CMR INSTITUTE OF TECHNOLOGY	USN										

Internal Assesment Test - I

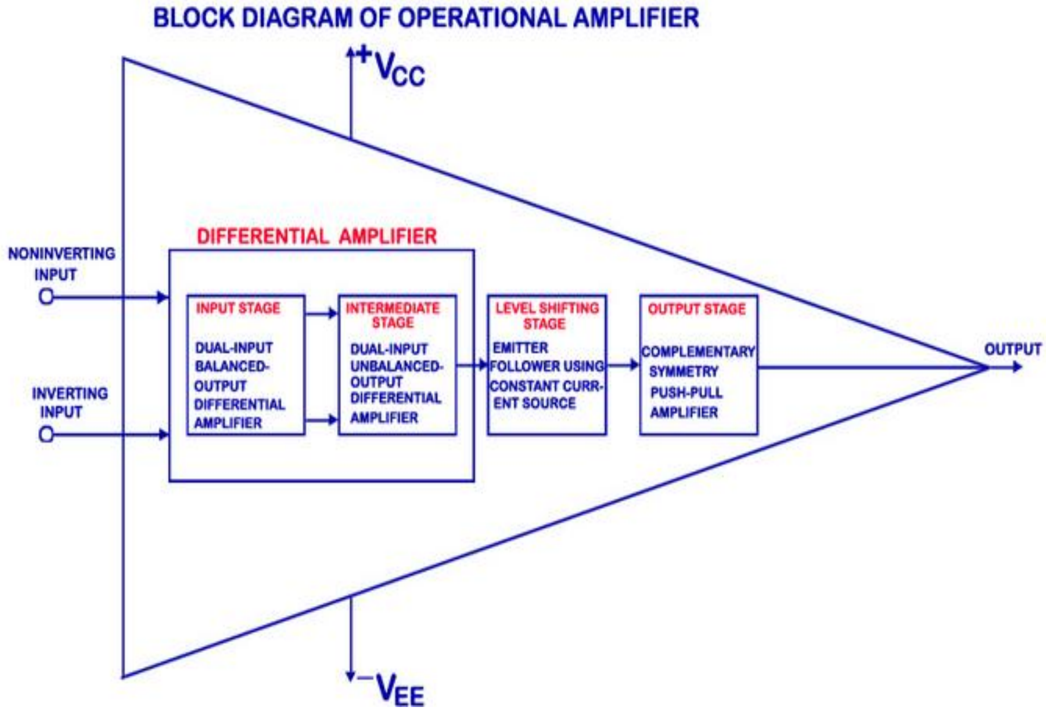
Sub:	**OPERATIONAL AMPLIFIERS AND LINEAR ICs**							Code:	15EE46
Date:	13/ 03/ 2018	Duration:	90 mins	Max Marks:	50	Sem:	4^{TH}	Branch:	EEE

Answer Any FIVE FULL Questions

		Marks	OBE	
			CO	RBT
1	With a block diagram explain the different stages of a typical Operational amplifier. Define slew rate, CMRR and input offset voltage.	10	CO1	L2
2	Derive the expression for closed loop gain, Ideal closed loop gain, Input resistance and output resistance of a voltage series feedback amplifier with circuit diagrams.	10	CO1	L2
3	Demonstrate an Instrumentation amplifier with transducer bridge input. Derive the expression of output voltage for the same.	10	CO1	L2
4	Design a two stage wide band pass filter and band reject filter having f_L=200Hz and f_H=1kHz and pass band gain of 4.Calculate Q value and center frequency. Assume capacitor values for high pass section=0.05uF and for the low pass section=0.01uF.Draw the circuit diagram.	10	CO6	L3
5	For the second order LPF, show that the pass band voltage gain is equal to 1.586 and also obtain the expression for high cut off frequency f_H.Draw the circuit diagram.	10	CO6	L2
6	A peaking amplifier has the following values R_1=1kΩ,L=100uH with a 3Ω internal resistance. Given C=0.01uf,R_F=6.8kΩ,and R_L=10kΩ. Determine (a)the peak frequency f_p,(b)the gain of the amplifier at f_p and the bandwidth of the amplifier.	10	CO1	L3
7	Design a first order and second order Low pass Butterworth filter with cut off frequency 1.2kHz.	10	CO6	L3
8	Explain how an Op-amp can be used as a non-inverting summer and subtractor.	10	CO1	L2

Solution

1.



(4 marks)

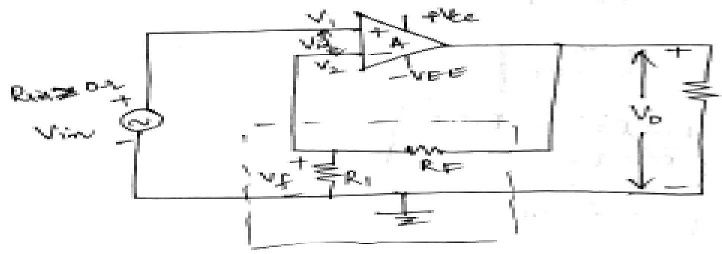
Slew Rate : The slew rate is the maximum rate of change of output voltage caused by a step input voltage and is usually specified in V/µS. For example 1V/µS slew rate means that the output rises or falls by 1V in one microseconds. Ideally slew rate is infinite which means that op-amp's output should be changed instantaneously in response to input step voltage. Practical op-amps are available with slew rates from 0.1V/µS to well above 1000V/µS.

CMRR : It can be defined as the ratio of the differential gain A_D to the common mode gain A_{CM} that is, $CMRR=A_D/A_{CM}$.

Input Offset Voltage Defined. The **input offset voltage** is defined as the **voltage** that must be applied between the two **input** terminals of the **op amp** to obtain zero volts at the output. (2+2+2 marks)

2.

(1) Voltage - series feedback amplifier



→ Used as Non-inverting amplifier.

open loop voltage gain $\left(A = \frac{V_o}{V_{id}}\right)$

closed loop voltage gain $A_F = \frac{V_o}{V_{in}}$

Gain of feedback circuit $B = \frac{V_f}{V_o}$

Negative feedback

$V_{id} = V_{in} - V_f$

V_{in} → input voltage V_f - feedback voltage V_{id} = diff I/p V.

feedback always the input voltage (180°).

closed loop voltage gain

$A_F = \frac{V_o}{V_{in}}$

$V_o = A(V_1 - V_2)$.

From fig $V_1 = V_{in}$

$V_2 = V_f = V_o \times \frac{R_1}{R_1 + R_F}$

$$V_o = A\left[V_{in} - \frac{R_1 V_o}{R_1 + R_F}\right]$$

$$V_o = A\left[\frac{V_{in}(R_1 + R_F) - R_1 V_o}{R_1 + R_F}\right]$$

$$V_o\left[1 + \frac{R_1}{R_1 + R_F}\right] = A V_{in}$$

$$V_o = \frac{A(R_1 + R_F) V_{in}}{R_1 + R_F + A R_1}$$

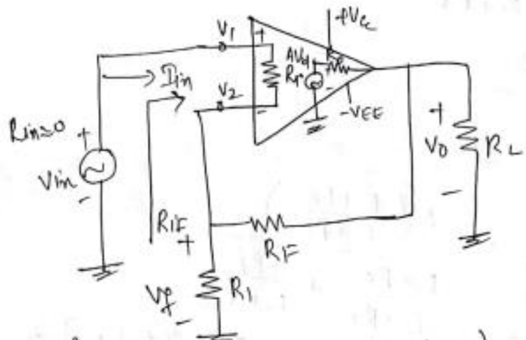
$$A_F = \frac{V_o}{V_{in}} = \frac{A(R_1 + R_F)}{R_1 + R_F + A R_1}$$

A is very large (10^5)

$A R_1 >> (R_1 + R_F)$ so $R_1 + R_F + A R_1 \simeq A R_1$

$$A_F = \frac{V_o}{V_{in}} = \frac{A(R_1 + R_F)}{A R_1} = 1 + \frac{R_F}{R_1} \text{ (ideal)}$$

Input resistance with feed back



R_i is i/p resistance (open-loop)

R_{iF} = input resistance with feed back.

$$R_{iF} = \frac{v_{in}}{I_{in}} = \frac{v_{in}}{(v_{id}/R_i)}$$

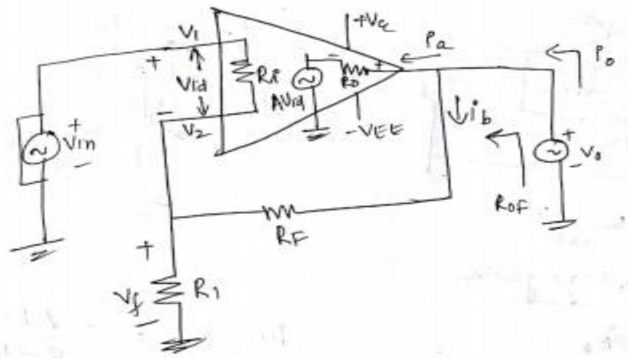
$$v_{id} = \frac{v_0}{A} \qquad v_0 = \frac{A}{1+AB} v_{in}$$

$$\cancel{R_{iF} = \frac{v_{in}}{\frac{v_0}{AR_i}}} \qquad R_{iF} = \frac{v_{in}}{\frac{v_0}{A} \times \frac{1}{R_i}}$$

$$R_{iF} = AR_i \cdot \frac{v_{in}}{v_0}$$

$$= AR_i \cdot \frac{v_{in}}{\frac{A}{1+AB} v_{in}}$$

$$\boxed{R_{iF} = R_i(1+AB)}$$



$$R_{OF} = \frac{v_0}{i_0} \qquad i_0 = i_a + i_b.$$

$$i_a$$

$$\left[(R_F + R_1) \,||\, R_i\right] >> R_0 \qquad i_a >> i_b.$$

$$i_0 \approx i_a \qquad v_0 - R_0 i_0 - AV_{id} = 0$$

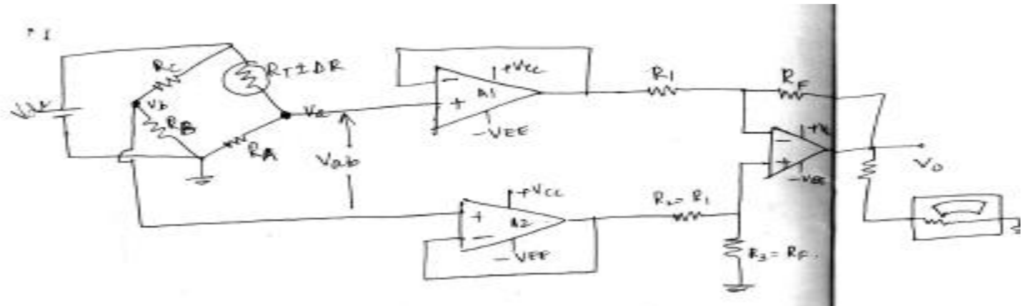
$$i_0 = \frac{v_0 - AV_{id}}{R_0}$$

$$v_{id} = v_1 - v_2 = 0 - v_f = -\frac{R_1 \cdot v_0}{R_1 + R_F} = -Bv_0$$

$$i_0 = \frac{v_0 + ABv_0}{R_0}$$

$$R_{OF} = \frac{v_0}{(v_0 + ABv_0)/R_0} = \frac{R_0}{1 + AB}$$

3



Resistance changes as physical energy

$R_T \pm \Delta R$

$V_a = V_b$

$$\frac{R_B \cdot V_{dc}}{R_B+R_C} = \frac{R_A \cdot V_{dc}}{R_A+R_T}$$

$$R_B(R_A+R_T) = R_A(R_B+R_C)$$

$$\cancel{R_A R_B} + R_B \cdot R_T = \cancel{R_A R_B} + R_A \cdot R_C$$

$$R_B R_T = R_A \cdot R_C$$

$$\boxed{\frac{R_C}{R_B} = \frac{R_T}{R_A}}$$

when resistance changes

V_a

15

$$V_a = \frac{R_A \cdot V_{dc}}{R_A + (R_T + \Delta R)}$$

$$V_b = \frac{R_B \cdot V_{dc}}{R_B + R_C}$$

$$V_{ab} = V_a - V_b$$

$$V_{ab} = \frac{R_A \cdot V_{dc}}{R_A + R_T + \Delta R} - \frac{R_B \cdot V_{dc}}{R_B + R_C}$$

$$R_A = R_B = R_C = R_T = R$$

$$V_{ab} = \frac{R \cdot V_{dc}}{\underbrace{R + R + \Delta R}_{2R+\Delta R}} - \frac{R \cdot V_{dc}}{\underbrace{R + R}_{2R}}$$

$$\frac{R \cdot V_{dc}}{2R + \Delta R} - \frac{R \cdot V_{dc}}{2R}$$

$$= R \cdot V_{dc}\left[\frac{2R - 2R - \Delta R}{2R(2R+\Delta R)}\right]$$

$$= \cancel{R} \cdot V_{dc}\left[\frac{-\Delta R}{2\cancel{R}(2R+\Delta R)}\right] = -\left[\frac{\Delta R \cdot V_{dc}}{2(2R+\Delta R)}\right]$$

$$V_o = V_{ab}\left(\frac{-R_F}{R_1}\right) = \left(-\frac{R_F}{R_1}\right)\left(\frac{-\Delta R \cdot V_{dc}}{2(2R+\Delta R)}\right)$$

$$2R + \Delta R \simeq 2R \qquad V_o = \frac{R_F}{R_1}\frac{\Delta R}{4R} V_{dc}$$

$$\boxed{V_o \propto \Delta R}$$

4.

4) $f_L = 200Hz$ $f_H = 1KHz$ $A_v = 4$

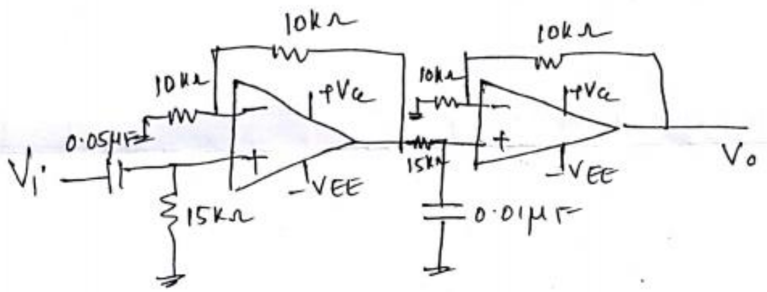
$C_1 = 0.05\mu F$ $C_2 = 0.01\mu F$

$$f_L = \frac{1}{2\pi R_1 C_1} \qquad R_1 = \frac{1}{2\pi f_L C_1} = \frac{1}{2\pi \times 200 \times 0.05\mu F}$$

$$= 15.91 k\Omega$$

$$f_H = \frac{1}{2\pi R_2 C_2} \qquad R_2 = \frac{1}{2\pi f_H C_2} = \frac{1}{2\pi \times 1\times10^3 \times 0.01\times10^{-6}}$$

$$= 15.91 K\Omega$$



5.

For deriving the expression for the cut-off frequency, let us use the Laplace transform ethod.

The input RC network can be represented in the Laplace domain as shown in g. 2.6.2.

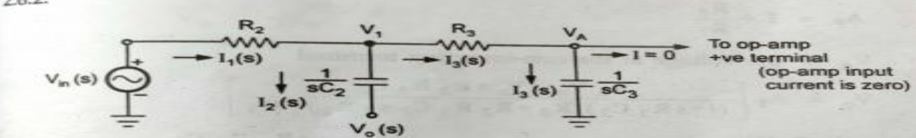


Fig. 2.6.2

ow

$$I_1 = I_2 + I_3 \quad \ldots (2.6.1)$$

$$\frac{V_{in} - V_1}{R_2} = \frac{V_1 - V_o}{\left(\frac{1}{sC_2}\right)} + \frac{V_1 - V_A}{R_3} \quad \ldots (2.6.2)$$

Using potential divider rule, we can write,

$$V_A = V_1 \left[\frac{\frac{1}{sC_3}}{R_3 + \frac{1}{sC_3}} \right] \quad \ldots (2.6.3$$

$$V_A = \frac{V_1}{1 + sR_3 C_3} \qquad \text{... (2.6.}$$

$$\therefore \quad V_1 = V_A (1 + s R_3 C_3)$$

Substituting in (2.6.2) and solving for V_A, we get

$$\frac{V_{in} - V_A (1+sR_3 C_3)}{R_2} = \frac{V_A (1+s R_3 C_3) - V_o}{\left(\frac{1}{sC_2}\right)} + \frac{V_A (1+s R_3 C_3) - V_A}{R_3}$$

$$\frac{V_{in}}{R_2} + V_o (s C_2) = V_A \left[\frac{(1+s R_3 C_3)}{R_2} + s C_2 (1+s R_3 C_3) + \frac{(1+s R_3 C_3)}{R_3} - \frac{1}{R_3} \right]$$

$$\therefore \frac{V_{in}}{R_2} + V_o (s C_2) = V_A \left[\frac{R_3 (1+s R_3 C_3) + R_2 R_3 s C_2 (1+s R_3 C_3) + R_2 (1+s R_3 C_3) - R_2}{R_2 R_3} \right]$$

$$\therefore (R_3 V_{in} + V_o s R_2 R_3 C_2) = V_A [(1 + s R_3 C_3) (R_3 + R_2 R_3 s C_2 + R_2) - R_2]$$

$$V_A = \frac{R_3 V_{in} + V_o s R_2 R_3 C_2}{[(1+s R_3 C_3)(R_3 + R_2 R_3 C_2 s + R_2) - R_2]} \qquad \text{... (2.6}$$

Now, for op-amp in non-inverting configuration,

$$V_o = A_F V_A \qquad \text{... (2.}$$

where $A_F = 1 + \frac{R_f}{R_1}$

and V_A = the voltage at the non-inverting terminal

$$\therefore \quad V_o = A_F \left[\frac{R_3 V_{in} + V_o s R_2 R_3 C_2}{(1+s R_3 C_3)(R_3 + R_2 R_3 C_2 s + R_2) - R_2} \right]$$

$$\frac{A_F R_3 V_{in}}{(1+s R_3 C_3)(R_3 + R_2 R_3 C_2 s + R_2) - R_2} = V_o \left[1 - \frac{s R_2 R_3 C_2}{(1+s R_3 C_3)(R_3 + R_3 R_2 C_2 s + R_2) - R_2} \right]$$

$$A_F R_3 V_{in} = V_o [(1 + s R_3 C_3) (R_3 + R_3 R_2 C_2 s + R_2) - R_2 - s R_2 R_3 C_2]$$

$$\frac{V_o}{V_{in}} = \frac{A_F}{s^2 + \frac{(R_3 C_3 + R_2 C_3 + R_2 C_2 - A_F R_2 C_2) s}{R_2 R_3 C_2 C_3} + \frac{1}{R_2 R_3 C_2 C_3}} \qquad \text{... (2.}$$

As the order of s in the gain expression is two, the filter is called **second order filt**

The standard form of the transfer function of any second order system is

$$\boxed{\frac{V_o (s)}{V_{in} (s)} = \frac{A}{s^2 + 2 \xi \omega_n s + \omega_n^2}}$$

Note : For $R_2 = R_3 = R$ and $C_2 = C_3 = C$, the transfer function takes the form

$$\frac{V_o (s)}{V_{in} (s)} = \frac{A_F}{s^2 + \frac{3 - A_F}{RC} s + \frac{1}{R^2 C^2}} \qquad \text{... (2.6.12)}$$

From this we can write that,

$$\xi = \text{damping factor} = \frac{3 - A_F}{2} \qquad \text{... (2.6.13)}$$

Now, for second order Butterworth filter, the middle term required is $\sqrt{2} = 1.414$, om the normalised Butterworth polynomial.

$$3 - A_F = \sqrt{2} = 1.414$$

$$\boxed{A_F = 1.586} \qquad \text{... (2.6.14)}$$

Thus, to ensure the **Butterworth response,** it is necessary that the gain A_F is 1.586.

$$1.586 = 1 + \frac{R_f}{R_1}$$

$$\boxed{R_f = 0.586 R_1} \qquad \text{... (2.6.15)}$$

6.

Sol^n (a) $f_p = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{10^{-4}\times 10^{-8}}} = \frac{1}{2\pi\times 10^{-6}} = \boxed{159\,KHZ}$

(b) Gain of the amplifier at f_p,

$$A_F = -\frac{R_F \parallel R_P}{R_1} \quad // \quad \left\{ R_p = Q_{coil}^2 \times R \text{ and } \frac{X_L}{R} = Q_{coil} \right\}$$

$$* \; Q_{coil} = \frac{2\pi f L}{R} = \frac{2\pi\times 159K\times 10^{-4}}{3} = \frac{99.9}{3}$$

$$Q_{coil} = 33.3$$

$$* \; R_p = Q_{coil}^2 \times R = (33.3)^2 \times R = 1108.89 \times 3 = 3.326\,K\Omega$$

$$A_F = -\frac{6.8K\times 3.3K}{(6.8K + 3.3K)} \Big/ 1K\Omega = -\frac{2.22K\Omega}{1K\Omega} = \boxed{-2.22}$$

inverting

(c) $B.W = \frac{f_p}{Q_p} = \frac{159\,KHZ}{32.87}$ $\qquad \frac{R_p}{X_L} = \frac{3.3k}{2\pi\times 15.9} = 33.032$ $\qquad Q_p = \frac{6.8K\times 33.032}{6.8K + 33.032} = 32.87$

$\boxed{B.W = 4.8\,KHZ}$

7.

7) First order low pass

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

$f = 1.2\,kHZ$

Let $C = 0.01\,\mu F$

$$C = \frac{1}{2\pi f C}$$

$$= \frac{1}{2\pi \times 1.2\times10^{3} \times 0.01\times10^{-6}}$$

$= 13\,k\Omega$

Second order LPF

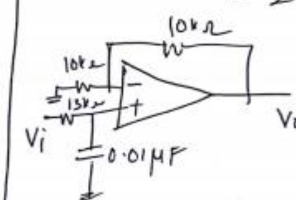
$R_1 = R_2 = R$

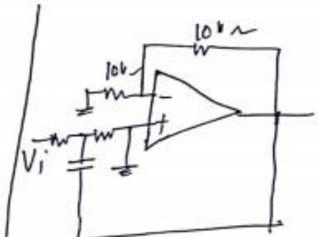
$C_1 = C_2 = C$

Let $C = 0.0047\,\mu F$

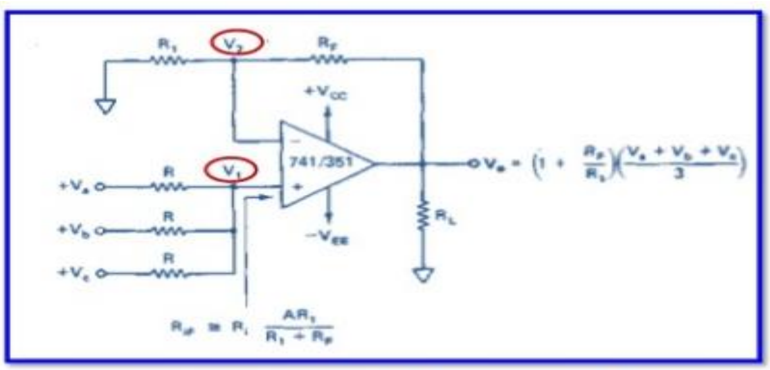
$$R = \frac{1}{2\pi \times 1.2\times10^{3} \times 0.0047\times10^{-6}}$$

$= 28\,k\Omega$





8.



Non-inverting Summing Amplifier

Therefore, using the superposition theorem, the voltage $V_2 = V_1$
V_b & $V_c = 0$. Net resistance $= R+R/2$

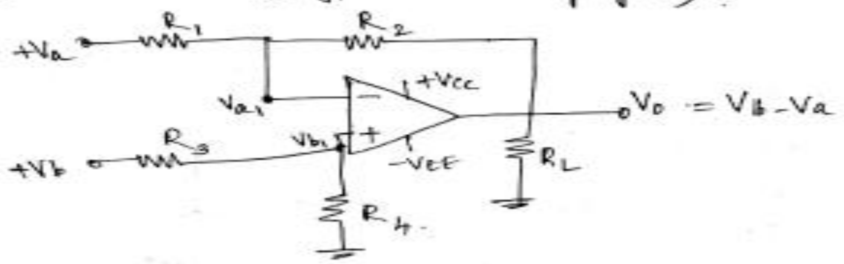
$$V_1 = \frac{R/2}{R + R/2} V_a + \frac{R/2}{R + R/2} V_b + \frac{R/2}{R + R/2} V_c$$

$$V_1 = \frac{R/2}{3R/2} V_a + \frac{R/2}{3R/2} V_b + \frac{R/2}{3R/2} V_c$$

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

If $R_F=2R_1$, $1+R_F/R_1=3$
$V_o= V_a+V_b+V_c$

(b) Subtractor (differential amplifier)



Applying superposition theorem,

Considering V_a, $V_b = 0$

$$V_{o1} = -\frac{R_2}{R_1} V_a$$

Considering V_b, $V_a = 0$

$$V_{b1} = \frac{V_b \times R_4}{R_3 + R_4}$$

$$V_{o2} = \left(1 + \frac{R_2}{R_1}\right) V_{b1} = \left(1 + \frac{R_2}{R_1}\right) \times \left(\frac{R_4}{R_3 + R_4}\right) V_b$$

$$= \left(\frac{R_1 + R_2}{R_1}\right)\left(\frac{R_4}{R_3 + R_4}\right) V_b$$

If $R_1 = R_2$ & $R_3 = R_4$.

$V_{o1} = -V_a$ $\qquad$ $V_{o2} = +V_b$.

$$V_o = V_{o1} + V_{o2} = V_b - V_a$$

$$\boxed{V_o = V_b - V_a}$$