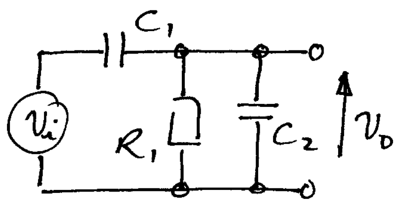
Q1(a) (i) If gain $\to 0$ as $\omega \to 0$.

hf gain $\to \dfrac{C_1}{C_1+C_2}$ as $\omega \to \infty$

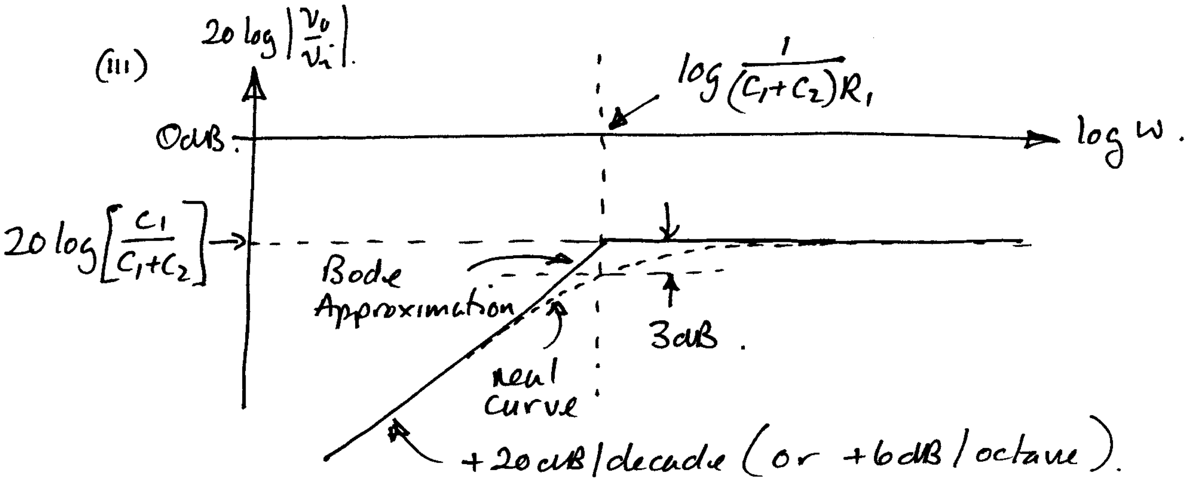


(ii)
$$\frac{v_o}{v_i} = \frac{R_1 \| C_2}{\frac{1}{j\omega C_1} + R_1 \| C_2} = \frac{\dfrac{R_1/j\omega C_2}{R_1 + 1/j\omega C_2}}{\dfrac{1}{j\omega C_1} + \dfrac{R_1/j\omega C_2}{R_1 + 1/j\omega C_2}}.$$

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

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

(iii)



(iv) If an R is placed in $\|$el with C_1 such that the resistive potential division ratio is the same as the capacitive division ratio, behaviour is frequency independent ... ie

$$\frac{C_1}{C_1+C_2} = \frac{R_1}{R_1+R} \quad \text{or} \quad \cancel{C_1R_1} + C_1R = \cancel{C_1R_1} + C_2R_1$$

$$\text{or} \quad R = \frac{C_2R_1}{C_1} = \underline{\underline{20k\Omega}}.$$

This result could also have been obtained by saying that the time constant C_1R must be made the same as time constant C_2R_1

(b) (i) If $GBP = 10MHz$ and $G = 100$,

$$BW = \frac{GBP}{G} = \frac{10^7}{100} = 10^5\,Hz. = f_o.$$

Now τ, system time constant $= 1/\omega_o = 1/2\pi f_o$

$$\therefore\ \tau = 1/2\pi.10^5 = 1.59\mu s.$$

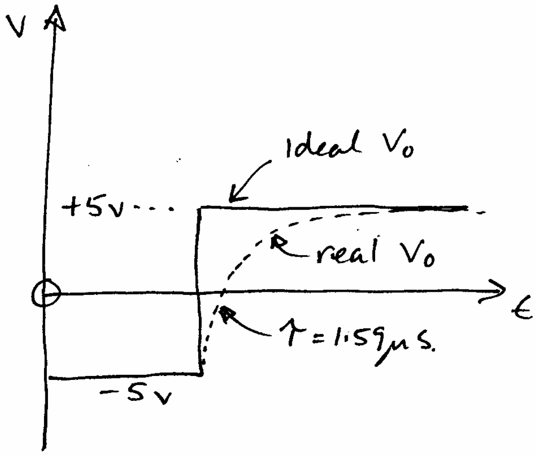
and risetime, t_r, $= 2.2\tau = \underline{\underline{3.5\mu s}}$

(ii) The change in input is from $-50mV$ to $+50mV$ so the change in output will be 100 times bigger – ie from $-5V$ to $+5V$..

Biggest $\frac{dV_o}{dt}$ occurs at instant of input step so

$$\left.\frac{dV_o}{dt}\right|_{max} = \frac{5V-(-5V)}{\tau}$$

This is because the initial slope of an exponential crosses the aiming level after a time τ.



The slew rate must be at least $\left.\frac{dV_o}{dt}\right|_{max}$

$$\text{ie} \geq \frac{10}{1.59\times10^{-6}} = \underline{\underline{6.29\ MVs^{-1}}}$$

Q2 (i) The five terms are ...

second order
analogue
low pass
active
unconditionally stable.

(ii) $K = 1$

$$\omega_0 = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

$$\frac{1}{\omega_0 q} = C_2(R_1 + R_2)$$

or $$\frac{1}{q} = \omega_0 C_2(R_1+R_2) = \frac{C_2(R_1+R_2)}{\sqrt{R_1R_2C_1C_2}} = \sqrt{\frac{C_2}{C_1}} \cdot \frac{R_1+R_2}{\sqrt{R_1R_2}}$$

$$= \sqrt{\frac{C_2}{C_1}}\left[\sqrt{\frac{R_1}{R_2}} + \sqrt{\frac{R_2}{R_1}}\right].$$ q is the inverse of any of these.

(iii) a minimum in $1/q$ corresponds to a maximum in q.

Let $\sqrt{\frac{R_1}{R_2}}$ be x. The last expression for $1/q$ can then be written $\frac{1}{q} = \sqrt{\frac{C_2}{C_1}}\left[x + \frac{1}{x}\right].$

$$\frac{d(1/q)}{dx} = \sqrt{\frac{C_2}{C_1}}\left[1 - \frac{1}{x^2}\right] = 0 \text{ for a minimum}$$

ie $x^2 = 1$ or $\underline{R_1 = R_2}$ for a minimum in $1/q$ or a maximum in q.

(iv) Using this condition, $\frac{1}{q} = 2\sqrt{\frac{C_2}{C_1}}$

$$\therefore q = \frac{1}{2}\sqrt{\frac{C_1}{C_2}} \quad \text{or} \quad 4q^2 = \frac{C_1}{C_2}$$

so for a q of 3, $C_1/C_2 = 36$.

capacitances less than 100pF should be avoided to ensure that the capacitors used are large compared to circuit and op-amp parasitic capacitances

choose $C_2 = 100pF$
then $C_1 = 3.6nF$

and $\omega_0 = 2 \times \pi \times 4 \times 10^3 = \dfrac{1}{R\sqrt{100p \times 3.6n}}$

$$\text{or } R = \frac{1}{2.\pi.4.10^3.\sqrt{36 \times 10^{-20}}}.$$

$$= \frac{1}{2.\pi.4.6.10^{-7}}$$

$$= \underline{\underline{66k\Omega}}.$$

A wide range of combinations is acceptable.
both Cs should be $\gtrsim 100pF$.
R should be $< M\Omega$. but $> 100s\ \Omega$.

Q3 (a) (i) evaluate each contribution in turn...

$$\overline{v_o^2}\Big|_{1.7nV} = \left[1.7\times10^{-9}\right]^2\cdot\left[\frac{R_2}{R_1+R_2}\right]^2 = 2.89\times10^{-18}\cdot\frac{1}{9} = 0.321\times10^{-18}$$

$$\overline{v_o^2}\Big|_{1.5pA} = \left[1.5\times10^{-12}\right]^2\cdot\left[\frac{R_1R_2}{R_1+R_2}\right]^2 = 2.25\times10^{-24}\cdot\frac{10^4}{4} = 0.563\times10^{-20}$$

$$\overline{v_o^2}\Big|_{R_1} = 4kT\,1.5\times10^{2}\left[\frac{R_2}{R_1+R_2}\right]^2 = 2.48\times10^{-18}\cdot\frac{1}{9} = 0.276\times10^{-18}$$

$$\overline{v_o^2}\Big|_{R_2} = 4kT.75\left[\frac{R_1}{R_1+R_2}\right] = 1.24\times10^{-18}\cdot\frac{4}{9} = 0.552\times10^{-18}$$

$$\overline{v_{oT}^2} = \overline{v_o^2}\Big|_{1.7nV} + \overline{v_o^2}\Big|_{1.5pA} + \overline{v_o^2}\Big|_{R_1} + \overline{v_o^2}\Big|_{R_2}$$

$$= (0.321 + 0.0056 + 0.276 + 0.552)\times10^{-18}$$

$$= 1.155\times10^{-18}\ V^2\,Hz^{-1} \equiv \underline{\underline{1.075\times10^{-9}\ V\,Hz^{-1/2}}}$$

$R_{Th} = R_1 /\!/ R_2 = \underline{\underline{50\Omega}}$. ($R_1 /\!/ R_2$ by inspection).

(ii) If all the noise is ascribed to R_{Th} its effective temperature must be ...

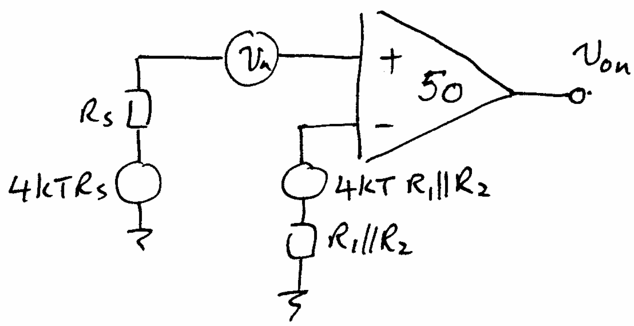
$$\overline{v_{oT}^2} = 4k\,T_{eff}\,R_{Th}.$$

$$\text{or}\quad T_{eff} = \frac{\overline{v_{oT}^2}}{4k\,R_{Th}} = \frac{1.155\times10^{-18}}{4.1.38\times10^{-23}\times50} = \underline{\underline{418\ K}}.$$

(b)(i) noise equivalent cct is

$\overline{v_{on}^2}$ due to v_n is ...

$$\overline{v_{on}^2}\Big|_{v_n} = v_n^2.(50)^2.$$



$\overline{v_{on}^2}$ due to $R_1/\!/R_2$ is ...

$$4kT\,R_1\|R_2\,(50)^2 = \overline{v_{on}^2}\Big|_{R_1\|R_2}.$$

If the contribution due to $R_1\|R_2$ must be no more than 10% of that due to v_n,

$$4kT\,R_1\|R_2\,.\,(50)^2 = 0\cdot 1\ v_n^2\,(50)^2$$

$$\text{or}\quad R_1\|R_2 = \frac{0\cdot 1\ v_n^2}{4kT} = \frac{0\cdot 1\times 25\times 10^{-18}}{4\times 1\cdot 38\times 10^{-23}\times 300}$$

$$= 151\,\Omega.$$

$$\therefore\ \frac{R_1R_2}{R_1+R_2} = 151 \quad \text{and} \quad \frac{R_1+R_2}{R_1} = 50$$

(1) (2)

substituting (2) in (1) $\frac{R_2}{50} = 151$ or $\underline{\underline{R_2 = 7\cdot 55\,k\Omega}}$

and from (2) $R_2 = 49R_1$ or $\underline{\underline{R_1 = 154\,\Omega}}$.

(ii) Total mean squared output noise is ....

$$\overline{v_{onT}^2} = (50)^2\big(\overline{v_n^2} + 0\cdot 1\,\overline{v_n^2} + 4kTR_s\big).$$

contribution from v_n — contribution from $R_1 + R_2$ — contribution from R_s.

$$= 2500\,(25\times 10^{-18} + 2\cdot 5\times 10^{-18} + 9\cdot 9\times 10^{-18})$$

$$= 2500\times 37\cdot 4\times 10^{-18} = 9\cdot 35\times 10^{-14}\,V^2\,Hz^{-1}.$$

total m.s. voltage over 10 kHz

$$= 9\cdot 35\times 10^{-14}\times 10^4\ V^2 = 9\cdot 35\times 10^{-10}\ V^2$$

$\therefore$ true rms meter reads $\underline{\underline{30\cdot 6\,\mu V}}$

Q4 (i) $P_D = P_S - P_L$

$$= 2V_{cc}I_{AVE} - \frac{V_p^2}{2R_L}.$$

$$= \frac{2V_{cc}V_p}{\pi R_L} - \frac{V_p^2}{2R_L}.$$

to find max P_D, differentiate P_D w.r.t. V_p ...

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

$$\therefore \frac{2V_{cc}}{\pi R_L} = \frac{V_p}{R_L} \text{ or max } P_D \text{ when } V_p = \frac{2V_{cc}}{\pi}$$

$$P_{D\,max} = \frac{2V_{cc}\left(\frac{2V_{cc}}{\pi}\right)}{\pi R_L} - \frac{\left(\frac{2V_{cc}}{\pi}\right)^2}{2R_L}$$

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

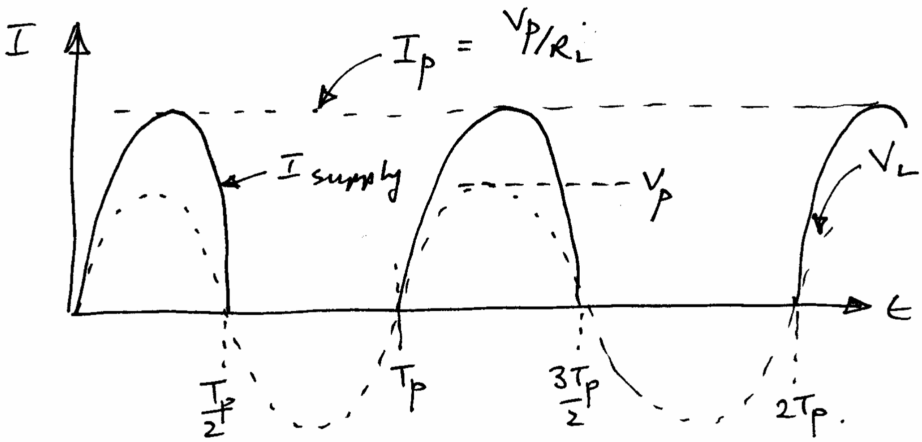
and this occurs when $P_L = \frac{\left(\frac{2V_{cc}}{\pi}\right)^2}{2R_L} = \frac{2V_{cc}^2}{\pi^2 R_L}$

$\therefore$ dissipation is max when $\underline{\underline{P_D = P_L = \frac{2V_{cc}^2}{\pi^2 R_L}}}$.

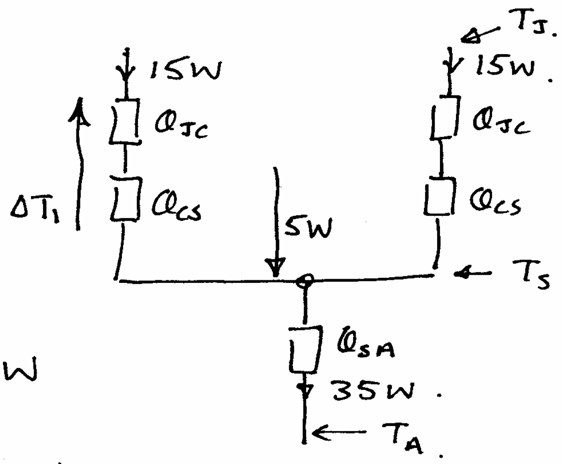
(ii) $P_L = V_p^2/2R_L$ or $V_{pm} = V_{cc} = \pm\sqrt{2R_L P_L}$

$$= \sqrt{1200} = \underline{\underline{\pm 35\text{V}}}$$

(iii)



(iv) The P_{DISS} of part (i) is for the whole output stage; each output device dissipate half of this whole....



$$P_{DISS(whole)} = \frac{2V_{CC}^2}{\pi^2 R_L}$$

$$= \frac{2 \times 1200}{\pi^2 \cdot 8} = 30\text{W}$$

$\therefore$ 15W/transistor is dissipated.

$$\Delta T_1 = 15\text{W}(\theta_{JC} + \theta_{CS}) = 15 \times 3.5 = 52.5\,^\circ\text{C}.$$

If this is added to the sink temp. of 100°C, T_J becomes 152.5°C, which exceeds the max T_J.

So $T_J = 150$ is the limit and T_S is less than its maximum specified value (of 100°C) at

$$150 - 52.5 = 97.5\,^\circ\text{C}.$$

$$\therefore \theta_{SA} = \frac{T_S - T_A}{P_T} = \frac{97.5 - 35}{35\text{W}} = 1.79\,^\circ\text{C/W}.$$

so...
- biggest $T_J - T_S = \Delta T_1 = 52.5\,^\circ\text{C}$
- max θ_{SA} allowable $= 1.79\,^\circ\text{C/W}$.

(v) If the load was an 8Ω inductance, V_{CC} would be unchanged, the current drawn would be unchanged (ie it would still be of the form of the answer to part (iii) but there would be a phase shift of 90° between V_L + I_L), no power would be dissipated in the load so it would all be dissipated in the output devices

$$\text{Total } P_D = \text{Total } P_S = V_{CC} \times \frac{V_{CC}}{\pi R_L} \times 2.$$

$$= \underline{95.5\text{ W}}$$

(Note that worst case dissipation would now occur at max V_P since this condition gives maximum I_{AVE}.)