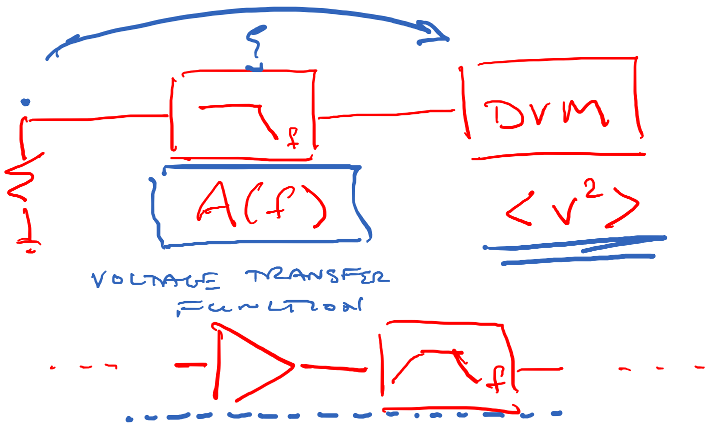
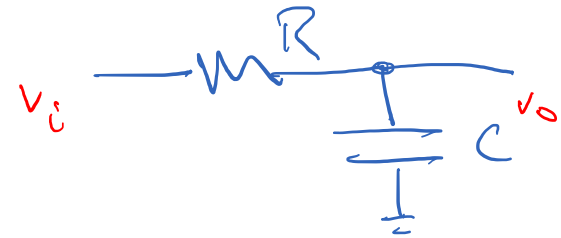
NOISE BANDWIDTH REVISITED

$S_v = 4k_BTR$

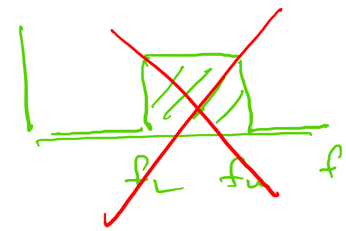
R @ T



e.g.



"BRICK WALL" FILTER



$A = \frac{v_o}{v_i}$

NOISE BANDWIDTH:

$$\Rightarrow \Delta f_N = \int |A(f)|^2 df$$

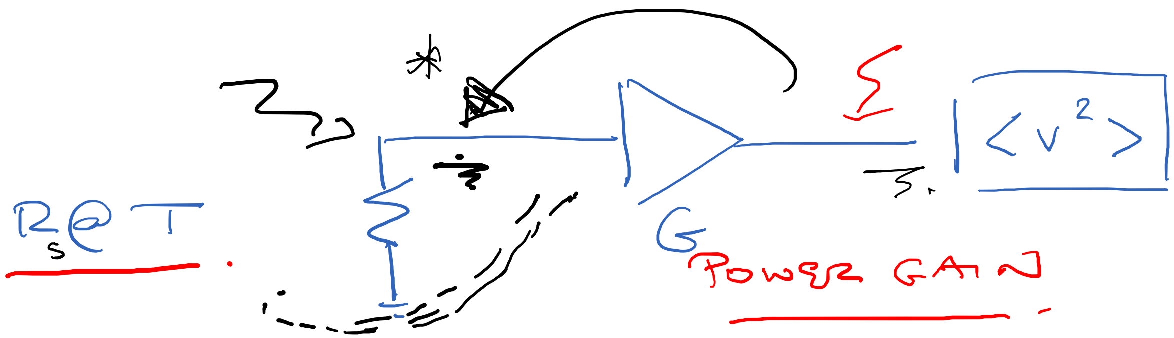
$$\langle v^2 \rangle = 4k_BTR\,\Delta f_N$$

$\tau = RC$

$$\rightarrow \Delta f_N = \frac{1}{4RC}$$

(COMPARE: $\Delta f_{3dB} = \frac{1}{2\pi RC}$)

AMPLIFIER ADDED NOISE



δx, δy

TOTAL FLUCTUATION $\left[\delta x^2 + \delta y^2\right]^{1/2}$

$\delta z^2 = \delta x^2 + \delta y^2$

ADDING NOISE INCOHERENTLY

OUTPUT: $\langle v^2 \rangle = G\left[4 k_B T R_S \Delta f_N\right] + \text{NOISE [AMP]}$.

$= G\left[4 k_B T R_S \Delta f_N + \text{AMP INPUT NOISE}\right]$

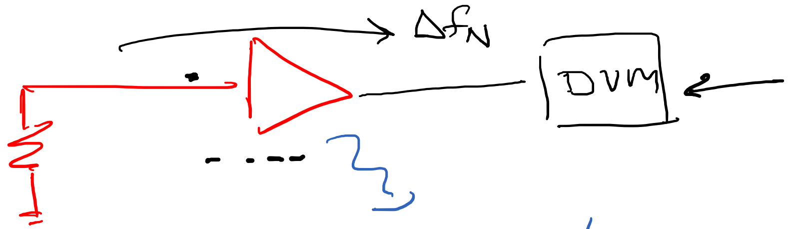
$= G\left[4 k_B R_S \Delta f_N \left(T + T_N\right)\right]$

→ NOISE TEMPERATURE T_N

FUNCTION OF f, OF R_S

EXAMPLE

$1\,k\Omega$ @ 300 K



$\rightarrow S_V \sim 1.7 \cdot 10^{-17} \frac{V^2}{Hz}$

$\rightarrow S_V^{1/2} \sim 4 \, nV/\sqrt{Hz}$

AMP w/ INPUT NOISE $1 \, nV/\sqrt{Hz}$

$S_{V, AMP} \simeq 10^{-18} \, V^2/Hz$.

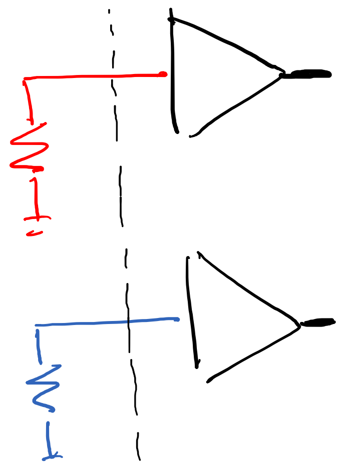
S_V TOTAL @ INPUT

$\simeq 1.8 \cdot 10^{-17} \, V^2/Hz$

[ADD INCOHERENTLY]

$$T_N = 300\,K \; \frac{10^{-18} \frac{V^2}{Hz}}{1.7 \cdot 10^{-17} \, V^2/Hz} = 18\,K$$

HOT LOAD / COLD LOAD



R@T_H $S_{v,\,HOT}$; $\langle v^2 \rangle_{HOT}$

R@T_C $S_{v,\,COLD}$; $\langle v^2 \rangle_{COLD}$

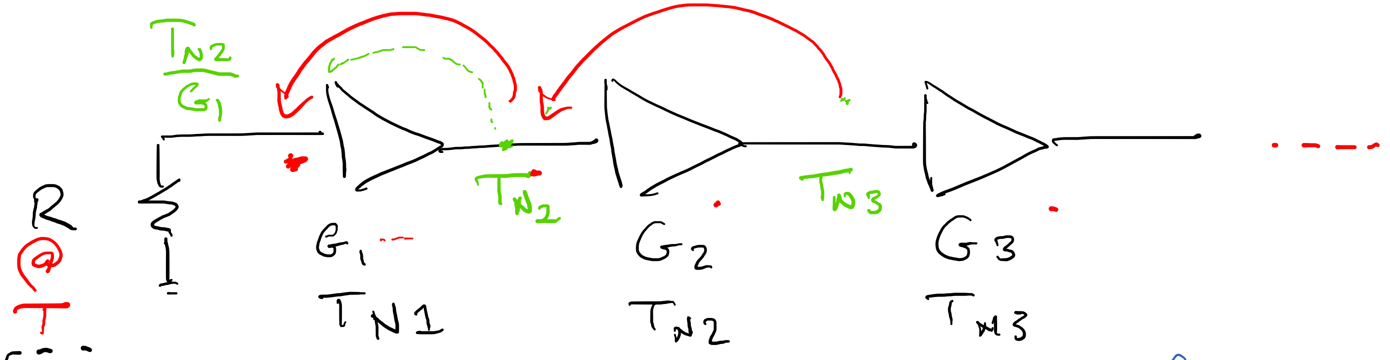
$$\frac{\langle v^2 \rangle_H}{\langle v^2 \rangle_C} = \frac{\cancel{4k}(T_H + T_N)\cancel{R\Delta f_N}}{\cancel{4k}(T_C + T_N)\cancel{R\Delta f_N}}$$

$$\frac{\langle v^2 \rangle_H}{\langle v^2 \rangle_C} = \frac{S_{v,\,HOT}}{S_{v,\,COLD}} = \frac{T_H + T_N}{T_C + T_N}$$

SELF-CALIBRATING ?

NOTE: T_x GENERALLY A FUNCTION OF FREQUENCY.

T_N of Cascaded Amplifiers



Power gain G

Noise power @ output $\sim G_3\left\{G_2\left[G_1\left(T+T_{N1}\right)+T_{N2}\right]+T_{N3}\right\}$

Refer to input

$$\boxed{T_{N,\text{total}} = T_{N1} + \frac{T_{N2}}{G_1} + \frac{T_{N3}}{G_1 G_2} + \dots}$$

NOISE FIGURE

$$\rightarrow \quad NF = 10\log_{10}\left(\frac{T+T_N}{T}\right) \qquad \underline{T = 300K}$$

$NF \sim 1dB \iff 80K\ T_N$

$3dB \iff \underline{300K}\ T_N$

example

CASCADED AMP

3000K >> 80K

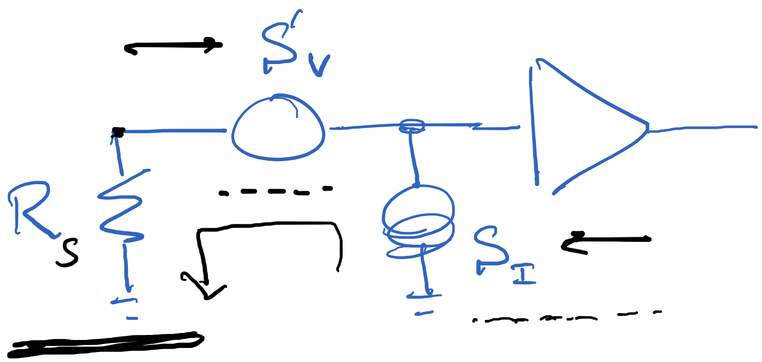
G: 30dB

HEMT

T_N @ 3K $\qquad T_N \sim 80K$

$$T_{N,\text{total}} = 3K + \frac{80K}{10^3} \sim \underline{3.08K}$$

AMPLIFIER NOISE ... MORE DETAILED



$$\boxed{S_V + S_I R^2 = 4 k_B T_N R_S}$$

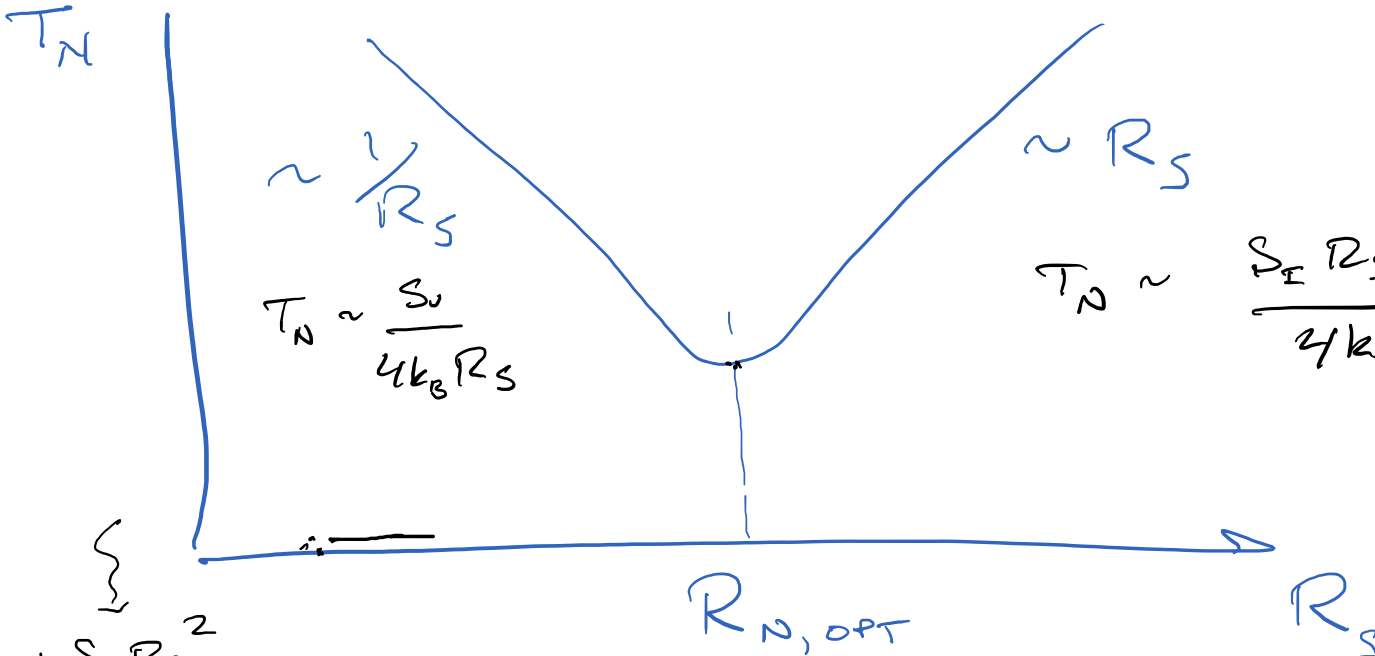
AMP CONTRIBUTION TO NOISE:

$$\longrightarrow \quad S_V + S_I R_S^2$$

AMP NOISE TEMPERATURE: $\longrightarrow$

$$\boxed{T_N = \frac{S_V + S_I R_S^2}{4 k_B R_S}}$$

DEPENDENCE ON SOURCE RESISTANCE

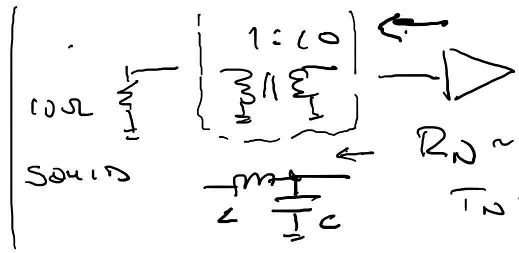


$$T_N \sim \frac{S_V}{4 k_B R_S}$$

$$T_N \sim \frac{S_I R_S}{4 k_B}$$

$$T_N = \frac{S_V + S_I R_S^2}{4 k_B R_S}$$

$$\rightarrow T_N = \frac{S_V + S_I R^2}{4kR}$$



$R_N \sim 1k\Omega$

$T_N \sim 10K$

$$\frac{\partial T_N}{\partial R} = 0 \implies -\frac{S_V}{R^2} + S_I = 0$$

$$\implies \underline{R_{N,OPT} = \sqrt{\frac{S_V}{S_I}}}$$

→ OPTIMAL SOURCE RESISTANCE FOR LOW ADDED AMPLIFIER NOISE

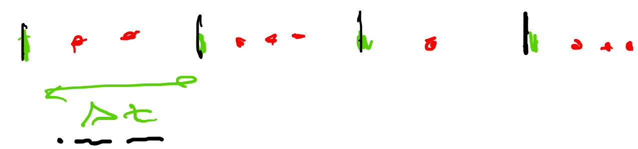
NOISE AMPLITUDE e_n OR v_n → $nV/\sqrt{Hz}$

i_n → $pA/\sqrt{Hz}$

$$\underline{R_{N,OPT} = \frac{e_n}{i_n}}$$

OTHER NOISE PROCESSES

SHOT NOISE $S_I = 2eI \Rightarrow$ DUE TO DISCRETENESS OF CHARGE



POISSON STATISTICS

$\rightarrow$ MEAN-SQUARE CHARGE FLUCTUATION

$$\langle \delta I^2 \rangle = \frac{Ne^2}{\Delta t^2} = \frac{I\,e}{\Delta t}$$

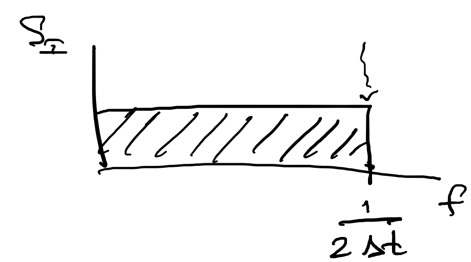
$N \rightarrow$ MEAN # OF CHARGES PER INTERVAL.

$$I = \frac{Ne}{\Delta t}$$

BUT $\langle \delta I^2 \rangle = S_I \frac{1}{2\Delta t}$

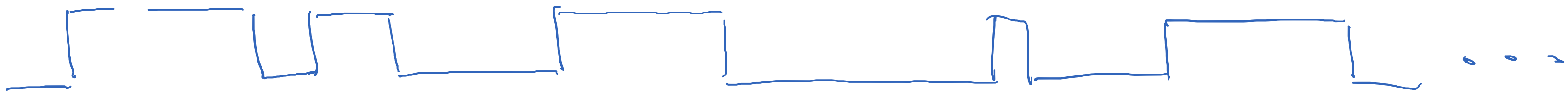
$\underbrace{\frac{1}{2\Delta t}}$ NYQUIST FREQUENCY

$\langle \delta I^2 \rangle = \int S_I \, df$



$\therefore \; S_I = 2eI$

TELEGRAPH NOISE



TWO-STATE SYSTEM

MEAN DWELL TIME τ

RECALL, $S(f) = \int \langle v(t)\, v(0) \rangle\, e^{-2\pi j f t}\, dt$

$$\langle V(t) V(0) \rangle = +1 \cdot P(\text{EVEN}) - 1\, P(\text{ODD})$$

$$P_n(\lambda, t) = e^{-\lambda} \frac{\lambda^n}{n!}$$

$$\langle v(t)\, v(0) \rangle = e^{-\lambda} \left\{ \sum_{n\ \text{EVEN}} \frac{\lambda^n}{n!} - \sum_{n\ \text{ODD}} \frac{\lambda^n}{n!} \right\} = e^{-2\lambda}$$

$$\lambda = t/\tau$$

$$\therefore \langle v(t)\, v(0) \rangle = e^{-2t/\tau}$$

$$S(f) = \int e^{-2t/\tau}\, e^{-2\pi j f t}\, dt$$

$$S(f) = \frac{\tau}{1 + 4(2\pi f \tau)^2}$$