$

$$= 2M\Omega(1 + 2,00000)$$

$$= 4.000 \times 10^{11}\Omega$$

Output impedance with feedback is given by

$$Z_{of\,min} = \frac{Z_o}{(1 + A_{OL\,max})}$$

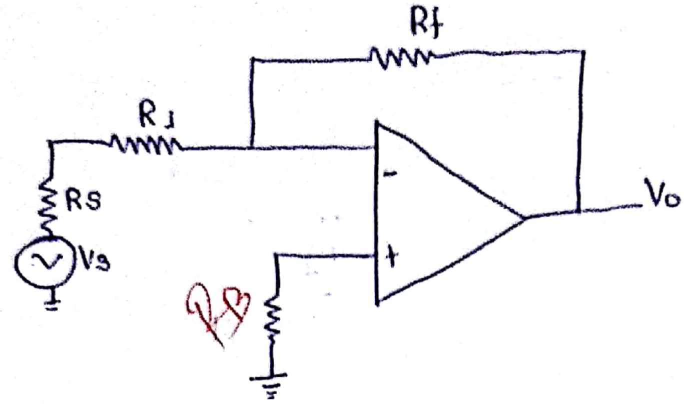
$$= \frac{75\Omega}{(1 + 2,00,000)}$$

$$= 3.749 \times 10^{-4}\Omega \; 10^{-2}$$

$$= \cancel{3.744.9 \times 10^{-2}} = 0.3749\,m\Omega$$

$$Z_{of\,max} = \frac{Z_o}{(1 + A_{OL\,min})} = \frac{75\Omega}{(1 + 50,000)} = 1.499\,m\Omega.$$

Sol:3(b). Direct Coupled Inverting amplifier:-



Given output voltage = 2.5V
& gain = AOL = 50

So, ∴ gain = $\frac{V_o}{V_i}$

$V_{in} = \frac{2.5V}{50} = 0.05V$

& $i_p = 100 \times 500nA = 50\mu A$

So, $R_1 = \frac{V_{in}}{i_p}$

$= \frac{0.05V}{50\mu A}$

$= 1000\Omega$

$= 1k\Omega$

5

& $A_{OL} = \frac{R_f}{R_1}$

$R_f = R_1 \times A_{OL}$

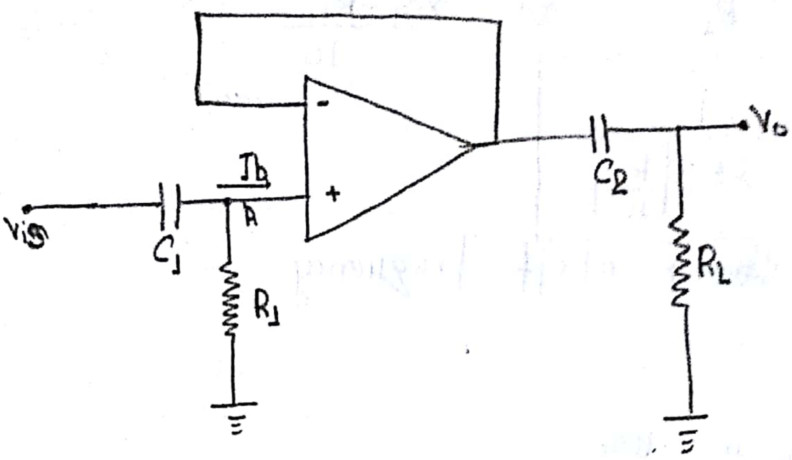
$= 1k\Omega \times 50$

$= 50k\Omega$

& $R_{Bias} = R_1 || R_f = 1k\Omega || 50k\Omega = \frac{1k\Omega \times 50k\Omega}{1 + 50k\Omega} = 0.980 k\Omega$

$= 980\Omega$

Sol.4. Capacitor Coupled Voltage follower:-



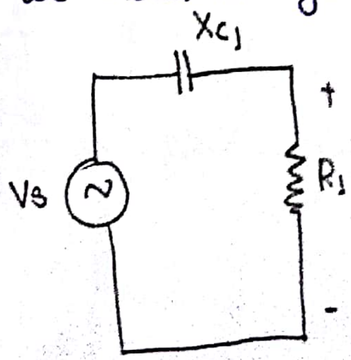
For converting into ~~dc~~ ac -amplifier we use capacitor coupled voltage follower. Here in input side we place a capacitor but it can block the dc base voltage required for operation of transistor so a resistance R_1 is placed but ~~there~~ so in order of matching the impedance we use C_2 at the output so there is no use of resistance in another terminal:-

Design:-

(i) For Calculating R_1 we need

$$R_1 = \frac{0.1 V_{BE}}{I_{Bmax}} \quad \text{which} \quad \frac{0.07V}{500nA} = 140k\Omega .$$

(ii) Now to find voltage across A we need voltage divider circuit:-



So $$V_A = \frac{V_S \times R_1}{R_1 - jX_{C_1}}$$

$$|V_A| = \frac{V_S \times R_1}{\sqrt{R_1 + X_{C_1}^2}}$$

But here R_1 is very high

So, $\sqrt{R_1^2 + X_{C_1}^2} = R_1$ So, $X_{C_1} = \frac{R_1}{10}$

$$\boxed{C_1 = \frac{1}{2\pi f\left(\frac{R_1}{10}\right)}}$$

where f is lower cutoff frequency

Now, across R_L we use:-

$$\frac{V_o \times R_L}{R_L - jX_{C_2}} = V_B$$

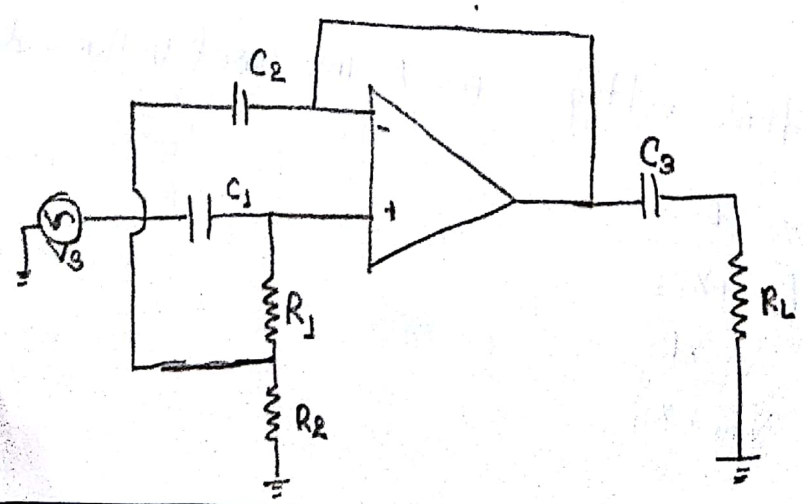
$$|V_B| = \frac{V_o \times R_L}{\sqrt{R_L^2 + X_{C_2}^2}}$$ when $R_L = X_{C_2}$

$\frac{V_o}{\sqrt{2}}$ which means it $-3dB$ frequency which is cut-off frequency so,

$R_L = X_{C_2}$

$$\boxed{C_2 = \frac{1}{2\pi f R_L}}$$

* High impedance Voltage follower:-



In the previous case the input impedance R_1 was not so high so, we are using this configuration to make it a perfect buffer amplifier:-

We know,
$$V_S = V_1 + V_o$$
$$V_S = V_1 + \frac{V_{in}}{A_{OL}}$$
$$V_1 = \frac{V_S}{(1+A_{OL})}$$
$$Z_{in} = \frac{V_S}{\frac{V_S}{R_1(1+A_{OL})}} = R_1(1+A_{OL})$$

Design:-

* $$R_{max} = \frac{0.1 V_{BE}}{I_{Bmax}} = 140K\Omega$$

$$R_1 + R_2 = R_{max}.$$
$$R_1 = R_2 = \frac{R_{max}}{2} = 70K\Omega \simeq 68K\Omega.$$

good

Now as discussed previously.
$$X_{C1} = \frac{R_1}{10}$$
$$C_1 = \frac{1}{2\pi f_L\left[\frac{R_1}{10}\right]}$$
$$C_2 = \frac{1}{2\pi f_L\left[\frac{R_2}{10}\right]}$$
& $$C_3 = \frac{1}{2\pi f_L R_L}$$ as $\boxed{X_{C3} = R_L}$

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CMR

Sol: Given $R_L = 22K\Omega$

$V_S = 1.5V$

$R_S = 56K\Omega$

$Z_0 = 75\Omega$, $Z_{in} = 2M\Omega$. $A_{OL} = 2\times10^5$

(i) Load is directly connected.

$$So,\ V_L = \frac{V_S \times R_L}{(R_S + R_L)}$$

$$= \frac{1.5 \times 22K\Omega}{(22K\Omega + 56K\Omega)}$$

$$1.5 \times 0.282$$

$$= 0.423V$$

(ii). Load is connected through voltage follower:-

$$Z_{inf} = Z_{in}(1 + A_{OL}\beta) \quad \text{where } \beta = 1.$$

$$(2\times10^6)(1 + 2\times10^5)$$

$$= 4\times10^{11}\Omega.$$

$$So,\quad V_{in} = \frac{V_S \times Z_{inf}}{Z_{inf} + R_S}$$

$$= 1.4999V.$$

$$So,\ now\ V_0 = V_{in}\left[1 - \frac{1}{A_{OL}}\right]$$

$$= 1.5\left(1 - \frac{1}{2\times10^5}\right)$$

$$= 1.49999V.$$

5+5 = 10

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So, $V_L = \frac{V_0 \times R_L}{R_L + Z_{of}}$

$= 1.4999 \times \frac{22\times10^3}{(22\times10^3) + (3.749\times10^{-4})}$

$\boxed{V_L = 1.49998\ V}$

$Z_{of} = \frac{Z_0}{1 + A_{OL}}$

$= \frac{75\Omega}{(1 + (2\times10^5))}$

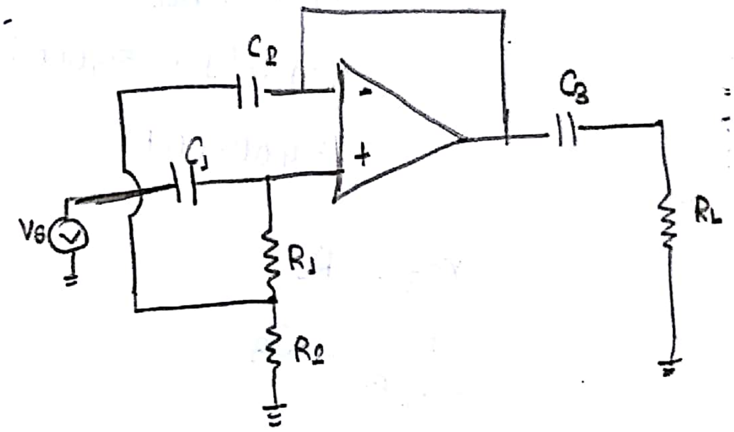
$= 3.7499\times10^{-4}\ \Omega.$

Sol#: Given lower cutoff frequency = 50Hz.

$I_{Bias} = 500nA$

$R_L = 3.3K\Omega$

$A_{OL} = 10^5$



Now, we R_{max} $R_{max} = \frac{0.1 V_{BE}}{500nA}$

$= \frac{0.07}{500nA}$

$= 140K\Omega$

So, $R_1 = R_2 = \frac{R_{max}}{2} = 70K\Omega \simeq 68K\Omega$

Now, $X_{C1} = \frac{R_1}{10}$

$\frac{1}{2\pi f C_1} = 6.8K\Omega$

$C_1 = \frac{1}{2\pi f(6.8\times10^3)}$

$= \frac{1}{2\pi \underset{50}{\cancel{f}}(6.8\times10^3)} = 4.681\times10^{-7}\times F$

$= 0.468\ \mu F$

$$\boxed{C_1 = C_2 = 0.468\,\mu f}$$

$$Z_{in} = R_1(1 + A_{OL})$$
$$= 68k\Omega(1 + (10^5))$$
$$= 6.8 \times 10^9 \Omega.$$

But ideally it will be

$$R_1(1 + A_{OL})$$
$$= 68k\Omega(1 + 50{,}000)$$
$$= 3400.06\,M\Omega.$$

$$X_{C_3} = R_L$$

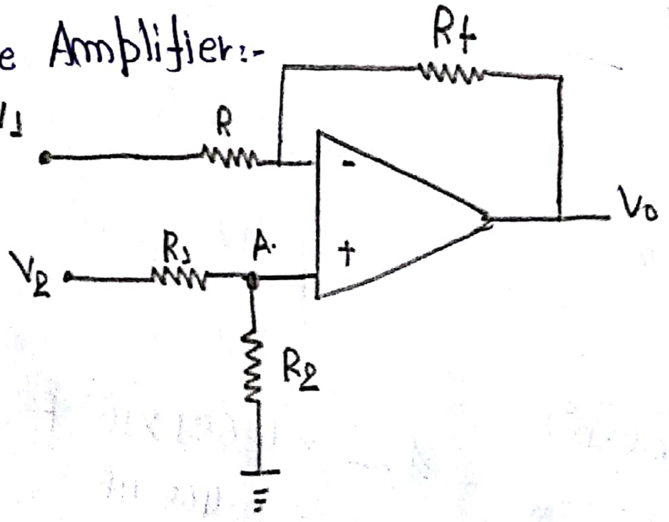
$$\frac{1}{2\pi f_L R_L} = C_3$$

$$C_3 = \frac{1}{2\pi \times 50 \times (3.3 \times 10^3)}$$
$$= 9.645 \times 10^{-7} F$$

$$\boxed{C_3 = 0.9645\,\mu f}$$

10

5(a). Difference Amplifier:-



Difference amplifier is also called subtractor which is used to amplify the difference between the two voltages V_1 & V_2.
In order to calculate it we have to make one active and another ground

Case I) Suppose V_1 is active & V_2 is grounded then then it will be inverting amplifier so, the output voltage will be

$$V_o = -\frac{R_f}{R_1}(V_1)$$

Now,
Case II. Suppose here V_2 is active & V_1 is grounded then it will become non-inverting amplifier with output voltage

$$V_o = \left(1 + \frac{R_f}{R}\right) V_A$$

good

& by potential divider we have

$$V_A = V_2 \times \frac{R_2}{(R_1 + R_2)}$$

$$V_o = \left(1 + \frac{R_f}{R}\right) \frac{V_2 R_2}{(R_1 + R_2)}$$

5

$$V_o \quad -\frac{R_f}{R} V_1 = \frac{V_2 R_2}{(R_1 + R_2)} + \frac{R_f}{R} \frac{V_2 R_2}{(R_1 + R_2)}$$

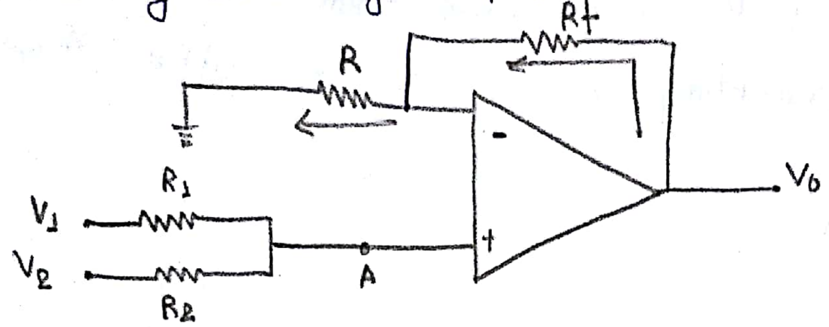
So, $V_o = \frac{R_f}{R}(V_1 - V_2) = \frac{R_2}{R_1}(V_1 - V_2)$

And it's input resistance is.

$$Z_{in} = R + R_1 + R_2$$

$$Z_{on} = R \parallel (R_1 + R_2)$$

5(b). Non-Inverting summing amplifier:-



Here, $I_1 = \frac{V_1 - V_A}{R_1}$

$I_2 = \frac{V_2 - V_A}{R_2}$

$I_1 + I_2 = 0.$

$$\frac{V_1 - V_A}{R_1} + \frac{V_2 - V_A}{R_2} = 0.$$

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} = V_A\left[\frac{1}{R_1} + \frac{1}{R_2}\right]$$

$$\boxed{\frac{V_1 R_2 + V_2 R_1}{R_1 + R_2} = V_A}$$

Now by virtual ground we have

$V_A = V_B.$

5

Now, $\frac{V_o - V_B}{R_f} = \frac{V_B}{R}$

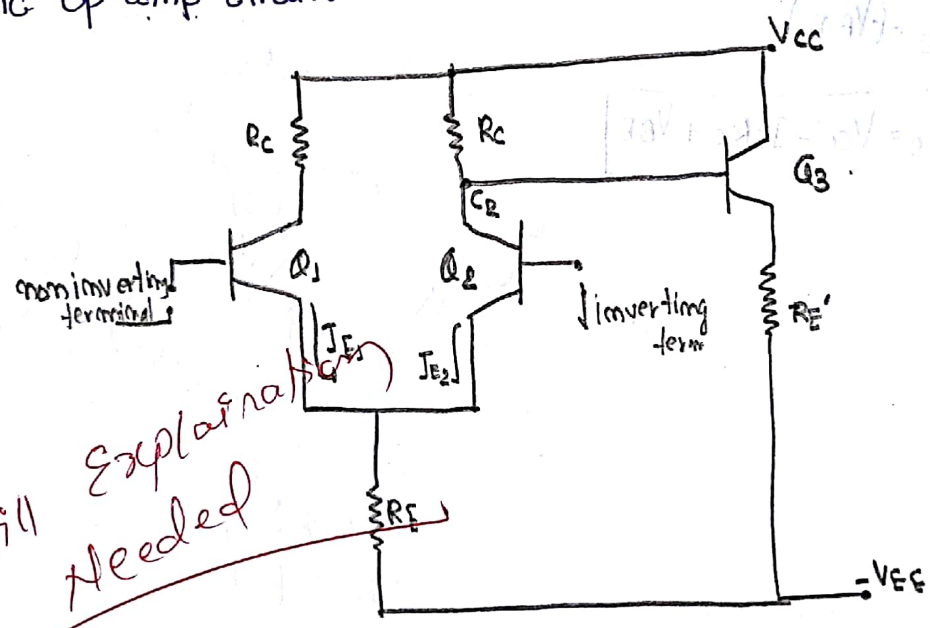
$$V_o = \left[1 + \frac{R_f}{R}\right] V_B$$

So, here we have to substitute the value of V_B

$$V_o = \left[1 + \frac{R_f}{R}\right] \left[\frac{V_1 R_2 + V_2 R_1}{R_1 + R_2}\right]$$

As the two voltages V_1 & V_2 are applied to the non-inverting terminal as it is non-inverting summer.
Here it is collectively amplifying the voltage V_1 & V_2 to V_o.

Sol+1. Basic op-amp circuit:-



Still Explanation Needed

Here the base terminal of Q_1 is non-inverting terminal
Where as base terminal of Q_2 is inverting terminal.

Here in op-amp all the voltages V_{BE_1} & V_{BE_2} should be perfectly matched
i.e $V_{BE_1} = V_{BE_2} = V_{BE}$

& all the currents I_{E_1} & I_{E_2} should be same

so, $I_{E_1} = I_{E_2} = I_E$

$$V_{BE} + 2I_E R_E = V_{EE}$$

$$\boxed{I_E = \frac{V_{EE} - V_{BE}}{2R_E}}$$

Now at output side

$$I_C = I_E = I_{CQ}$$

So, $V_{C_2} = V_{CC} - I_C R_C$

where as

$$V_{CE_2} = V_{C_2} - (-V_{BE})$$

$$\boxed{V_{CE_2} = V_{CC} - I_C R_C + V_{BE}}$$

Taking some Resistor values finding o/p voltage when i/p is applied to inverting & non inverting.