Module – 7

Unit – 7

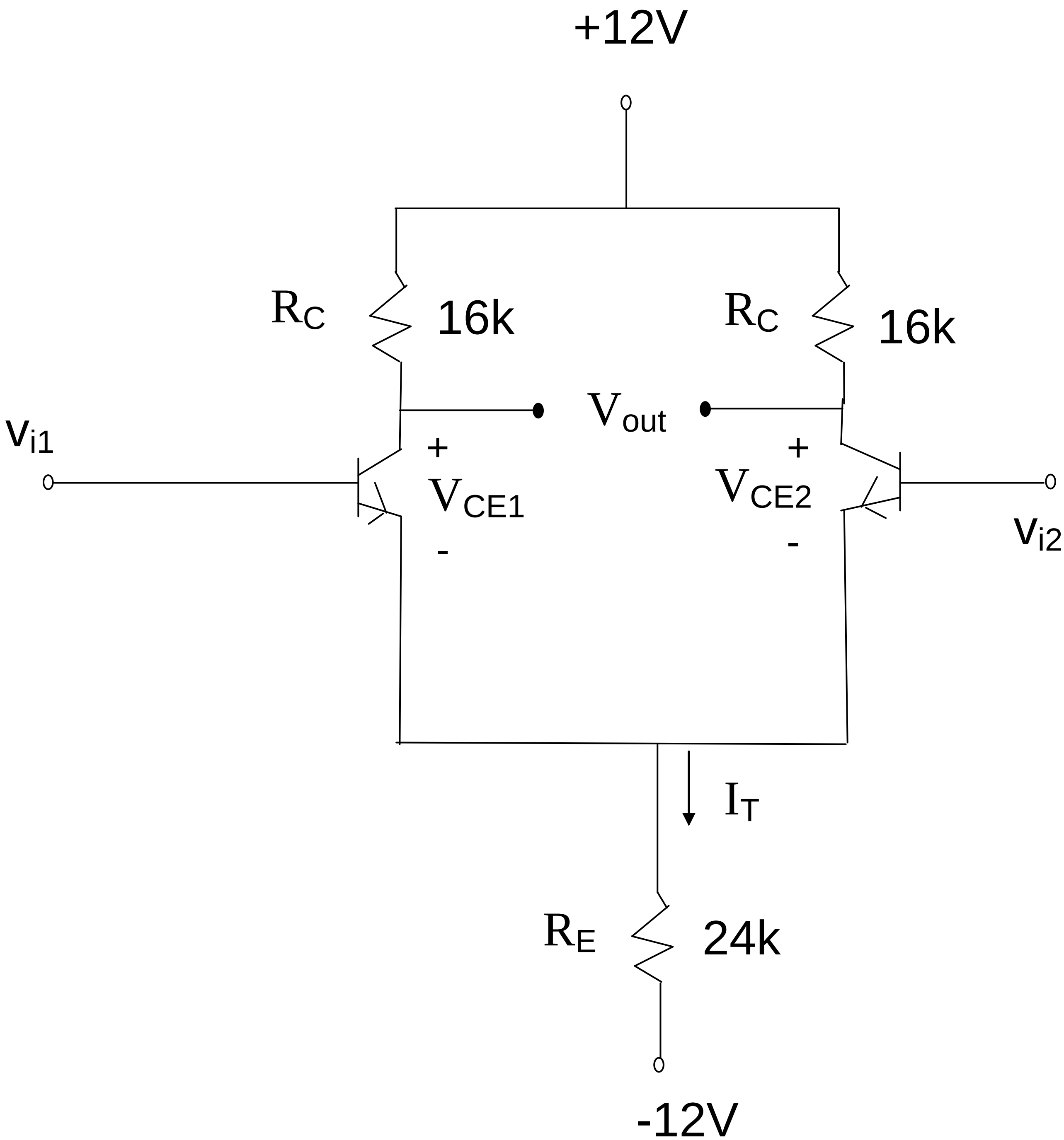
Differential and Operational Amplifiers

Review Question:-

1. How is basic structure of a differential amplifier different from, for example, a conventional RC coupled common – emitter amplifier?
2. In what different configurations can a differential amplifier be used?
3. How are the two inputs of an differential amplifier different? Explain inverting and non-inverting nature of inputs.
4. Symmetry in construction of two halves of differential amplifier is emphasized. Give reasons.
5. What is tail current? Efforts are made and several circuits suggested for the constancy of tail current. Discuss.
6. The input impedance of differential amplifier is much higher (~ M Ω) than a conventional common – emitter amplifiers. Explain.
7. Define an ideal operational amplifier.
8. Draw the approximate block diagram of an op amp giving various stages of the amplifier.
9. An op amp is rarely used in open loop (i.e. without feedback) for linear amplifying applications. Why?
10. Inverting input is a 'virtual ground' in op amp. What does it mean and what is its significance?
11. What reasons would you assign for very wide use of op amps in analog and digital circuits?
12. Define common mode rejection ratio(CMRR). Give its significance in device performance.
13. Define 'slew rate'. When does it start showing its effect on amplifier performance.
14. How does input off-set voltage in an op amp arise? And how can it be corrected?

Problems:

7.1 Estimate dc emitter current in each transistor of differential amplifier shown in fig. How much is dc voltage from each collector to ground? How much is V_{out}?



Solution:-

The tail current through 24k resistor is,

$$I_T = \frac{|V_{EE} - V_{BE}|}{R_E} \simeq \frac{|V_{EE}|}{R_E}$$
$$or,\ I_T = \frac{12V}{24k\Omega} = 0.5\ mA$$

The emitter current, I_E, in each transistor is,

$$I_E = \frac{1}{2}I_T = \frac{0.5mA}{2} = 0.25mA$$
$$I_E = 0.25mA$$

Since $I_C = I_E$, voltage summation in the output circuit gives,

$V_{CC} = I_C R_C + V_{CE1}$

$V_{CE1} = V_{CC} – I_C R_C = 12 – 0.25X10^{-3}$ X $16X10^{3}$

Or, $V_{CE1} = 8.0$ V $= V_{CE2}$ (due to symmetry)

Then,

$V_{out} = V_{CE1} – V_{CE2} = 8 - 8 = 0V$

7.2 Design an inverter amplifier with gain of 120 and input impedance of 5kΩ. Give the circuit.

Solution:-

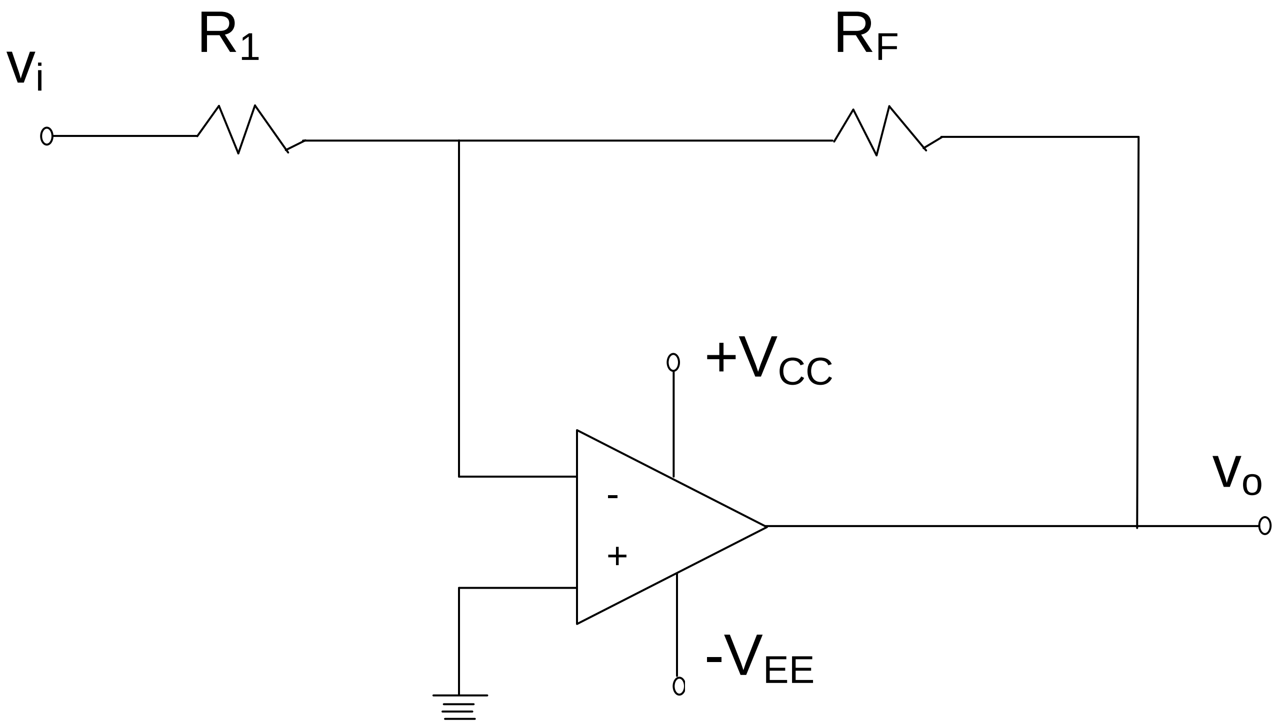


Figure shows the circuit for an inverting amplifier.

Since for an inverting amplifier, the input impedance Z_i is,

$Z_i = R_1 = 5k\Omega$ (desired)

Therefore, $R_1 = 5k\Omega$

Further, the gain A_V of inverting amplifier is,

$$A_V = \frac{R_F}{R_1}$$

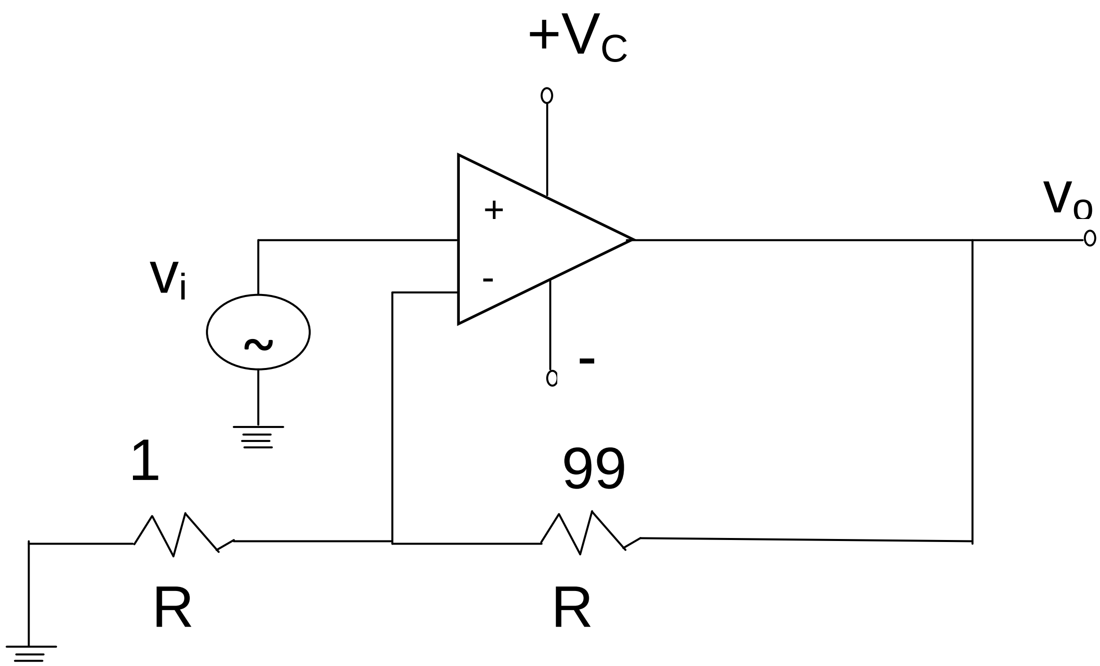
And, A_V desired is 120, $R_1 = 5k\Omega$

Therefore,

$R_F = A_V.R_1 = 120 \text{ X } 5k$

or, $R_F = 600\ k\Omega$

7.3 Find out the voltage gain of the non-inverting amplifier shown in fig.



Solution:-

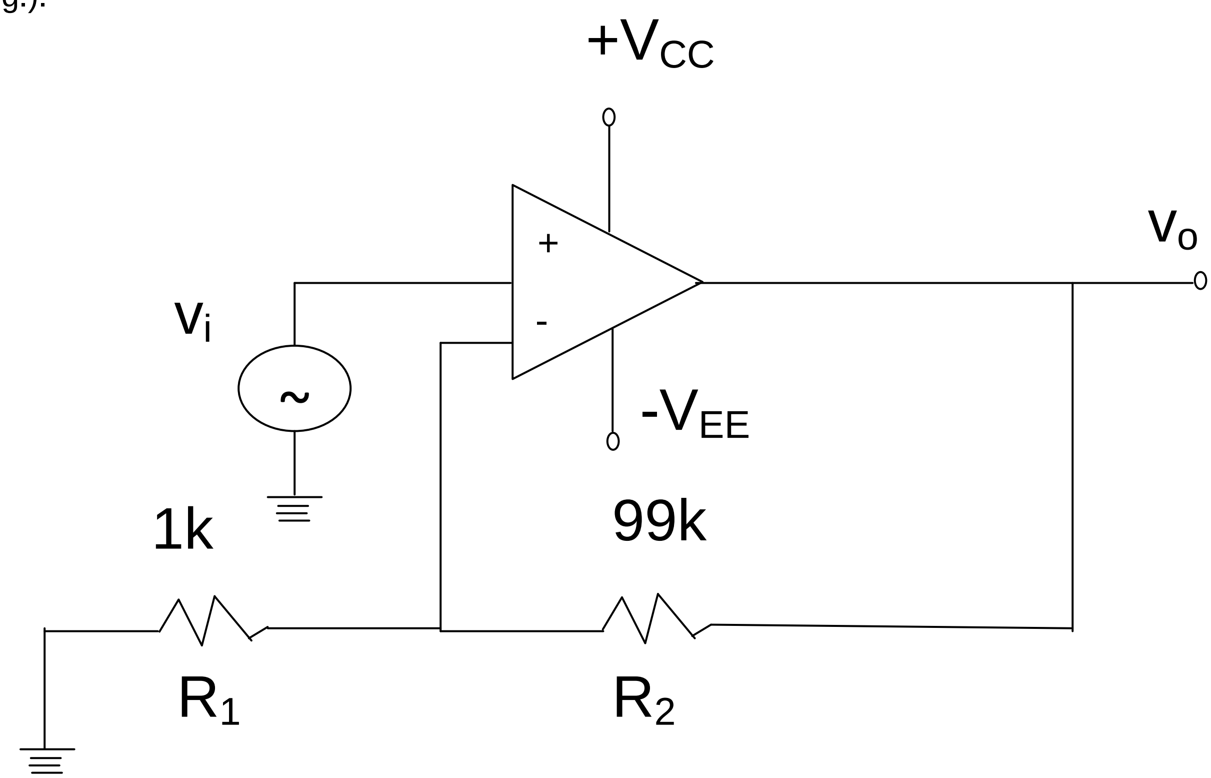
The voltage gain of a non-inverting amplifier is,

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

$$= 1 + \frac{99\,k\Omega}{1k\Omega}$$

$$or\ A_V = 100$$

7.4 In the amplifier circuit shown in fig., if open loop gain and open loop band width of the op amp respectively are 10^5 and 10 H_Z, Calculate the bandwidth of feedback amplifier (in fig.).



Solution:-

If open loop band width is f_2, the band width with feedback, $f_{2(FB)}$ is given by

$f_{2(FB)} = f_2(1 + AB) \approx f_2.AB$ because AB>>1

Now, $A = 10^5$ (given)

And the gain of feedback network, B in the circuit shown in fig. is

$$B = \frac{R_1}{R_1 + R_F} = \frac{1k}{1k+99k} = \frac{1}{100} = 10^{-2}$$

Then,

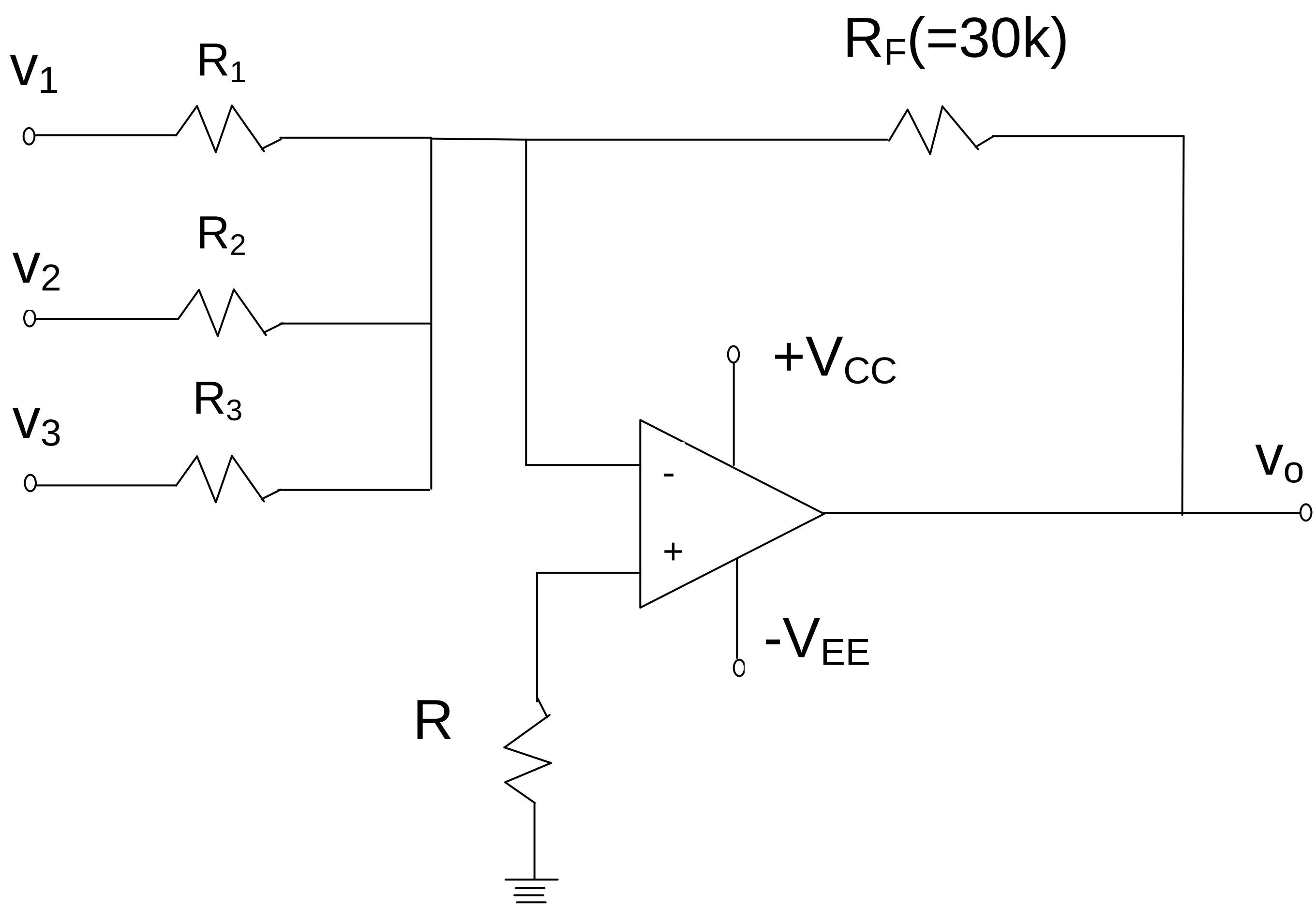
$f_{2(FB)} = 10 \times 10^5 \times 10^{-2}$ H_Z

or, $f_{2(FB)} = 10kH_Z$

7.5 For the summing amplifier shown in fig., estimate the values of resistors R_1,R_2 and R_3 so that the output V_0 is,

$$V_0 = -\ (3V_1 + V_2 + 0.2V_3)$$

What is the approximate value of the compensating resistor R?



Solution:-

The output voltage, V_0, for the summing amplifier is,

$$V_0 = \left[\left(\frac{R_F}{R_1} \right) V_1 + \left(\frac{R_F}{R_2} \right) V_2 + \left(\frac{R_F}{R_3} \right) V_3 \right]$$

Thus for the desired output,

$$\frac{R_F}{R_1} = 3 \text{ , } or \ \frac{30k}{R_1} = 3$$
$$or, \ R_1 = 10k\Omega$$

Similarly,

$$\frac{R_F}{R_2} = 1 \text{ , } or \ R_2 = R_F = 30k\Omega$$
$$or, \ R_2 = 30k$$

And,

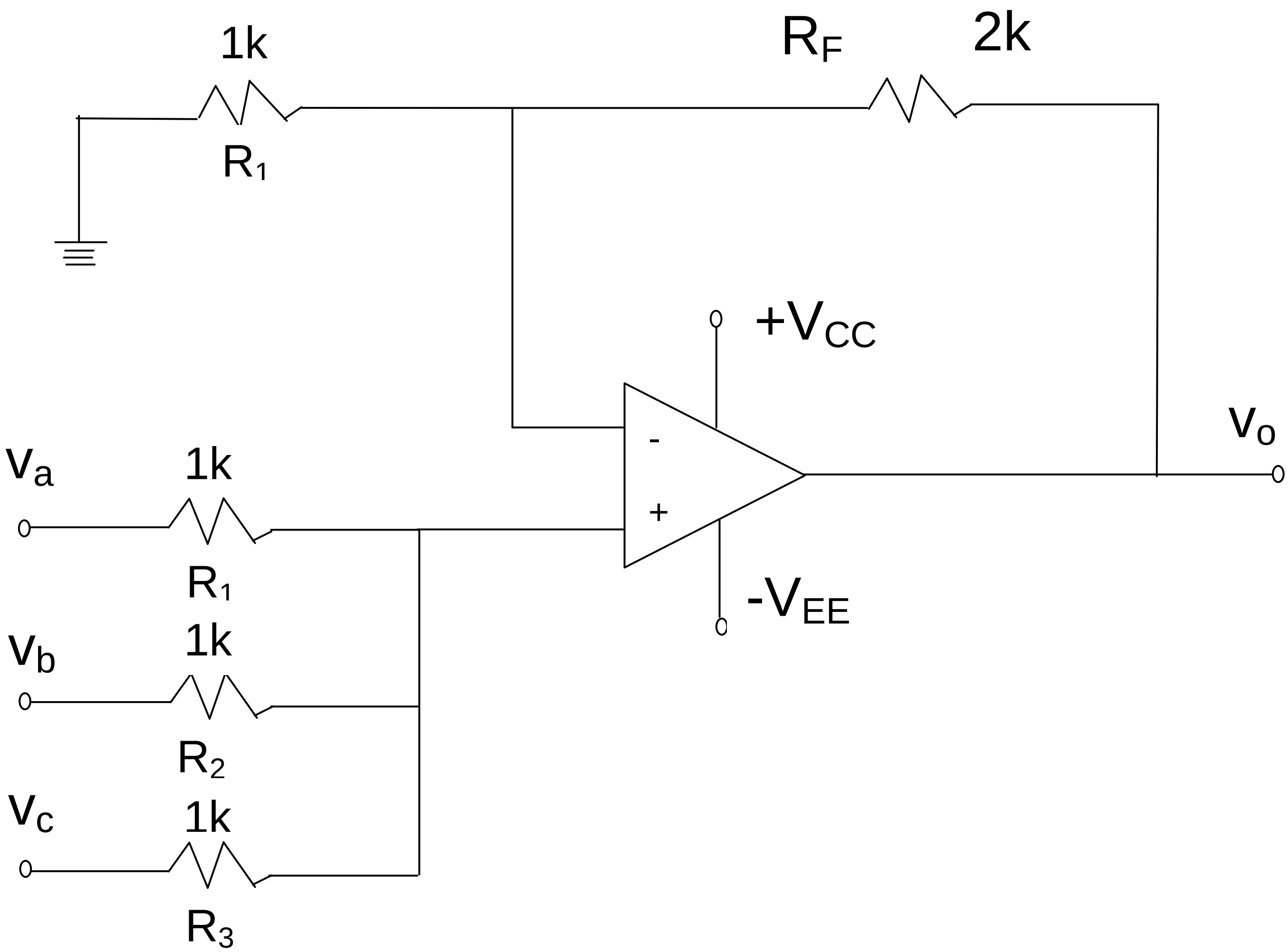
$$\frac{R_F}{R_3} = 0.2 \ or, \ R_3 = \frac{R_F}{0.2} = \frac{30k}{0.2}$$
$$or \ R_3 = 150k$$

And,

$R = R_1 || R_2 || R_3 = 10k || 30k || 150k$

or, R = 7.0kΩ

7.6 Determine the output voltage in the circuit shown in fig. If V_a= 5V, V_b= -2V and V_c = 3b



Solution:-

In the amplifier circuit shown in fig. Since the resistors R_1, R_2, and R_3 are all equal to 1kΩ, the voltage V_1, at non-inverting input terminal will be average of the three voltages, V_a, V_b, and V_c.

Thus,

$$V_1 = \frac{V_a + V_b + V_c}{3} = \frac{5V - 2V + 3V}{3} = 2V$$

And the gain for non-inverting amplifier, A_V, is

$$A_V = \frac{V_0}{V_1} = 1 + \frac{R_F}{R}$$

$$or, V_0 = \left(1 + \frac{R_F}{R}\right)V_1 = \left(1 + \frac{2k}{1k}\right) \times 2V$$

$$or, V_0 = 6V$$

7.7 Differential gain A_d, of an op amp measures 100. In the measurement of common-mode gain experiment when 1.0V is applied common to both the inputs, output voltage measured is 0.01V. How much is common-mode rejection ratio (CMRR)?

Solution:-

By definition, common mode rejection ratio (CMRR) is

$$CMRR\ (in\, dB) = 20\log_{10}\frac{|A_d|}{|A_{cm}|}$$

Where A_d is gain in differential mode which is given as 100.

And, the gain in common mode, A_{CM} is,

$$A_{CM} = \frac{V_0}{V_{i(cm)}} = \frac{0.01V}{1.0V} = 10^{-2}$$

Therefore,

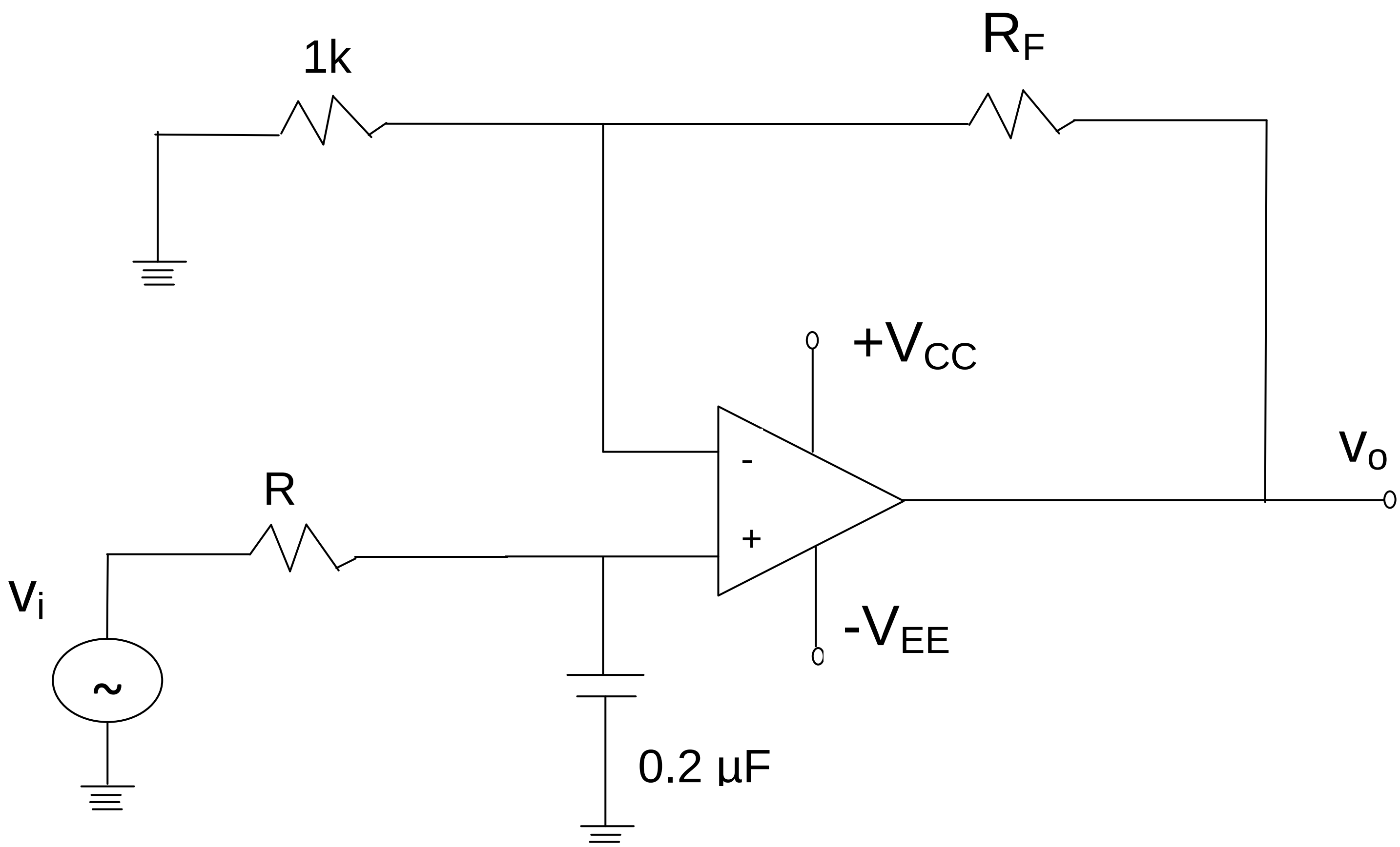
$$CMRR = 20\log_{10}\frac{100}{10^{-2}}$$

$$= 20\log_{10}(10^4)$$

or, CMRR = 20 X 4 = 80 dB

CMRR = 80 dB

7.8 Figure shows a low-pass filter. Calculate the value of feedback resistor R_F so that band-pass gain is 100. Also calculate the value of resistor R to get cut-off frequency of 2kHz.



Solution:-

The gain in band-pass region is that of non-inverting amplifier and it is,

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

$$A_V = 100, \quad R_1 = 1k, \ then$$

$$100 = 1 + \frac{R_F}{1k}$$

$$or, \ R_F = 99k\Omega$$

The cut-off frequency, f, for low-pass fitter is given by

$$f = \frac{1}{2\Pi RC}$$

$$or, R = \frac{1}{2\Pi fC} \quad = \frac{1}{2\times 3.14\times 2\times 10^3 \times 0.2\times 10^{-6}}$$

$$or, \ R = 398\,\Omega$$

$$(\text{Pr}\,actically \ \ R = 400\Omega)$$