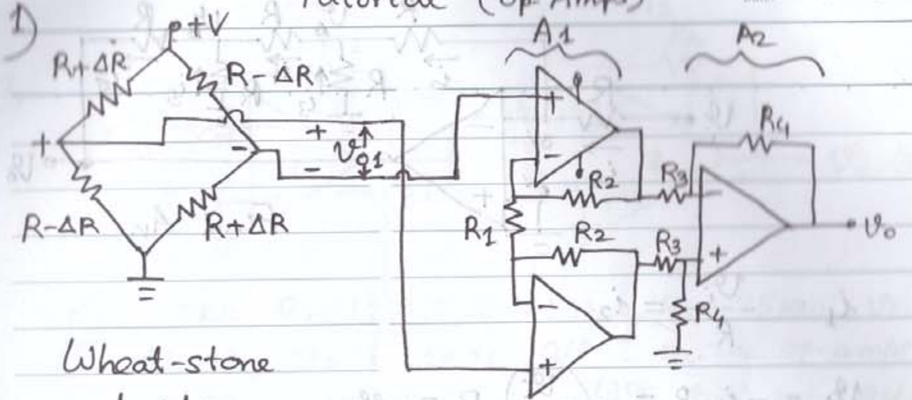
Tutorial (Op-Amps)

1)



Wheat-stone bridge

→ Calc. values of R $\quad R = 10k\Omega,\ \Delta R = 50\Omega,\ +V = 3.5V$

Design an amp. for $v_o = 5V$ when $\Delta R = 50\Omega$

Sol^n: $$v_{o1} = \left[\frac{R-\Delta R}{(R-\Delta R)+(R+\Delta R)} - \frac{R+\Delta R}{(R+\Delta R)+(R-\Delta R)}\right] \cdot V$$

(V-divider eq^{n}s.)

$$= \left[\frac{R-\Delta R}{2R} - \frac{R+\Delta R}{2R}\right] \cdot +V$$

$$= -\frac{\Delta R}{R} \cdot (+V) = -\frac{50}{10\times10^3}(3.5) = -1.75\times10^{-2}$$

$$= 17.5\,mV$$

$$\text{Required gain} = A_d = \frac{v_o}{v_i} = \frac{5}{17.5m} = 285.714$$

For an instrumentation amp.,

$$|A_d| = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{R_1}\right) = 285.714$$

Assume, $R_3 = 10k\Omega$ & $R_4 = 150k\Omega$

$\therefore \frac{R_2}{R_1} = 9.02$

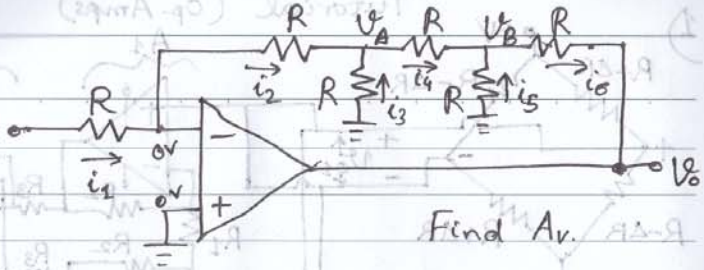
Let, $R_2 = 100k\Omega$, $\quad \therefore R_1 = 11.1k\Omega$

(Ans)

No.

Date.

2.



Find A_v.

$$i_1 = \frac{v_i}{R} = i_2$$

$$v_A = -i_2 . R = -\left(\frac{v_i}{R}\right). R = -v_i$$

$$i_3 = -\frac{v_A}{R} = -\frac{v_i}{R}$$

$$i_4 = i_2 + i_3 = -\frac{v_A}{R} - \frac{v_A}{R} = \frac{-2.v_A}{R} = +\frac{2.v_i}{R}$$

$$v_B = v_A - i_4 . R = -v_i - \left[+\frac{2\,v_i}{R}\right].R = -3.v_i$$

$$i_5 = -\frac{v_B}{R} = -\frac{-3.v_i}{R} = \frac{3.v_i}{R}$$

$$i_6 = i_4 + i_5 = \frac{2v_i}{R} + \frac{3.v_i}{R} = \frac{5.v_i}{R}$$

$$v_o = v_B - i_6 . R = -3.v_i - \left(\frac{5.v_i}{R}\right).R = -8.v_i$$

$$\Rightarrow \frac{v_o}{v_i} = A_v = -8 \quad \text{(Ans)}$$

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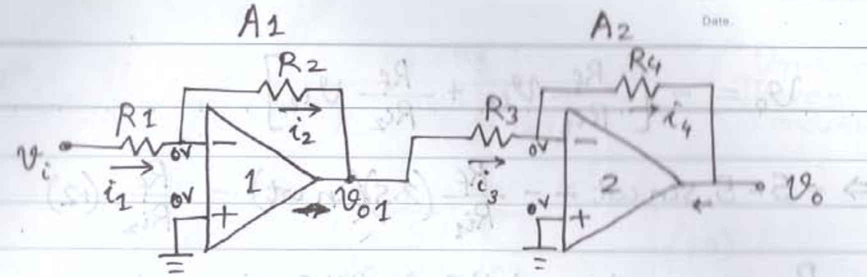
3.



$R_1 = 20k\Omega$, $R_2 = 120k\Omega$, $R_3 = 15k\Omega$, $R_4 = 75k\Omega$, $v_i = 0.2V$

Find: v_{o1}, v_o, i_1 to i_4, O/P I in the op-amps.

Solⁿ

$$v_{o1} = -\frac{R_2}{R_1}. v_i = -\frac{120k}{20k}.(0.2) = -1.2V \quad \text{(Ans)}$$

$$v_o = -\frac{R_4}{R_3}. v_{o1} = -\frac{75k}{15k}.(-1.2) = +6V \quad \text{(Ans)}$$

$$i_1 = i_2 = \frac{0.2 \leftarrow v_i}{20k \leftarrow R_1} = 10\mu A \quad \text{(Ans)}$$

$$i_3 = i_4 = \frac{v_{o1}}{R_3} = \frac{-1.2}{15k} = -80\mu A \quad \text{(Ans)}$$

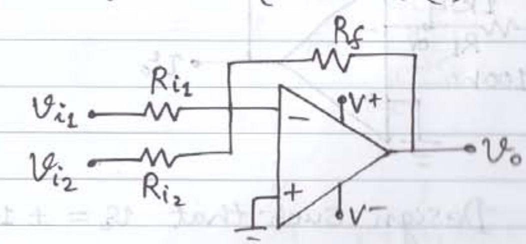
O/P I (op-amp.1) $= -(10\mu + 80\mu) = -90\mu A$ ← Sink I

O/P I (op-amp.2) $= +80\mu A$ ← Source I

(Ans)

4. Design a Summing amp: $v_{i1} = (2.5)\sin\omega t$ (V), $v_{i2} = +2V$, $v_o = -5(1+\sin\omega t)$(V). Largest R is $200k\Omega$.

Solⁿ.



$$v_o = -\left[\frac{R_f}{R_{i_1}} v_{i_1} + \frac{R_f}{R_{i_2}} v_{i_2}\right]$$

$$\Rightarrow -5 - 5.\sin\omega t = -\frac{R_f}{R_{i_1}}(2.5\sin\omega t) - \frac{R_f}{R_{i_2}}(+2)$$

By separating LHS & RHS elements,

$$\cancel{-}5 = \cancel{-}\frac{R_f}{R_{i_2}} \cdot 2$$

$$\Rightarrow \frac{R_f}{R_{i_2}} = 2.5$$

Indicates $\Rightarrow R_f > R_{i_2}$

$\therefore$ $R_f = 200\,k\Omega$ (largest R in the ckt)

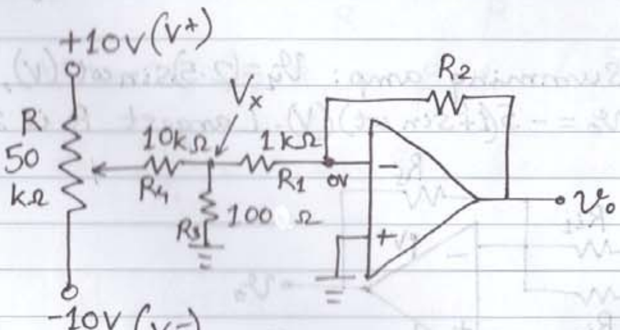
Now,

$$\cancel{-}5.\cancel{(\sin\omega t)} = \cancel{-}\frac{200k}{R_{i_1}} \cdot (2.5)\cancel{(\sin\omega t)}$$

$$\Rightarrow R_{i_1} = \frac{200k.(2.5)}{5} = 100\,k\Omega \quad \text{(Ans)}$$

Also, $R_{i_2} = \frac{R_f}{2.5} = \frac{200k}{2.5} = 80\,k\Omega$ (Ans)

5.



Design such that $v_o = \pm 10V$.

Solⁿ. $V_{x(max)} = \frac{R_3 // R_1}{R_3 // (R_1 + R_4)} \cdot V^+$ (Under Thevenin's condition)

$$= \frac{\frac{(0.1)(1)}{0.1+1}}{\frac{(0.1)(1+10)}{0.1+1+10}} \cdot (10)$$

$$= 0.090\ V$$

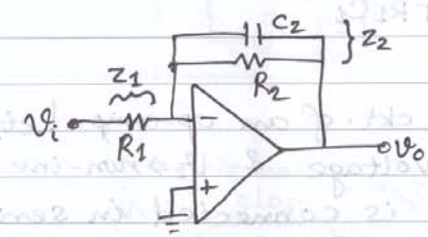
Now,

$$|v_o| = \frac{R_2}{R_1} \cdot V_{x(max)}$$

$$\Rightarrow 10 = \frac{R_2}{1k}(0.090)$$

$$\Rightarrow R_2 = 111\,k\Omega \quad \text{(Ans)}$$

6.



Derive V- transfer funcⁿ → Gain

← Active Integrator (LPF)

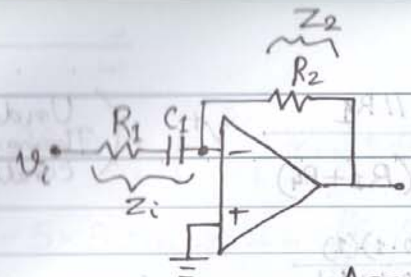
Solⁿ. $A_v = \frac{v_o}{v_i} = -\frac{Z_2}{Z_1} = \frac{R_2 // \frac{1}{j\omega C_2}}{R_1}$

$$= \frac{\frac{R_2 \cdot \frac{1}{j\omega C_2}}{R_2 + \frac{1}{j\omega C_2}}}{R_1}$$

$$= -\frac{R_2}{R_1} \cdot \frac{1}{1 + j\omega R_2 . C_2} \quad \text{(Ans)}$$

Corner (-3 db) freq. w.r.t. pass-band gain $= f_c = \frac{1}{2\pi R_2 . C_2}$

← Differentiator (Active HPF)

7. 

Derive for $\frac{v_o}{v_i}$

Assume the op-amp is an ideal one.

Sol^n. $$\frac{v_o}{v_i} = -\frac{Z_2}{Z_1} = -\frac{R_2}{R_1 + \frac{1}{j\omega C_1}}$$

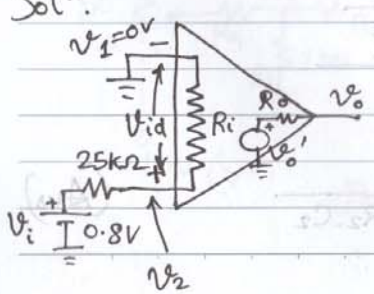
$$= -\frac{R_2(j\omega C_1)}{1 + j\omega R_1 C_1}$$

$$= -\frac{R_2}{R_1} \cdot \frac{j\omega R_1 C_1}{1 + j\omega R_1 C_1} \quad \text{(Ans)}$$

Corner (−3 db w.r.t. pass-band gain) freq: $f_c = \frac{1}{2\pi R_1 C_1}$

8. Draw an equivalent ckt. of an op-amp. Let, $v_1 \Rightarrow$ Inv. terminal voltage & $v_2 \Rightarrow$ non-inv. terminal voltage. v_2 is connected in series with a 25kΩ resistor from a source of 0.8V & $v_1 = 0$ V. What is $R_{i\,min}$ (op-amp) such that $v_{id} = 0.79$ V?

Sol^n.



$$v_{id} = v_2 - v_1 = \left(\frac{R_i}{R_i + 25k\Omega}\right) \cdot v_i$$

$$\Rightarrow 0.79 = \frac{R_i}{R_i + 25k} \cdot (0.8)$$

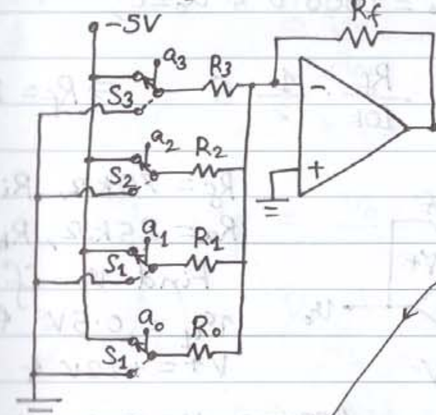
$$\Rightarrow R_i = 1975 \text{ k}\Omega \quad \text{(Ans)}$$

9. Draw the circuit of a digital-to-analog converter (DAC) by using op-amp. Write the expression for its O/P voltage as a function of digital logic. Find the feedback resistor's value such that $v_o = +2.5$V while digital I/Ps are: $a_3 a_2 a_1 a_0 = 1000$, where, a_3 is the most significant bit (MSB), & a_0 is the least significant bit (LSB).

I/P code, O/P V, Closed loop

Sol^n.

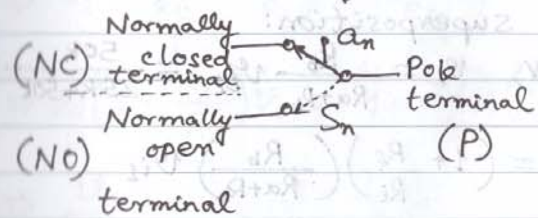
$R_3 = R$
$R_2 = 2R$
$R_1 = 4R$
$R_0 = 8R$



← Modified Summing amp.

S_3 to S_0: Single pole double throw switches (SPDT)

a_3 to a_0: Swith control I/Ps (logic values)



When, $a_n = '0' \Rightarrow$ 'P' is connected to 'NC'
" $a_n = '1' \Rightarrow$ 'P' " " " 'NO'

$$v_o = -\frac{R_f}{R_3} \cdot a_3 \cdot (-5) - \frac{R_f}{R_2} \cdot a_2 \cdot (-5) - \frac{R_f}{R_1} \cdot a_1 (-5) - \frac{R_f}{R_0} \cdot a_0 (-5)$$

$$= \frac{R_f}{R} \cdot a_3 (5) + \frac{R_f}{2R} \cdot a_2 (5) + \frac{R_f}{4R} \cdot a_1 \cdot (5) + \frac{R_f}{8R} \cdot a_0 \cdot (5)$$

Let, $R = 20k\Omega$,

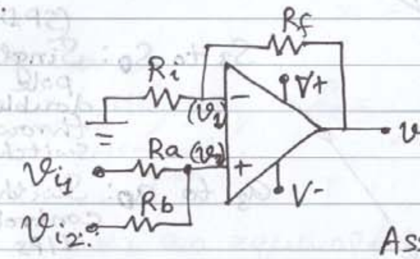
$$\therefore v_o = \frac{R_f}{20k} \cdot a_3 \cdot 5 + \frac{R_f}{40k} \cdot a_2 \cdot 5 + \frac{R_f}{80k} \cdot a_1 \cdot 5 + \frac{R_f}{160k} a_0 \cdot 5$$

$$\therefore v_o = \frac{R_f}{10k}\left[\frac{a_3}{2} + \frac{a_2}{4} + \frac{a_1}{8} + \frac{a_0}{16}\right](5) \quad \text{(Ans)}$$

While, $a_3 = 1,\ a_2 = 0,\ a_1 = 0\ \&\ a_0 = 0$;

$$v_o = 2.5 = \frac{R_f}{10k} \cdot \frac{1}{2} \cdot 5 \Rightarrow R_f = 10k\Omega \quad \text{(Ans)}$$

10.



$R_f = 70k\Omega,\ R_i = 5k\Omega,$
$R_a = 25k\Omega,\ R_b = 50k\Omega$
Find v_o if $v_{i1} = 0.5V$ & $v_{i2} = 0.8V$
$V^+ = +12V$ & $V^- = -12V$

Assume the op-amp is ideal.

Soln. Apply superposition:

For, $v_{i2} = 0V$, $v_2 = \frac{R_b}{R_a+R_b} v_{i1} = \frac{50k}{25k+50k} \cdot v_{i1}$

$$v_o(v_{i1}) = \left(1 + \frac{R_f}{R_i}\right)\left(\frac{R_b}{R_a+R_b}\right) v_{i1}$$

$$= \left(1 + \frac{70k}{5k}\right)\left(\frac{50k}{25k+75k}\right) v_{i1} = 10\, v_{i1}$$

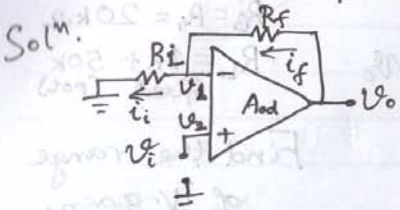
For, $v_{i1} = 0V$, $v_2 = \frac{R_a}{R_a+R_b} v_{i2}$

$$v_o(v_{i2}) = \left(1 + \frac{R_f}{R_i}\right)\left(\frac{R_a}{R_a+R_b}\right) v_{i2} = 5\, v_{i2}$$

$$\therefore v_o = v_o(v_{i1}) + v_o(v_{i2})$$
$$= 10\, v_{i1} + 5\, v_{i2} \checkmark$$
$$= 10(0.5) + 5(0.8) = 9V \quad \text{(Ans)}$$

11. Derive the eqn of the gain of a practical non-inv. amp. using an op-amp.

Soln.



$$v_o = A_{od}(v_2 - v_1)$$
$$\Rightarrow v_o = A_{od}(v_i - v_1)$$
$$\Rightarrow \frac{v_o}{A_{od}} - v_i = -v_1$$
or, $v_1 = v_i - \frac{v_o}{A_{od}}$

Now,
$$i_i = \frac{v_1}{R_i} = i_f = \frac{v_o - v_i}{R_f}$$

$$\therefore v_1\left(\frac{1}{R_i}\right) = \frac{v_o - v_i}{R_f}$$

$$\Rightarrow v_1\left(\frac{1}{R_i} + \frac{1}{R_f}\right) = \frac{v_o}{R_f}$$

$$\Rightarrow v_o\left(1 + \frac{R_f}{R_i}\right) v_1 = \left(1 + \frac{R_f}{R_i}\right)\left(v_i - \frac{v_o}{A_{od}}\right)$$

$$\Rightarrow \frac{v_o}{v_i} = \frac{\left(1 + \frac{R_f}{R_i}\right)}{1 + \frac{1}{A_{od}}\left(1 + \frac{R_f}{R_i}\right)} \quad \text{(Ans)}$$