UNIT-2

LICA

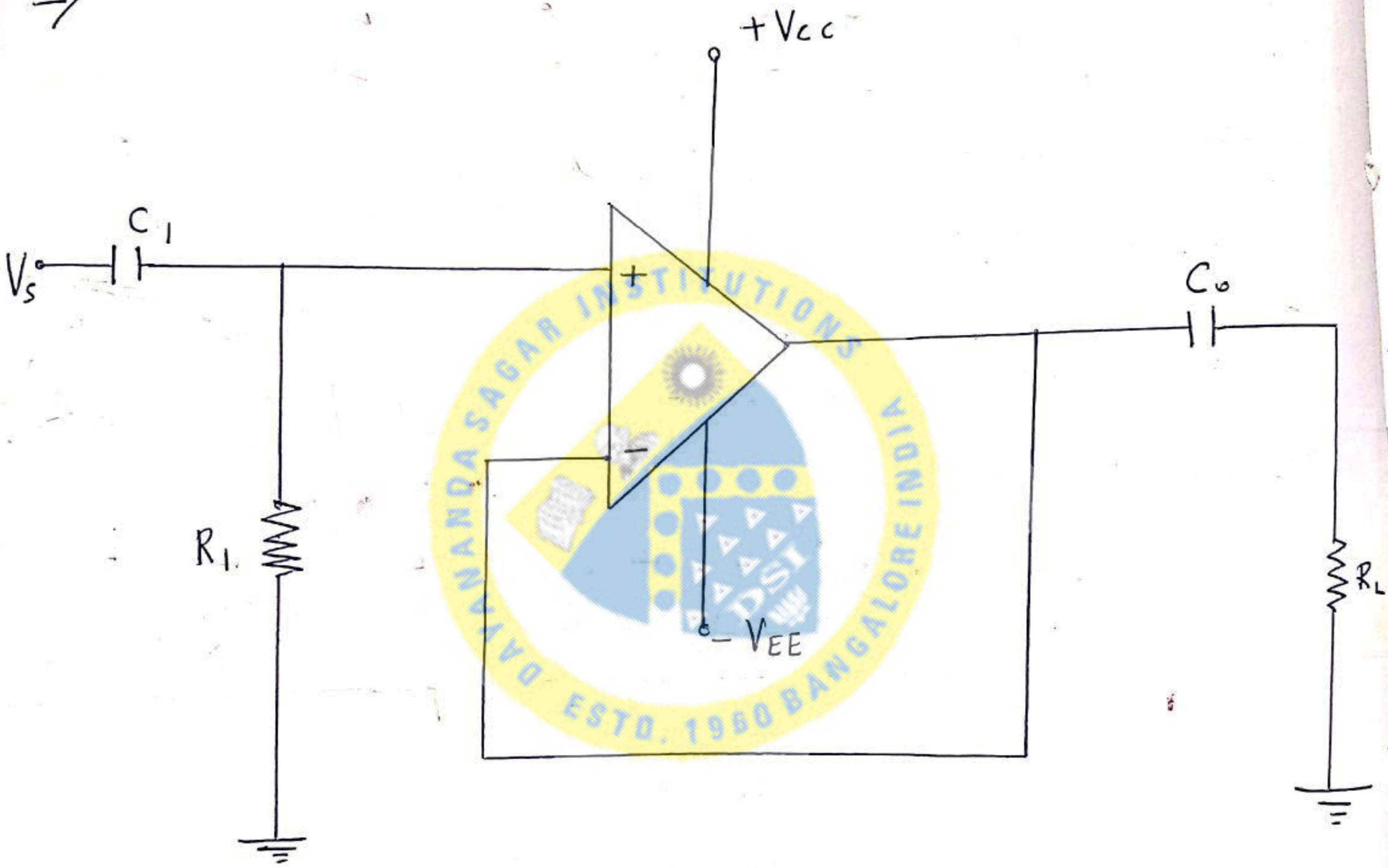
Syllabus ⇒

Op-amp as AC-ampr ⇒

- ✓ → Capacitor coupled voltage follower.
- ✓ → High Zin CC vtg follower.
- ✓ → CC non-inv. ampr.
- ✓ → High Zin non-inv ampr.
- ✓ → CC inv. ampr.
- ✓ → Setting the upper cut-off frequency.
- ✓ → CC difference ampr.
- ✓ → Use of single polarity power supply.

Q.1. With a neat ckt diagram, explain Capacitor-coupled voltage follower with relevant circuit diagram.

⇒

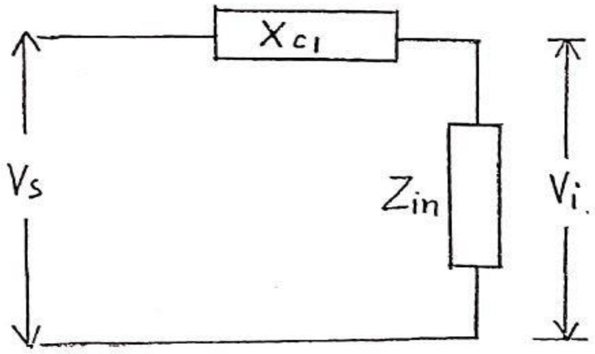


→ The NON-INV terminal must be grounded via a resistor 'R1'.

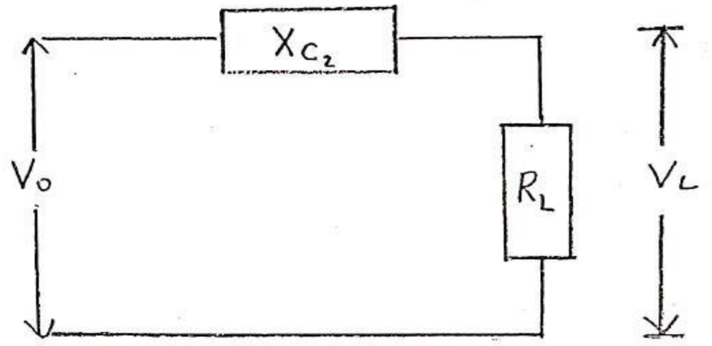
→ This resistor is required to pass the bias current to the ampr NON-INV terminal.

→ A resistor equal to 'R1' might be include in series with the inverting terminal to equalize the $I_B R_B$ voltage and thus minimize the o/p offset voltage.

→ The output capacitor C_2 blocks the small dc offset voltage.



(a). The signal vtg is divided across X_{C_1} & Z_{in}



(b). The o/p voltage is divided across X_{C_2} and R_L.

Design ⇒

→ Design involves calculation of R_1, C_1 and C_2

→ The maximum value of R_1 is determined as :

$$\boxed{R_{1(max)} = \frac{0.1 \cdot V_{BE}}{I_{B\,max}}}$$

→ Input impedance of the ckt is :

$$\boxed{Z_{in} = R_1 \,||\, Z_i'}$$

where, $Z_i' = (1+M\beta) Z_i$

Z_i' is the i/p impedance at the NON-INV terminal & is very much larger than R1.

$$\therefore \boxed{Z_{in} = R_1}$$

→ Load resistor R_L normally has a lower resistance than R1.

→ At the lower 3dB frequency 'f_1', the impedance of C_1 should be much smaller than Zin.

∴ At f_1,

$$X_{C_1} = \frac{Z_{in}}{10}$$

$$\Rightarrow \frac{1}{2\pi f_1 C_1} = \frac{R_1}{10}$$

$$\Rightarrow \boxed{C_1 = \frac{10}{2\pi f_1 R_1}} \quad \Rightarrow \boxed{C_1 = \frac{1}{2\pi f_1 \left(\frac{R_1}{10}\right)}}$$

→ The ckt low 3 dB frequency f_1 occur when $X_{C_2} = R_L$

$$\therefore X_{C_2} = R_L \text{ at } f_1$$

$$\Rightarrow \frac{1}{2\pi f_1 C_2} = R_L$$

$$\Rightarrow \boxed{C_2 = \frac{1}{2\pi f_1 R_L}}$$

<u>For LF 353 BIFET</u> ⇒

(1). $R_1 = 1\,M\Omega$.

(2). $C_1 = \frac{1}{2\pi f_1 \left(\frac{R_1}{10}\right)}$

(3). $C_2 = \frac{1}{2\pi f_1 R_L}$

(4). $Z_{in} = R_1$

Q. 9. With a neat diagram explain High input impedance capacitor coupled voltage follower with relevant design steps and obtain the expression for the input impedance of the circuit.

⇒

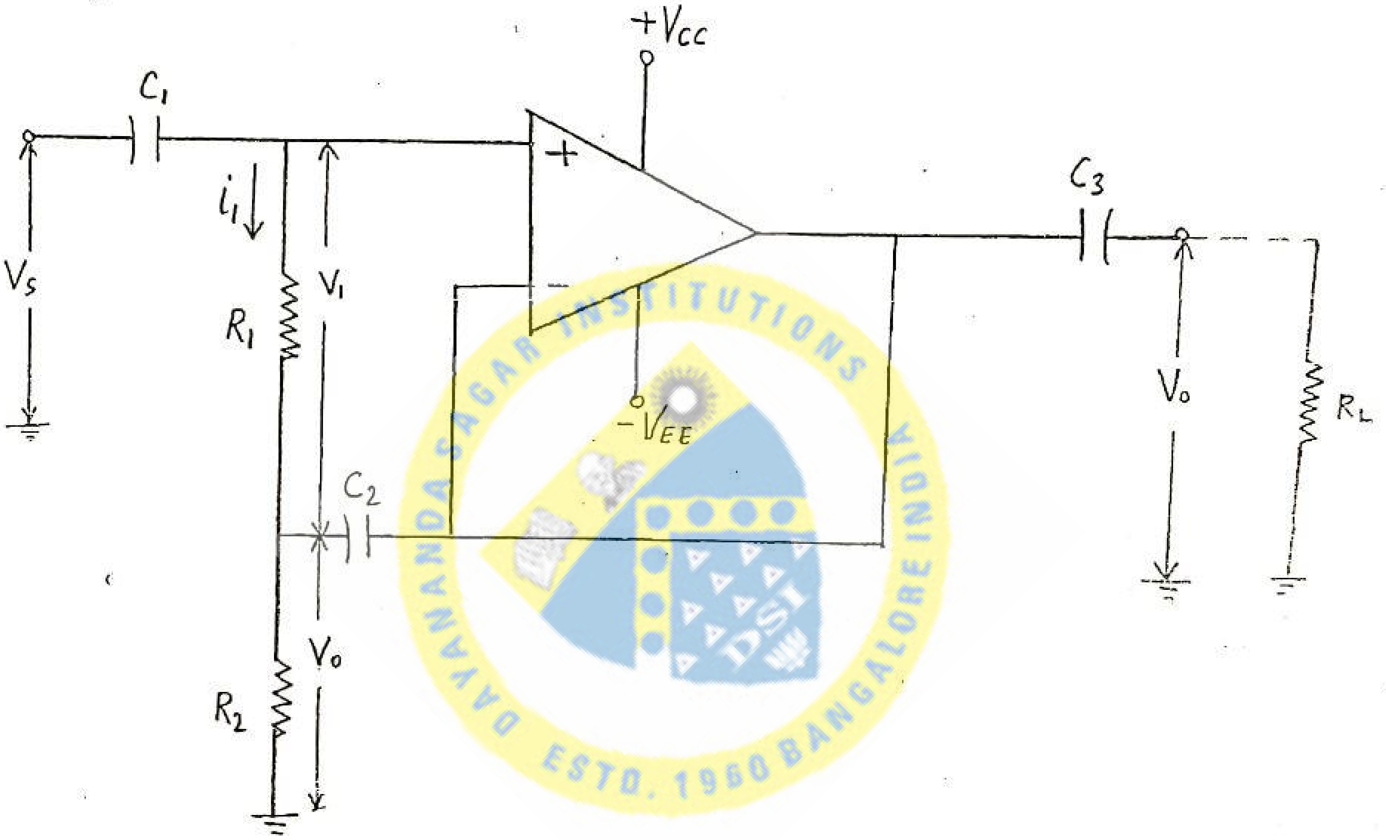


Fig. High input impedance capacitor coupled V.F

→ The i/p impedance of the capacitor-coupled voltage follower is set by the value of resistor R1. This gives a much smaller i/p impedance than the direct coupled voltage follower.

→ Above figure shows a method by which the i/p impedance of the capacitor-coupled vtg follower can be substantially increased.

→ Capacitor C_2 couples the circuit o/p vtg to the junc of resistors R_1 & R_2.

→ C_2 behaves as an ac short circuit. so that 'V_o' is developed across R_2.

→ Applying KVL from source, R_1 & R_2,

$$V_S - V_1 - V_o = 0.$$

→ The vtg across R_1 is V_1 & is given by:

$$\boxed{V_1 = V_S - V_o} \quad \text{--- (1)}$$

→ WKT open-loop gain is given by $M = \frac{V_o}{V_1}$

$$\boxed{V_o = M V_1} \quad \text{--- (2)}$$

→ Substituting equ^n (2) in (1);

$$V_1 = V_S - MV_1$$

$$\Rightarrow MV_1 + V_1 = V_S$$

$$\Rightarrow V_1(1+M) = V_S$$

$$\Rightarrow \boxed{V_1 = \frac{V_S}{1+M}} \quad \text{--- (3)}$$

→ The current i_1 is given by:

$$\boxed{i_1 = \frac{V_1}{R_1}} \quad \text{--- (4)}.$$

→ Substituting equ^n (3) in equ^n (4), we get:

$$\boxed{i_1 = \frac{V_S}{(1+M)R_1}} \quad \text{--- (5)}$$

→ I/p resistance: $\boxed{Z_{in} = \frac{V_S}{i_1}}$ --- (6)

$$\therefore \quad Z_{in} = \frac{V_S}{\frac{V_S}{(1+M)R_1}}$$

$$\Rightarrow \boxed{Z_{in} = (1+M)R_1} \quad \text{--- (7)}$$

→ Since open loop gain (M) is very high, this modifies the ckt very high I/p impedance.

→ But if stray capacitance b/w the i/p & ground is present, then i/p impedance reduces.

Design steps:

(1). $R_{1(max)} = \dfrac{0.1\, V_{BE}}{I_{B(max)}}$.

(2). $R_1 = R_2 = \dfrac{R_{1(max)}}{2}$

(3). $C_2 = \dfrac{1}{2\pi f_1 \left(\frac{R_2}{10}\right)}$

(4). $C_1 = C_2$

(5). $C_3 = \dfrac{1}{2\pi f_1 R_L}$

(6). $Z_{in} = (1+M)R_1$.

Q.03 With a neat circuit diagram, explain the operation of a capacitor-coupled Non-inverting amplifier with relevant design steps.

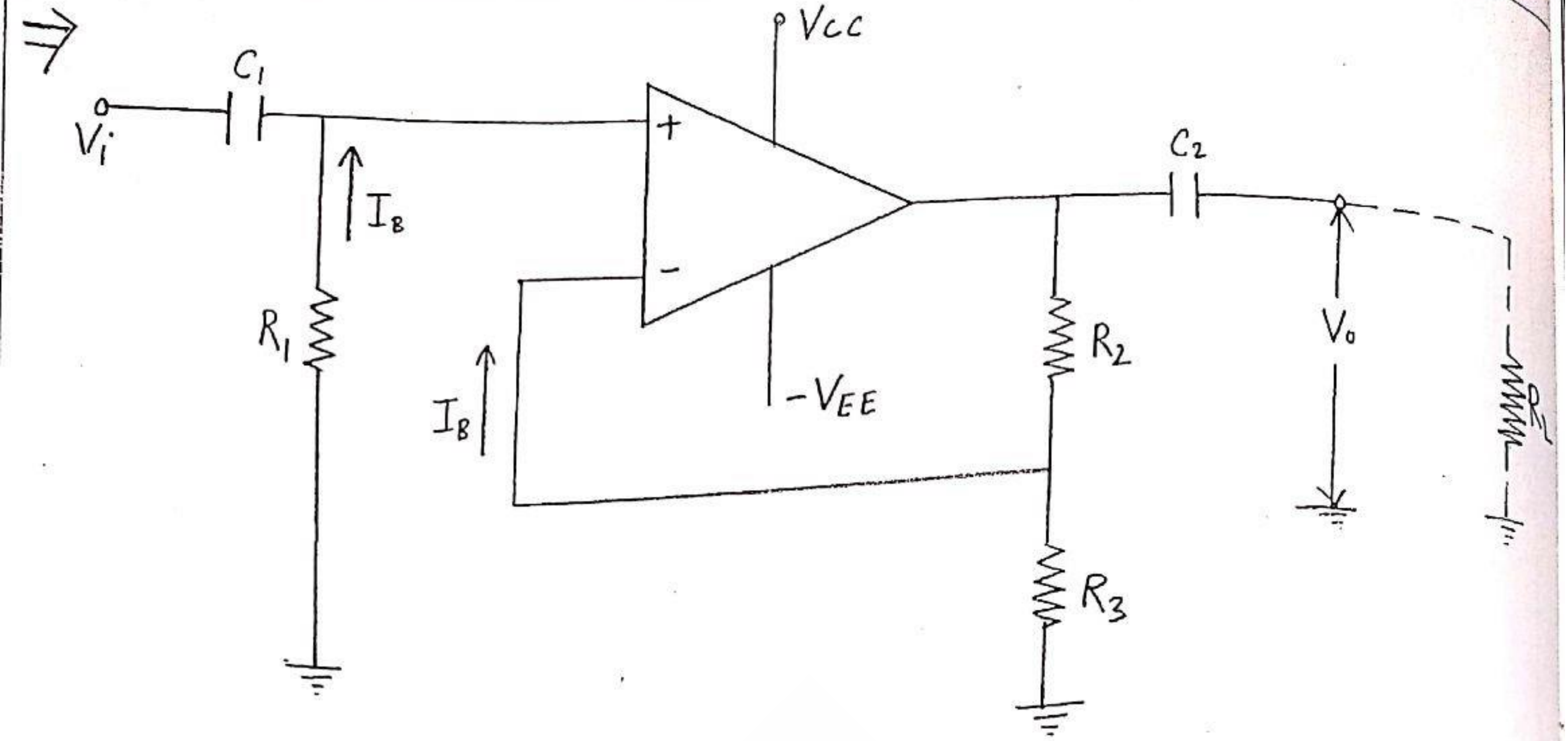


Fig. Capacitor coupled NON-INV ampr.

→ In capacitor-coupled NON-INV amplifier, the NON-INV I/p terminal is grounded via a resistor to provide a path for the i/p bias current.

→ The resistor R_1 may be made equal to $R_2 \| R_3$ to compensate for the dc offset voltage at the o/p.

→ Since the output is also capacitor coupled, it is not of much importance.

→ The input impedance is given by $\boxed{Z_{in} = R_1}$.

Design steps:

(1). $R_1 = R_{1(max)} = \dfrac{0.1 \cdot V_{BE}}{I_{B(max)}}$.

(2). $X_{C_1} = \dfrac{R_1}{10} \Rightarrow C_1 = \dfrac{1}{2\pi f_1 \left(\frac{R_1}{10}\right)}$

(3). $X_{C_2} = R_L$ at f_1

$$\therefore \boxed{C_2 = \frac{1}{2\pi f_1 R_L}}$$

(4) $I_2 = 100 \cdot I_{B\,max}$

(5). $\boxed{R_3 = \frac{V_i}{I_2}}$

(6). $A_V = \frac{V_o}{V_i} \Rightarrow \boxed{V_o = A_V \cdot V_i}$

(7). $R_2 + R_3 = \frac{V_o}{I_2}$ or $A_V = 1 + \frac{R_2}{R_3}$

$\Rightarrow \boxed{R_2 = \frac{V_o}{I_2} - R_3}$ $\Rightarrow \boxed{R_2 = R_3(A_V - 1)}$

(8). I/p impedance $\Rightarrow$

$$\boxed{Z_{in} = R_1}$$

→ The i/p impedance of ... improved by using capacitor C_2.

→ The voltage is fed back to i/p from the o/p via R2, C2 and R3.

→ The feedback factor 'β' is given by

$$\boxed{\beta = \frac{R_3}{R_2 + R_3}} \quad (1)$$

→ Applying KVL from V_s, R_1 & R_3, we get

$$V_s - V_1 - \beta V_o = 0$$

$$\Rightarrow \boxed{V_1 = V_s - \beta V_o} \quad (2)$$

→ $M = \frac{V_o}{V_i}$

$$\Rightarrow \boxed{V_o = MV_1} \quad (3)$$

→ From eqn (2):

$$V_1 = V_s - \beta \cdot M \cdot V_1$$

$$\Rightarrow V_1 + \beta M V_1 = V_s$$

$$\Rightarrow V_1(1 + \beta M) = V_s$$

$$\Rightarrow \boxed{V_1 = \frac{V_s}{1+\beta M}} \quad (4)$$

→ The current $i_1 = \frac{V_1}{R_1}$

$$\Rightarrow \boxed{i_1 = \frac{V_s}{(1+\beta M)R_1}} \quad (5)$$

→ Impedance is given by:

$$\boxed{Z_{in} = \frac{V_s}{i_1}} \quad (6)$$

$$\therefore Z_in = \frac{\cancel{V_s}}{\frac{\cancel{V_s}}{(1+\beta M)R_1}}$$

$$\Rightarrow \boxed{Z_{in} = (1+\beta M)R_1}.$$

Design steps $\Rightarrow$

① $R_1 + R_3 = R_{1max}$

$$R_1 + R_3 = R_{1max} = \frac{0.1 V_{BE}}{I_{Bmax}}$$

② $R_1 + R_3 = R_2$

③ $R_1 \approx R_2$

④ $A_V = 1 + \frac{R_2}{R_3} \Rightarrow R_3 = \frac{R_2}{A_V - 1}$

⑤ $R_1 + R_3 = R_{1max} \Rightarrow \boxed{R_1 = R_{1max} - R_3}$

⑥ $X_{C_2} = \frac{R_2}{10}$ at f_1

$$\therefore C_2 = \frac{1}{2\pi f_1 R_3}$$

⑦ Choose, $\boxed{C_1 = 1000\,pF}$

⑧ $X_{C_3} = R_L$ at f_1

$$C_3 = \frac{1}{2\pi f_1 \left(\frac{R_L}{10}\right)}$$

⑨. Input impedance:

$$Z_{in} = (1+M\beta)R_1.$$

Design for LF 353 ⇒

① Select, $\boxed{R_2 = 1\ M\Omega}$

② $A_v = \frac{V_o}{V_i}$

$A_v = 1 + \frac{R_2}{R_3}$

$$\boxed{R_3 = \frac{R_2}{A_v - 1}}$$

③ $\boxed{R_1 = R_2 - R_3}$

④ $X_{C_2} = R_3$ at f_1,

$$\boxed{C_2 = \frac{1}{2\pi f_1 R_3}}$$

⑤ $X_{C_3} = \frac{R_L}{10}$ at f_1

$$\therefore \boxed{C_3 = \frac{1}{2\pi f_1 \left(\frac{R_L}{10}\right)}}$$

⑥ Choose, $\boxed{C_1 = 1000\,pF}$.

Q5. Draw a neat diagram of a single supply capacitor coupled voltage follower and explains it operation.

⇒

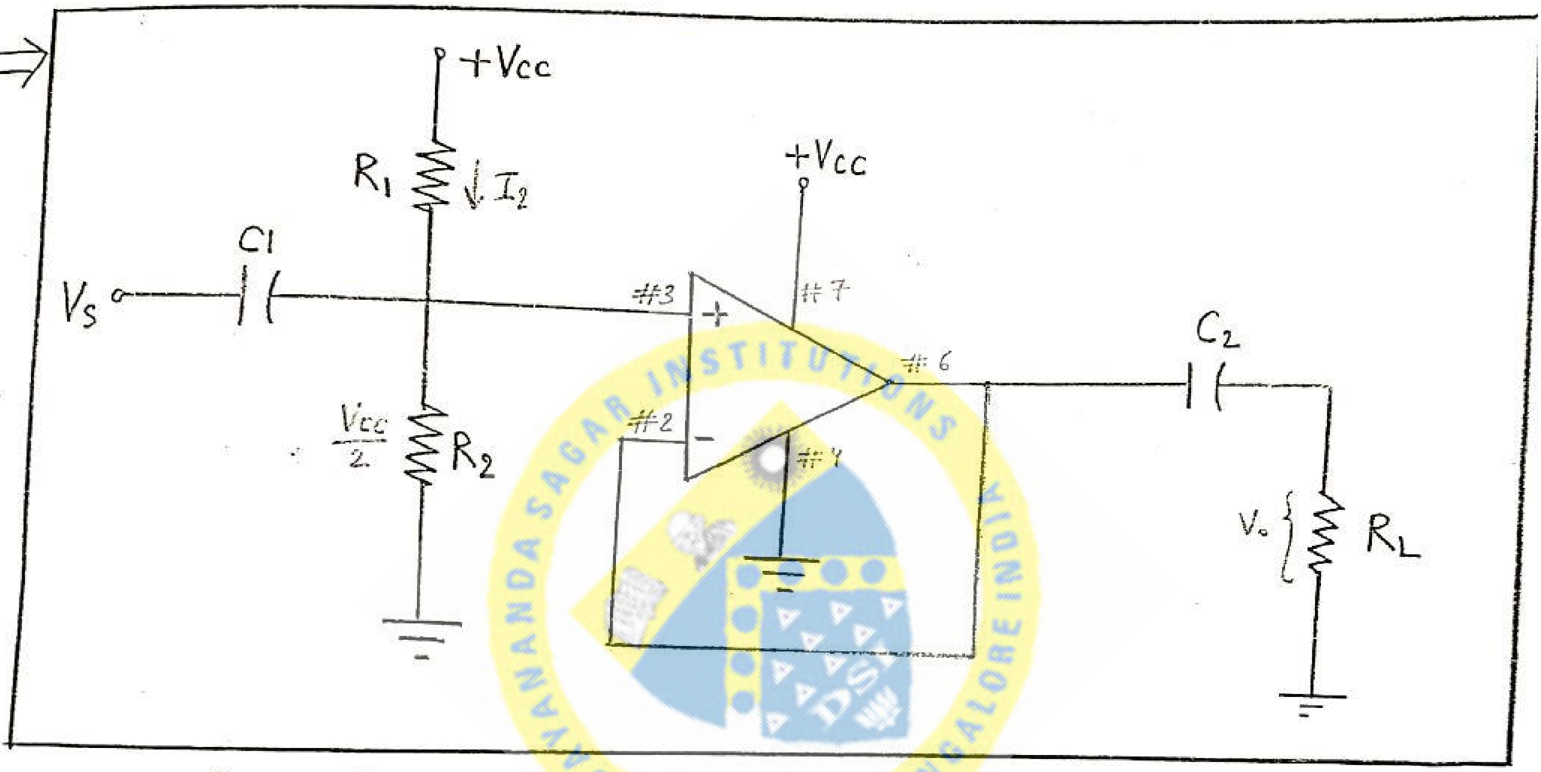


Fig. CC voltage follower using single supply

→ A capacitor coupled voltage follower circuit using a single polarity supply is illustrated in above fig.

→ The capacitor block the dc bias voltages at the input and the output.

→ If the op-amp data-sheet lists the minumum supply voltage as ±9V, then a minimum of 18V should be used in a single polarity supply.

→ The potential divider R_1 & R_2 sets the bias voltage at the NON-INV i/p terminal as $\frac{V_{cc}}{2}$ .i.e the dc o/p voltage & the INV input are also at $\frac{V_{cc}}{2}$ ($\because$ Voltage follower).

→ The input impedance of the ckt is $Z_{in} = R_1 \| R_2$.

Design steps:

(1). Let. $I_1 = 100 \times I_{B\,max}$

(2). $R_1 = R_2 = \frac{V_{cc}}{2I_1}$

(3). $Z_{in} = (R_1 \| R_2)$

(4). $X_{C_1} = \frac{(R_1 \| R_2)}{10}$ at f_1 $\Rightarrow C_1 = \frac{1}{2\pi f_1 \left(\frac{R_1 \| R_2}{10}\right)}$

(5). $X_{C_2} = R_2$ at f_1 $\Rightarrow C_2 = \frac{1}{2\pi f_1 R_2}$.

Q.6 Write the neat diagram of a capacitor coupled inverting amplifier using single polarity supply with design equations.

⇒ The circuit of an inverting ampr using a single-polarity supply is illustrated in fig. shown below:

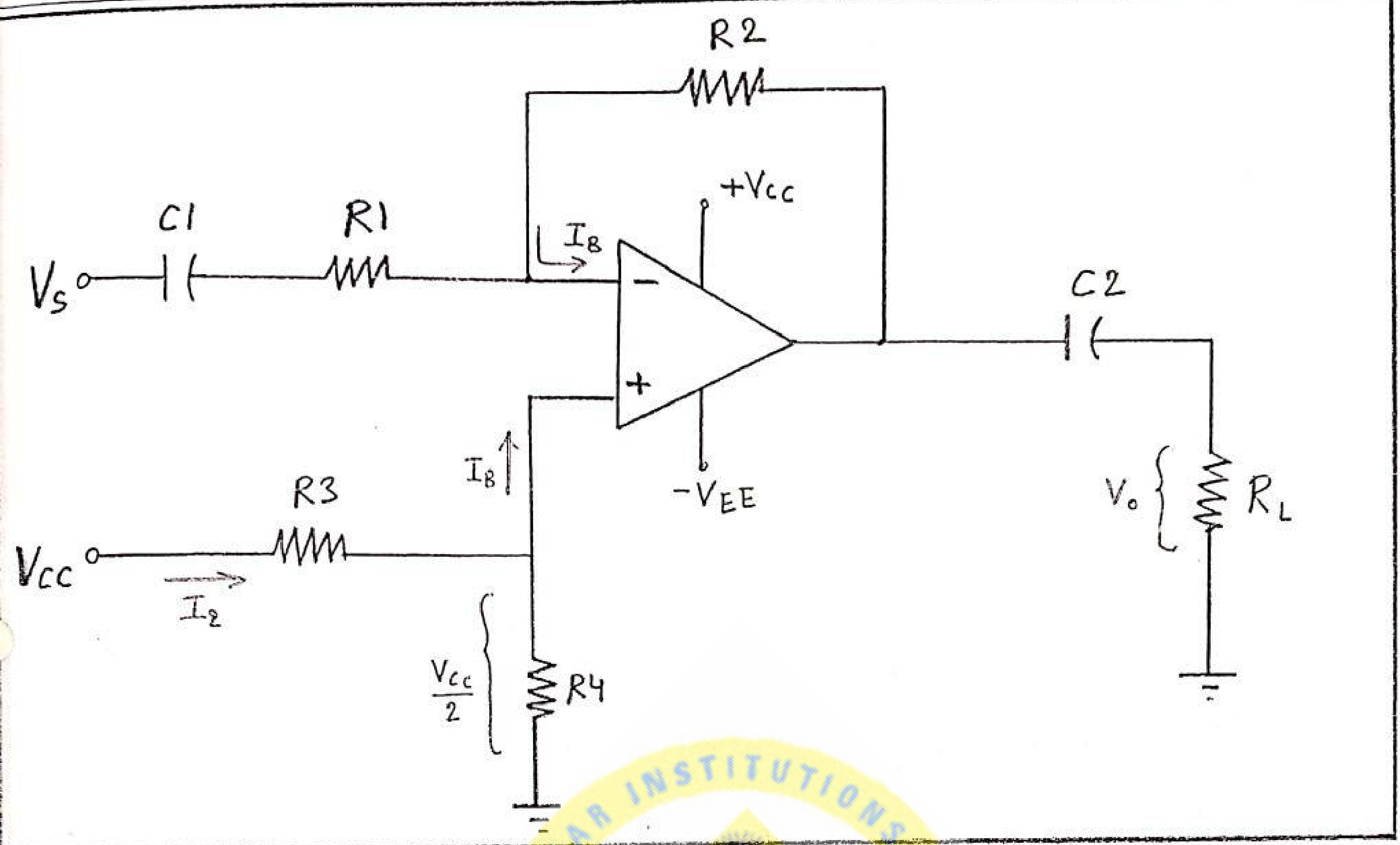


Fig. CC inv. ampr using a single polarity supply

→ Two resistors R3 & R4 form the voltage divider ckt setting the bias voltage to $\frac{V_{cc}}{2}$ at the non-inv. terminal.

→ This makes inv i/p & o/p vtg equal to $\frac{V_{cc}}{2}$.

Design steps:

(1). Let, $I_1 = I_4 = 100 \times I_{B\,max}$.

(2). $\boxed{R_1 = \frac{V_i}{I_1}}$

(3). $A_v = \frac{V_o}{V_i} \Rightarrow V_o = A_v \cdot V_i$

$\therefore \boxed{R_2 = \frac{V_o}{I_1}}$

(4). $A_v = \frac{R_2}{R_1} \Rightarrow \boxed{R_2 = A_v . R1}$

(5). $$R_3 = R_4 = \frac{V_{cc}/2}{I_4}$$

(6). $$C_1 = \frac{1}{2\pi f_1 \left(\frac{R_1}{10}\right)}$$

(7). $$C_2 = \frac{1}{2\pi f_1 R_L}$$

Q.7 What is meant by setting upper cut-off in a CC op-amp?
Explain how it is done in an inv. amp.

⇒ → The highest signal frequency that can be processed by an op-amp ckt depends on the op-amp selected (for eg. 741, LF353, etc)

→ for example:

If very low frequency signals are to be amplified, as there would be interference from high frequency noise voltages, since these also get amplified.

→ If these high frequency noise voltages are to be eliminated, there must be a provision for their effective attenuation.

→ This can be achieved by setting the upper cut-off frequency just above the highest desired signal frequency.

→ This can be done by connecting a feedback capacitor C_f from the op-amp o/p to its INV i/p as shown

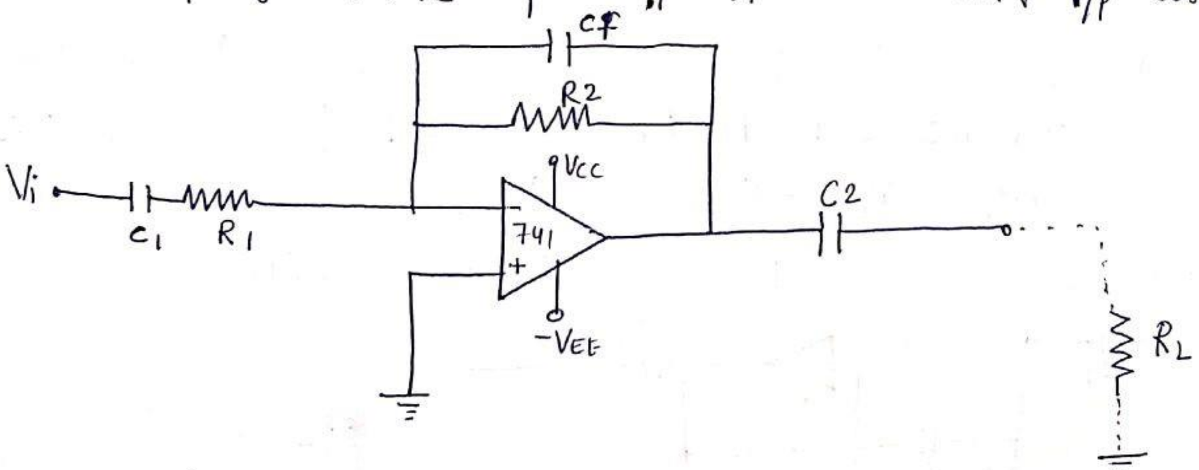


fig. INV amp^r with feedback capacitor C_f to set the upper cut-off frequency.

$$A_v = \frac{R_2 \,||\, X_{CF}}{R_1}$$

$$= \frac{R_2 \cdot X_{CF}}{R_1 (R_2 + X_{CF})}$$

$$= \frac{1}{R_1 \left[\frac{R_2}{R_2 \cdot X_{CF}} + \frac{X_{CF}}{R_2 \cdot X_{CF}} \right]}$$

$$= \frac{1}{R_1 \left[\frac{1}{X_{CF}} + \frac{1}{R_2} \right]}$$

Magnitude of A_v :

$$A_v = \frac{1}{R_1 \sqrt{\left(\frac{1}{X_{CF}}\right)^2 + \left(\frac{1}{R_2}\right)^2}}$$

when, $X_{CF} = R_2$

$$= \frac{1}{R_1 \sqrt{\left(\frac{1}{R_2}\right)^2 + \left(\frac{1}{R_2}\right)^2}}$$

$$= \frac{1}{R_1 \sqrt{2 \left(\frac{1}{R_2}\right)^2}}$$

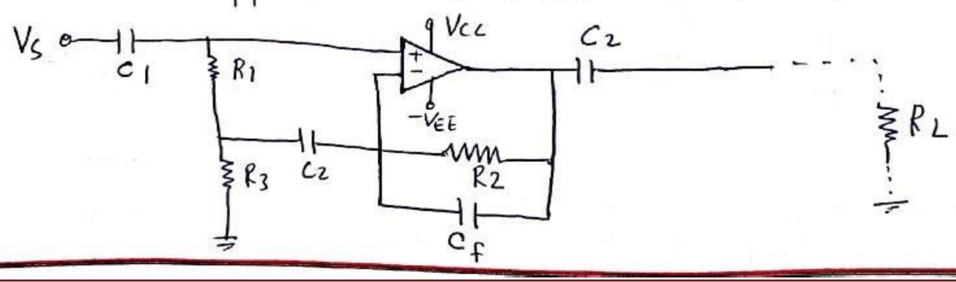
$$= \frac{1}{\frac{R_1}{R_2} \sqrt{2}}$$

$$= \frac{1}{\sqrt{2}} \cdot \left(\frac{R_2}{R_1}\right) \quad (1)$$

→ The eqn (1) indicates that the gain is 3dB down the normal voltage gain.

→ Thus upper cut-off frequency f_2 (or f_H) for the ckt can be set to the desired frequency f_2 by making $X_{CF} = R_2$ at f_2.

→ This is applicable to NON-INV ampr also.



Numericals :

Q.1. Desigh High Zin CC-VF using an op-amp having lower cut-off frequency of 50 Hz and max^m input bias current of 500 nA. The load resistance is 3.9 kΩ. If the open loop gain is 2×10^5. Find the value of input Zin (consider Mmin = 50,000).

⇒ $f_1 = 50\,Hz$

$R_L = 3.9\,k\Omega$

$M_{min} = 50,000$

$I_{B\,max} = 500\,nA$

$V_{BE} = 0.7\,V$

$$\therefore R_{1max.} = \frac{0.1 V_{BE}}{I_{B max}} = 140\,k\Omega.$$

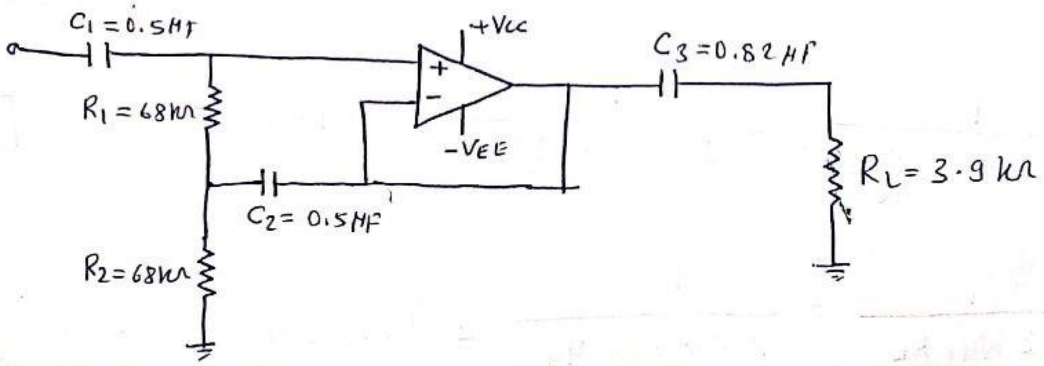
$$R_1 = R_2 = \frac{R_{1max}}{2} = 70\,k\Omega \quad \text{choose } \boxed{R_1 = R_2 = 68\,k\Omega}$$

$$C_2 = \frac{1}{2\pi f_1 \left(\frac{R_2}{10}\right)} = 0.5\,\mu F \quad \therefore \boxed{C_1 = C_2 = 0.5}$$

$$\boxed{C_3 = 0.82\,\mu F}.$$

$$C_3 = \frac{1}{2\pi f_1 R_L} = 0.82\,\mu F$$

$$Z_{in\,(min.)} = (1 + M_{min}) R_1$$
$$= (1 + 50000)\, 68\,k\Omega$$
$$= 3400\,M\Omega.$$



Q.2. Design a CC-inv ampr using a IC741 op. amp to have a voltage gain of 75 output voltage amplifier of 3V and a signal frequen. range of 20 Hz to 12KHz. the load resistan. is 470 Ω.

⇒ $A_V = 75$

$V_o = 3V$

$R_L = 470\Omega$

$f_1 = 20\ Hz$

$f_2 = 12\ KHz$.

$I_{Bmax} = 500\ nA$

* Let, $I_1 = 100 \times I_{Bmax}$

$\Rightarrow \boxed{I_1 = 50\mu A}$

* $A_V = \dfrac{V_o}{V_i}$

$\Rightarrow V_i = \dfrac{V_o}{A_V} = \dfrac{3V}{75}$

$\Rightarrow \boxed{V_i = 40mV}$

* $R_1 = \dfrac{V_i}{I_1} = \dfrac{40\ mV}{50\ \mu A} = 800\Omega$ Choose $\boxed{R_1 = 820\ \Omega}$

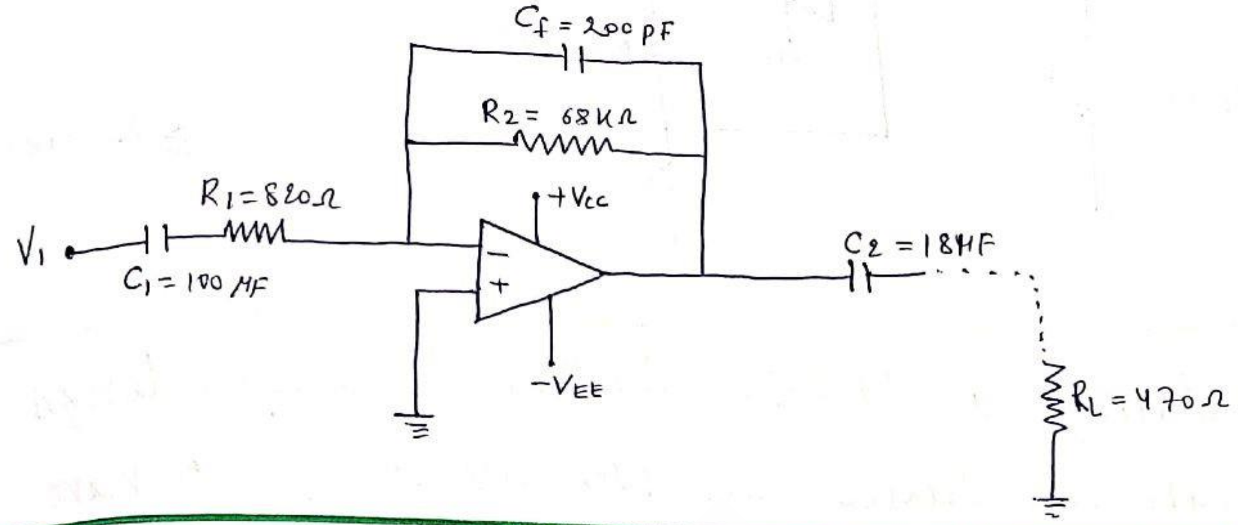
* $A_V = \dfrac{R_2}{R_1} \Rightarrow R_2 = R_1 \cdot A_V = 820\Omega \times 75 = 61.5\ K\Omega$

Choose. $\boxed{R_2 = 68\ K\Omega}$

* $C_1 = \dfrac{1}{2\pi f_1 \left(\frac{R_1}{10}\right)} = \dfrac{1}{2\pi \times 20 \times \left(\frac{820}{10}\right)} = 97.5\ \mu F$ Choose $\boxed{C_1 = 100\mu F}$

* $C_2 = \dfrac{1}{2\pi f_1 R_L} = \dfrac{1}{2\pi \times 20 \times 470} = 16.93\mu F$ Choose $\boxed{C_2 = 18\mu F}$

$$C_f = \frac{1}{2\pi f_2 R_2} = \frac{1}{2\pi \times 12\times10^3 \times 68\times10^3} = 195\,pF$$ choose $\boxed{C_F = 200\,pF}$



Q.3. A capacitor coupled non-inv op-amp is to have $A_F = 100$ and $V_o = 5V$, $R_L = 10K\Omega$ and $f_1 = 100Hz$. Design suitable ckt.

⇒ $A_F = 100$

$V_o = 5V$

$V_i = \frac{V_o}{A_F} = \frac{5V}{100} = 50\,mV$

$R_L = 10K\Omega$

$f_1 = 100Hz$

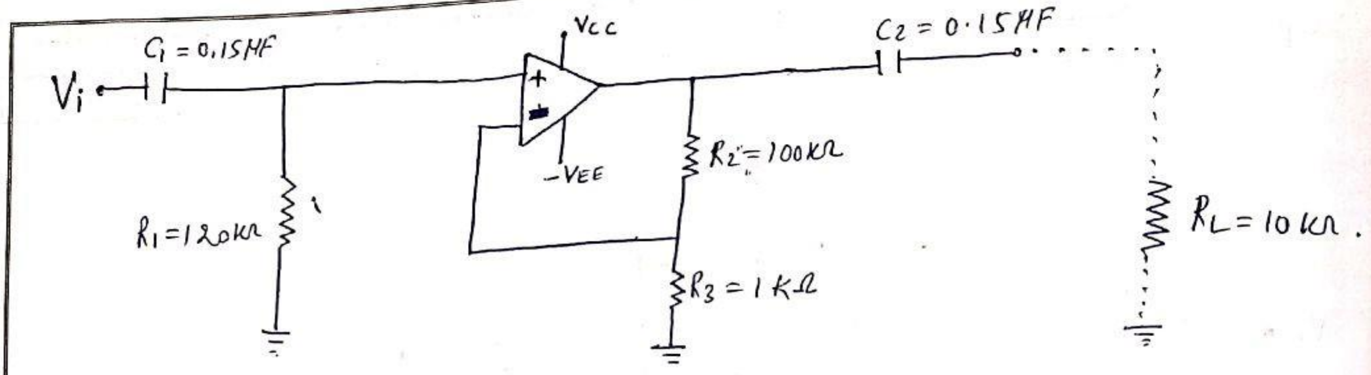
* $R_{1max} = \frac{0.1 V_{BE}}{I_{Bmax}} = 140K\Omega$ Choose $\boxed{R_1 = 120\,k\Omega}$

* $C_1 = \frac{1}{2\pi f_1 \left(\frac{R_1}{10}\right)} = 0.132\,\mu F$ Choose $\boxed{C_1 = 0.15\,\mu F}$

* $C_2 = \frac{1}{2\pi f_1 R_L} = 0.159\,\mu F$ choose $\boxed{C_2 = 0.15\,\mu F}$

* $R_3 = \frac{V_i}{I_2} = \frac{50\,mV}{50\,\mu A} = 1K\Omega$.

* $R_2 = \left(\frac{V_o}{I_2} - R_3\right) = \left(\frac{5V}{50\mu A} - 1K\Omega\right) = 99K\Omega$ Choose $\boxed{R_2 = 100\,K\Omega}$



\# Q.4. Using a LF353 BIFET op-amp, design a high impedance CC Non-inv ampr to have a low cut-off frequency of 200 Hz. The i/p & o/p voltages are to be 15 mV and 3V respectively, & and minimum load resistance is 12KΩ.

⇒ $f_1 = 200\,Hz$

$V_i = 15\,mV$

$V_o = 3V$

$R_L = 12\,k\Omega$

$$A_v = \frac{V_o}{V_i} = \frac{3V}{15mV} = 200$$

For BIFET ⇒

Choose: $\boxed{R_2 = 1M\Omega}$

$$R_3 = \frac{R_2}{A_v - 1} = \frac{1M\Omega}{200-1} = 5.02\,k\Omega$$ choose $\boxed{R_3 = 4.7k\Omega}$

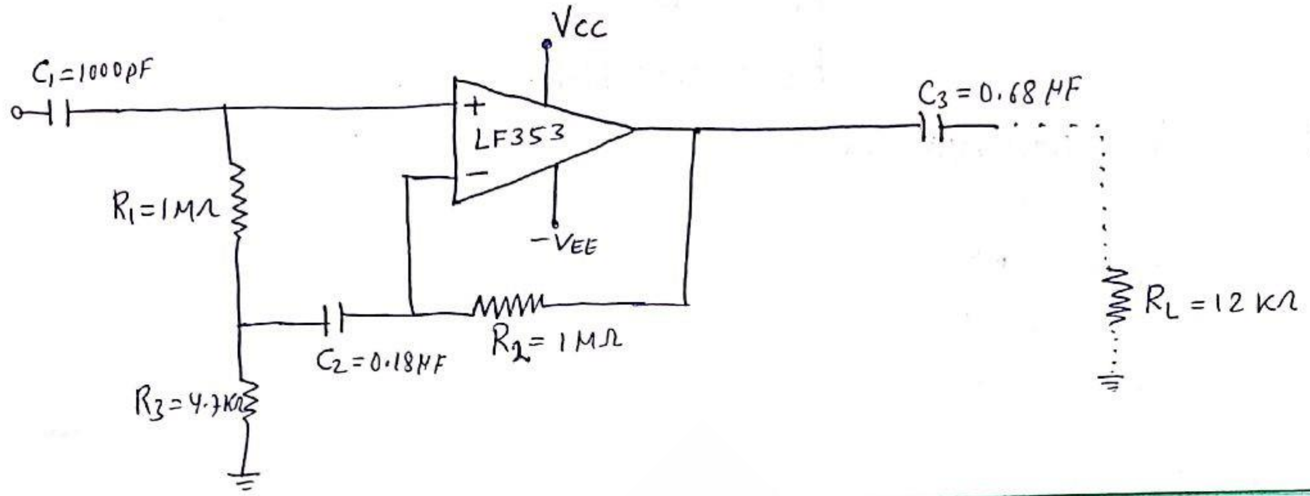
$$R_1 = R_2 - R_3 = 1M\Omega - 4.7k\Omega = 995.3\,k\Omega$$ Choose $\boxed{R_1 = 1M\Omega}$

Choose $\boxed{C_1 = 1000pF}$

$$C_2 = \frac{1}{2\pi f_1 R_3} = \frac{1}{2\pi \times 200 \times 4.7K} = 0.17\mu F$$

Choose $\boxed{C_2 = 0.16k}$

$$C_3 = \frac{1}{2\pi f_1 \left(\frac{R_L}{10}\right)} = 0.66\,\mu F$$ Choose $\boxed{C_3 = 0.68\,\mu F}$



Q.4. Design a BIFET op-amp based high input impedance CC non-inv ampr for a lower cut-off frequency of 120 Hz. Given: $V_{in} = 20\,mV$, $V_o = 5V$ and $R_{Lmin} = 10K\Omega$.

⇒ Same as above.

Q.5. Design a high Zin CC - non-inv ampr to have a cutoff frequency of 200Hz. The i/p and o/p vtg are to be 16 mV and 4 V respectively and minimum load resistance is 10KΩ. Select, $R_2 = 1M\Omega$ and $C_1 = 0.1\mu F$.

⇒ Same as above.

Q.6 A CC non-inv-ampr is to have a +24V supply, a vtg gain of 100, an output amplitude of 5V, a lower cutoff frequency of 75 Hz and a minimum load of 5.6KΩ.

Using 741 op-amp, design a suitable ckt

Given $I_{B\,max} = 500\,nA$

$f_1 = 75\,Hz$

$R_L = 5.6\,K\Omega$.

$\Rightarrow$ $A_v = 100$.

$V_o = 5V$

$R_L = 5.6\,K\Omega$

$f_1 = 75\,Hz$

$I_{Bmax} = 500\,nA$.

* $R_1 + R_3 = R_{1max} = \dfrac{0.1 V_{BE}}{I_{B\,max}} = \dfrac{0.1 \times 0.7V}{500\,nA} = 140\,K\Omega$

Choose, $\boxed{R_{1max} = 150\,K\Omega}$

* $R_1 + R_3 \approx R_2 = R_{1max} \Rightarrow \boxed{R_2 = 150\,K\Omega}$

* $R_3 = \dfrac{R_2}{A_v - 1} = \dfrac{150\,K\Omega}{100 - 1} = 1.515\,K\Omega \Rightarrow$ Choose: $\boxed{R_3 = 1.5\,K\Omega}$

* $R_1 + R_3 = R_{1max}$

$\Rightarrow R_1 = R_{1max} - R_3$

$= 150\,K\Omega - 1.5\,K\Omega$

$= 148.5\,K\Omega$ Choose $\boxed{R_1 = 150\,K\Omega}$

* $\boxed{R_1 \approx R_2 = 150\,K\Omega}$

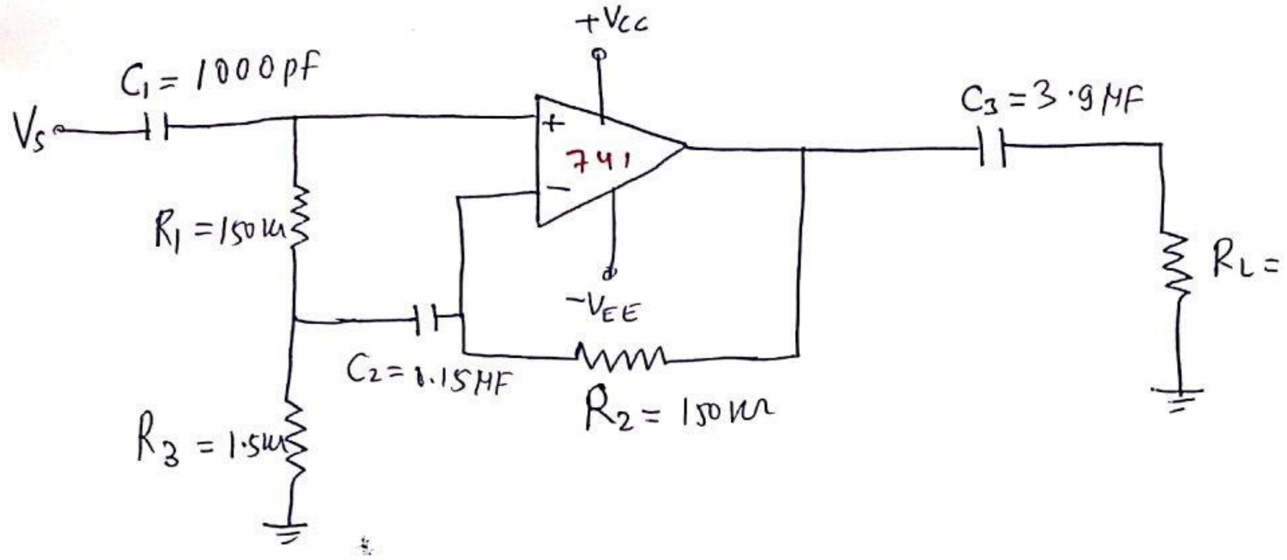
* $C_2 = \dfrac{1}{2\pi f_1 R_3} = \dfrac{1}{2\pi \times 75 \times 1.5K} = 1.41\,\mu F$

Choose, $\boxed{C_2 = 0.15\,\mu F}$

* Choose $\boxed{C_1 = 1000\,pF}$

* $C_3 = \dfrac{1}{2\pi f_1 \left(\frac{R_L}{10}\right)} = \dfrac{1}{2\pi \times 75 \times \left(\frac{5.6\,K\Omega}{10}\right)} = 3.789\,\mu F$

Choose $\boxed{C_3 = 3.9\,\mu F}$


+Vcc
C1 = 1000pF
Vs
R1 = 150kΩ
741
C3 = 3.9μF
RL =
-VEE
C2 = 1.15μF
R2 = 150kΩ
R3 = 1.5kΩ