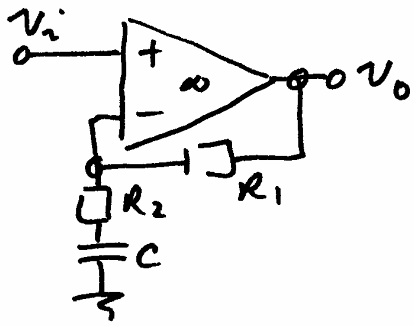
Q1 (i). l.f. gain ; $X_c \Rightarrow \infty$

$$\therefore \frac{v_0}{v_i} \Rightarrow \underline{1}.$$

h.f. gain ; $X_c \Rightarrow 0$

$$\therefore \frac{v_0}{v_i} \Rightarrow \underline{\frac{R_1 + R_2}{R_2}}$$



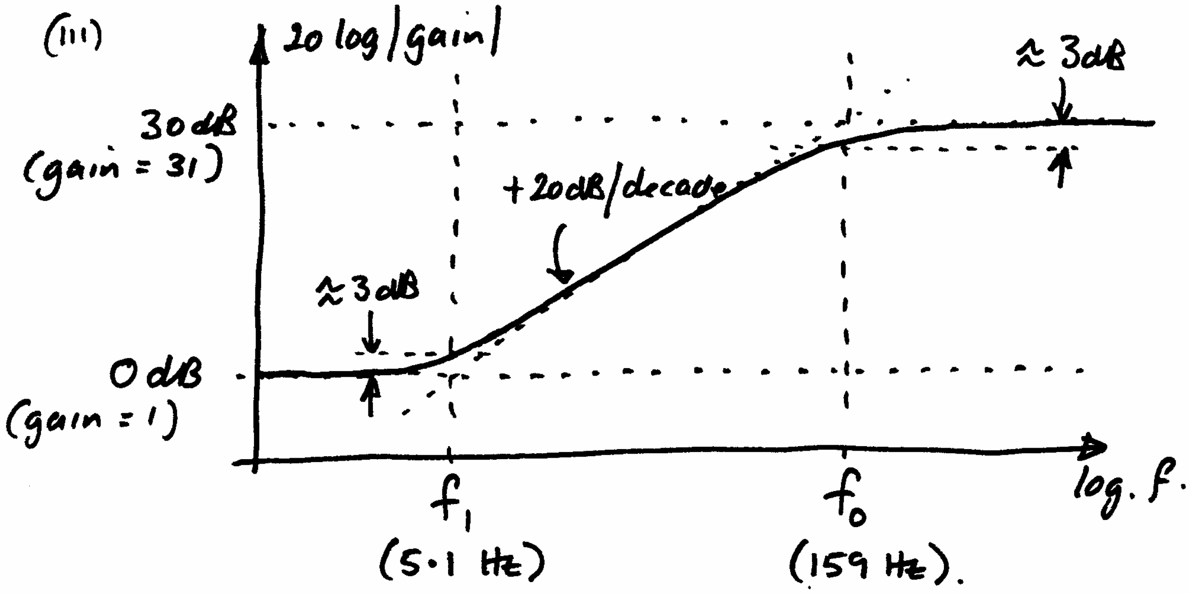

(ii)

$$\frac{v_0}{v_i} = \frac{Z_1 + Z_2}{Z_2} = \frac{R_1 + R_2 + 1/j\omega C}{R_2 + 1/j\omega C}$$

$$= \frac{1 + j\omega C(R_1 + R_2)}{1 + j\omega C R_2} \equiv k \cdot \frac{1 + j\,\omega/\omega_1}{1 + j\,\omega/\omega_0}$$

where $k = 1$, $f_1 = \frac{1}{2\pi C(R_1 + R_2)}$, $f_0 = \frac{1}{2\pi C R_2}$.

(iii)




(iv) For a −3dB corner of ≥ 500kHz,

$$GBP \geq 500\,\text{kHz} \times 31 = \underline{15.5\ \text{MHz}}$$

(or 97.4 M rad s$^{-1}$).

(v) The amplifier must support 10V peak @ 500 kHz

$$\text{Max } \frac{dv}{dt} \text{ of } V_p \sin \omega t = V_p \omega$$
$$= 10 \cdot 2 \cdot \pi \cdot 500 \cdot 10^3$$

min slew rate requirement = max $\frac{dv}{dt}$ specified

ie $SR \geq 10 \cdot 2 \cdot \pi \cdot 500 \cdot 10^3 = \underline{\underline{31 \cdot 4 \ V\mu s^{-1}}}$

(vi) All of $i_b^-$ will flow through $R_1$ (C will prevent flow through $R_2$).

$i_b^- = i_b' \pm i_{os}/_2$ so taking worst case...

$i_b^- = i_b' + i_{os}/_2 = 100nA + 50nA = 150nA.$

$\therefore v_{oso}$ due to $i_b^- = i_b^- R_1 = 150 \cdot 10^{-9} \cdot 30 \cdot 10^3$
$= 4 \cdot 5 \ mV.$

input offset voltage, $v_{os} = 4mV$. The d.c. gain of the amplifier is unity so $v_{oso}$ due to $v_{os} = 4mV$.

for the worst case assume effects add so biggest offset at output $= 4mV + 4 \cdot 5mV$
$= \underline{\underline{8 \cdot 5mV}}.$

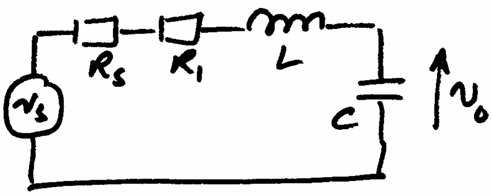
Q2 (i) Active filters are attractive alternatives to LCR filters because they do not use inductors and do not have the same sensitivity to circuit impedances as do LCR circuits. Generally an active fiter will be smaller, lighter and more accurate (for a given cost) than the LCR version.

The upper limit to the operating frequency range of active filters is set by the bandwidth of the op-amps (or other amplifying devices) used.

Resistors have parasitic series inductance and parasitic parallel capacitance. These are not usually troublesome until a few 10s of MHz.

Capacitors have series resistance, series inductance and a parallel resistance that is caused by dielectric imperfections.

(ii)
$$\frac{v_o}{v_s} = \frac{1/j\omega C}{R_s + R_1 + j\omega L + 1/j\omega C}$$
$$= \underline{\frac{1}{1 + j\omega C(R_s + R_1) + j^2\omega^2 LC}}$$




(iii)
$$\omega_n = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{126.6\,\text{mH} \times 0.2\,\mu\text{F}}} = \underline{6.28\ \text{k rad s}^{-1}}$$

$$\frac{1}{\omega_n q} = C(R_s + R_1)$$

$$\text{or } q = \frac{1}{\omega_n C(R_s + R_1)} = \underline{0.71}$$

(iv) For the Sallen + Key

$$\omega_n = \frac{1}{R\sqrt{C_1 C_2}}$$

and $\dfrac{1}{\omega_n q} = 2C_2R$

or $q = \dfrac{1}{2C_2R\,\omega_n} = \dfrac{R\sqrt{C_1C_2}}{2C_2R} = \dfrac{1}{2}\sqrt{\dfrac{C_1}{C_2}}$

$\therefore$ for a $q$ of 0.71,

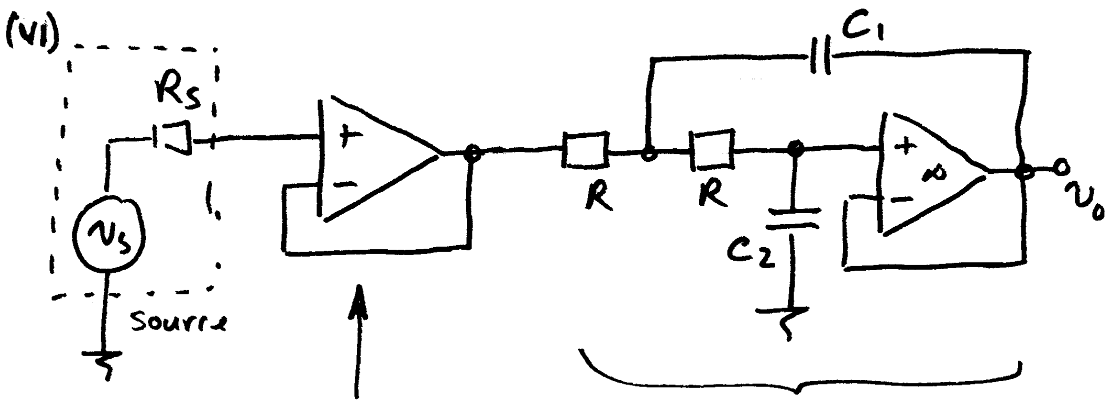
$$\frac{C_1}{C_2} = 4q^2 = \underline{\underline{2.0}}\,.$$

$$\omega_n = \frac{1}{R\sqrt{C_1C_2}} = \frac{1}{R\sqrt{C_2\cdot 2C_2}} = \frac{1}{\sqrt{2}\;C_2R}.$$

$$\therefore\; C_2R = \frac{1}{\sqrt{2}\,\omega_n} = \frac{1}{\sqrt{2}\,.\,6{\cdot}28\times10^3} = \underline{\underline{113\,\mu S}}$$

(v)

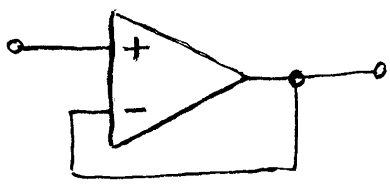
(vi)




extra op-amp connected as unity gain buffer.

Sallen – Key cct.

Unity gain buffer

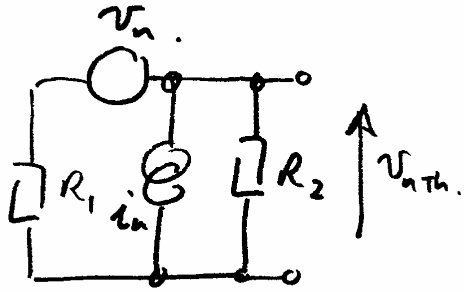


Q3 (a) (i) .....

by inspection, $R_{Th} = R_1 \| R_2$

$= 10k\Omega \| 20k\Omega$

$= \underline{6{\cdot}67\,k\Omega}$




$$\overline{v_{on}^2}\Big|_{R_1} = 4kTR_1\cdot\left(\frac{R_2}{R_1+R_2}\right)^2 = \frac{331\times10^{-18}}{9} = 36{\cdot}8\times10^{-18}$$

$$\overline{v_{on}^2}\Big|_{v_n} = \overline{v_n^2}\left(\frac{R_2}{R_1+R_2}\right)^2 = \frac{625\times10^{-18}}{9} = 69{\cdot}4\times10^{-18}$$

$$\overline{v_{on}^2}\Big|_{i_n} = \overline{i_n^2}\,(R_1\|R_2)^2 = 1\times10^{-24}\times(6{\cdot}67\times10^3)^2 = 44{\cdot}5\times10^{-18}$$

$$\overline{v_{on}^2}\Big|_{R_2} = 4kTR_2\left(\frac{R_1}{R_1+R_2}\right)^2 = 166\times10^{-18}\cdot\frac{4}{9} = 73{\cdot}6\times10^{-18}$$

$$\overline{v_{onT}^2} = (36{\cdot}8+69{\cdot}4+44{\cdot}5+73{\cdot}6)\times10^{-18} = 224\times10^{-18}.$$

$$\therefore\; v_{nTh} = \sqrt{224\times10^{-18}} = \underline{15\,nV\,Hz^{-1/2}}.$$

(a) (ii) Effective noise temp. of $R_{Th}$ given by

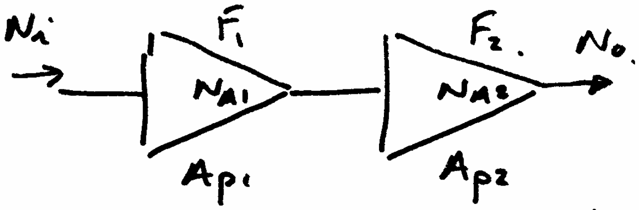
$$4kT_{eff}R_{Th} = 224\times10^{-18}\ V^2\,Hz^{-1}$$

$$\text{or}\quad T_{eff} = \frac{224\times10^{-18}}{4.1{\cdot}38.10^{-23}.\,6{\cdot}67.10^3} = 608\,K.$$

Total rms across 50pF

$$= \sqrt{\frac{k\,T_{eff}}{C}} = \sqrt{\frac{1{\cdot}38\times10^{-23}\times608}{50\times10^{-12}}} = \underline{13\mu V}.$$

(b) (i) The output noise contains three components ....




$N_o$ due to $N_i$

$$= N_{o1} = kT\Delta f . A_{p1} . A_{p2} .$$

[note that $N_i$ is available noise $kT\Delta f$]

$N_o$ due to amplifier 1

$$= N_{o2} = N_{A1} . A_{p2} = (F_1 - 1) kT\Delta f . A_{p1} . A_{p2} .$$

$N_o$ due to amplifier 2

$$= N_{o3} = N_{A2} = (F_2 - 1) kT\Delta f . A_{p2} .$$

$$\text{Overall } F = \frac{\text{actual output noise}}{\text{output noise from ideal amp}}$$

$$= \frac{kT\Delta f \left( A_{p1}A_{p2} + (F_1 - 1) A_{p2} A_{p1} + (F_2 - 1) A_{p2} \right)}{kT\Delta f \, A_{p1} . A_{p2} .}$$

$$= \underline{\underline{F_1 + \frac{F_2 - 1}{A_{p1}}}}$$

(ii) Power gains must be converted to linear ratios ...

6dB = power gain of 4

10dB = power gain of 10.

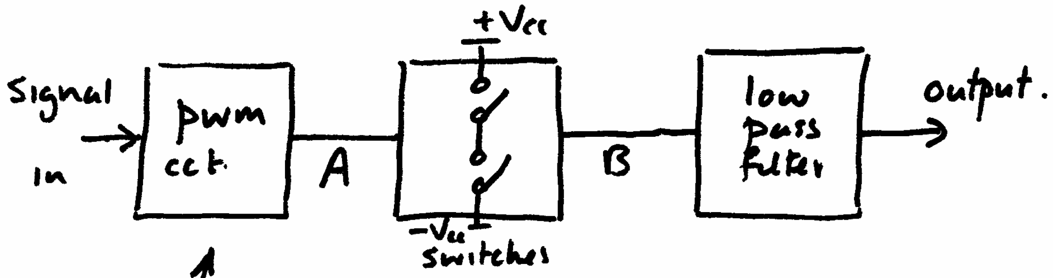
high gain first ... $F = 3 + \frac{2-1}{10} = 3.1$

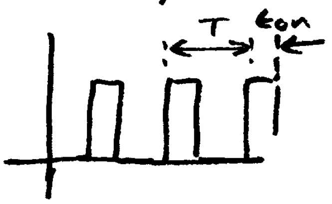
high gain second .. $F = 2 + \frac{3-1}{4} = 2.5$

So the $F = 2$, gain = 6dB should be the front end and $F_{overall} = \underline{\underline{2.5}}$.

Q4 (a) class D is much more efficient than class A or class B.

class A or B are more linear than class D.




signal converted to pwm – ie the duty cycle at point A is proportional to the value of signal at that instant. $\frac{1}{T} \gg$ max $f_{sig}$ of interest.

switches switch node B either to +Vcc or −Vcc depending on whether A is high or low. Level of power at output determined by ± Vcc.

B then put through low pass filter to average the pwm at B and hence extract the original signal that is now in amplified form.

(b) (i) max o/p V = ± 32V ; max o/p I = 3A

$\therefore R_L$ for max power $= \frac{32}{3} = \underline{10\frac{2}{3}\ \Omega}$.

value of max power $= \frac{V_p I_p}{2} = \frac{96}{2} = \underline{48W}$.

(ii) for load of 15Ω, $I_p = \frac{32}{15}$ which is less than 3A so power output is <u>voltage</u> limited maximum power into 15Ω is

$$\frac{V_p^2}{2R_L} = \frac{32^2}{2.15} = \underline{\underline{34W}}.$$

(iii). With a 15Ω load, each power supply would need to supply half cycles of current with a peak value of 32/15 A.

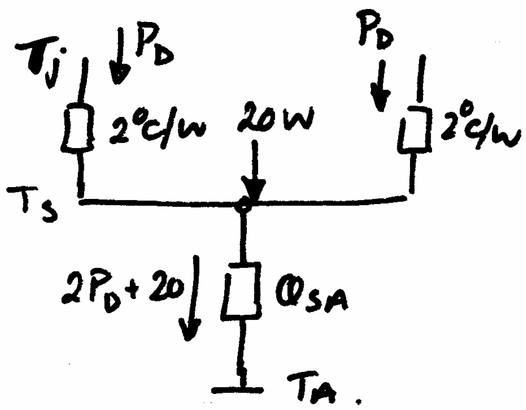
The supply must be able to cope with the average value of this demand which is

$$I_{ave} = \frac{I_p}{\pi} = \frac{32}{15.\pi} = \underline{\underline{0.68\,A}}.$$

(iv) $P_D = \dfrac{2V_{cc}^2}{\pi^2 R_L}$

$= \dfrac{2.35^2}{\pi^2 R_L}$

$= 16{\cdot}5W$




$T_j - T_s = P_D . 2°c/W$
$= 33°C.$

so at $T_j = 125$, $T_s = (125-33) = 92°C$. But max $T_s = 90$ so $T_s$ spec is limit.

$T_s - T_A = (2P_D + 20W).\theta_{SA} = 53\,\theta_{SA}$

$90 - 35 = 55 = 53\,\theta_{SA}$

$\underline{\underline{\theta_{SA} \leq 1°c/W.}}$ (1.04 °c/w)