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18EE35014

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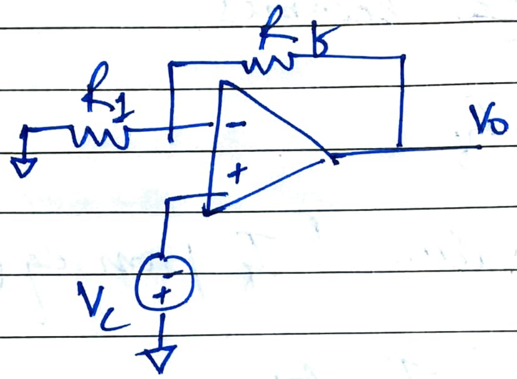
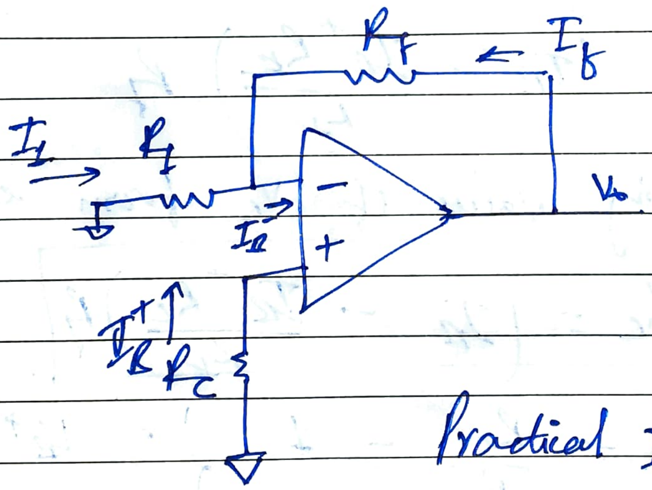
Input Bias Current

How to compensate the output offset due to input bias current?



Conceptual Development



Practical Implementation.

Here, $V_c = I_B^+ R_c$ — (1)

$V_c = I_1 R_1$ — (2)

$V_o - (-V_c) = I_f R_f$

$V_o + V_c = I_f R_f$ — (3)

Also, $I_1 + I_f = I_B^-$ — (4)

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Because of compensation,

$$V_o = 0$$

Then, Eq^n (3) becomes.

$$V_c = I_f R_f$$

Substituting value of I_f from eq (4),

$$V_c = (I_B^- - I_1) R_f$$

Substituting value of I_1 from eq (1) & (2),

$$V_c = \left(I_B^- - \frac{I_B^+ R_c}{R_1}\right) R_f$$

Substituting value of V_c from eq (1),

$$\boxed{I_B^+ R_c = \left(I_B^- - \frac{I_B^+ R_c}{R_1}\right) R_f}$$

$$\Rightarrow \frac{R_c}{R_f} + \frac{R_c}{R_1} = 1 \quad \left\{ \because I_B^+ = I_B^- \right\}$$

$$\Rightarrow \boxed{\frac{1}{R_c} = \frac{1}{R_f} + \frac{1}{R_1}}$$

$$\boxed{R_c = R_f \parallel R_1}$$

This configuration compensates the drop and minimize the additional offset voltage error.

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Input Offset Current

How much output offset is getting created?

From the previous proof,

After substituting values on RHS of eqn (3), we got that,

$$V_0 + V_c = \left(I_B^- - \frac{I_B^+ R_c}{R_1}\right) R_f$$

$$\Rightarrow V_0 + I_B^+ R_c = I_B^- R_f - \frac{I_B^+ R_c R_f}{R_1}$$

$$\Rightarrow V_0 = I_B^- R_f - R_c I_B^+ \left(\frac{R_f}{R_1} + 1\right)$$

$$\Rightarrow V_0 = I_B^- R_f - I_B^+ \times \frac{R_1 R_f}{R_1 + R_f} \times \frac{R_1 + R_f}{R_1}$$

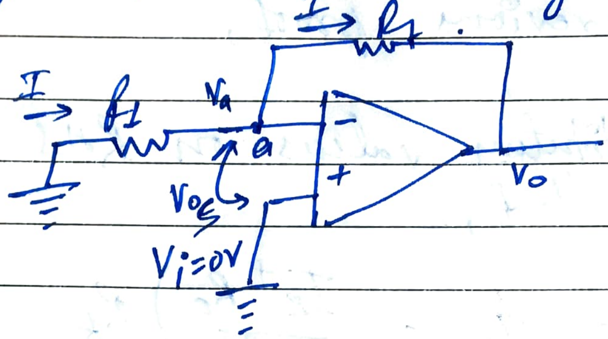
$$\Rightarrow \boxed{V_0 = (I_B^- - I_B^+) R_f}$$

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

$$\boxed{V_0 = I_{os} R_f}$$

Input offset voltage

Calculate the output voltage due to input offset of an inverting amplifier.



Taking $\boxed{V_a = V_{os}}$

$$I = \frac{-V_a}{R_1};$$

$$V_a - V_o = IR_f$$

$$V_{os} - V_o = \frac{-V_{os}}{R_1} R_f$$

$$\Rightarrow \boxed{V_o = V_{os}\left(1 + \frac{R_f}{R_1}\right)}$$

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Tutorial Problems:-

1. (a) Maximum output voltage due to V_{ios} & I_B =

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

$$=\left(10\times10^{-3}\left(1+\frac{10}{1}\right)+10\times10^{3}\times300\times10^{-9}\right)V$$

$$=\left(110\times10^{-3}+3\times10^{-3}\right)V$$

$$=113\ mV.$$

(b) As derived earlier,
to compensate the effect of bias current,

$$R_{comp}=(R_1 \parallel R_f)$$

$$=\frac{R_1 R_f}{R_1+R_f}=\left(\frac{1\times10}{1+10}\right)k\Omega$$

$$=\frac{10}{11}k\Omega=909.09\ \Omega$$

(c) Now after connecting the R_{comp},
the maximum output offset voltage becomes

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

$$=\left(110\times10^{-3}+10\times10^{3}\times50\times10^{-9}\right)V$$

$$=\left(110\times10^{-3}+0.5\times10^{-3}\right)V$$

$$=110.5\ mV$$

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2. (a) Maximum output offset voltage caused by input offset voltage =

$$V_{ios}\left(1+\frac{R_f}{R_1}\right)$$

$$= 6\times10^{-3}\left(1+\frac{10\times10^{3}}{100}\right) V$$

$$= 606\ mV$$

(b) Maximum output offset voltage caused by input bias current I_B =

$$= I_B R_f$$

$$= 500\times10^{-9}\times10\times10^{6}\ V$$

$$= 5V$$

Analog Signal Processing

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~~Lecture-4~~

Power Supply Rejection Ratio

Q1.

$$PSR = 90\,dB$$

$$PSRR = \frac{\Delta V_i}{\Delta V_o}$$

$$90 = 20 \log \frac{0.5}{\Delta V_o}$$

$$\Rightarrow \Delta V_o = \frac{0.5}{10^{4.5}}\,V = \cancel{15.81\,\mu V}$$

$$= 15.81\,\mu V$$

Lecture-4

Q1.

$$f_{3dB,cl} = \frac{0.35}{\text{Rise Time}}$$

$$= \frac{0.35}{0.7 \times 10^{-6}\,s} = 500\,kHz$$

Q2.

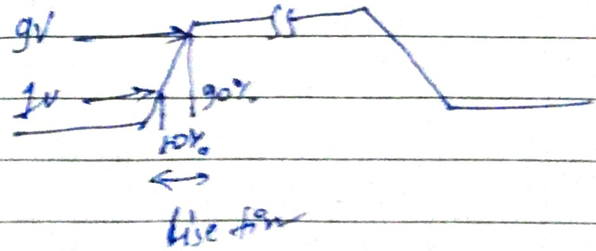
$$f_{3dB} \times A(0) = f_{3dB,cl} \times A_{cl}(0)$$

$$5 \times 200000 = 10 \times f_{3dB,cl}$$

$$\Rightarrow f_{3dB,cl} = 100\,kHz$$

Lecture-5

Q1.



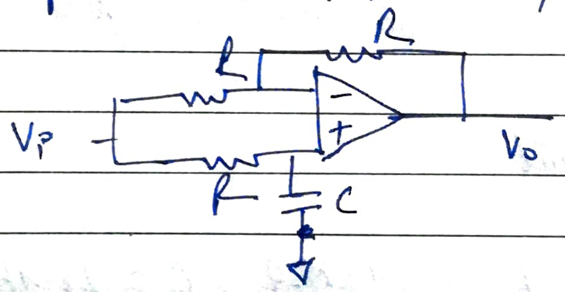
Slew Rate $= \dfrac{\Delta V_0}{\text{Rise time}}$

$$\Rightarrow 2\,V/\mu s = \frac{(9-1)V}{\text{Rise Time}}$$

$$\Rightarrow \text{Rise Time} = \frac{8}{2}\,\mu s = 4\,\mu s.$$

Lecture-7

Q-1. Determine the phase angle & the time delay for the circuit shown in figure for a frequency of 2kHz, $R = 39\,k\Omega$, $C = 1\mu F$.



Phase-lag Circuit.

$$\rightarrow \frac{V_o(j\omega)}{V_i(j\omega)} = \frac{1 - j\omega RC}{1 + j\omega RC}$$

$$\theta = -\tan^{-1}\omega RC - \tan^{-1}\omega RC$$

$$= -2\tan^{-1}(\omega RC)$$

$$= -2\tan^{-1}\left(\frac{f_1}{f_0}\right) \qquad f_0 = \frac{1}{2\pi RC}$$

Phase angle $= -2\tan^{-1}\{2\pi \times 2\times 10^3 \times 39\times 10^3 \times$

Phase angle

$$\theta = -2\tan^{-1}\left(2\pi \times 2\times10^{3} \times 39\times10^{3}\times 10^{-9}\right)$$

$$= -52.22^{\circ}$$

$$f_0 = \frac{1}{2\pi \cancel{RC}}$$

$$\text{Time delay} = \frac{|\theta|}{2\pi f_0} = \cancel{2\pi RC\theta}\ \cancel{2\pi|\theta|}$$

$$= \frac{52.22 \times \cancel{180}\ \cancel{2\pi}}{180 \times 2\pi \times 2000} s$$

$$= 72.527\ \mu s.$$

Q2 Phase-lead Circuit

$f = 2kHz$, $R = 39k\Omega$, $C = 1nF$.

$$\theta = 180^{\circ} - 2\tan^{-1}\left(\frac{f}{f_0}\right)$$

$$= 180^{\circ} - 2\tan^{-1}(2\pi f RC)$$

$$= 180^{\circ} + 52.22^{\circ} = 232.22^{\circ}$$

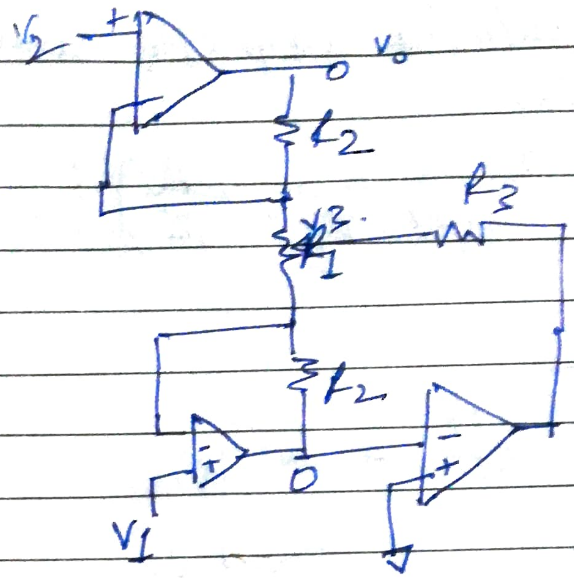
$$\simeq 127.78^{\circ}$$

$$\text{Time delay} = \frac{|\theta|}{2\pi f_0} = \frac{127.78^{\circ} \times \pi}{180^{\circ} \times 2\pi \times 2000} s.$$

$$= 177.47\ \mu s$$

lecture-9

Q10



Prove that $V_o = \left(1 + \frac{2R_2}{R_1}\right)(V_2 - V_1)$

when wiper is at middle.

$\Rightarrow$ ~~V_o~~ $V_3 = \left(\frac{R_1}{2} + R_2\right)\frac{V_1}{R_2}$

$$\frac{V_o - V_2}{R_2} = \frac{V_2 - V_3}{\frac{R_1}{2}}$$

$$\Rightarrow V_o - V_2 = \left(\frac{2R_2}{R_1}\right)\left(V_2 - \left(\frac{R_1}{2} + R_2\right)\frac{V_1}{R_2}\right)$$

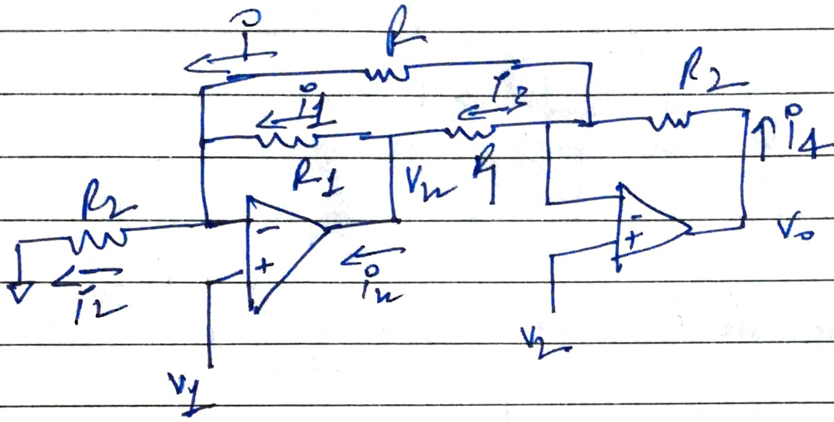
$$\Rightarrow V_o = \left(\frac{2R_2}{R_1} + 1\right)V_2 - \frac{2R_2}{R_1}V_1\left(\frac{2R_2 + R_1}{2R_2}\right)$$

$$\Rightarrow V_o = \left(\frac{2R_2}{R_1} + 1\right)(V_2) - V_1\left(1 + \frac{2R_2}{R_1}\right)$$

$$\Rightarrow V_o = (V_2 - V_1)\left(\frac{2R_2}{R_1} + 1\right)$$

Q20 For the instrumentation amplifier shown in figure, verify

$$V_o = \left(1 + \frac{R_2}{R_1} + \frac{2R_2}{R}\right)(V_2 - V_1)$$



$$V_o - V_2 = R_2 i_4$$

$$i_2 = \frac{V_1}{R_2}$$

$$V_x - V_1 = i_1 R_1$$

$$V_2 - V_1 = iR.$$

$$i + i_1 = i_2$$

$$\frac{V_2 - V_1}{R} + \frac{V_x - V_1}{R_1} = \frac{V_1}{R_2}$$

$$\Rightarrow \frac{V_x - V_1}{R_1} = \frac{V_1}{R_2} + \frac{V_1}{R} - \frac{V_2}{R}$$

$$\Rightarrow V_x = \left(1 + \frac{R_1}{R_2} + \frac{R_1}{R}\right)V_1 - \frac{R_1}{R}V_2$$

$$i_4 = i_3 + i$$

$$\frac{V_0 - V_2}{R_2} = \frac{V_2 - V_n}{R_1} + \frac{V_2 - V_1}{R}$$

$$\Rightarrow \frac{V_0 - V_2}{R_2} = \frac{V_2\left(1 + \frac{R_1}{R}\right) - \left(1 + \frac{R_1}{R_2} + \frac{R_1}{R}\right)V_1}{R_1} + \frac{V_2 - V_1}{R}$$

$$\Rightarrow V_0 = V_2\left(1 + \frac{R_2}{R_1} + \frac{R_2}{R}\right) - \frac{R_2}{R_1}\left(1 + \frac{R_1}{R_2} + \frac{R_1}{R}\right)V_1 + \left(\frac{V_2 - V_1}{R}\right)R_2$$

$$\Rightarrow V_0 = V_2\left(1 + \frac{R_2}{R_1} + \frac{R_2}{R}\right) - V_1\left(\frac{R_2}{R} + \frac{1}{\cancel{R_2}} + \frac{R_2}{R_1}\right) + \left(\frac{V_2 - V_1}{R}\right)R_2$$

$$\Rightarrow V_0 = (V_2 - V_1)\left[1 + \frac{R_2}{R_1} + \frac{R_2}{R} + \frac{R_2}{R}\right]$$

$$\Rightarrow \boxed{V_0 = \left(1 + \frac{2R_2}{R} + \frac{R_2}{R_1}\right)(V_2 - V_1)}$$

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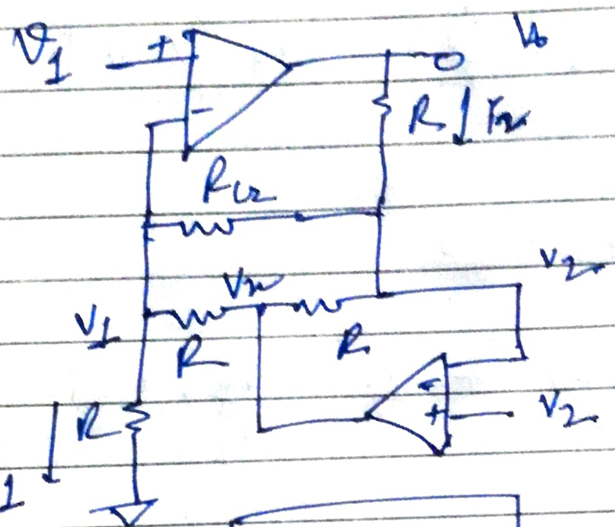
Q3. For the given amplifier below, show that

$$V_o = 2\left(1+\frac{R_2}{R_{G2}}\right)(V_2 - V_1)$$



$$\boxed{i_1 = \frac{V_1}{R}}$$

$$\frac{V_2 - V_1}{R_{G2}} + \frac{V_x - V_1}{R} = \frac{V_1}{R}$$

$$\cancel{\Rightarrow \frac{V_x}{R} = V_1\left(\frac{1}{R} + \frac{1}{R_{G2}}\right)}$$

$$\Rightarrow V_x = V_1\left(2 + \frac{R}{R_{G2}}\right) - \frac{R}{R_{G2}} V_2$$

$$\frac{V_o - V_2}{R} = \frac{V_2 - V_1}{R_{G2}} + \frac{V_2 - V_x}{R}$$

$$\Rightarrow \frac{V_o - V_2}{R} = \frac{V_2 - V_1}{R_{G2}} + \frac{V_2\left(1 + \frac{R}{R_{G2}}\right) - V_1\left(2 + \frac{R}{R_{G2}}\right)}{R}$$

$$\Rightarrow \quad V_0 = V_2\left(\frac{R}{R_{12}} + 1\right) - V_1 \frac{R}{R_{12}}$$

$$+ V_2\left(1 + \frac{R}{R_{12}}\right) - V_1\left(2 + \frac{R}{R_{12}}\right)$$

$$\Rightarrow \quad V_0 = 2V_2\left(1 + \frac{R}{R_{12}}\right) - 2V_1\left(1 + \frac{R}{R_{12}}\right)$$

$$\Rightarrow \quad \boxed{V_0 = 2\left(1 + \frac{R}{R_{12}}\right)\left(V_2 - V_1\right)}$$