$\frac{3}{3}$

Key Friday - L1 Slot

Summana . Subramanian
21BLC 1500
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D. Sai Manish
21BLC1089

(19) (a) $V_{OT} = \left(1 + \frac{R_f}{R_1}\right) V_{ios} + R_f I_B$

$= \left(1 + \frac{10\,k\Omega}{1\,k\Omega}\right)(10\,mV) + (10\,k\Omega)(300\,nA)$

$= 110\,mV + 3\,mV \quad = 113\,mV$

(b) Rcomp is needed:

$R_{comp} = 1\,k\Omega \parallel 10\,k\Omega \quad = 990\,\Omega$

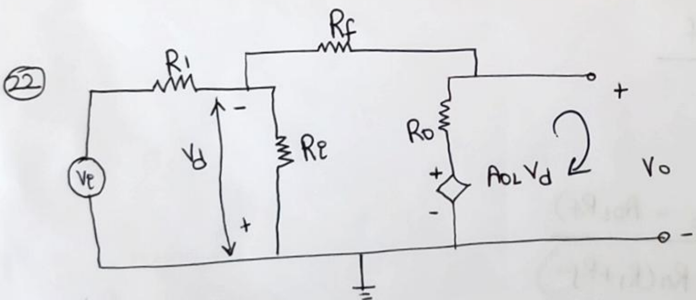
(c) Rcomp in circuit is found so with that we can find

$V_{OT} = \left(1 + \frac{R_f}{R_1}\right) V_{ios} + R_f I_{os}$

$= 110\,mV + 0.5\,mV$

$= 110.5\,mV$

(22)



The input impedance Ri of an ~~amp~~ op - amp is usually much greater than R1, so we may assume.

$v_{eq} = v_1 \; ; \; R_{eq} = R_1$

From outer loop:

$v_o = iR_o + A_{OL} V_d$.

$V_d + iR_f + v_o = 0$.

Putteng vo value

$$v_o(1 + A_{OL}) = i(R_o - A_{OL} R_f)$$

By KCL:

$$v_i = i(R_1 + R_f) + v_o$$

$$A_{CL} = \frac{v_o}{v_i} = \frac{R_o - A_{OL} R_f}{R_o + R_f + R_1(1 + A_{OL})}$$

$$A_{CL} \cong -\frac{R_f}{R_i}$$

for output resistance R_{of}:

$$i_A = \frac{v_i - 0}{R_1 + R_f}.$$

$$i_B = \frac{A_{OL} V_d}{R_o}$$

$$\because V_d = -i_A R_f$$

So, $$i_B = \frac{-A_{OL} i_A R_f}{R_o}$$

$$i_{sc} = i_A + i_B$$

$$\Rightarrow i_{sc} = v_i \frac{(R_o - A_{OL} R_f)}{R_o (R_1 + R_f)}$$

$$\because R_{of} = \frac{v_{oc}}{i_{sc}}.$$

and $$A_{CL} = \frac{v_{oc}}{v_i}$$

$$R_{of} = \frac{A_{CL} v_i}{v_i \left[R_o - A_{OL} R_f \Big/ R_o (R_1 + R_f) \right]}$$

$$R_{of} = \frac{R_o (R_1 + R_f)}{R_o + R_f + R_1(1 + A_{OL})}$$

also can be written as

$$R_{of} = \frac{\dfrac{R_o(R_1 + R_f)}{R_o + R_1 + R_f}}{1 + \dfrac{R_1 A_{OL}}{R_o + R_1 + R_f}}$$

21BLC1089
D. Sai Manish

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(20) input off set voltage due to tempurature rise

$= 0.15\,(50-30)$

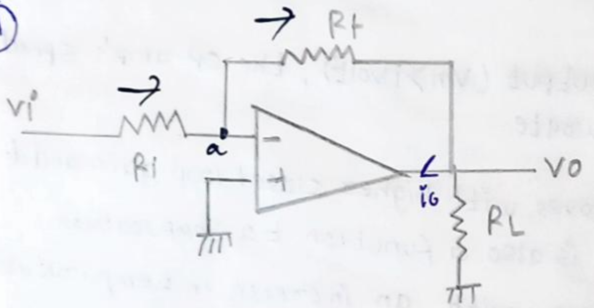
$= 4.5\,mV$

Output voltage change $\Rightarrow V_O = V_{as} \times A_{CL}$

$= 4.5 \times 100$

$= 450\,mV$

(21)



KCl:- at node a

$$\frac{V_i - 0}{R_1} = \frac{0 - V_O}{R_f}$$

$$V_O = \frac{-R_f}{R_i} V_i$$

$$= -\frac{100K}{1K} V_i$$

$$= -100\,V_i$$

$$i_L + i_1 \leq i_O$$

$$i_1 = \frac{V_1 - 0}{R_1}$$

$$= \frac{V_i}{1K}$$

$$i_L = \frac{V_O}{R_L} = \frac{-100V_i}{R_L} = \frac{-2V_i}{1K} \quad [R_L = 50K]$$

$$= \frac{-2V_i}{1K}$$

$$i_0 = i_1 + i_L$$
$$= \frac{v_1}{1K} - \frac{2v_i}{1K}$$
$$= \frac{-v_1}{1K}$$

(23)

Slew rate:- The slew rate is defined as the maximum rate of output voltage coused by a step input voltage and is usually specified in V/us.

* For large signal output ($V_m > 1$ volt), the op-amp's speed is limited by slew rate

* The slew rate improves with higher closed loop gain and dc supply voltage. it is also a function to tempurature and genrally decreases with an increase in tempurature

=> the rate ~~at~~ at which the voltage across the capacitor V_c increases is given by,

$$\frac{dv_c}{dt} = \frac{I}{C}$$

* OP-amp should have either higher current or a small. Compensating capacitor. [For 741C capacitor charging current is limited 15 uA]

$$SR \text{ (Slew rate)} = \frac{I_{max}}{C} = \frac{15\mu A}{30PF} = 0.5 V/\mu s$$

$\Rightarrow$ $V_S = V_m \sin\omega t$

$V_O = V_m \sin\omega t$

$$\frac{dv_o}{dt} = V_m \,\omega \cos\omega t$$

The maximum rate of change of the output occurs when

$\cos\omega t = 1$. that is

$$SR = \frac{dv_o}{dt}\Big|_{max} = \omega V_m$$

$$\text{Slew Rate} = 2\pi f V_m \ V/s \quad -(1)$$

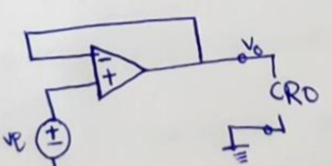
$$= \frac{2\pi f V_m}{10^6} \ V/\mu s \quad \begin{bmatrix} f \rightarrow \text{frequency} \\ V_m \rightarrow \text{peak output amplitude} \end{bmatrix}$$

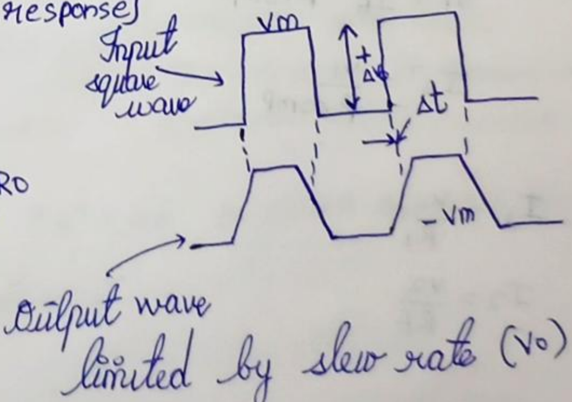
* ~~if might ha~~

* if eq-(1) is less than slew rate of the op-amp, then output will be undistorted. if frequency or amplitude of input signal is increased to exceed slew rate of op-amp the output will be distorted

$$F_{max}(Hz) = \frac{\text{slew rate}}{6.28 \times V_m} \times 10^6$$

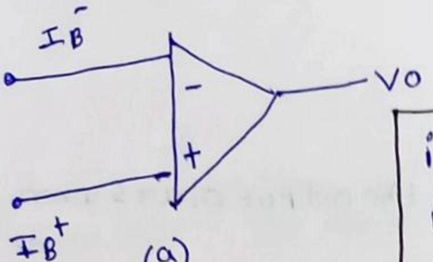
[Fmax = Full power response]





(24)

DC Characteristics



(a)

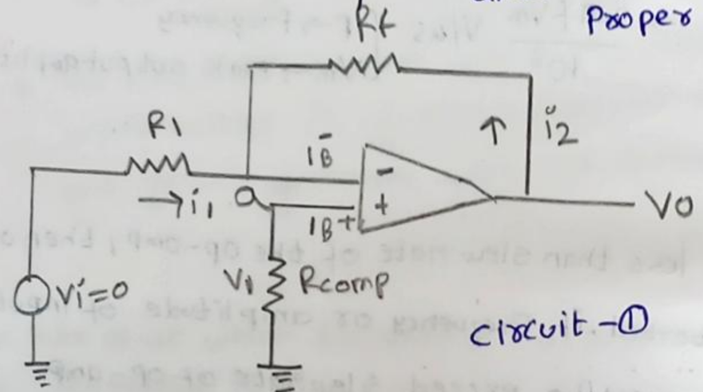
$$I_B = \frac{I_B^+ + I_B^-}{}$$

Input bias current:-

it is a current parameter I_B is defined as the average of the currets into the two input termials with the output at a specified level. it is expressed in units of ampre.

all opamps require certain amount of bias current for proper function

① Input Bias current:-



circuit - ①

KVL :-

$$-V_1 + 0 + V_2 - V_0 = 0$$

$$V_0 = V_2 - V_1$$

$$V_1 = I_B^+ R_{comp}$$

$$I_B^+ = \frac{V_1}{R_{comp}}$$

$$I_1 = \frac{V_1}{R_1}$$

$$I_2 = \frac{V_2}{R_f}$$

For compensation $V_o = 0$, $v_i = 0$ so, $V_2 = V_1$

$$\Rightarrow I_2 = \frac{V_1}{R_f}$$

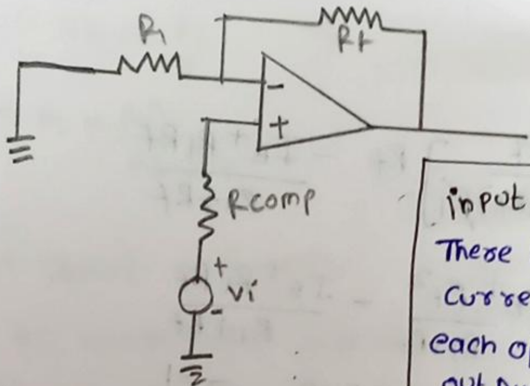
KCl at node a

$$I_B^- = I_2 + I_1 = \frac{V_1}{R_f} + \frac{V_1}{R_1} = V_1 \frac{(R_1 + R_f)}{R_1 R_f}$$

$$V_1 \frac{(R_1 + R_f)}{R_1 R_f} = \frac{V_1}{R_{comp}}$$

$$R_{comp} = \frac{R_1 R_f}{R_1 + R_f} = R_1 \| R_f$$

The effect of input bias current in a non inverting amplifier can also be compensated by placing a compensated R_{comp} in series with input signal V_i as shown.



$R_{comp} = R_1 \| R_F$ //

input offset current:-
There is a difference in the input current that flows in or out of each of the input pins even if the output voltage of operational amplifier is 0V. The difference is known as the input offset current

② input offset current:-

the difference of I_B^+ & I_B^- is called offset current I_{os}

$$I_{os} = I_B^+ - I_B^-$$

$V_1 = I_B^+ R_{comp}$

$I_1 = \frac{V_1}{R_1}$

KCl at node "a" :- from circuit - ①

$$I_2 = (I_B^- - I_1) = I_B^- - \left(I_B^+ \frac{R_{comp}}{R_1}\right)$$

$$V_O = I_2 R_f - V_1 = I_2 R_f - I_B^+ R_{comp}$$

$$= \left[I_B^- - I_B^+ \frac{R_{comp}}{R_1}\right] R_f - I_B^+ R_{comp} \quad \text{— ①}$$

but $R_{comp} = \frac{R_1 R_f}{R_1 + R_f}$

so, we get

$$V_O = R_f \left[I_B^- - I_B^+\right] \,//$$

⇒ substituting R_{comp}

$$\Rightarrow \left[I_B^- - I_B^+ \frac{\cancel{R_1} R_f}{(R_1+R_f)\cancel{R_1}}\right] R_f - \frac{I_B^+ R_1 R_f}{R_1 + R_f}$$

$$= I_B^- R_f - I_B^+ \frac{R_f^2}{R_1+R_f} - \frac{I_B^+ R_1 R_f}{R_1 + R_f}$$

$$= I_B^- R_f - I_B^+ R_f \underbrace{\left[\frac{R_f + R_1}{R_1 + R_f}\right]}_{=1}$$

$$= I_B^- R_f - I_B^+ R_f$$

$$= R_f \left[I_B^- - I_B^+\right]$$

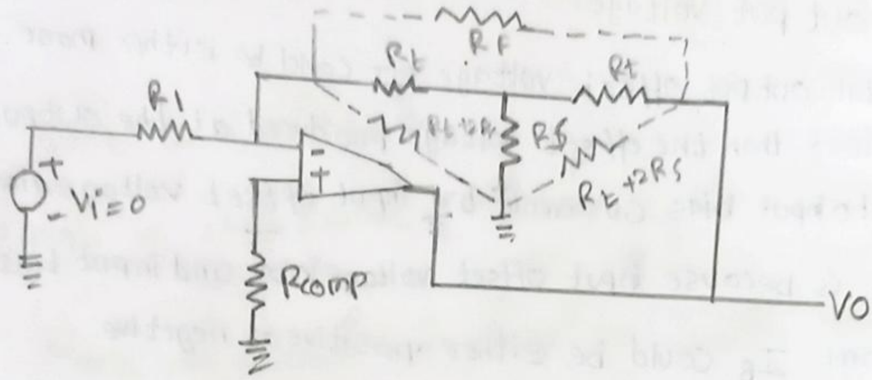
$$V_O = R_f I_{os}$$

F. we can say that effect of offset current can be minimized by keeping feed back restance small.

but R_1 must be large

So,

T-feed back is the solution



$$R_f = \frac{R_t^2 + 2R_tR_s}{R_s}$$

To design a T-network, first pick

$$R_t << \frac{R_f}{2}$$

calculate, $R_s = \dfrac{R_t^2}{R_f - 2R_t}$

(3) input offset voltage:-

due to unavoidable imbalnces in the op-amp the output voltage is not zero when input voltage is zero, this voltage is called input offset voltage

(2)

$$V_2 = \left(\frac{R_1}{R_1+R_f}\right)V_0 \rightarrow \text{from circuit} - (1)$$

$$V_0 = \left(\frac{R_1+R_f}{R_1}\right)V_2 = \left[1+\frac{R_f}{R_1}\right]V_2$$

$V_{ios} = |V_1 - V_2|$ and $V_1 = 0$

$$V_{ios} = V_2$$

$$V_o = \left[1 + \frac{R_f}{R_1}\right] V_{ios}$$

(4) Total output Voltage:-

The total output offset voltage V_{OT} could be either more (or) less than the offset voltage produced at the output due to input bias current or input offset voltage alone

- This is becouse input offset voltage V_{ios} and input bias current I_B could be either positive or negitive with respect to ground.

=> the maximum offset voltage at the output of amplifer without compensating techique used.

$$\boxed{V_{OT} = \left[1 + \frac{R_f}{R_1}\right] V_{ios} + R_f I_B}$$

with R_{comp}

$$\boxed{V_{OT} = \left[1 + \frac{R_f}{R_1}\right] V_{ios} + R_f I_{os}}$$