

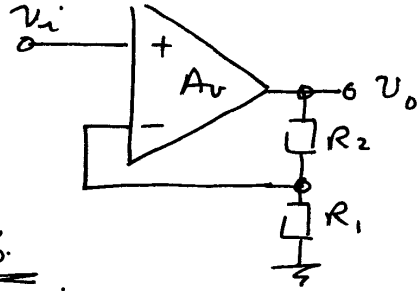
EEE103 / EEE121 / EEE141 Problem Solutions

Operational AmplifiersQ1 a) if $A_v \rightarrow \infty$

$$v_i = v^+ = v^- = v_o \frac{R_1}{R_1 + R_2}$$

$$\text{or } \frac{v_o}{v_i} = \frac{R_1 + R_2}{R_1}$$

$$= \frac{75\text{kn} + 15\text{kn}}{15\text{kn}} = \underline{\underline{6}}$$



[You can quote $\frac{v_o}{v_i} = \frac{R_1 + R_2}{R_1}$ if you can remember it]

Q2 if A_v finite

$$v^+ = v_i \quad (\text{connected by wire})$$

$$v^- = v_o \frac{R_1}{R_1 + R_2} \quad (\text{by potential division})$$

$$v_o = A_v (v^+ - v^-) \quad (\text{op-amp eq.})$$

putting v^+ + v^- into op-amp equation ...

$$v_o = A_v \left(v_i - v_o \frac{R_1}{R_1 + R_2} \right)$$

$$\text{or } v_o \left[\frac{1}{A_v} + \frac{R_1}{R_1 + R_2} \right] = v_i$$

$$\text{or } \frac{v_o}{v_i} = \frac{1}{\frac{1}{A_v} + \frac{R_1}{R_1 + R_2}}$$

a) when $R_2 = 9R_1$, ideal gain = 10.

$$\text{actual gain} = \frac{1}{\frac{1}{10^5} + \frac{1}{10}} = 9.999$$

$$\therefore \text{error} = \underline{\underline{-0.01\%}}$$

(2)

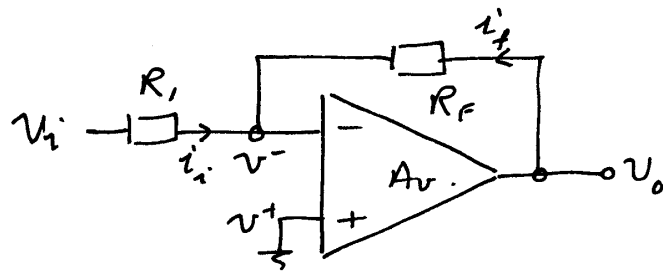
b) when $R_2 = 299 R_1$, ideal gain = 300

$$\text{actual gain} = \frac{1}{\frac{1}{10^5} + \frac{1}{300}} = 299.1$$

$$\text{error} = \underline{\underline{-0.3\%}}$$

(both these errors are very small).

Q3



Summing currents at v^- node...

$$i_i + i_f = 0 \quad (\text{since op-amp input current} \approx 0)$$

$$\frac{v_i - v^-}{R_i} + \frac{v_o - v^-}{R_f} = 0$$

but since $A_v \Rightarrow \infty$, $v^+ = 0 \approx v^-$

$$\therefore \frac{v_i}{R_i} + \frac{v_o}{R_f} = 0 \quad \text{or} \quad \underline{\underline{\frac{v_o}{v_i} = -\frac{R_f}{R_i}}}$$

The virtual earth node is the inverting input node. It exists because $A_v \Rightarrow \infty$ so $v^+ \approx v^-$ and since v^+ is connected to 0V, v^- must always be very close to 0V.

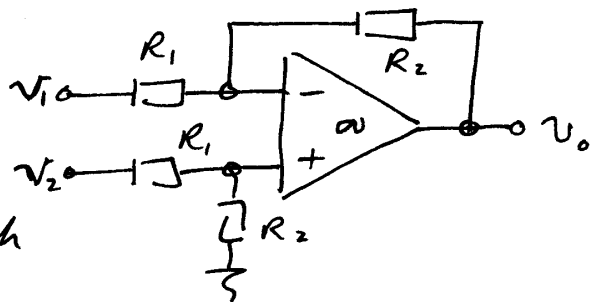
Q4

v_o due to $v_1 \dots$

with v_2 grounded...

$v^+ = 0V$ because both v_2 and v_1 grounded

$$\therefore v_o = -\frac{R_2}{R_1} \cdot v_1$$



(3)

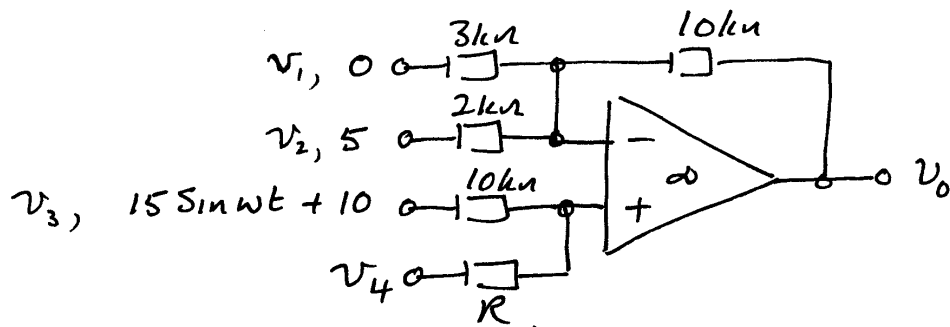
v_o due to v_2 with v_1 grounded....

v^+ is now a potentially divided version of v_2 $v^+ = v_2 \cdot \frac{R_2}{R_1 + R_2}$ and the amplifier operates as a non-inverting amplifier on v^+ , so

$$v_o = v^+ \frac{R_1 + R_2}{R_1} \\ = v_2 \cdot \frac{R_2}{R_1 + R_2} \cdot \frac{R_1 + R_2}{R_1} = v_2 \frac{R_2}{R_1}$$

$$\therefore v_{o\text{TOT}} = v_o(v_1) + v_o(v_2) \\ = -R_2/R_1 v_1 + R_2/R_1 v_2 \\ = \frac{R_2}{R_1} (v_2 - v_1)$$

Q5



Start with ac...

ground v_1, v_2, v_4 and the dc part of v_3 .

$$v^+ \text{ is } 15 \sin \omega t \times \frac{R}{10k + R}$$

$$v_o \text{ is } v^+ \cdot \frac{10k + 3k \parallel 2k}{3k \parallel 2k} \text{ — ie a non-}$$

inverting amp operates on v^+

$$\text{so } v_{o\text{ac}} = \cancel{5} \sin \omega t = \cancel{15} \sin \omega t \frac{R}{10k + R} \cdot \frac{10k + 3k \parallel 2k}{3k \parallel 2k}$$

$$1 = 3 \cdot \frac{R}{10k + R} \cdot \frac{11.2k}{1.2k}$$

$$\text{or } \underline{R = 370 \Omega}$$

(4)

considering the d.c. bit (ignore the a.c.).

$$V_o(v_1) = v_1 \cdot (-) \frac{10k\Omega}{3k\Omega} \quad \left(\begin{array}{l} \text{since } v_3 + v_4 \text{ are zero, } v^+ \\ \text{is zero + } v^- \text{ is virtual} \\ \text{earth.} \end{array} \right)$$

$$V_o(v_2) = v_2 (-) \frac{10k\Omega}{2k\Omega} \quad (\text{for same reasons}).$$

$$V_o(v_3) = v_3 \cdot \underbrace{\frac{370}{10k + 370}}_{v^+} \cdot \underbrace{\frac{10k + 1.2k}{1.2k}}_{\text{non-inv gain}} = 0.333 v_3.$$

$$V_o(v_4) = v_4 \cdot \frac{10k}{10k + 370} \cdot \frac{10k + 1.2k}{1.2k} = 9 v_4$$

$$\therefore V_{oT} = -\frac{10}{3} v_1 - 5 v_2 + 0.33 v_3 + 9 v_4$$

$$= 0 - 25 + 3.3 + 9 v_4 = 0$$

↑
dc component of 0
required.

$$\therefore v_4 = \frac{21.7}{9} = \underline{\underline{2.4 V}}$$

- (ii) This question is really asking what value of v_1 will put a dc offset of +5V and -5V on the output. The + v_1 will be the same as the - v_1 in magnitude terms so lets consider only the + v_1 term

We know the $v_2, v_3 + v_4$ contributions sum to zero so...

$$V_o = -\frac{10}{3} v_1 = 5$$

$$\text{or } v_1 = -\frac{15}{10} = 1.5 V$$

so $v_1 = \underline{\underline{\pm 1.5 V}}$ to make peak V_o reach -10 + +10 respectively.