

$$S_{V_o}(f) = \frac{4kTR}{1 + (2\pi fCR)^2}$$

$$\overline{V_o^2} = \frac{kT}{C}$$

(mean-square)



$$S_{V_n} |H(j2\pi f)|^2$$

mean sq.

$$\int_0^{\infty} S_{V_n}(f) |H(j2\pi f)|^2 df$$

$$S_o \int_0^{\infty} |H(j2\pi f)|^2 df$$

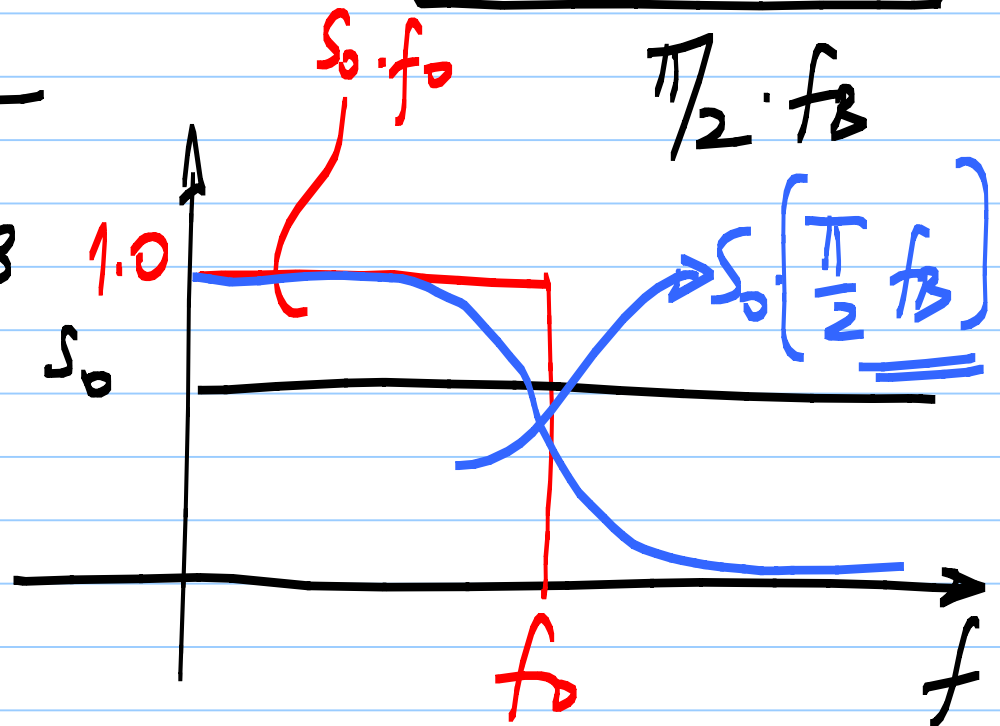
white noise driving a filter $H(s)$

$$\% \text{ mean squared value} = S_0 \int_0^{\infty} |H(j2\pi f)|^2 df$$

$$H(j2\pi f) = \frac{1}{1 + jf/f_B}$$

f_B : 3dB bandwidth

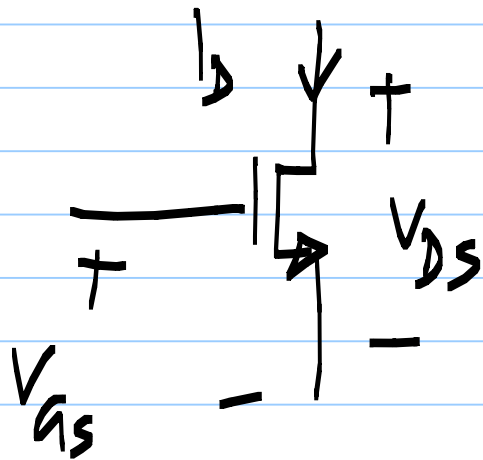
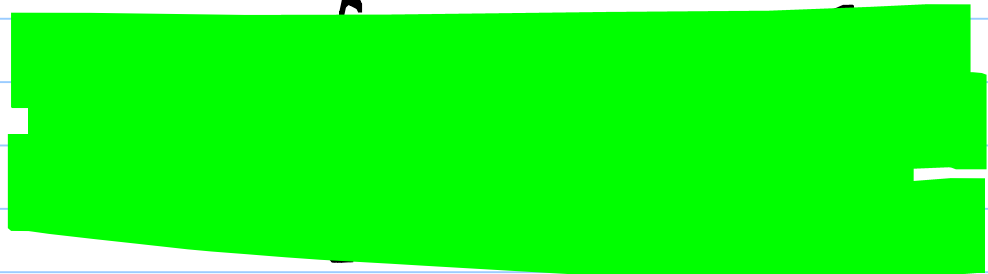
$$\left[\frac{1}{2\pi RC} \right]$$



$\frac{\pi}{2} f_B$: Noise bandwidth of a first order filter of $-3dB$ $bw = f_B$

Noise models:

0 $\frac{V_{GS} < V_T$



$I_D =$

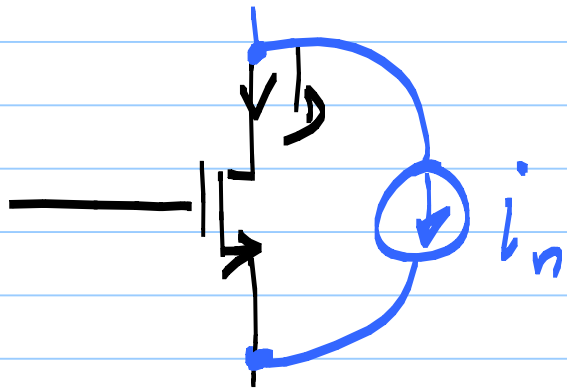
$V_{GS} > V_T, V_{DS} < V_{GS} - V_T$

Saturation

$$\frac{\mu_n C_{ox}}{2} \frac{W}{L} [(V_{GS} - V_T)^2]$$

$V_{GS} - V_T, V_{GS} > V_{GS} - V_T$

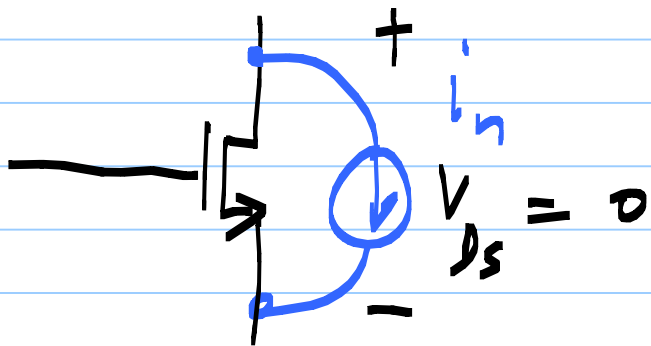
Noise in saturation region



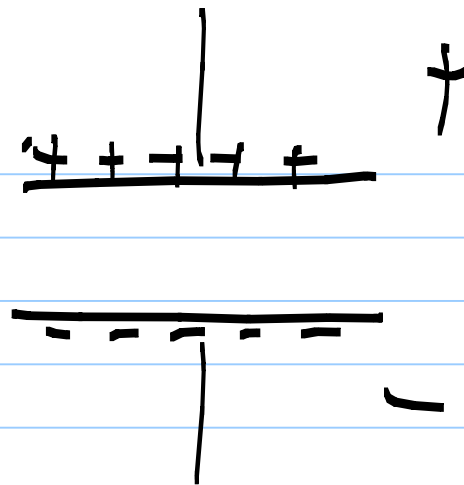
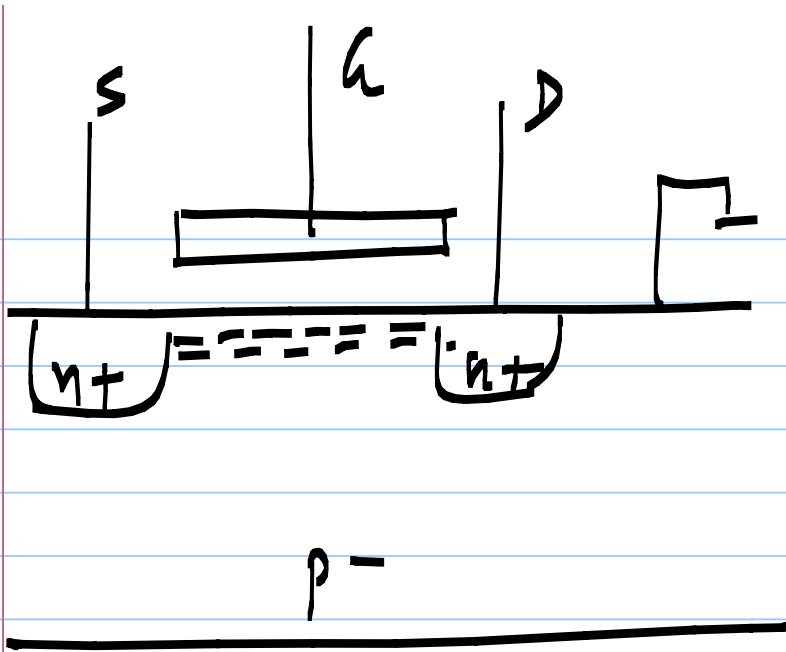
$$S_{i_n} = \frac{8}{3} kT \cdot g_m$$

(Thermal noise: white)

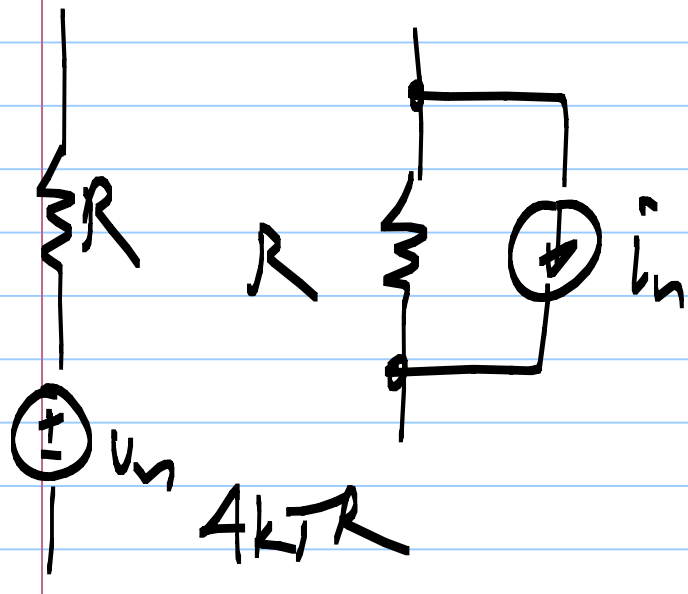
Noise in triode region



$$S_{i_n} = 4kT \cdot g_{ds}$$



$$i_n = v_n / R$$



$$S_{i_n} = \frac{S_{v_n}}{R^2} = \frac{4kT}{R}$$

$$4kTR$$

MOS transistor noise

$$4kT \cdot \frac{\mu \cdot |Q_I|}{L^2}$$

μ : mobility

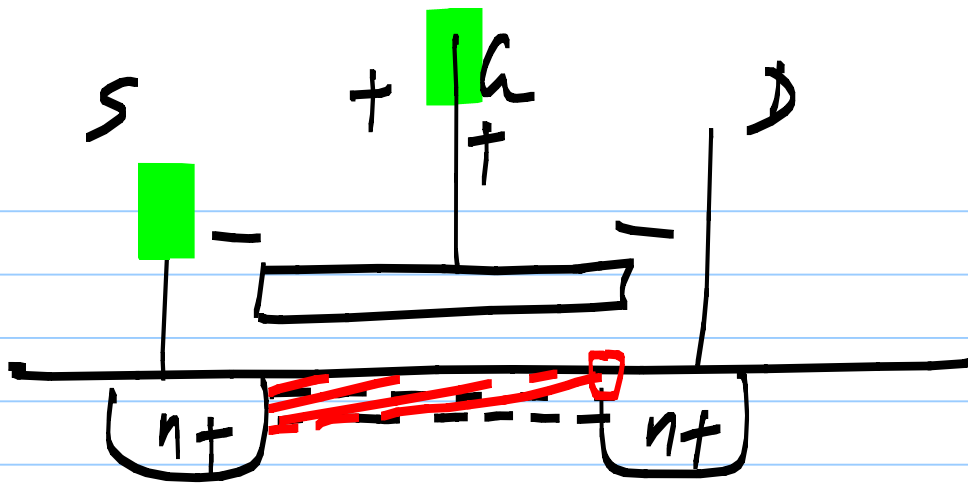
$|Q_I|$: Inversion charge

L : length

$$|Q_I|: C_{ox} WL (V_{GS} - V_T)$$

($V_{DS} = 0$)

$$|Q_I|: \frac{2}{3} C_{ox} WL (V_{GS} - V_T) \quad [\text{saturation region}]$$



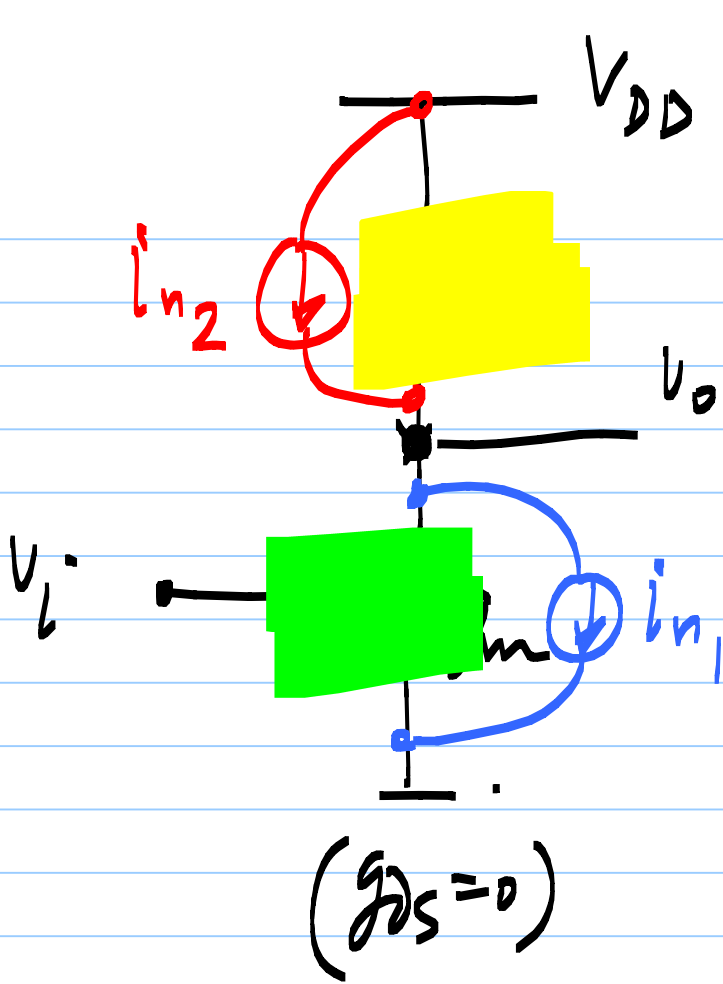
Triode: $V_{GS} > V_T$
 $V_{DS} < V_{GS} - V_T$

$V_{GD} > V_T$

Sat: $V_{GS} > V_T$

$V_{DS} > V_{GS} - V_T$

$V_{GD} < V_T$



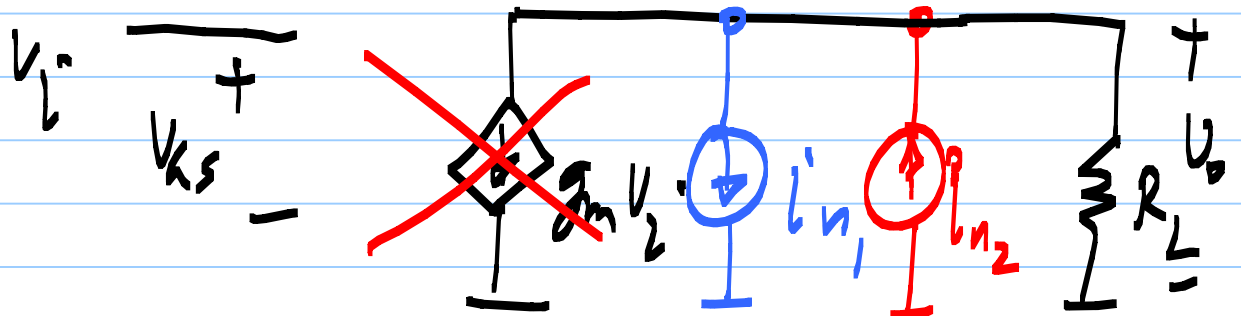
$$S_{V_o} =$$

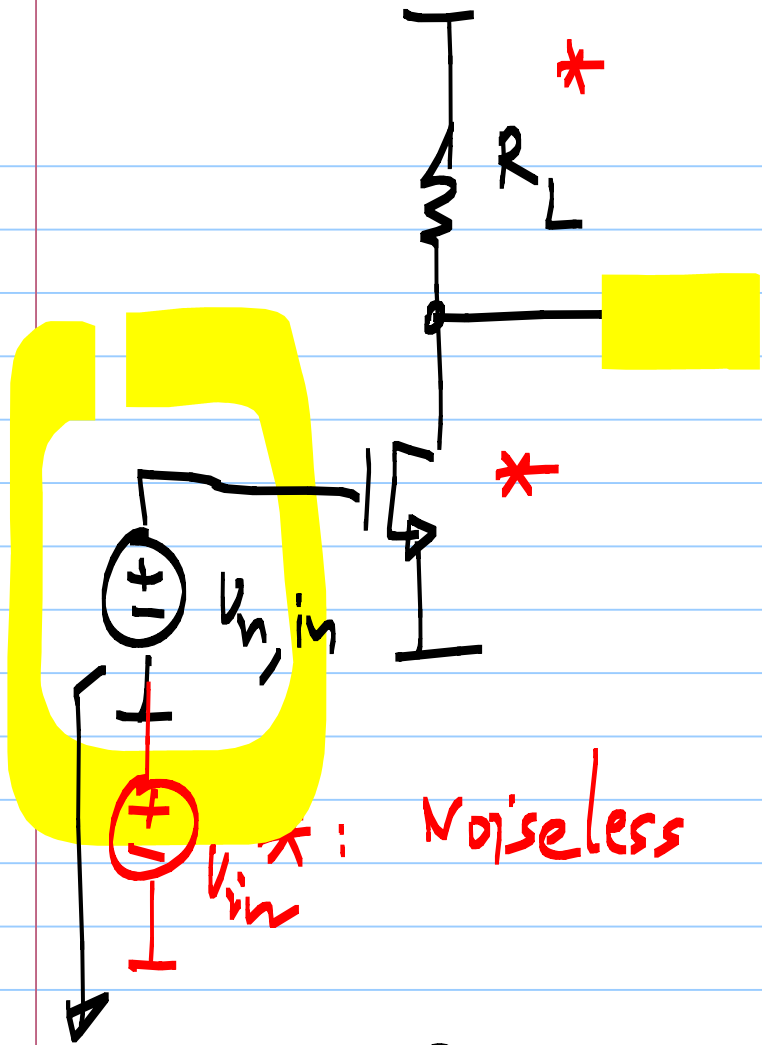
+

$$= 4kTR_L \left(1 + \frac{2}{3} g_m R_L \right)$$

$$S_{V_o} = S_{i_{n2}} R_L + S_{i_{n1}} R_L$$

$$V_o = i_{n2} R_L - i_{n1} R_L$$



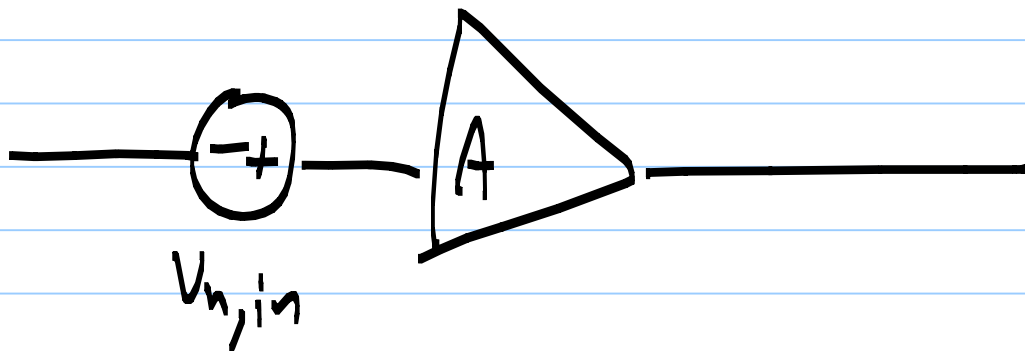
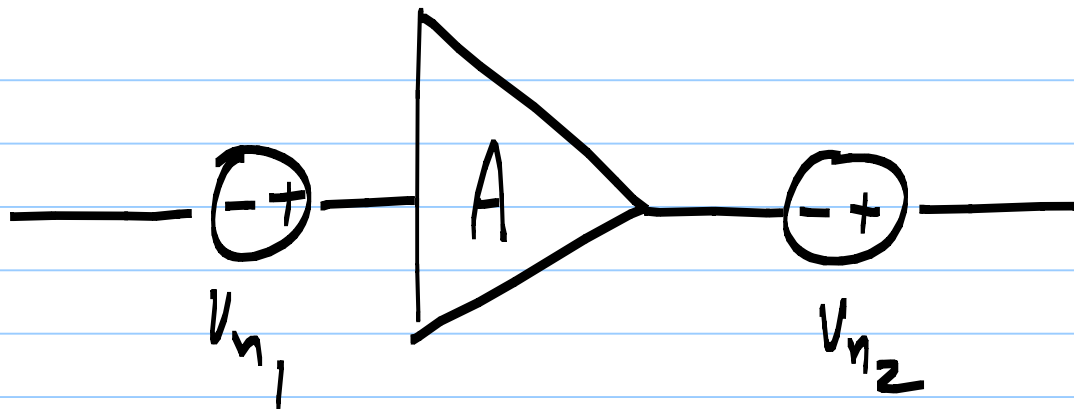


Input referred noise

$$S_{v_{n,in}} = \frac{S_{v_{n,out}}}{|H|^2}$$

Input ref. noise spectral density

$$= \frac{8}{3} \frac{kT}{g_m} + \frac{4kT}{g_m^2 R_L}$$



$$= v_{n1} + \frac{v_{n2}}{A} ; S_{v_{n,in}} = S_{v_{n1}} + S_{v_{n2}} \cdot \frac{1}{A^2}$$