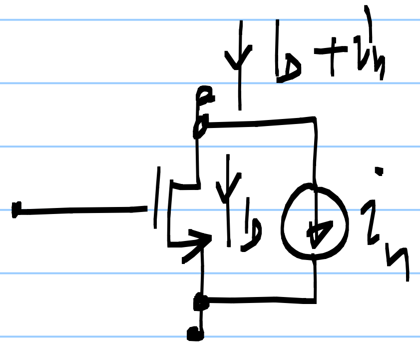
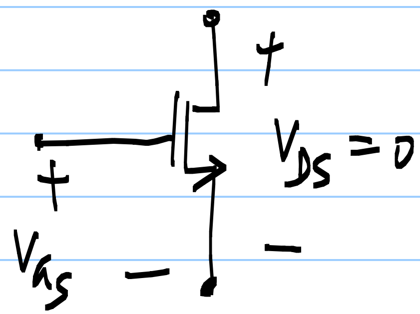
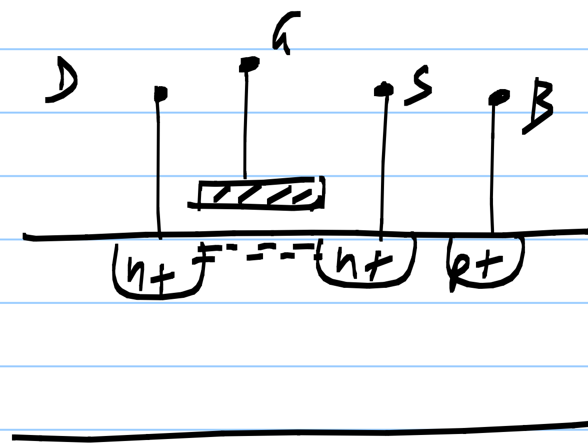
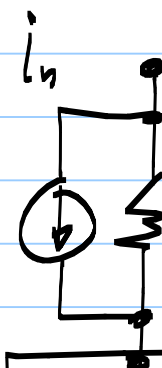
# Lecture 25: MOS transistor noise




Drain current $= I_D(V_{GS}, V_{DS}) + i_n$




$$G_{mos} = \mu C_{ox} \frac{W}{L}(V_{GS} - V_T)$$

$$\boxed{4kT \cdot G_{mos} = S_{i_n}}$$

MOS transistor's current noise in the triode region

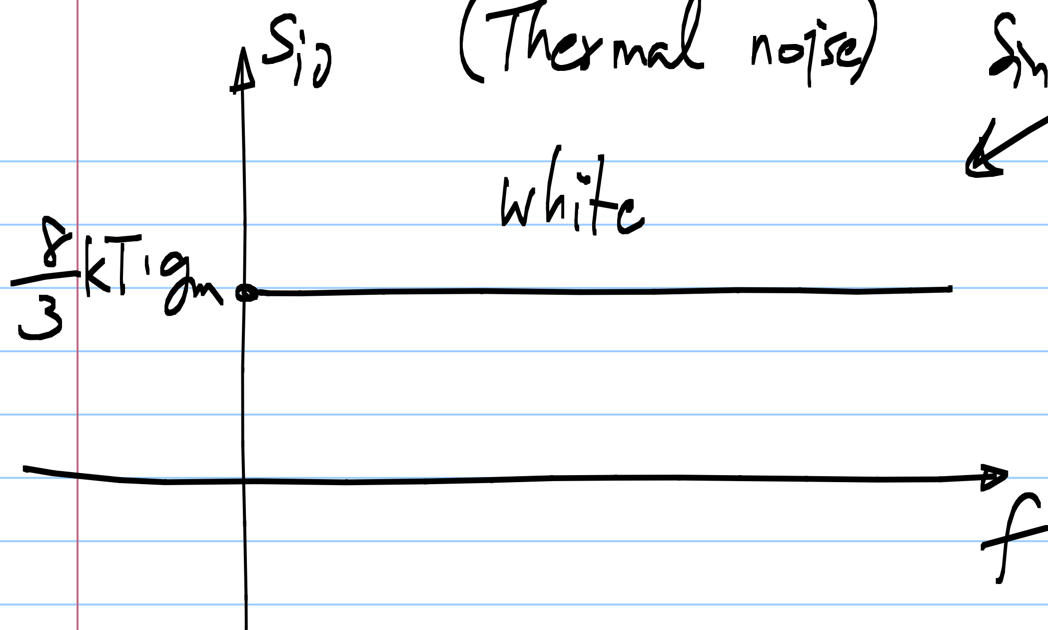
$S_{i_n} = 4kT \cdot G_{MOS}$ $\qquad G_{MOS} = \mu C_{ox} \frac{W}{L}(V_{GS}-V_T)$

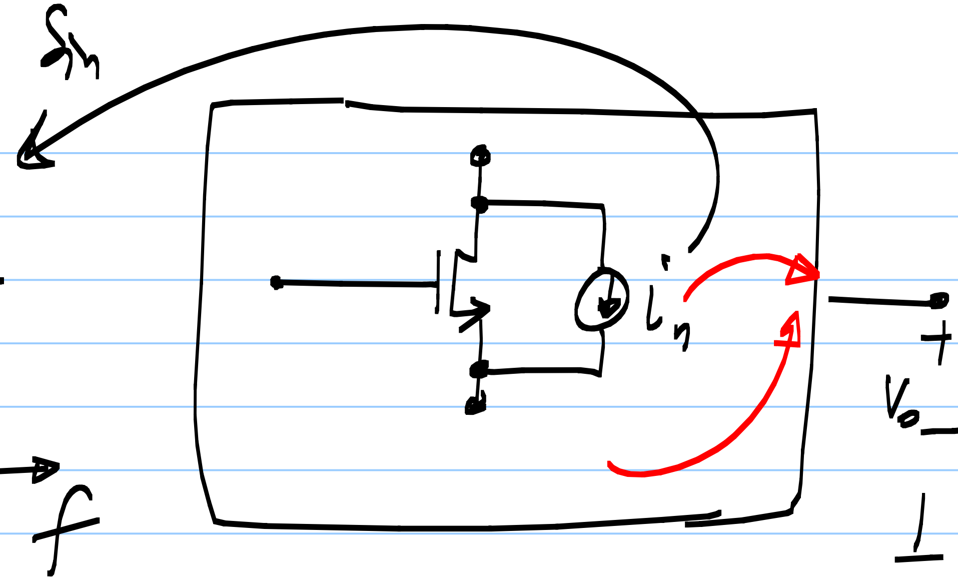
In the saturation region,

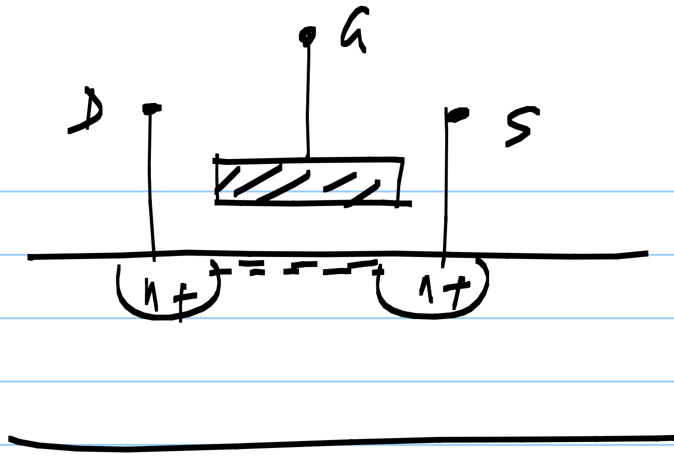
✓ $S_{i_n} = \frac{8}{3} kT \cdot g_m \Big|_{\text{OPERATING POINT}}$ $\qquad g_m = \mu C_{ox} \frac{W}{L}(V_{GS}-V_T)$

$S_{i_n} = \frac{4kT\mu|Q_I|}{L^2}$ } in all regions

(Thermal noise)

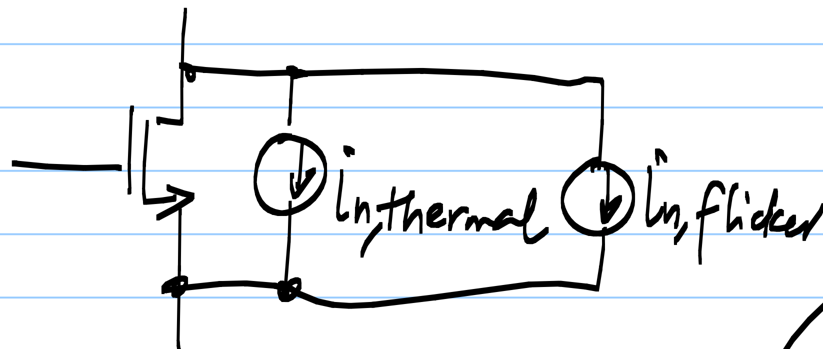


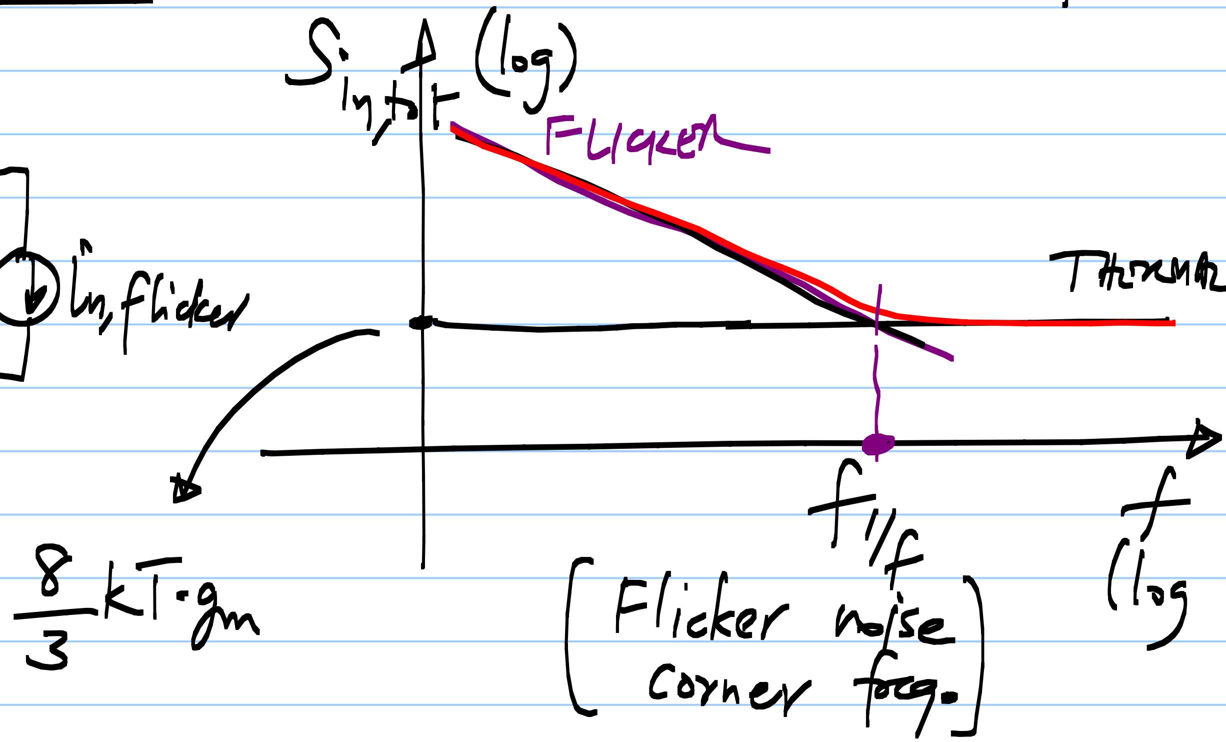





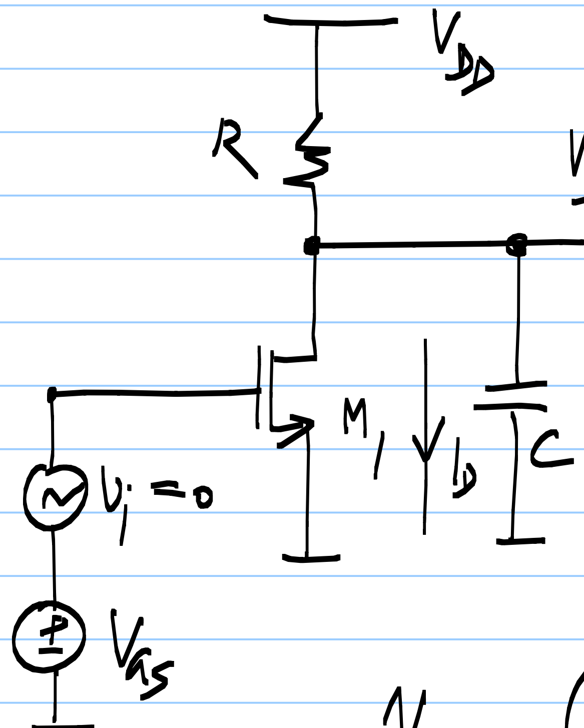

## Flicker noise:

$$S_{i_n,\,flicker} = K \cdot \frac{I_D}{L^2} \cdot \frac{1}{f}$$

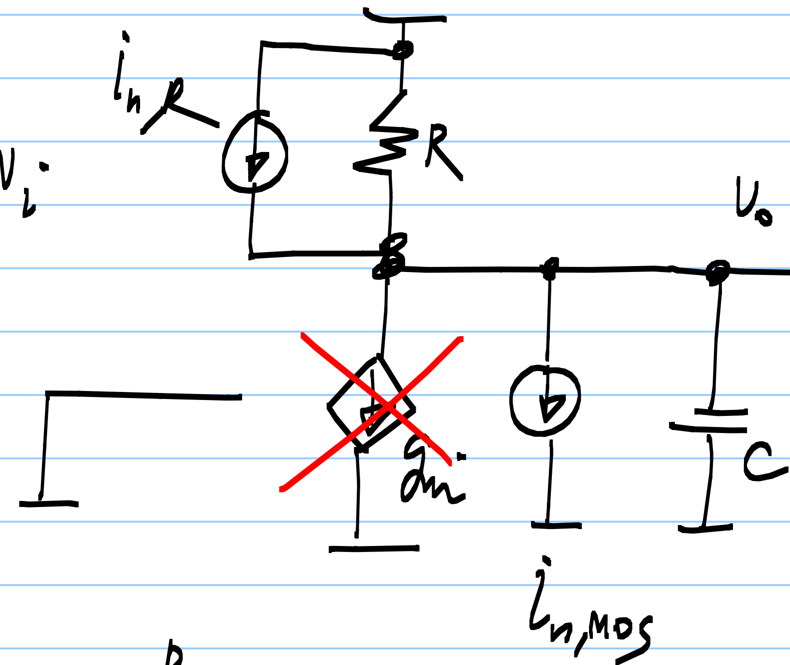


# Noise in a common source amplifier:



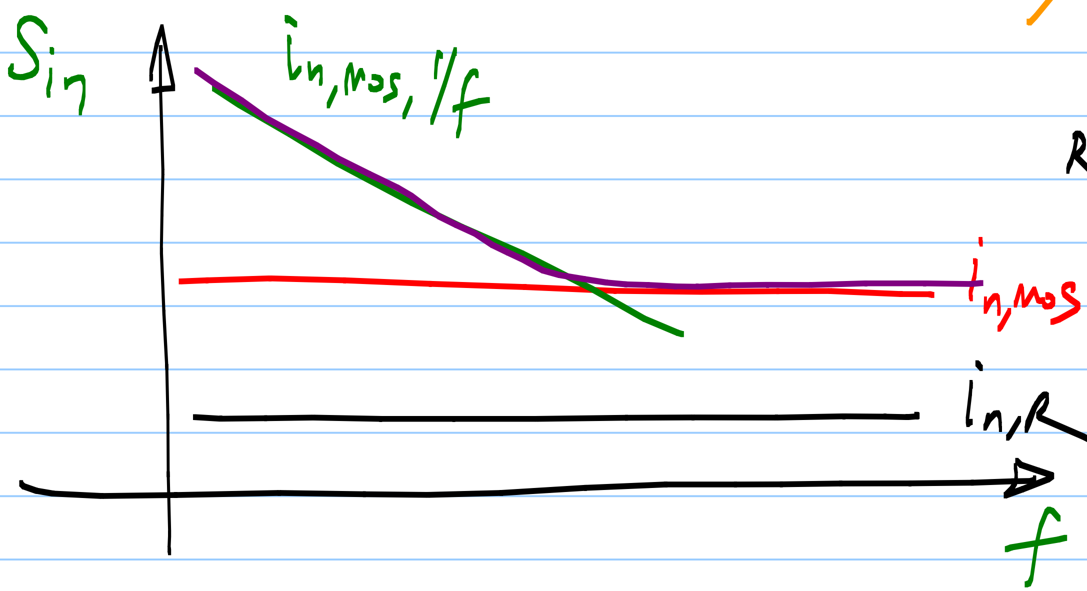

$V_{DD} - I_D R - (g_m R) v_i$

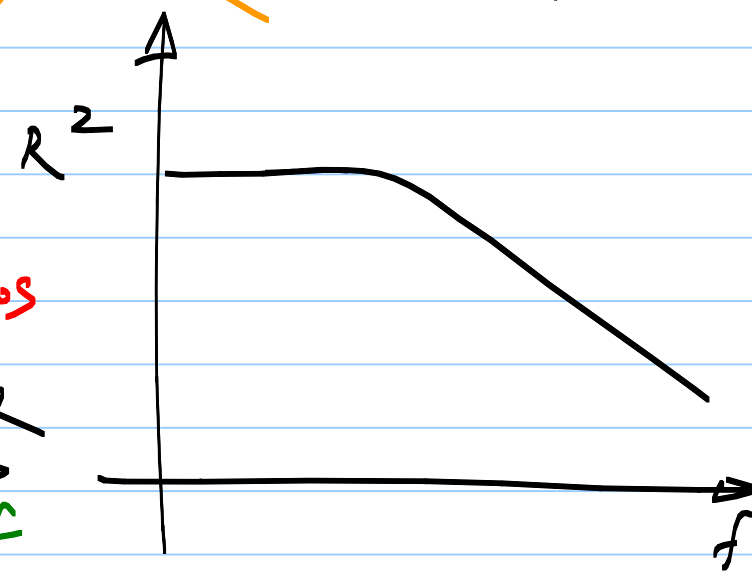



$$V_o = \left(I_{N,MOS} - I_{N,R}\right) \frac{R}{1 + sCR}$$

$$S_{v_o}(f) = \left(S_{i_{n,R}} + S_{i_{n,MOS}}\right)\frac{R^2}{1+4\pi^2 f^2 C^2 R^2}$$

$$S_{v_o}(f) = \left(\frac{4kT}{R} + \frac{8}{3}kT g_m + \cancel{K\cdot\frac{1}{L^2}\cdot\frac{1}{f}}\right)\frac{R^2}{1+4\pi^2 f^2 C^2 R^2}$$



$$S_{v_o}(f) = \left(\frac{4kT}{R} + \frac{8}{3}kT\cdot g_m\right)\cdot\frac{R^2}{1+4\pi^2 f^2 C^2 R^2}$$

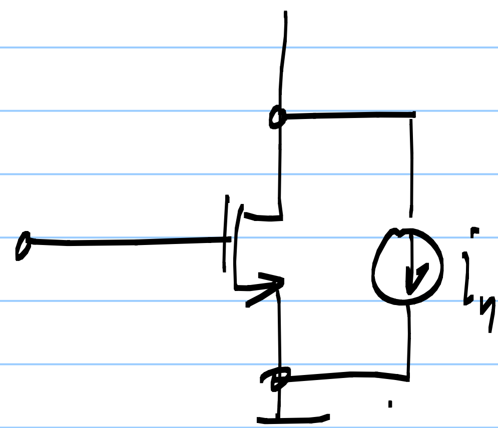
$$= \frac{8}{3}kT g_m\left(1+\frac{3}{2}\cdot\frac{1}{g_m R}\right)\frac{R^2}{1+4\pi^2 f^2 C^2 R^2}$$

MOS RESISTOR

$$\overline{v_n^2} = \int_0^\infty S_{v_o}(f)\,df = \frac{8}{3}kT g_m\left(1+\frac{3}{2}\cdot\frac{1}{g_m R}\right)\cdot\frac{R^2}{4RC}$$

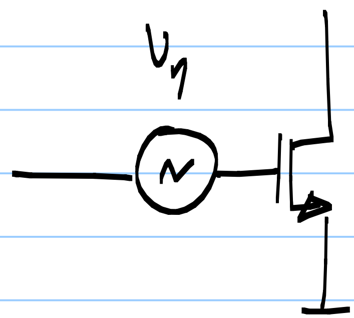
$$= \underbrace{\frac{2}{3}\cdot\frac{kT}{C}\cdot g_m R\left(1+\frac{3}{2}\cdot\frac{1}{g_m R}\right)}$$

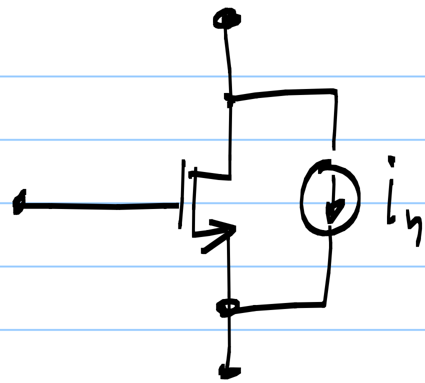
$$S_{i_n} = \frac{8}{3} kT \cdot g_m$$

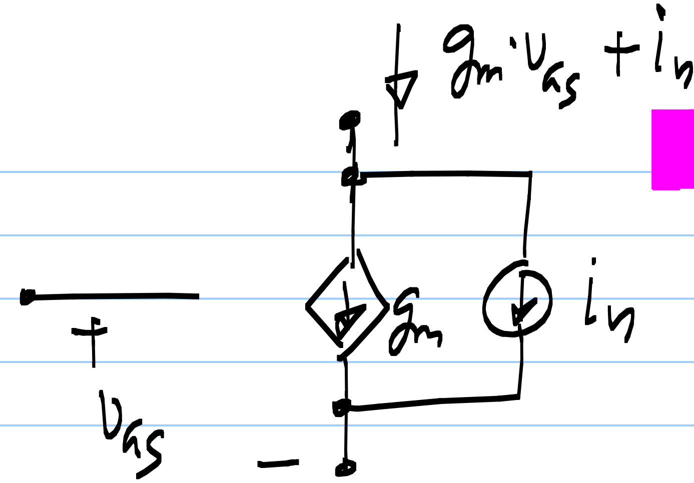


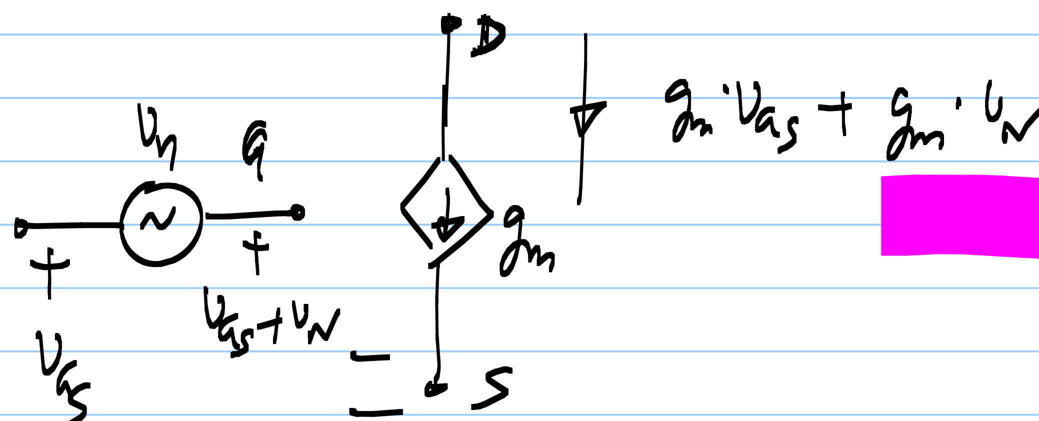

$$S_{v_n} = \frac{8}{3} \cdot \frac{kT}{g_m}$$

$=$

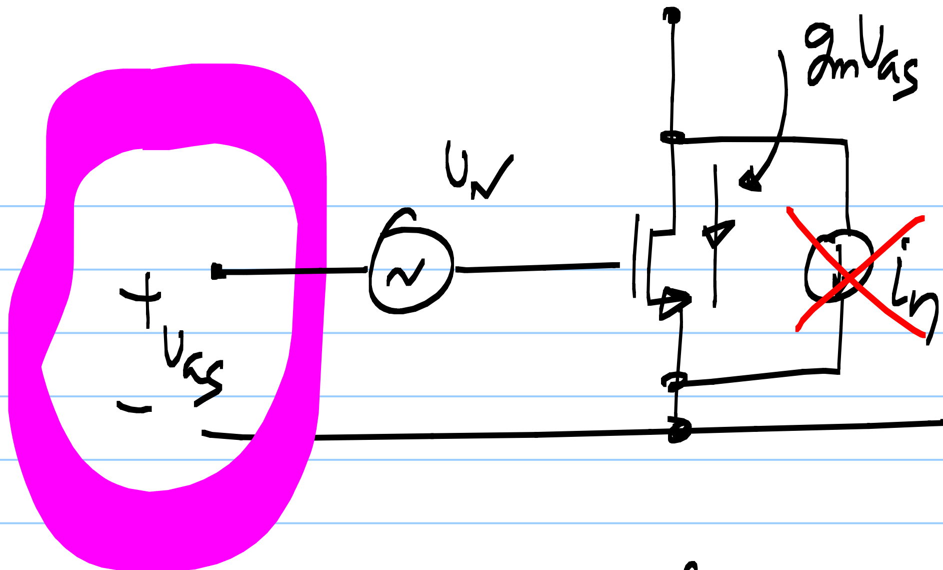




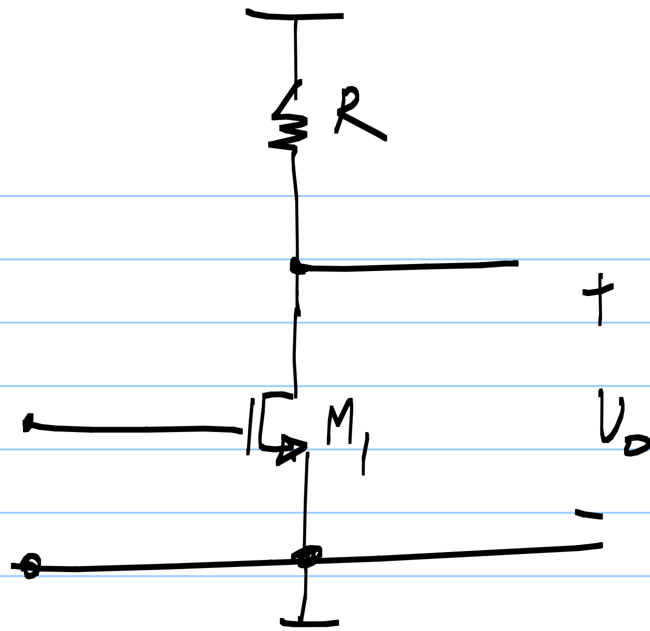

$$\boxed{i_n = g_m v_n}$$

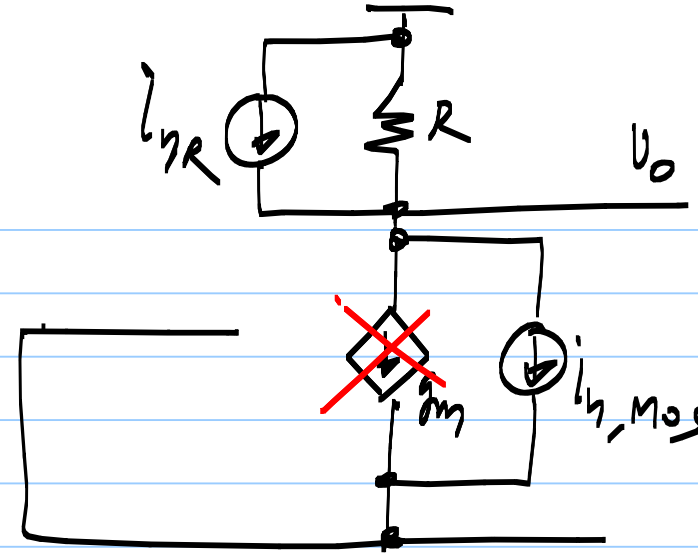



$$v_n = i_n / g_m$$

$$S_{v_n} = \frac{S_{i_n}}{g_m^2} = \frac{8}{3} \cdot \frac{kT}{g_m}$$

| | MOS | R |
|---|---|---|
| $i_n$ | $\frac{8}{3} kT \cdot g_m$ | $4kT \cdot G = 4kT/R$ |
| $v_n$ | $\frac{8}{3} kT \frac{1}{g_m}$ | $4kT \frac{1}{G} = 4kT \cdot R$ |

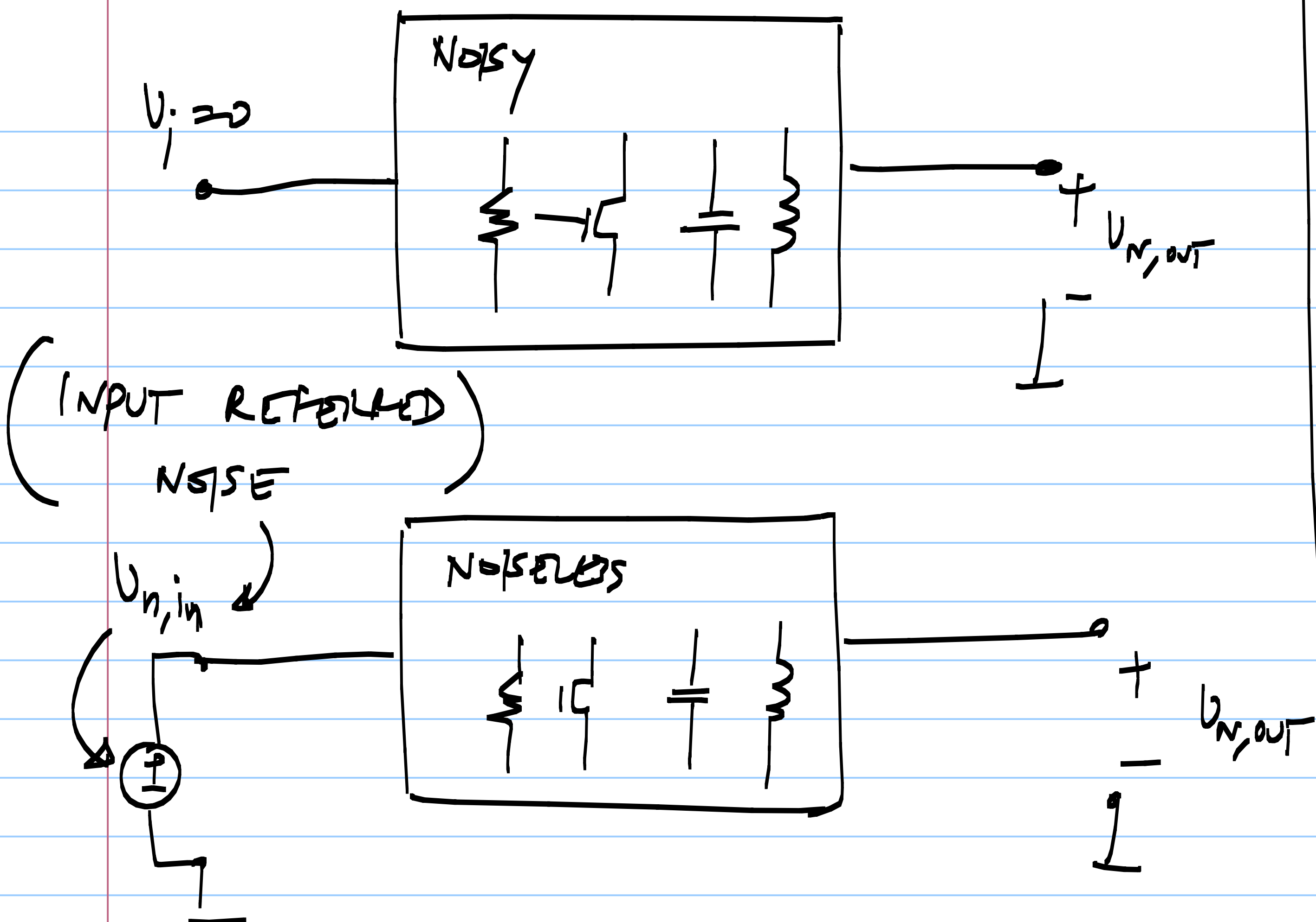


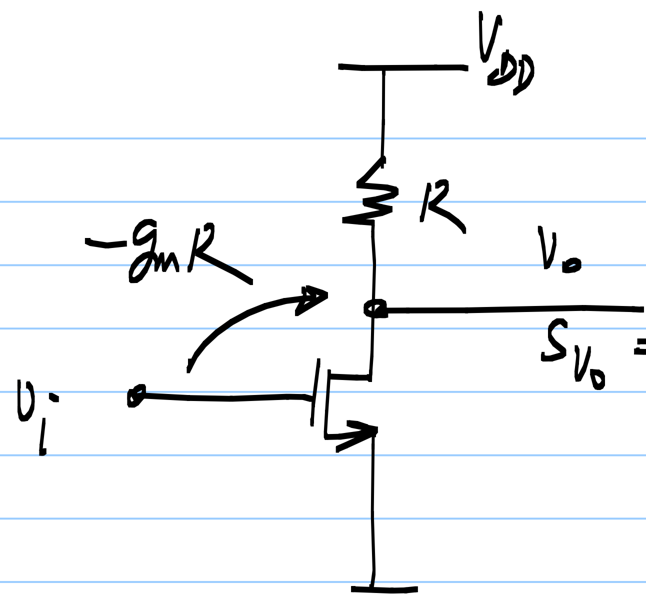

$$v_o = (i_{n,R} - i_{n,mos})\,R$$

$$S_{v_o} = \left(S_{i_{n,R}} + S_{i_{n,mos}}\right) R^2$$

$$= \left(\frac{4kT}{R} + \frac{8}{3} kT g_m\right) R^2$$




$v_{n,in}$: The input voltage that results in $v_{n,out}$ in a noiseless version of the circuit

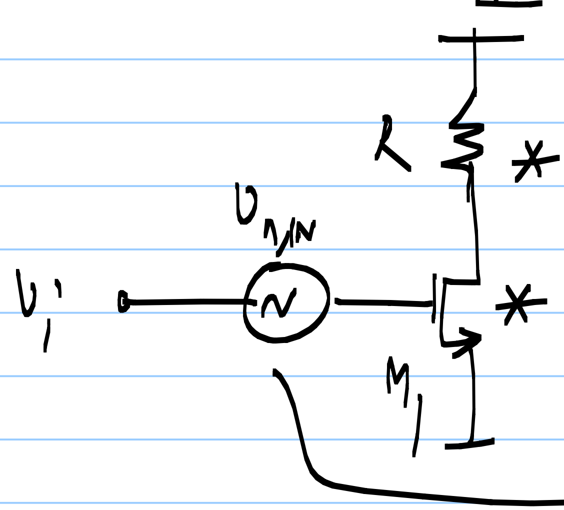



$$v_o = -g_m R \cdot v_i$$

$$v_{n,out} = -g_m R \cdot v_{n,in}$$

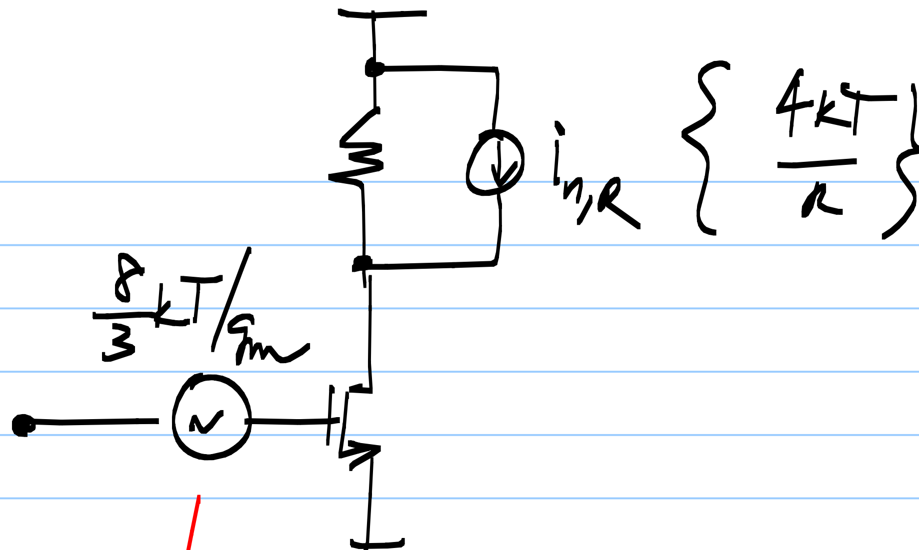
$$S_{v_o} = \left(\frac{4kT}{R} + \frac{8}{3} kT g_m\right) R^2$$

$$S_{v_{n,in}} = \frac{S_{v_o}}{(g_m R)^2}$$




$$= \underbrace{\frac{8}{3}\frac{kT}{g_m}}_{\text{MOS noise referred to } V_{GS}} + \frac{4kTR}{(g_m R)^2}$$

$$\frac{4kT/R}{g_m^2}$$




$$S_{v_{in}} = \frac{8}{3} \frac{kT}{g_m} + \frac{4kT/R}{g_m^2}$$