Q1(i) at h.f. $X_c \ll R_1$ and $X_c \ll R_2$ $\therefore$ $\frac{v_o}{v_i} \approx 1$

at l.f. $X_c \gg R_1$ and $X_c \gg R_2$ $\therefore$ $\frac{v_o}{v_i} \approx \frac{R_1+R_2}{R_1}$

(ii) $$\frac{v_o}{v_i} = \frac{R_1 + \frac{R_2/sC}{R_2 + 1/sC}}{R_1} = \frac{R_1 + \frac{R_2}{1+sCR_2}}{R_1}$$

$$= \frac{R_1 + sCR_1R_2 + R_2}{R_1(1+sCR_2)} = \underline{\underline{\frac{R_1+R_2}{R_1} \cdot \frac{1 + sC\frac{R_1R_2}{R_1+R_2}}{1+sCR_2}}}$$

$$\equiv k \cdot \frac{1+j^{f}/_{f_1}}{1+j^{f}/_{f_0}} \quad \text{where } k = \frac{R_1+R_2}{R_1}, \; f_1 = \frac{R_1+R_2}{2.\pi.C.R_1R_2}.$$

and $f_0 = \frac{1}{2\pi CR_2}$

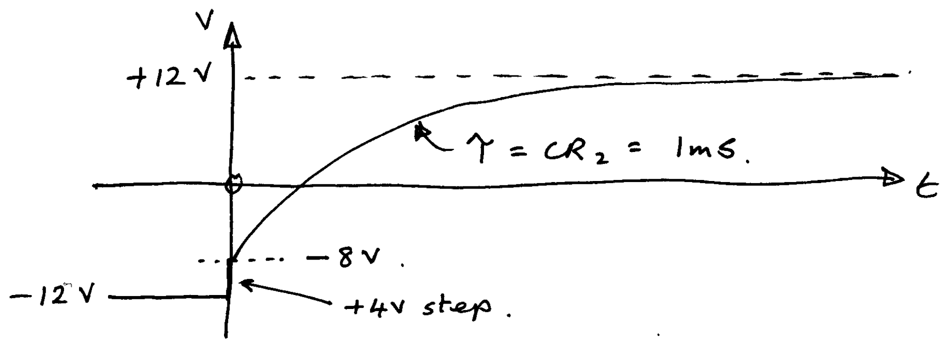
(iii). immediately before the step, l.f gain dominates

so $v_o|_{t=0^-} = -2 \times$ l.f gain $= -12$V

$v_o|_{t=0^+} = -12 + \Delta v_o$ due to step.

$= -12 + 4 \times$ h.f gain $= -12+4 = -8$V.

$v_o|_{t\to\infty} = +2 \times$ l.f gain $= +12$V.



(iv) $$\frac{v_o}{v_i} = 6 \cdot \frac{1+j\frac{400}{955}}{1+j\frac{400}{159}}$$

$$\left|\frac{v_o}{v_i}\right| = 6\left[\frac{1+\left(\frac{400}{955}\right)^2}{1+\left(\frac{400}{159}\right)^2}\right]^{1/2} = 6\left[\frac{1+0.175}{1+6.329}\right]^{1/2} = \underline{\underline{2.40}}$$

$$\angle\left(\frac{V_o}{V_i}\right) = \tan^{-1}\frac{400}{955} - \tan^{-1}\frac{400}{159}$$
$$= 22.7^\circ - 68.3^\circ = \underline{\underline{-45.6^\circ}}$$

(v) With two identical circuits in series

overall $|\text{gain}|$ = gain(1) × gain(2) = 2.4^2 = $\underline{\underline{5.76}}$.

overall phase = phase(1) + phase(2) = $2\times(-45.6)$
$= \underline{\underline{-91.2^\circ}}$

(vi) The pole frequency is 159 Hz, the zero frequency is 995 Hz. At 100kHz neither will be having a significant effect and so design gain ≈ 1.

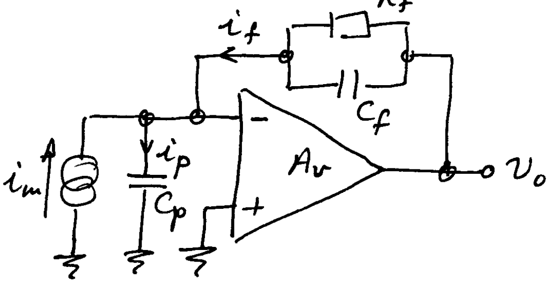
The required GBP is therefore 1 × 100kHz
$= \underline{\underline{100\text{kHz}}}$

Q2 (i) parasitic second order behaviour arises when unwanted component reactances interact to form an underdamped second order behaviour.

note that the question asks only about transient responses. No marks are available for frequency domain comments

the commonest indicator of parasitic second order responses is ringing in response to transient signal changes. In the frequency domain one would observe gain peaking at particular frequencies and phase shifts that approached -180.

(ii) Sum currents at v^- node ....



$$i_{in} - i_p + i_f = 0$$

$$v^- = -v_o/A_v .$$

$$\therefore i_p = v^- sC_p = -\frac{v_o sC_p}{A_v}.$$

$$i_f = \frac{v_o - v^-}{Z_f} = \frac{v_o}{Z_f}\left(1 + 1/A_v\right)$$

$$= v_o\left(1 + 1/A_v\right)\left(\frac{1+sC_fR_f}{R_f}\right).$$

$$\therefore i_{in} = -v_o\left[\frac{sC_p}{A_v} + \frac{1+sC_fR_f}{R_f} + \frac{1+sC_fR_f}{A_vR_f}\right]$$

$$= -\frac{v_o}{R_f}\left[\frac{sC_pR_f}{A_v} + 1 + sC_fR_f + \frac{1}{A_v} + \frac{sC_fR_f}{A_v}\right].$$

$$= -\frac{v_o}{R_f}\left[1 + \frac{1}{A_v} + sR_f\left(C_f\left(1+\frac{1}{A_v}\right) + \frac{C_p}{A_v}\right)\right]$$

$$\text{or } \frac{v_o}{i_{in}} = -\frac{R_f}{1 + \frac{1}{A_v} + sR_f\left[C_f\left(1+\frac{1}{A_v}\right) + \frac{C_p}{A_v}\right]}.$$

(iii)
$$\frac{v_o}{i_{in}} \approx -\frac{R_f}{1 + s\left[\frac{1}{GBP} + C_fR_f\right] + s^2\frac{C_pR_f}{GBP}}.$$

This is a low pass transfer function.

ω_n, the undamped natural frequency is

$$\omega_n = \sqrt{\frac{GBP}{C_p R_f}}$$ by comparison with standard form.

$$\frac{1}{\omega_n q} = \frac{1}{GBP} + C_f R_f = \text{coefficient of "s" in the denominator.}$$

$$\therefore \frac{1}{q} = \omega_n\left[\frac{1}{GBP} + C_f R_f\right] = \sqrt{\frac{GBP}{C_p R_f}}\left[\frac{1}{GBP} + C_f R_f\right]$$

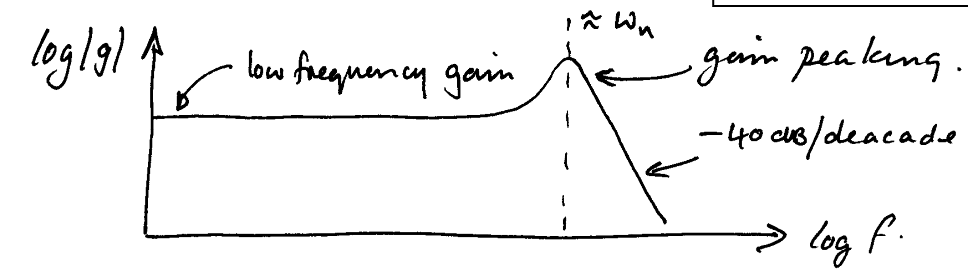
$$= \frac{1}{\sqrt{GBP\, C_p R_f}} + \frac{\sqrt{GBP\, R_f}}{\sqrt{C_p}} \cdot C_f$$

$$= \frac{1 + \sqrt{GBP\, R_f} \cdot C_f \cdot \sqrt{GBP\, R_f}}{\sqrt{GBP\, C_p R_f}}.$$

or $$q = \frac{\sqrt{GBP.\, C_p.\, R_f}}{1 + GBP.\, R_f.\, C_f.}$$

note that the labels are not required by the question so are not necessary in order to get the 2 marks for part (iv)

(iv)



(v)(a) When $C_f = 0$, $$q = \sqrt{GBP.\, C_p.\, R_f}$$
$$= \sqrt{2.\pi.4.10^6.50.10^{-12}.10^4}$$
$$= 3.54$$

(b) For a q of 0.707 ...

$$0.707 = \frac{3.54}{1 + GBP.\, R_f C_f} \quad \text{or} \quad C_f = \frac{\frac{3.54}{0.707} - 1}{GBP.\, R_f}$$

$$= \frac{4}{2.\pi.4 \times 10^6 \times 10^4} = 15.9\ pF \approx 16\ pF$$

Q3(a)(i) $R_{Th} = 2k\Omega // 1k\Omega = \underline{\underline{667\,\Omega}}$ by inspection

$$\overline{v_{on}^2}\Big|_{\text{due to } R_1} = 4kTR_1\left(\frac{R_2}{R_1+R_2}\right)^2 = 33.1\times10^{-18}\times\frac{1}{9} = 3.68\times10^{-18}$$

$$\overline{v_{on}^2}\Big|_{\text{due to 1pA}} = (1\text{pA})^2\times R_{Th}^2 = 10^{-24}\times 445\times10^3 = 0.44\times10^{-18}$$

$$v_{on}^2\Big|_{\text{due to 5nV}} = (5\text{nV})^2\times\left(\frac{R_2}{R_1+R_2}\right)^2 = 25\times10^{-18}\times\frac{1}{9} = 2.78\times10^{-18}$$

$$\overline{v_{on}^2}\Big|_{\text{due to 5pA}} = (5\text{pA})^2\times R_{Th}^2 = 25\times10^{-24}\times445\times10^3 = 11.13\times10^{-18}$$

$$\overline{v_{on}^2}\Big|_{\text{due to } R_2} = 4kTR_2\left(\frac{R_1}{R_1+R_2}\right) = 16.56\times10^{-18}\times\frac{4}{9} = 7.36\times10^{-18}$$

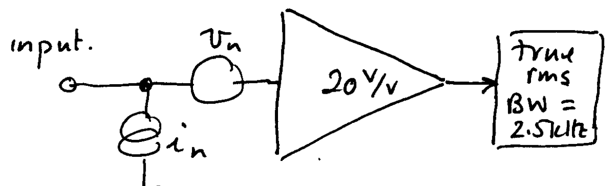
$$\overline{v_{onT}^2} = \left[3.68+0.44+2.78+11.13+7.36\right]\times10^{-18} = 25.39\times10^{-18}$$

$$\therefore\quad v_{nTh} = \sqrt{25.39\times10^{-18}} = \underline{\underline{5.04\text{ nV Hz}^{-1/2}}}.$$

(ii) $$\overline{v_{onT}^2} = 4kT_eR_{Th}$$

or $$T_e = \frac{\overline{v_{onT}^2}}{4k\,R_{Th}} = \underline{\underline{690\text{ K}}}.$$

(b)(i).



when input is short cctd to ground, i_n has no effect so meter reading is...

$$8\times10^{-6} = \sqrt{v_n^2(20)^2\,2500}$$

or $$v_n = \frac{8\times10^{-6}}{20\sqrt{2500}} = \underline{\underline{8\text{ nV Hz}^{-1/2}}}.$$

(ii) when input grounded by 3.9 kΩ, meter reading is

$$13\,\mu V = \sqrt{\left(v_n^2 + i_n^2\, 3.9k\Omega^2 + 4kT\, 3.9k\Omega\right)(20)^2\, 2500}$$

$$= \sqrt{\left(64\times10^{-18} + i_n^2\, 3.9k\Omega^2 + 64.6\times10^{-18}\right)\times 10^{6}}$$

$$13\,nV = \sqrt{128.6\times10^{-18} + (i_n\, 3.9k\Omega)^2}$$

$$(169-128.6)\times10^{-18} = (i_n \times 3.9k\Omega)^2$$

$$40.4\times10^{-18} = i_n^2 \times 3.9k\Omega^2$$

$$i_n = \sqrt{\frac{40.4\times10^{-18}}{15.21\times10^{6}}} = \underline{\underline{1.63\ pA\ Hz^{-1/2}}}$$

(iii) Optimum R_s from an F point of view ...

$$F = \frac{v_n^2 + i_n^2 R_s^2 + 4kTR_s}{4kTR_s}$$

$$= \frac{v_n^2}{4kTR_s} + \frac{i_n^2 R_s}{4kT} + 1$$

$$\frac{dF}{dR_s} = -\frac{v_n^2}{4kTR_s^2} + \frac{i_n^2}{4kT} = 0 \text{ for min.}$$

$$\therefore \frac{i_n^2}{\cancel{4kT}} = \frac{v_n^2}{\cancel{4kT}\, R_s^2} \quad \text{or} \quad R_s = \frac{v_n}{i_n}$$

$$\therefore R_{s\,opt} = \frac{8\times10^{-9}}{1.63\times10^{-12}} = \underline{\underline{4.9\ k\Omega}}$$

(If they remember the result & use it correctly they'll get the marks but if their memory is faulty they will get no marks.)

Q4 (i) Class A In a class A amplifier, the output devices both conduct throughout the signal cycle.

Class B In a class B amplifier, the output devices are never on together and never off together. One device deals with +ve half cycles and the other with −ve half cycles.

(ii) Power Supplied = Power Dissipated + Load Power

$$V_s I_{S\,AVE}/\text{supply} = P_D + V_P^2/2R_L$$

$$2V_s \frac{I_P}{\pi} = P_D + V_P^2/2R_L$$

$$2V_s \frac{V_P}{\pi R_L} = P_D + V_P^2/2R_L.$$

or $$P_D = 2\frac{V_s V_P}{\pi R_L} - \frac{V_P^2}{2R_L}.$$

$$\frac{dP_D}{dV_p} = \frac{2V_s}{\pi R_L} - \frac{2V_p}{2R_L} = 0 \text{ for maximum}$$

ie max P_D when $\frac{2V_s}{\pi R_L} = \frac{2V_p}{2R_L}$ or $\underline{V_p = \frac{2V_s}{\pi}}$.

When $V_p = \frac{2V_s}{\pi}$, total dissipation is.

$$P_D = \frac{2V_s\left(\frac{2V_s}{\pi}\right)}{\pi R_L} - \frac{\left(\frac{2V_s}{\pi}\right)^2}{2R_L} = \frac{4V_s^2}{\pi^2 R_L} - \frac{2V_s^2}{\pi^2 R_L}$$

$= \frac{2V_s^2}{\pi^2 R_L}$ for both output devices.

$\therefore$ for one device, $\underline{P_D = \frac{V_s^2}{\pi^2 R_L}}$.

(iii) $P = \frac{V_P^2}{2R_L}$ $\quad 1000 = \frac{V_P^2}{2.4}$

or $V_p^2 = 8000$ so $V_p = V_s \approx \underline{90V}$.

(iv) $I_{pm} = V_{pm}/R_L = 90/4 = \underline{\underline{22.5\,A}}$

$I_{AVE} = \frac{I_p}{\pi}$ since each supply provides energy for alternate half cycles only

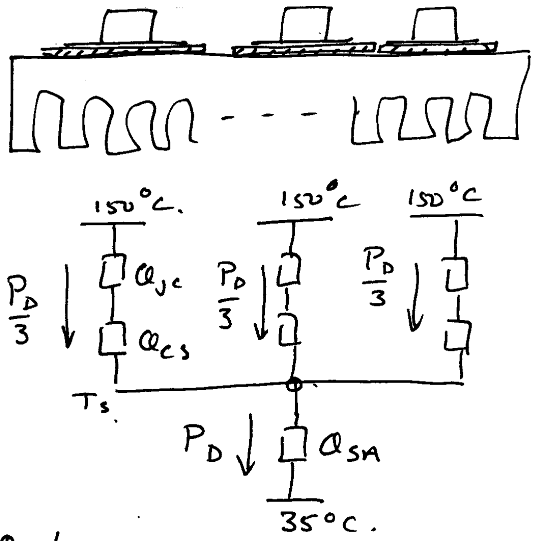
$= \frac{22.5}{\pi} = \underline{7.16\,A}$.

(v) peak output device current $= \underline{\underline{22.5\,A}}$.

peak output device voltage $= 2V_s = \underline{\underline{180\,V}}$.

maximum average power dissipation is $\frac{V_s^2}{\pi^2 R_L} = \frac{90^2}{\pi^2 R_L} = \underline{\underline{202\,W}}$

(vi)



$T_s = T_j - \frac{P_D}{3}(\theta_{JC} + \theta_{CS})$

$= 150° - 67.3(1.1\,°C/W)$

$= 150° - 74°$

$= 76°$

$T_s - T_A = P_D\,\theta_{SA}$

$76 - 35 = 202\,\theta_{SA}$

$\frac{41}{202} = \theta_{SA} = \underline{\underline{0.2\,°C/W}}$.

This would be a large heatsink and in most amplifiers would have fan assisted cooling to allow the heat to be removed from a much smaller dissipating area.

the comment is not required by the question and full marks can be gained without it