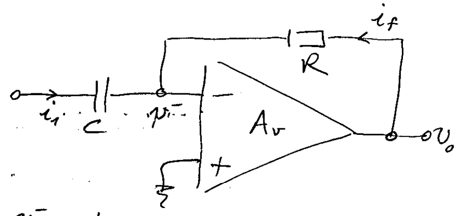
Parasitic second order responses

What goes wrong with the differentiator?



Sum currents at v^- node

$$i_f + i_i = 0$$

$$\frac{v_o - v^-}{R} + \frac{v_i - v^-}{1/sC} = 0$$

gives, with rearrangement, $v^- = \dfrac{v_i sCR + v_o}{1 + sCR}$.

using the op-amp equation $v_o = A_v(v^+ - v^-)$

$$v_o = -A_v v^-$$

eliminating v^-

$$-\frac{v_o}{A_v} = \frac{v_i sCR + v_o}{1 + sCR} \quad \text{———} ①$$

But $A_v = \dfrac{A_0}{1 + s\tau_0}$

Using this A_v in ① gives

$$\frac{v_o}{v_i} = \frac{-sCR}{1 + \boxed{\frac{1}{A_0}} + \frac{s(\tau_0 + CR)}{A_0} + \frac{s^2 \tau_0 CR}{A_0}}$$

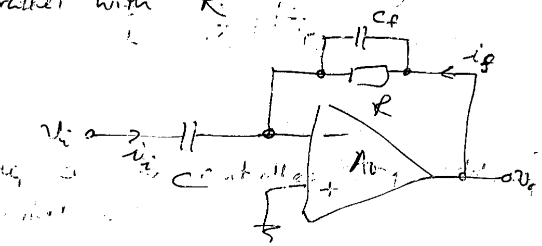
can be neglected

↑

since A_0 is very big, this damping term must be small — hence underdamped behaviour.

Can show that $\dfrac{1}{q_L} = \dfrac{1}{\sqrt{A_0}} \left[\sqrt{\dfrac{CR}{\tau_0}} + \sqrt{\dfrac{\tau_0}{CR}} \right]$.

The damping can be controlled by adding a C_f in parallel with R.



here

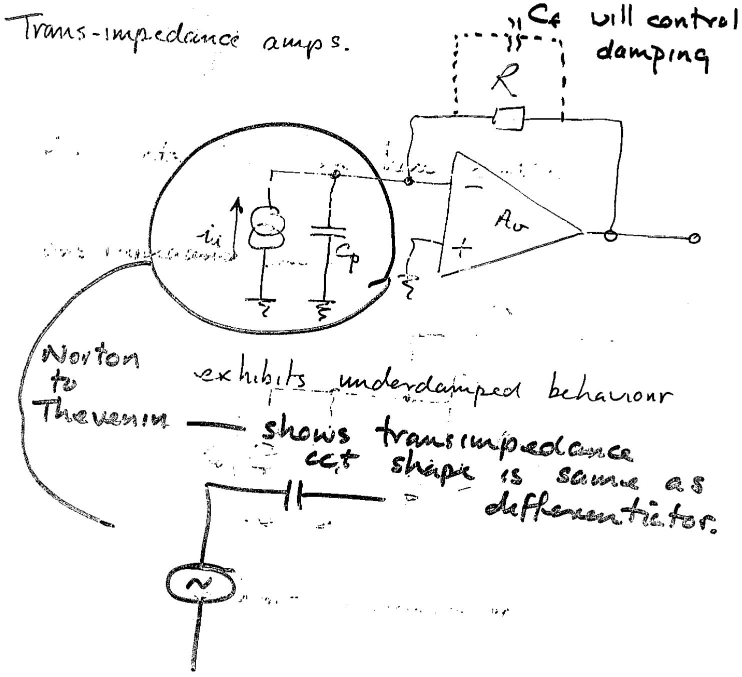
$$\frac{v_o}{v_i} = \frac{-sCR}{1 + s\left[\frac{\tau_0 + CR}{A_0} + C_f R\right] + \frac{s^2 \tau (C + C_f) R}{A_0}}$$

↑

C_f has a relatively big effect on damping because $C_f R$ is NOT divided by A_0

Other ccts that can have problems

Trans-impedance amps.

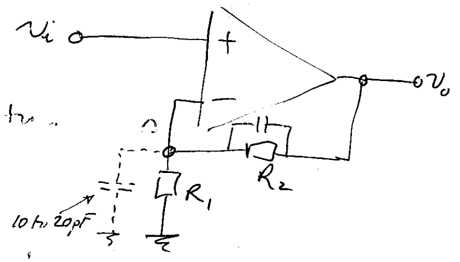


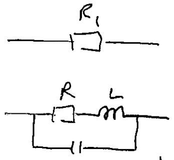
Cf will control damping

exhibits underdamped behaviour

Norton to Thevenin — shows transimpedance cct shape is same as differentiator.

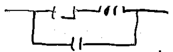
Non-inverting amps.



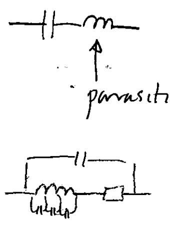


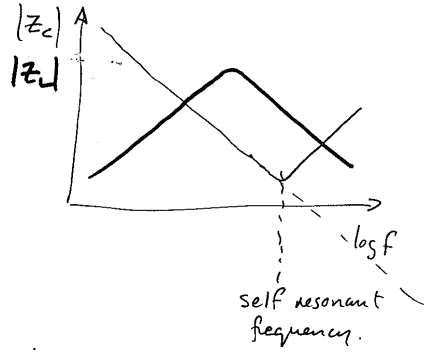
C_p → typically

|z| A



C_p → typically 1pF





Lets design a 3rd order Chebychev with 1dB ripple.

Frequency normalised transfer function is

$$\frac{v_o}{v_i} = \frac{1}{\underbrace{(s+0.494)}_{①}\underbrace{(s^2+0.494s+0.994)}_{②}}$$

first order section – section ①.

$$\frac{1}{s+0.494} = \frac{1}{\boxed{0.494}\left(\frac{s}{0.494}+1\right)}$$

This doesn't affect shape of frequency response

standard form

$$\frac{k}{1+j\omega/\omega_1}$$

$$\frac{1}{1+ s/0.494} \Rightarrow \frac{w_o}{w_c} = 0.494.$$

explicitly recognises that frequency variable in the polynomial that forms the transfer function is normalised to the overall cut off frequency.

Second order section. — section ②

$$\frac{1}{s^2 + 0.494 s + 0.994}$$

$$\equiv \frac{1}{0.994\left(\frac{s^2}{0.994} + \frac{0.494}{0.994} s + 1\right)}$$

$$\frac{w_o}{w_c} = \sqrt{0.994}$$

$$\frac{1}{w_o q} = \frac{0.494}{0.994}$$

$$\text{or } \frac{1}{q} = w_o \frac{0.494}{0.994} = \frac{\sqrt{0.994} . 0.494}{0.994}$$

$$= \frac{0.494}{\sqrt{0.994}} = 0.495$$

$$\text{or } q = 2.02$$

if cut off frequency for the overall filter of 20kHz is needed

for factor 1 $w_o = 0.494 w_c = 0.494 . 2.\pi . f_c$

or $f_o = 0.494 f_c$

if $f_c = 20\text{kHz}$, $f_o = 0.494 \times 20\text{kHz} = 9.88\text{kHz}$

$w_o = 2.\pi . 9.88\text{kHz} . \text{rad s}^{-1}$

for factor 2

$f_o = 0.997\ 20\text{kHz} = 19.94\ \text{kHz}$.

$q = 2.02$.

Noise

— of interest here is due to random thermal motion of electrons.

— average value of electronic noise is zero

$$\text{ie} \quad \frac{1}{t_1}\int_0^{t_1} v_n(t) \rightarrow 0 \quad \text{as} \quad t_1 \rightarrow \infty$$

— noise usually measured by its power delivering capability

$\Rightarrow$ ie mean squared value

mean squared $\overline{v_n^2}$ V^2

root mean squared $\sqrt{\overline{v_n^2}}$ V

— noise also classified by distribution of energy as a function of frequency.

→ Two sorts of noise distribution — white → equal energy / hertz at all frequencies

— pink more energy at low fs than at high.

Noise sources.

"Thermal" or "Johnson" noise (white)

— electrons moving around in a resistive medium.

$$\overline{v_n^2} = 4kTR \quad V^2\ Hz^{-1}$$

or $$\overline{v_{nT}^2}\Big|_{\text{over } \Delta f} = 4kTR\Delta f \quad V^2$$

$$v_n = \sqrt{4kTR} \quad V\ H^{-1/2}$$

Shot Noise

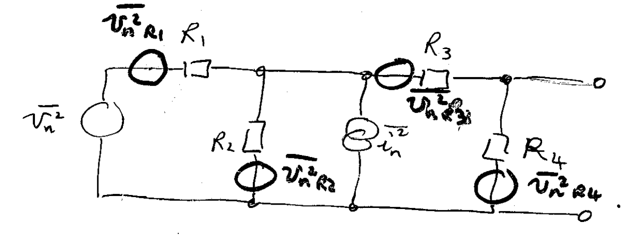
— occurs when electrons have to cross a potential barrier.

$$\overline{i_n^2} = 2eI$$

electronic charge. dc current

Handling noise sources in circuits

Handling noise sources in circuits



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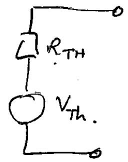


$$\overline{V_o^2}\Big|_{\overline{v_n^2}} = \left[\frac{R_2/\!/(R_3+R_4)}{R_1+R_2/\!/(R_3+R_4)} \cdot \frac{R_4}{R_3+R_4}\right]^2 \cdot v_n^2$$

$$\overline{V_0^2}\Big|_{\overline{v_{nR1}^2}} = \left[\qquad " \qquad\right]^2 \underbrace{4kTR_1}_{\overline{v_{n\,R1}^2}}$$

$$\overline{V_0^2}\Big|_{\overline{i_n^2}} = \overline{i_n^2}\,R_{eff}^2 \times \left(\frac{R_4}{R_3+R_4}\right)^2$$

$$R_{eff} = (R_3+R_4)/\!/R_1/\!/R_2$$

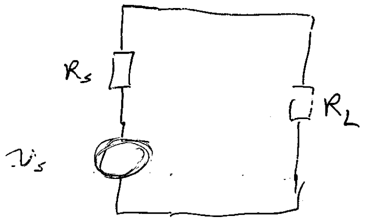
$$V_0^2\Big|_{\overline{v_{nR2}^2}} = \text{-- -- --}$$

$$\text{Total } \overline{V_o^2} = \overline{V^2}\Big| + \overline{V^2}\Big| + \overline{V^2}\Big| + \overline{V^2}\Big|$$

$$\text{Total } \overline{V_o^2} = \overline{V_o^2}\Big|_{\overline{v_n^2}} + \overline{V_o^2}\Big|_{\overline{v_{nR_1}^2}} + \overline{V_o^2}\Big|_{\overline{i_n^2}} + \overline{V_o^2}\Big|_{\overline{v_{nR_2}^2}}$$

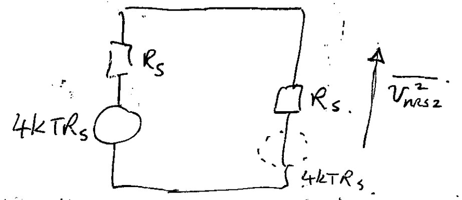
$$+ \; - - - -$$

Maximum available noise power.



when $R_L = R_s$ max power is transferred to R_L.

from a noise point of view this leads to



$$\overline{v_{nRs2}^2} = 4kTR_s \cdot \left(\frac{R_s}{R_s+R_s}\right)^2$$

$$= kTR_s$$

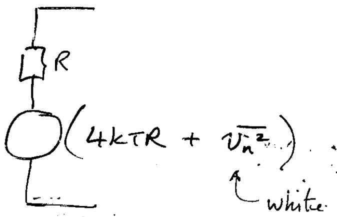
$$\text{Power delivered to } R_s = \frac{\overline{v_{nRs2}^2}}{R_s}$$

$$= \frac{kTR_s}{R_s}$$

$$N = \underline{\underline{kT}} \quad \text{W Hz}^{-1}$$

maximum available noise power.

Noise Temperature.



Noise temp, T_{eff} is value of T needed to account for total noise $(4kTR + \overline{v_n^2})$ such that

$$4kT_{eff}R = (4kTR + v_n^2)$$

actual ambient temp.

Systems descriptions of Noise.

Signal to Noise Ratio

$$S/N = \frac{\text{Signal Power}}{\text{Noise Power}}\Bigg|$$ at some node in the system.

for describing system noise behaviour noise factor, F, is used

$$F = \frac{\text{signal to noise ratio at system input}}{\text{'' '' '' '' at system output.}}$$

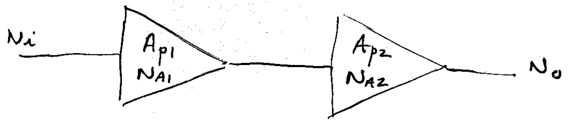
$$= \frac{S_i/N_i}{S_o/N_o} = \frac{S_i}{S_o}\frac{N_o}{N_i} = \boxed{\frac{1}{A_p}\cdot\frac{N_o}{N_i}}$$

but $N_o = A_pN_i + N_A$

$$= \frac{1}{A_p}\cdot\frac{(A_pN_i + N_A)}{N_i} = 1 + \frac{N_A}{A_pN_i}$$

$$F = \frac{\text{noise output from real amplifier}}{\text{noise output fr a perfect version of real amp}}$$

Noise Factor of a cascade of amplifiers (in an impedance matched system).



N_i = maximum available noise power = $kT\Delta f$. W.

$$F_1 = 1 + \frac{N_{A1}}{A_{p1}kT\Delta f} \qquad N_{A1} = A_{p1}kT\Delta f\,(F_1 - 1).$$

$$F_2 = 1 + \frac{N_{A2}}{A_{p2}kT\Delta f} \qquad N_{A2} = A_{p2}\,k.T.\Delta f\,(F_2 - 1).$$

N_o consists of 3 components

N_o consists of 3 components

(i) output noise due to N_i

$$N_{o(i)} = A_{p1}A_{p2}\underbrace{k.T.\Delta f}_{N_i}$$

(ii) output due to N_{A1}

$$N_{o(ii)} = N_{A1}\cdot A_{p2}$$
$$= A_{p1}\,k.T.\Delta f\,(F_1 - 1).A_{p2}$$

(iii) output due to N_{A2}

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

Total output noise

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

$$F_{cascade} = \frac{N_o}{N_{o\,ideal}} = \frac{N_{oT}}{N_{o(i)}} = \frac{\cancel{A_{p1}A_{p2}kT\Delta f}\left(F_1 + \frac{F_2-1}{A_{p1}}\right)}{\cancel{A_{p1}A_{p2}kT\Delta f}}$$

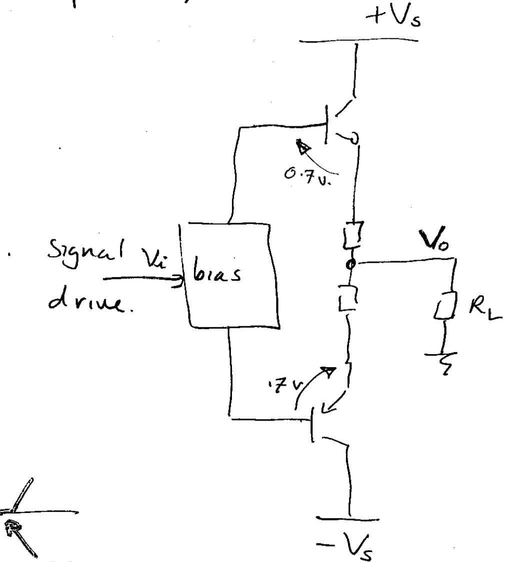
$$= F_1 + \frac{F_2 - 1}{A_{p1}}$$

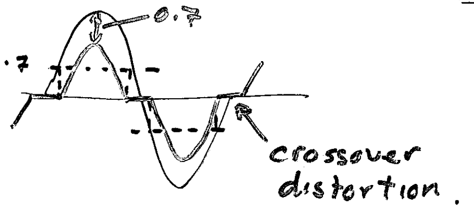
Amplifiers

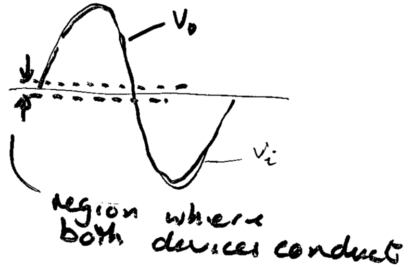
— 2 types of linear amp
  - — single ended
  - — double ended or push-pull.

(of interest in this module.

Double ended output stage

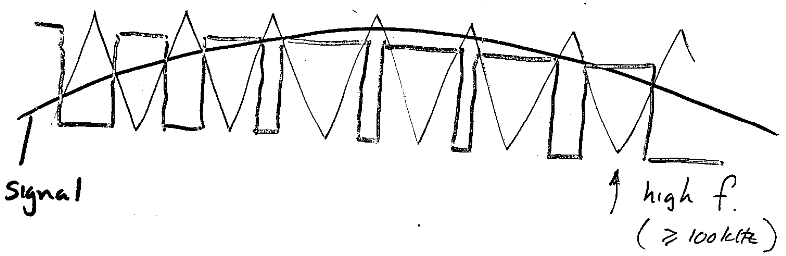


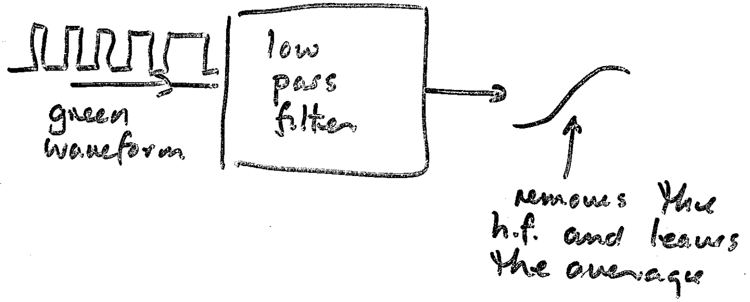




Class D

Class D





Designing a class B amp

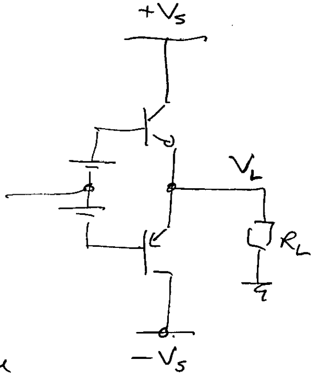
– given a spec which defines

P_{OUT} needed.

R_L into which P_{OUT} must be delivered.

Q! what value of ± Vs is needed.

Assume that V_L can reach a value $|V_s - \delta V|$ where



ΔV may be equal to 0 but may be a small value.

$$P_{out} = \frac{V_{LP}^2}{2R_L} \text{ (for a sinusoid)}$$

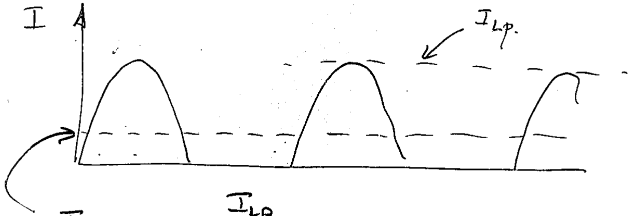
hence $V_{LP} = \sqrt{P_{out} \cdot 2 \cdot R_L}$.

to get V_S, simply add ΔV where it exists.

Peak load current [= peak output transistor current].

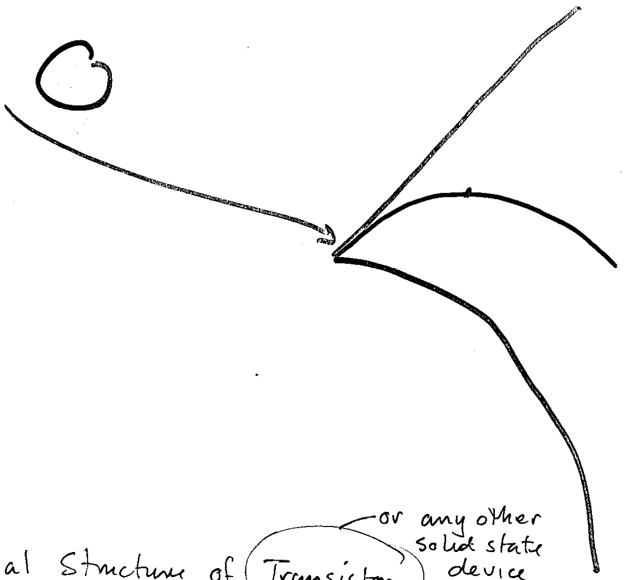
$$I_{LP} = \frac{V_{LP}}{R_L}$$

Supply current

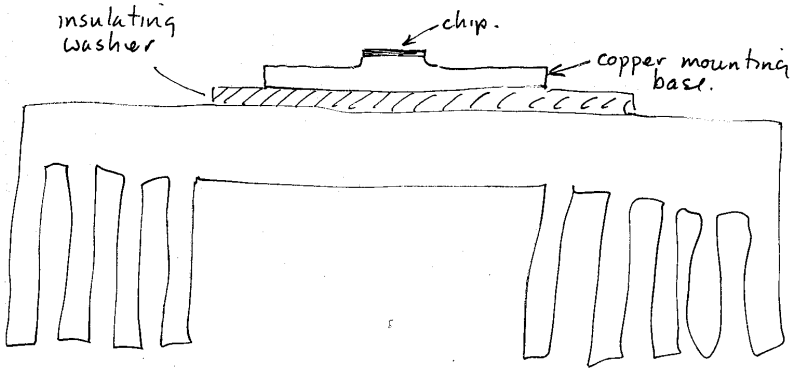


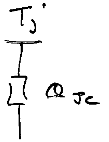
$$I_{AVE} = \frac{I_{LP}}{\pi}$$

Heat.

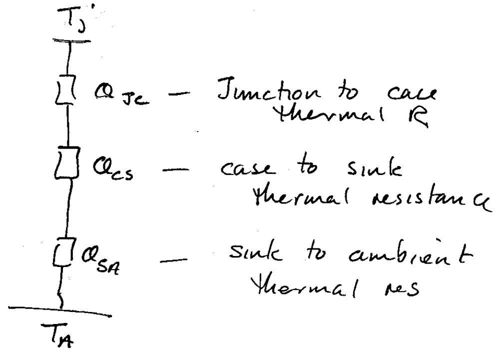


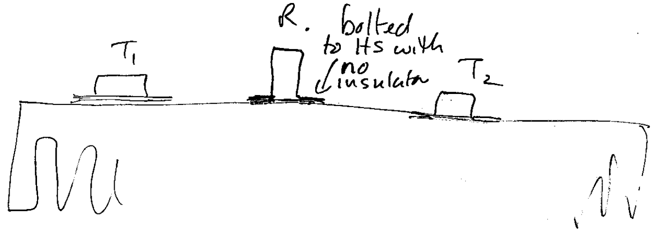
Thermal Structure of Transistor — or any other solid state device.

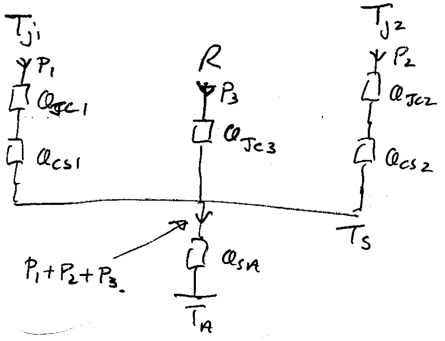




θ_{JC} — Junction to case thermal R


T_J'
θ_JC — Junction to case thermal R
θ_CS — case to sink thermal resistance
θ_SA — sink to ambient thermal res
T_A


T_1
R. bolted to HS with no insulator
T_2


T_J1
P_1
θ_JC1
θ_CS1
R
P_3
θ_JC3
T_J2
P_2
θ_JC2
θ_CS2
T_S
P_1+P_2+P_3
θ_SA
T_A