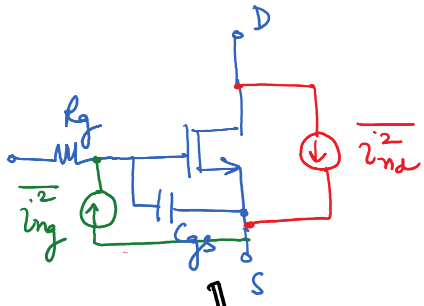
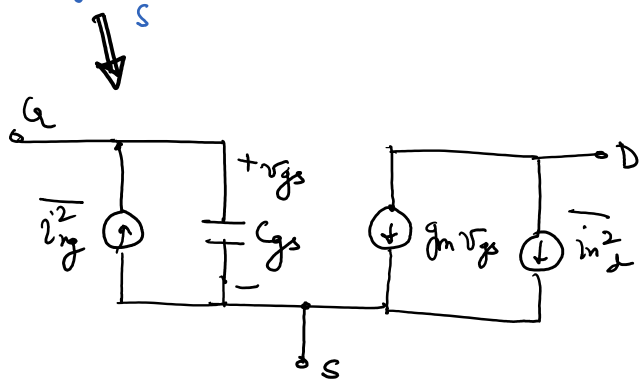
ECE 513 - Lecture 15

Tuesday, October 9, 2018 9:35 AM

(T. H. Lee's Book)

Two-port Noise of MOSFET





$\overline{i_{ng}^2}$ is not due to R_g

↳ Thermal noise of the fluctuating channel which couples into the gate terminal, leading to noisy gate current.

$$\overline{i_{nd}^2} = 4kT\gamma\, g_{do}\,\Delta f + \frac{K_1}{f}\Delta f$$

γ → Excess noise factor $= \frac{2}{3}$ for long-channel

$\frac{K_1}{f}\Delta f$: flicker noise

g_{do} → g_{ds} at $V_{DS}=0$ $\simeq k'_n \frac{W}{L}(V_{GS}-V_{THN})$ for long-channel CMOSFET

"Van der Ziel model"

$$\overline{i_{ng}^2} = 4kT\delta\, g_g\,\Delta f$$

↳ $g_g = \dfrac{\omega^2 C_{gs}^2}{5 g_{do}}$ ← noise coupled through Cgs

Correlation Coefficient:

$$c \triangleq \frac{\overline{i_{ng} \cdot i_{nd}^{*}}}{\sqrt{\overline{i_{ng}^{2}} \cdot \overline{i_{nd}^{2}}}}$$

for long channel $c = -j0.395 \simeq -j0.4$

* in short channel CMOS its within 2x range of the long-channel value

Assume:

* c remains at its long-channel value
* Neglect thermal noise due to the resistive gate material (R_g)
* Neglect C_{gd} to simplify derivation

* Need to find the two-port ~~IEEE~~ parameters

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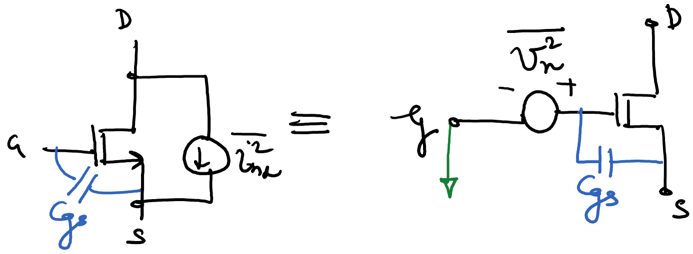
$G_{s,opt}$, $B_{s,opt}$, F_{min}, G_u, R_n

Reflect the drain noise current to the gate (input) side



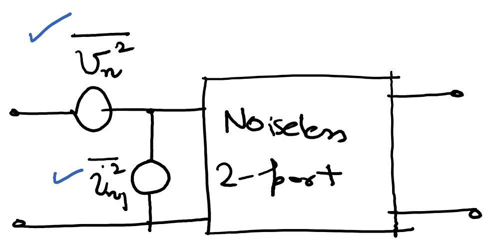
$$v_n = \frac{i_{nd}}{g_m} \quad \leftarrow i_d = g_m v_{gs}$$

$$\Rightarrow \overline{v_n^2} = \frac{\overline{i_{nd}^2}}{g_m^2}$$

$$\overline{v_n^2} = \frac{4kT\gamma g_{do} \Delta f}{g_m^2}$$

we see here that this input noise voltage, v_n, is correlated with the drain noise current (and also in the same phase).

$$\boxed{R_n \triangleq \frac{\overline{v_n^2}}{4kT\Delta f} = \frac{\gamma g_{do}}{g_m^2}}$$



* Also need to find $\overline{i_{n_1}^2}$ due to the drain noise

To find $v_n \Rightarrow$ we short circuit the input port

To find $i_n \Rightarrow$ we open circuit the input port

$$\overline{i_{n_1}^2} = \frac{\overline{i_{nd}^2} (j\omega C_{gs})^2}{g_m^2} = \underbrace{\frac{4kT\gamma g_{do} \Delta f}{g_m^2}}_{\overline{v_n^2}} (j\omega C_{gs})^2 = \overline{v_n^2} \cdot (j\omega C_{gs})^2$$

* i_{n_1} is correlated with v_n

Total input noise current = Sum of reflected drain noise current + gate current noise

$\Rightarrow$ gate induced noise current (i_{ng}) = $i_{ngc} + i_{ngu}$

i_{ngu}: uncorrelated with i_{n_1}

i_{ngc}: Correlated with i_{n_1}

$$\because \quad i_n = i_u + Y_{cor} v_n$$

$$\Rightarrow \quad Y_{cor} = \frac{i_{n_1} + i_{ngc}}{v_n} = j\omega C_{gs} + \frac{i_{ngc}}{v_n}$$

$$= j\omega C_{gs} + \frac{g_m}{i_{nd}} \cdot i_{ngc} = j\omega C_{gs} + \underbrace{g_m \cdot \left(\frac{i_{ngc}}{i_{nd}}\right)}_{\text{Need to express this explicitly in the form of correlation coefficient, } c} \longrightarrow (1)$$

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* Need to perform algebraic manipulations to incorporate the correlation coefficient c.

We have

$$g_m \cdot \frac{i_{ngc}}{i_{nd}} = g_m \cdot \frac{\overline{i_{ngc} \cdot i_{nd}^*}}{\overline{i_{nd} \cdot i_{nd}^*}}$$

$$= g_m \cdot \frac{\overline{i_{ngc} \cdot i_{nd}^*}}{\overline{i_{nd}^2}}$$

$$= \underbrace{g_m \cdot \frac{\overline{i_{ng} \cdot i_{nd}^*}}{\overline{i_{nd}^2}}}$$

only i_{ngc} is correlated with i_{nd}

going back to Eq^n ①

$$Y_{cor} = j\omega C_{gs} + g_m \cdot \frac{\overline{i_{ng} \cdot i_{nd}^*}}{\overline{i_{nd}^2}}$$

$$\Rightarrow \boxed{Y_{cor} = j\omega C_{gs} + g_m \cdot c\sqrt{\frac{\overline{i_{ng}^2}}{\overline{i_{nd}^2}}}}$$

This explains all the algebraic manipulations from the equation for $\overline{i_{ng}^2}$

$$Y_{cor} = j\omega C_{gs} + g_m \cdot c \cdot \sqrt{\frac{\delta \omega^2 C_{gs}^2}{5\gamma g_{do}}} = j\omega C_{gs} + \frac{g_m}{g_{do}} \cdot c \cdot \sqrt{\frac{\delta}{5\gamma}} \cdot \omega C_{gs}$$

Since $c = -j0.4$ for long. channel,

we assume $c = -j|c|$ ← c is purely imaginary

$$Y_{cor} = j\omega C_{gs} - j\omega C_{gs} \frac{g_m}{g_{do}} |c| \sqrt{\frac{\delta}{5\gamma}} = \boxed{j\omega C_{gs}\left(1 - \alpha |c| \sqrt{\frac{\delta}{5\gamma}}\right)}$$

where $\alpha \triangleq \frac{g_m}{g_{do}} \simeq 1$ for long-channel CMOSFETs

but shrinks with CMOS scaling

$$Y_{cor} = 0 + \underbrace{j\omega C_{gs}}\underbrace{\left(1 - \alpha|c|\sqrt{\frac{\delta}{5\gamma}}\right)} = g_{cor} + jB_{cor}$$

Y_{cor} is a scaled version of $j\omega C_{gs}$

$$g_{cor} = 0$$

$$B_{cor} = \omega C_{gs}\left(1 - \alpha|c|\sqrt{\frac{\delta}{5\gamma}}\right)$$

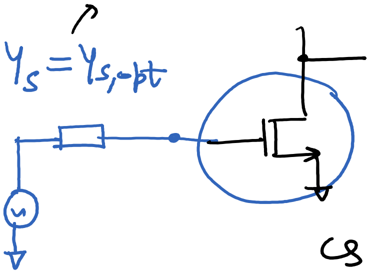
$g_u = ?$

$$R_n \triangleq \frac{\overline{v_n^2}}{4kT\Delta f} = \frac{\gamma g_{do}}{g_m^2} = \frac{\gamma}{\alpha} \cdot \frac{1}{g_m}$$

$$g_u \triangleq \frac{\overline{i_u^2}}{4kT\Delta f} = \frac{4kT\Delta f\, \delta g_g (1-|c|^2)}{4kT\Delta f} = \boxed{\frac{\delta\omega^2 C_{gs}^2 (1-|c|^2)}{5 g_{do}}}$$

$g_{s,opt} + jB_{s,opt}$

$Y_s = Y_{s,opt}$



CS

for $F = F_{min}$

$$B_{s,opt} = -B_{cor} = -\omega C_{gs}\left(1 - \alpha|c|\sqrt{\frac{\delta}{5\gamma}}\right)$$

$$g_{s,opt} = \sqrt{\frac{g_u}{R_n} + g_{cor}^2} = \alpha\omega C_{gs}\sqrt{\frac{\delta}{5\gamma}(1-|c|^2)}$$

"Noise - Match"

$$F = F_{min} = 1 + 2R_n(g_{s,opt} + g_{cor})$$

$$\simeq 1 + \frac{2}{\sqrt{5}} \cdot \frac{f}{f_T} \cdot \sqrt{\gamma\delta(1-|c|^2)}$$

* This is not the same as power match

$$Y_s = Y_{in}^*$$

$F\uparrow$ as $\frac{f}{f_T}\uparrow$

* for higher frequency operation $f\uparrow$

$\rightarrow$ Need higher f_T

$\Rightarrow$ better to use "faster" process.

* We trade-off noise matching with power matching

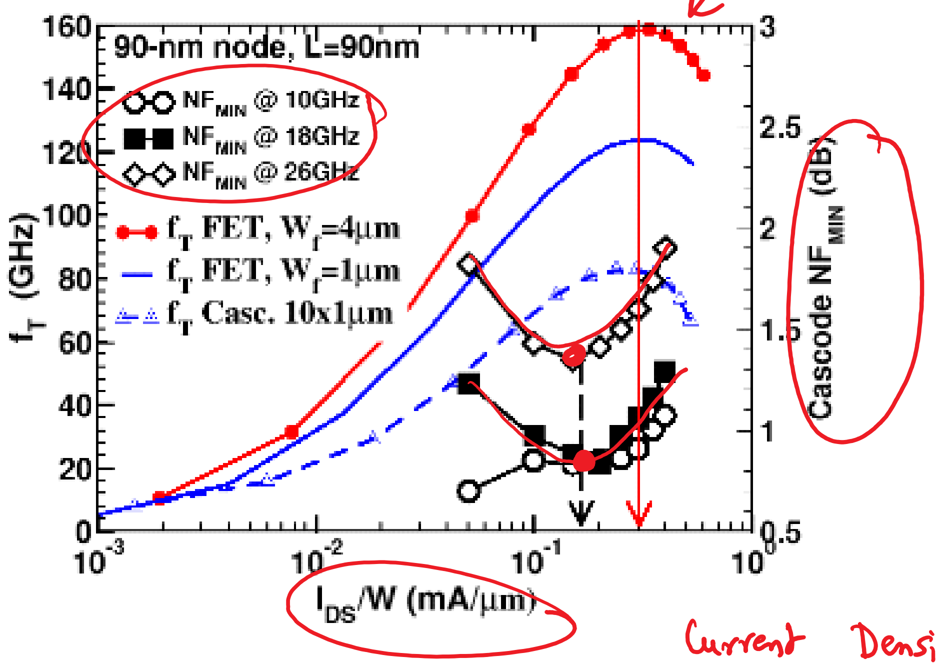
$\because$ noise match $\neq$ conjugate match

* In the book a generic model is given from

Eq^n 4.142 – 4.147

Substitute $R_i = 0$ for CMOS technology.

Best



Current Density $J_s = \frac{I_D}{W}$