Q1 (a)

(i) h.f. gain = 1 (since $X_{C_1} \ll R_1 + R_2$)

l.f. gain = $\frac{R_2}{R_1 + R_2}$ (since $X_{C_1} \gg R_1 + R_2$).

(ii).

$$\frac{V_o}{V_i} = \frac{R_2}{R_2 + R_1 // X_{C_1}} = \frac{R_2}{R_2 + \frac{R_1/j\omega C_1}{R_1 + 1/j\omega C_1}}$$

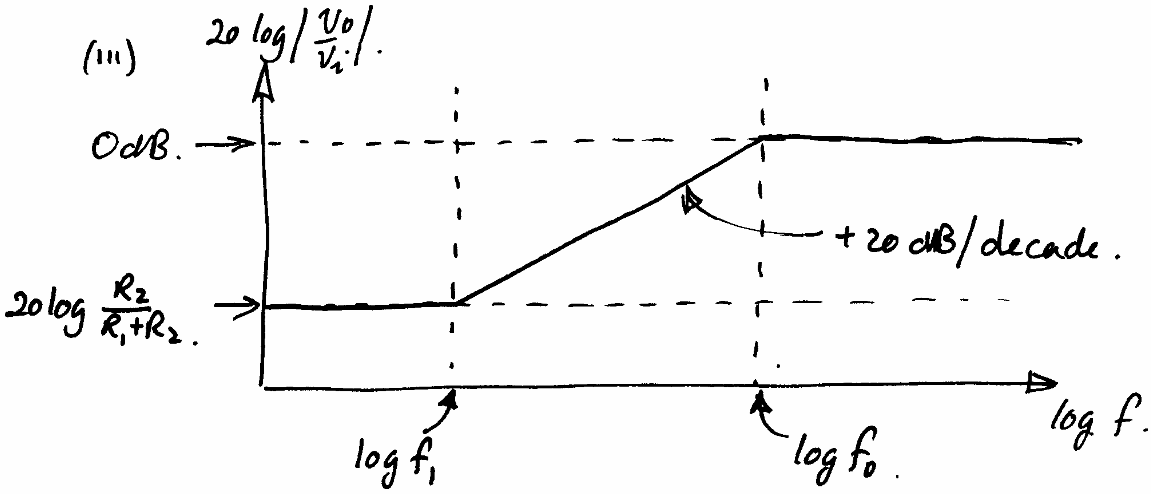
$$= \frac{R_2}{R_2 + \frac{R_1}{1 + j\omega C_1 R_1}}$$

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

$$= \frac{R_2}{R_1 + R_2} \cdot \frac{1 + j\omega C_1 R_1}{1 + j\omega C_1 \frac{R_1 R_2}{R_1 + R_2}} \equiv k. \frac{1 + j\,f/f_1}{1 + j\,f/f_0}.$$

$$k = \frac{R_2}{R_1 + R_2}, \quad f_1 = \frac{1}{2\pi C_1 R_1}, \quad f_0 = \frac{R_1 + R_2}{2\pi C_1 R_1 R_2}.$$

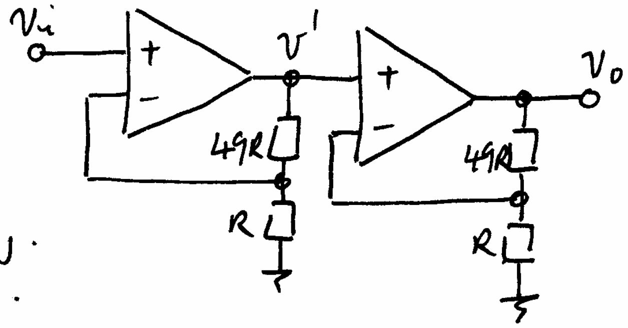
(iii)




(iv) addition of $C_2$ in parallel with $R_2$ must give $C_1 R_1 = C_2 R_2$ or alternatively, $\frac{R_2}{R_1 + R_2} = \frac{C_1}{C_1 + C_2}$.

so $C_2 = \frac{C_1 R_1}{R_2} = \frac{10^{-9} \times 10^{+4}}{10^{+3}} = \underline{\underline{10nF}}$.

Q1 (b)




(i). total gain
$= \text{gain}(1) \times \text{gain}(2)$
$= 50 \times 50 = \underline{\underline{2500\ V/V}}$.

(ii) GBP of each amplifier is 20MHz.

$\therefore$ for gain of 50, $BW = \dfrac{20 \times 10^6}{50} = \underline{\underline{400\text{kHz}}}$.

for each op-amp.

−3dB frequency of cascade is −1.5dB frequency of each op-amp. Considering only the frequency dependence .....

each op-amp $\dfrac{v_o}{v_i} = k \dfrac{1}{1 + j\, f/400\text{kHz}}$.

ignore this because it doesn't affect frequency domain

$\dfrac{v_o}{v_i} = -1.5\text{dB}$ when

$$\left| \frac{1}{1 + j\, f/400\text{kHz}} \right| = 10^{-1.5/20}$$

or $$\frac{1}{1 + f^2/(400\text{kHz})^2} = 10^{-3/20} = 0.708$$

or $$1.413 = 1 + \frac{f^2}{16 \times 10^{10}}$$

or $$0.413 = \frac{f^2}{(400\text{kHz})^2} = (0.642)^2$$

$$\therefore f = 400\text{kHz} \times 0.642 = \underline{\underline{257\text{kHz}}}$$

= −1.5dB f of each amp
= −3dB f of cascade.

Q1 (b)

(iii) max rate of change of sinusoid is

$$\frac{d(V_p \sin \omega t)}{dt} = V_p \omega \cos \omega t.$$

max $\cos \omega t = 1$ so max $\frac{dv}{dt} = V_p \omega$.

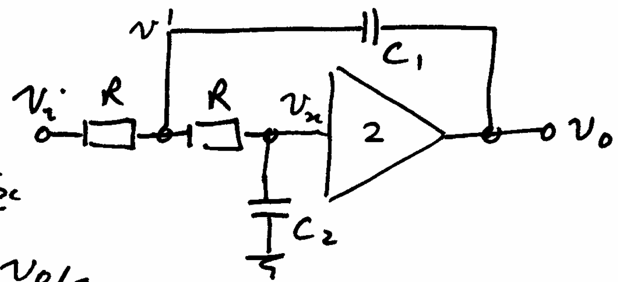
max signal frequency when its max $\frac{dv}{dt}$ = slew rate.

ie $70 \times 10^6 = V_p \omega = 10 \cdot 2 \cdot \pi \cdot f$

or $f_{max} = \underline{\underline{1.1 \text{ MHz}}}$

---

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




$$\frac{v_o - v'}{1/sC_1} + \frac{v_i - v'}{R} = \frac{v' - v_x}{R}$$

since gain is 2, $v_x = v_o/2$.

so $v_o sC_1R - v' sC_1R + v_i - v' = v' - v_o/2$

or $$v' = \frac{2v_i + v_o(1 + 2sC_1R)}{2(2 + sC_1R)}.$$

also $v_x = v' \dfrac{1/sC_2}{R + 1/sC_2}$ or $v' = \dfrac{v_o}{2}(1 + sC_2R)$.

$$\therefore \frac{v_o}{\cancel{2}}(1 + sC_2R) = \frac{2v_i + v_o(1 + 2sC_1R)}{\cancel{2}(2 + sC_1R)}$$

$$v_o\left[(1 + sC_2R)(2 + sC_1R) - (1 + 2sC_1R)\right] = 2v_i$$

$$v_o\left[1 + 2sC_2R - sC_1R + s^2C_1C_2R^2\right] = 2v_i$$

or $$\frac{v_o}{v_i} = \frac{2}{1 + s(2C_2R - C_1R) + s^2C_1C_2R^2}$$

(ii) second order, analogue, low pass, active, conditionally stable.

Q2 (iii) $k = 2.$

$$\omega_o^2 = \frac{1}{C_1 C_2 R^2} \quad \text{or} \quad \omega_o = \frac{1}{R\sqrt{C_1 C_2}}$$

$$\frac{1}{\omega_o q} = R(2C_2 - C_1).$$

$$\text{or} \quad \frac{1}{q} = \omega_o R(2C_2 - C_1) = \frac{\cancel{R}(2C_2 - C_1)}{\cancel{R}\sqrt{C_1 C_2}}$$

(they can leave it as $1/q$ or invert it).

(iv) For stability, damping term must be positive

$$(2C_2 - C_1)R > 0.$$

$$\text{or} \quad 2C_2 - C_1 > 0$$

$$2C_2 > C_1$$

$$\text{or} \quad \underline{\underline{\frac{C_2}{C_1} > \frac{1}{2}}} \quad \text{for stability.}$$

Q3(a) (i) $R_{Th}$, by inspection $= 1.2\,k\Omega$.

$$\overline{v_o^2}\Big|_{10nV} = \left[10\,nV \cdot \frac{2k\Omega}{2k\Omega + 3k\Omega}\right]^2 = 10^{-16} \times \frac{4}{25} = 16\times10^{-18}\,V^2Hz^{-1}$$

$$\overline{v_o^2}\Big|_{3pA} = \left[3\times10^{-12}\left(2k\Omega \,\|\, 3k\Omega\right)\right]^2 = 9\times10^{-24} \times 1.44\times10^{6} = 12.96\times10^{-18}\,V^2Hz^{-1}$$

$$\overline{v_o^2}\Big|_{2k\Omega} = 4kT\,2k\Omega\left(\frac{3k\Omega}{5k\Omega}\right)^2 = 33.1\times10^{-18}\times\frac{9}{25} = 11.9\times10^{-18}\,V^2Hz^{-1}$$

$$\overline{v_o^2}\Big|_{3k\Omega} = 4kT\,3k\Omega\left(\frac{2k\Omega}{5k\Omega}\right)^2 = 49.7\times10^{-18}\times\frac{4}{25} = 7.9\times10^{-18}\,V^2Hz^{-1}$$

$$\overline{v_{onT}^2} = \left[16.0 + 12.96 + 11.9 + 7.9\right]\times10^{-18} = 48.76\times10^{-18}\,V^2Hz^{-1}$$

$$\therefore v_{nTh} = \sqrt{48.76\times10^{-18}} = \underline{\underline{7.0\times10^{-9}\,V\,Hz^{-1/2}}}.$$

(ii) First find the noise temperature of $R_{Th}$ ....

$$4kT_{eff}R_{Th} = 48.76\times10^{-18}$$

$$\text{or}\quad T_{eff} = \frac{48.76\times10^{-18}}{4\times1.38\times10^{-23}\times1.2\times10^{3}} = 736\,K.$$

Then use $\overline{v_{nT}^2} = \frac{kT}{C}\,V^2$ from the useful info. page ...

$$\overline{v_{nT}^2} = \frac{1.38\times10^{-23}\times736}{10pF} = 1.016\times10^{-9}\,V^2$$

$$\therefore v_{nT} = \underline{\underline{31.9\,\mu V}}.$$

Q3 (b)

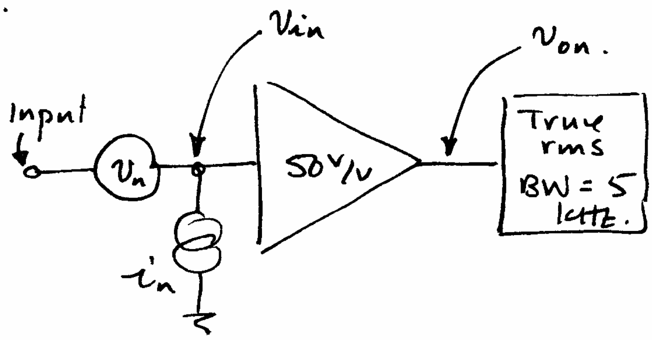
(1) Signal to Noise ratio is the ratio of signal power to noise power at a node in the circuit / system. ~~It~~ measures only signal quality.

Noise factor is defined as

$$\frac{\text{signal to noise ratio at input}}{\text{signal to noise ratio at output}}.$$

Since $S_i$ + $S_o$ are related by system power gain ($A_p$) the signal is eliminated from the expression. NF is thus a measure of system performance and gives no information about signal quality.

(C). System is...




when input is grounded, $i_n$ does not contribute to output...... so

$$\overline{V_{on}^2} = 50^2 . \overline{V_{in}^2}$$
$$= 50^2 . \overline{V_n^2} .$$

True rms will read $\sqrt{\overline{V_{on}^2} \times BW}$.

$$\text{so} \quad V_n = \frac{45\mu V}{\sqrt{5kHz} . 50.} = 12.7 nV . Hz^{-1/2}.$$

when input grounded via a noisy 8.2 kΩ resistor...

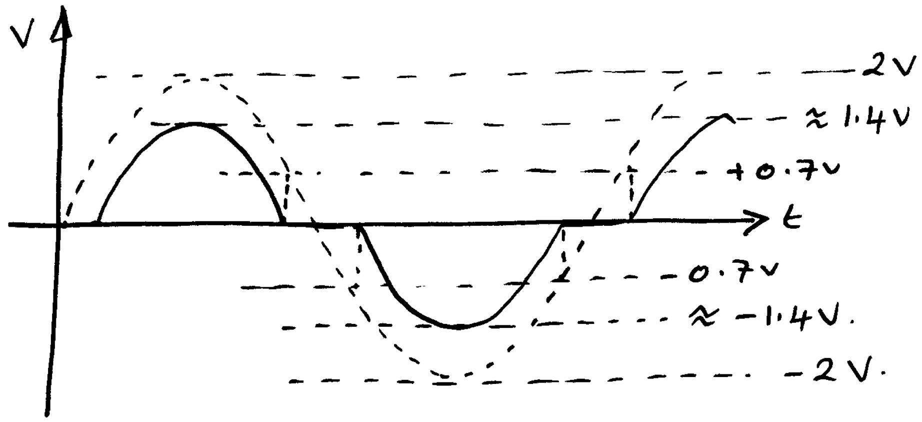
$$\overline{V_{on}^2} = \frac{(84 \times 10^{-6})^2}{5kHz} = 50^2 \left[ \overline{V_n^2} + \overline{i_n^2}(8.2k\Omega)^2 + 4kT\,8.2k\Omega \right]$$
$$= 50^2 \left[ 162 \times 10^{-18} + (8.2 \times 10^3)^2 \overline{i_n^2} + 136 \times 10^{-18} \right]$$

$$\text{or} \quad \overline{i_n^2} \times (8.2 \times 10^3)^2 = 5.65 \times 10^{-16} - 1.62 \times 10^{-16} - 1.36 \times 10^{-16}$$

$$\text{or} \quad i_n = \sqrt{3.96 \times 10^{-24}} = \underline{\underline{2\ pA\ Hz^{-1/2}}}.$$

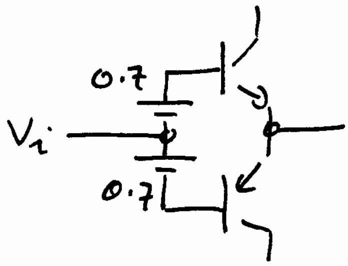
Q4 (a)

(i)

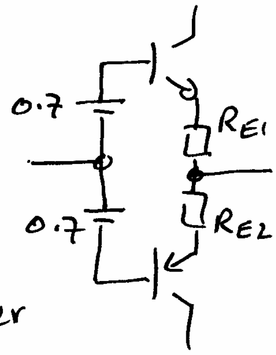



The flat region in the output waveshape is "crossover distortion". It arises because of the finite turn on voltages of $T_1$ + $T_2$. There is no positive output until $V_I$ reaches 0.7v and no negative output until $V_I$ falls below −0.7v.

(ii) batteries could be added as shown.




(iii) Thermal runaway arises because of the negative temperature coefficient of $V_{BE}$ for a given $I_c$ ..... or the positive temp coefficient of $I_c$ for a given $V_{BE}$.




With const. $V_{BE}$ (as in part (ii)), power dissipation in transistors will heat them up causing an increase in $I_c$ .... which heats them up further and so on. There is no mechanism in the cct of part (ii) to limit this process. By adding $R_{E1}$ + $R_{E2}$, $I_c$ develops a voltage between the transistor emitters and this voltage reduces $V_{BE}$ if the voltage between the bases is constant. Thus as $I_c$ tries to increase the circuit action is to reduce $V_{BE}$ + hence limit the possible rise in $I_c$.

Q4 (b)

(i) First identify whether current or voltage would limit output power....

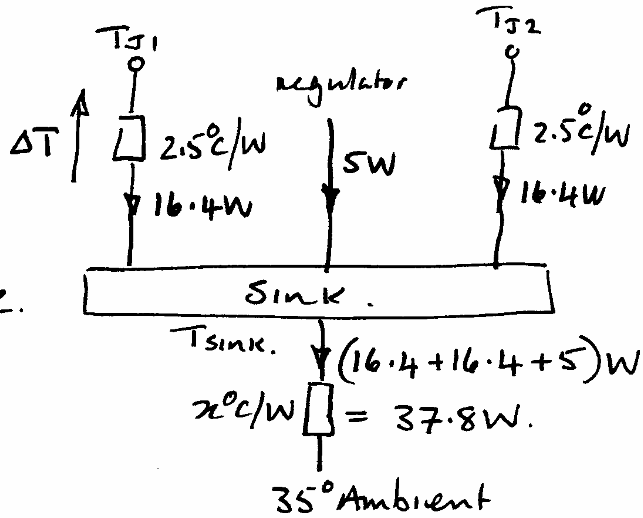
$\frac{15V}{4\Omega} = 3.75A$ ... but $I_c$ can only provide 3A so the limit is current

$$P_{Lmax} = \frac{I_p^2 R_L}{2} \quad \left[ \equiv I_{rms}^2 R_L \right].$$

$$= \frac{3^2 \times 4}{2} = \underline{\underline{18\,W}}.$$

(ii) Each $I_c$ will dissipate.

$$\frac{2 \cdot 18^2}{\pi^2 \cdot 4} = \underline{\underline{16.4\,W}}.$$




$$\Delta T = (2.5\,°C/W \times 16.4)\,°C.$$
$$= \underline{\underline{41°}}.$$

When $T_{J1}$ (and $T_{J2}$) are 120°C, $T_{sink}$

$$= 120 - 41 = 79°C.$$

$$\therefore\ x = \frac{T_{sink} - T_{AMB}}{\text{Total Power}} = \frac{79 - 35}{37.8}$$

$$= \underline{\underline{1.16\,°C/W}}.$$