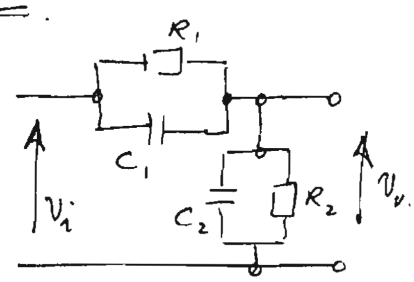
Q1 (a) (i) l.f. gain due to resistors.

$\therefore$ lf gain $= \dfrac{R_2}{R_1+R_2}$ 1

hf gain due to capacitors 2

hf gain $= \dfrac{C_1}{C_1+C_2}$

(ii).



$$\frac{v_o}{v_i} = \frac{\dfrac{R_2/j\omega C_2}{R_2 + 1/j\omega C_2}}{\dfrac{R_2/j\omega C_2}{R_2 + 1/j\omega C_2} + \dfrac{R_1/j\omega C_1}{R_1 + 1/j\omega C_1}}$$ 1

$$= \frac{\dfrac{R_2}{1+j\omega C_2 R_2}}{\dfrac{R_2}{1+j\omega C_2 R_2} + \dfrac{R_1}{1+j\omega C_1 R_1}} = \frac{R_2(1+j\omega C_1 R_1)}{R_2(1+j\omega C_1 R_1) + R_1(1+j\omega C_2 R_2)}$$

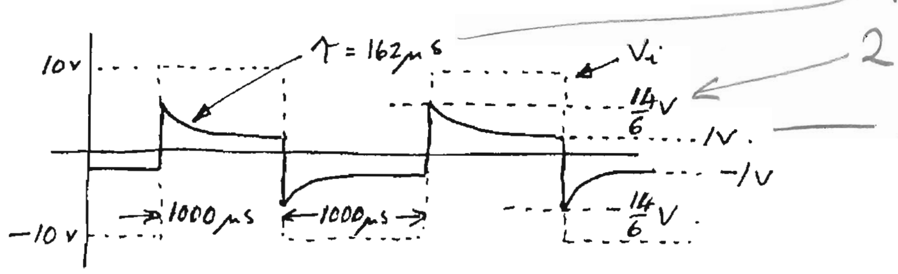
$$= \frac{R_2(1+j\omega C_1 R_1)}{R_1+R_2+j\omega R_1 R_2 (C_1+C_2)} = \frac{R_2}{R_1+R_2}\cdot\frac{1+j\omega C_1 R_1}{1+j\omega \frac{R_1 R_2}{R_1+R_2}(C_1+C_2)}$$ 2.

$$\equiv k.\ \frac{1+j\,f/f_0}{1+j\,f/f_1}$$

(iii) if $R_1 = 9M\Omega$, $R_2 = 1M\Omega$, $C_1 = 30p$, $C_2 = 150p$ ...

lf gain $= \dfrac{1}{10}$ hf gain $= \dfrac{30}{180} = \dfrac{1}{6}$

and $\tau = \dfrac{R_1 R_2}{R_1+R_2}(C_1+C_2) = 900k\Omega \times 180pF = 162\mu s$ 1



Q1 cont...

(a) (iv) to remove all frequency dependence we need to make:

$$C_1 R_1 = \frac{(C_1 + C_2) R_1 R_2}{R_1 + R_2}.$$ /

$$C_1 . 9\times10^6 = (C_1 + 150pF)\, 9\times10^5$$ /

or $10 C_1 = C_1 + 150\,pF$

or $9 C_1 = 150\,pF$

or $C_1 = \frac{150}{9}\,pF = \underline{16.7\,pF}$. /

(b) (i) single op-amp has GBP of 50MHz.

if gain required is 25, available -3dB BW is $\frac{50MHz}{25} = 2MHz \rightarrow$ too small.

[or could say, if BW required is 3MHz, available gain is $\frac{50MHz}{3MHz} = 16.7$ which is too small] 2

(ii) two identical stages so each must have a gain $= \sqrt{25} = \underline{5}$. /

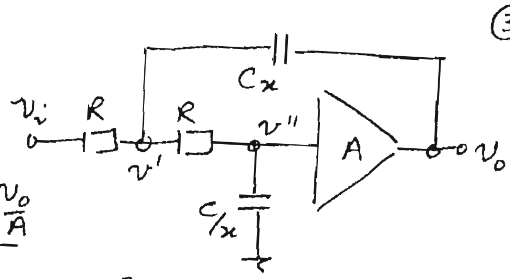
this means that each amplifier will have a -3dB bandwidth of $\frac{50MHz}{5} = 10MHz$ ..... we want the -1.5dB frequency of one stage to get the -3dB of the cascade. / /

for one stage $\frac{v_o}{v_i} = \frac{5}{1 + j\, f/10MHz}$ and we want to know when this falls to $5\times10^{-1.5/20}$. $(= 4.207)$.

$$\frac{25}{1 + f^2/10^{14}} = 17.70. \quad \text{or} \quad \frac{f^2}{10^{14}} = \frac{25}{17.7} - 1 = 0.412.$$

$$f_{-3dB\ \text{for cascade}} = 10^7\sqrt{0.412} = \underline{6.42\,MHz}$$ 2

Q2 (i) sum currents at v' node...



$$\frac{v_i - v'}{R} + (v_o - v')sCx = \frac{v' - \frac{v_o}{A}}{R}$$ 1

$$\frac{v_i}{R} + v_o sCx + \frac{v_o}{AR} = v'\left[\frac{1}{R} + sCx + \frac{1}{R}\right] = v'\left[\frac{2 + sCRx}{R}\right]$$

or $$v_i + v_o sCRx + \frac{v_o}{A} = v'(2 + sCRx)$$ 1

The relation between v' and v'' is

$$v'' = \frac{v_o}{A} = v' \frac{1/j\omega C/x}{R + 1/sC/x} = v' \frac{1}{1 + \frac{sCR}{x}}.$$ 1

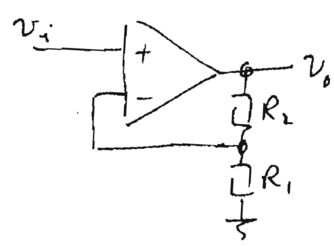
$$\therefore\ v_i + v_o sCRx + \frac{v_o}{A} = \frac{v_o}{A}\left(1 + \frac{sCR}{x}\right)(2 + sCRx).$$ 1

$$v_i A = v_o\left[2 + sCRx + \frac{2sCR}{x} + s^2C^2R^2 - 1 - AsCRx\right]$$

$$= v_o\left[1 + sCR\left(\frac{2}{x} + x(1-A)\right) + s^2C^2R^2\right]$$

or $$\frac{v_o}{v_i} = \frac{A}{1 + sCR\left(\frac{2}{x} + x(1-A)\right) + s^2C^2R^2}.$$ 2

(ii)



$$\frac{v_o}{v_i} = A$$

where $$A = \frac{R_1 + R_2}{R_1}$$ 2

(iii) for stability, damping term must be +ve 1

$$\therefore\ \frac{2}{x} + x(1-A) > 0 \quad \text{or} \quad x(1-A) > -\frac{2}{x}$$ 1

or $$-A > -\frac{2}{x^2} - 1 \quad \text{or} \quad A < \frac{2}{x^2} + 1$$ 1

Q2 cont...

(iv) by comparison with standard form..

$$\underline{\omega_o = \frac{1}{CR}} \quad \text{or} \quad f_o = \frac{1}{2\pi CR}. \qquad 1$$

$$\text{and } \frac{1}{\omega_o q} = CR\left(\frac{2}{x} + (1-A)x\right) = \frac{CR}{q} \qquad 2.$$

$$\text{or } \underline{q = \frac{1}{(2/x + (1-A)x)}}.$$

(v) 2nd order section

$$\frac{v_o}{v_i} = \frac{1}{1 + s + s^2} \qquad \therefore \left.\begin{array}{l} \omega_o = 1 \\ q = 1 \\ \omega_o = 1. \end{array}\right\} \text{1 = cut-off frequency of overall filter.} \qquad 2$$

1st order section

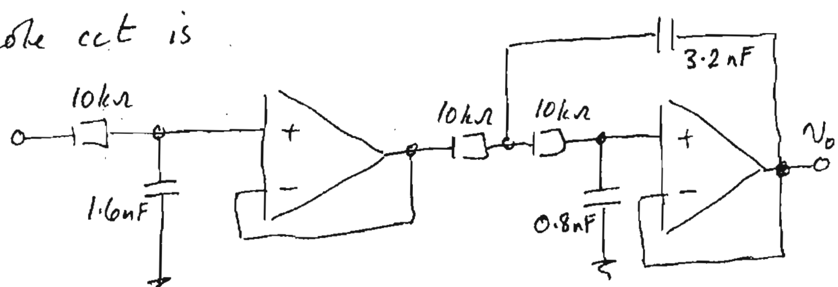
2nd order.

$$\omega_o = 2.\pi.10^4 = \frac{1}{CR} = \frac{1}{C.10k\Omega} \quad \text{or} \quad \underline{C = 1.6\,nF}. \qquad 1$$

$$q = \frac{x}{2} \; (\text{since } A = 1) \; \therefore \quad \underline{x = 2}. \qquad 1$$

$$\text{1st order...} \quad \omega_o = \frac{1}{RC} \quad \text{or} \quad \underline{C = 1.6\,nF} \qquad 1$$

whole cct is

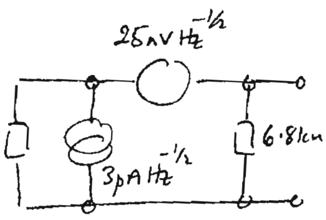


1

first order section must come before second order section.

(5)

Q3 (a) (i) we want the voltage across the 6.8kΩ resistor due to each source in turn, except for the 6.8k resistor noise where we want the noise developed across the 12k resistor.



$$\overline{V_{on}^2}\Big|_{12k\Omega} = 4kT\,12k\Omega\left(\frac{6.8k\Omega}{12k\Omega+6.8k\Omega}\right)^2 = 198\times10^{-18}\times0.131 = 26.1\times10^{-18}$$ 1

$$\overline{V_{on}^2}\Big|_{6.8k\Omega} = 4kT\,6.8k\Omega\left(\frac{12k\Omega}{12k\Omega+6.8k\Omega}\right)^2 = 113\times10^{-18}\times0.407 = 46.0\times10^{-18}$$ 1

$$\overline{V_{on}^2}\Big|_{25nV} = (25nV)^2\left(\frac{6.8k\Omega}{12k\Omega+6.8k\Omega}\right)^2 = 625\times10^{-18}\times.131 = 81.9\times10^{-18}$$ 1

$$\overline{V_{on}^2}\Big|_{3pA} = (3pA)^2\times\left(\frac{6.8k\Omega\times12k\Omega}{12k\Omega+6.8k\Omega}\right)^2 = 1296\times10^{-18}\times.131 = 169\times10^{-18}$$ 1

$$\therefore\ \overline{V_{onT}^2} = (26.1+46+81.9+169)\times10^{-18} = \underline{323\times10^{-18}\ V^2Hz^{-1}}$$ 2

By inspection R_{Th} is $12k\Omega//6k\Omega = \underline{4.34\ k\Omega}$. 2

(ii) The noise generated by R is $4kTR\ V^2Hz^{-1}$. If all the noise at the output of the network is assumed to emenate from R ....

$$323\times10^{-18} = 4\times1.38\times10^{-23}\times T_{eff.}\times4.34k\Omega.$$

or $\underline{T_{eff} = 1348\ K}$. 2

(b) (i) Signal to Noise ratio is the ratio of signal power to noise power at a specified node in the circuit. It is a measure of signal quality. 1

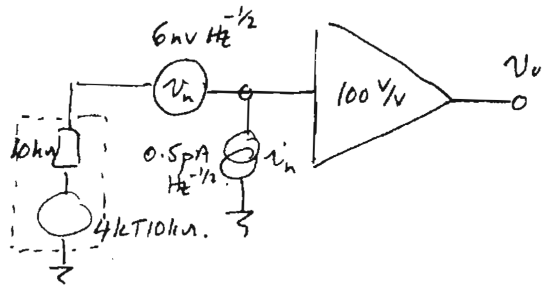
$$SNR = \frac{S_k}{N_k}$$ where k is the node of interest.

Q3 (b) cont...

Noise factor is defined as the S/N at a system input divided by S/N at system output. It is a measure of the degree to which the system degrades the signal.

$$F = \frac{S_i/N_i}{S_o/N_o} = \frac{S_i}{S_o} \times \frac{N_o}{N_i} = \frac{N_o}{A_p N_i}$$ 2.

(c) (i)



3. (minus 1 per error.)

(ii) $$\overline{v_o^2} = A^2\left[\overline{i_n^2} R_s^2 + \overline{v_n^2} + 4kT10k\Omega\right]$$

$$= 10^4\left[\left(0.5\times10^{-12}\times10^4\right)^2 + 36\times10^{-18} + 165.6\times10^{-18}\right]$$

$$= 2.26\times10^{-12}\ V^2 Hz^{-1}$$ 2.

Total voltage over a bandwidth of 10kHz

$$\overline{v_{oT}^2} = 2.26\times10^{-12}\times 10kHz$$

$$= 2.26\times10^{-8}\ volts^2$$

$\therefore$ rms reading = $\underline{150\mu V}$ 2.

Q4 (i) Power supplied = Power to load + Power dissipated

or $P_D = P_S - P_L$

$$P_D = \int_0^T V_s I_s \, dt - \frac{V_{L\,rms}^2}{R_L} = 2V_{cc} I_{AVE} - \frac{V_p^2}{3R_L}.$$

$$= \frac{2V_{cc}V_p}{4R_L} - \frac{V_p^2}{3R_L}$$

because there are 2 supplies.

$$\frac{dP_D}{dV_p} = \frac{2V_{cc}}{4R_L} - \frac{2V_p}{3R_L} = 0 \text{ for a maximum}$$

or $V_p = 3V_{cc}/4$.

$$\therefore P_D = \frac{2V_{cc} \cdot \frac{3V_{cc}}{4}}{4R_L} - \frac{\left(\frac{3V_{cc}}{4}\right)^2}{3R_L} = \frac{6V_{cc}^2}{16R_L} - \frac{3V_{cc}^2}{16R_L}$$

$$= \underline{\underline{\frac{3V_{cc}^2}{16R_L}}} \quad \text{and } P_L = \frac{V_p^2}{3R_L} = \frac{\left(\frac{3V_{cc}}{4}\right)^2}{3R_L} = \underline{\underline{\frac{3V_{cc}^2}{16R_L}}}.$$

(ii) max load power occurs when V_p is max...

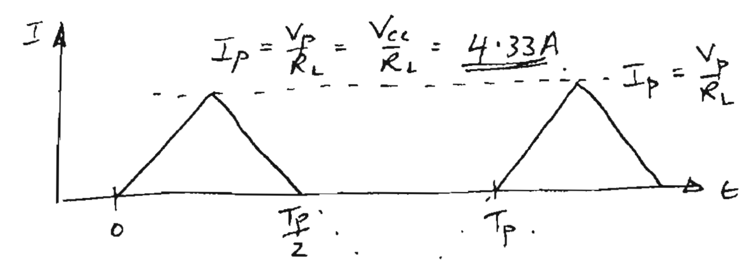
ie when $V_p = V_{cc}$

$$\therefore 50W = \frac{V_{cc}^2}{3.8}$$

$$\text{or } V_{cc} = \sqrt{1200} = \underline{\underline{\pm 34.6V}}.$$

(iii)

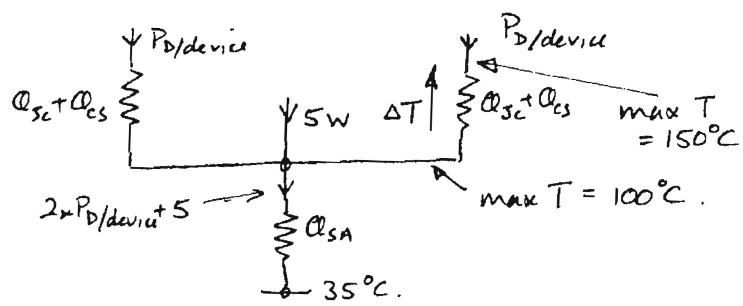
$I_p = \frac{V_p}{R_L} = \frac{V_{cc}}{R_L} = \underline{\underline{4.33A}}$



shape = 1
times = 1
I_p = 1.

Q4 cont...

(iv)



$$P_{DM} = \frac{3V_{cc}^2}{16R_L} = \frac{3\times 1200}{16\cdot 8} = 28\text{W in total}$$

$$= 14\text{W per device.}$$

$$\therefore \Delta T = 14\times(\theta_{JC}+\theta_{CS}) = 14\times 2.75 = 38.7°$$

$\therefore$ with heatsink at 100, T_j will be 138.7 → safe.
so heatsink temp is the limiting factor.

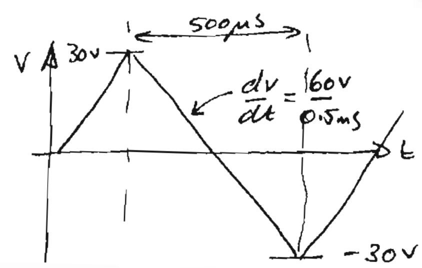
$$\therefore \frac{100-35}{\theta_{SA}} = 2\times 14+5 = 33$$

$$\text{or } \theta_{SA} = 65/33 = \underline{1.97°\text{C/W}}.$$

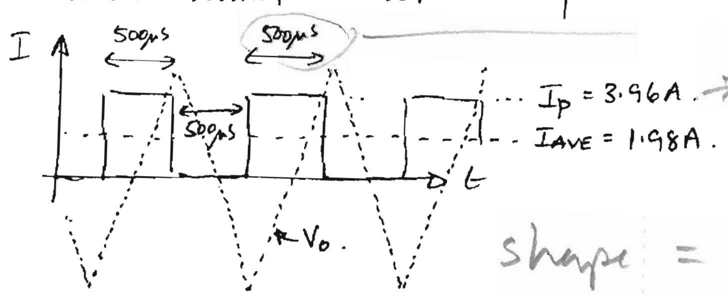
(v) during rising triangular half cycles.

$$I = C\frac{dv}{dt} = 33\times 10^{-6}\times\frac{60}{0.5\text{ms}}$$

$$= 3.96\text{A}.$$



Current waveform is:



shape = 2