RECALL:

$$F = F_{min} + \frac{R_n}{G_s} \left| Y_s - Y_{opt} \right|^2$$

$$\left.\begin{array}{l} Y_{opt} \\ F_{min} \\ R_n \end{array}\right\} \quad \text{FOUR PARAMETERS} \quad \left\{\begin{array}{l} \overline{v_n^2} \\ \overline{i_n^2} \\ Y_c \end{array}\right.$$

LET

$$Y_s = Y_0 \frac{1-\Gamma_s}{1+\Gamma_s}$$

$$Y_{opt} = Y_0 \frac{1-\Gamma_{opt}}{1+\Gamma_{opt}}$$

$$\left|Y_s - Y_{opt}\right|^2 = \left| \frac{1-\Gamma_s}{1+\Gamma_s} - \frac{1-\Gamma_{opt}}{1+\Gamma_{opt}} \right|^2 Y_0^2$$

$$= \left| \frac{(1-\Gamma_s)(1+\Gamma_{opt}) - (1-\Gamma_{opt})(1+\Gamma_s)}{(1+\Gamma_s)(1+\Gamma_{opt})} \right|^2 Y_0^2$$

$$N = \cancel{1} - 2\Gamma_s + 2\Gamma_{opt} - \Gamma_s \cancel{\Gamma_{opt}} \cancel{-1} + \cancel{\Gamma_{opt}} \cancel{-\Gamma_s} + \cancel{\Gamma_s}\Gamma_{opt}$$

$$= 4Y_0^2 \frac{\left|\Gamma_{opt} - \Gamma_s\right|^2}{\left|1+\Gamma_s\right|^2 \left|1+\Gamma_{opt}\right|^2}$$

$$G_S = Re(Y_S) = \frac{1}{2} Y_0 \left(y_s + \bar{y}_s \right)$$

$$= \frac{1}{2} Y_0 \left(\frac{1-\Gamma_s}{1+\Gamma_s} + \frac{1-\bar{\Gamma}_s}{1+\bar{\Gamma}_s} \right)$$

$$= \frac{1}{2} Y_0 \, \frac{(1-\Gamma_s)(1+\bar{\Gamma}_s) + (1-\bar{\Gamma}_s)(1+\Gamma_s)}{|1+\Gamma_s|^2}$$

$$= \frac{1}{2} Y_0 \, \frac{(1-\cancel{\Gamma_s}+\cancel{\bar{\Gamma}_s}-\Gamma_s\bar{\Gamma}_s+1-\cancel{\bar{\Gamma}_s}+\cancel{\Gamma_s}-\bar{\Gamma}_s\Gamma_s)}{|1+\Gamma_s|^2}$$

$$= Y_0 \, \frac{1-|\Gamma_s|^2}{|1+\Gamma_s|^2}$$

$$F = F_{min} + \frac{R_n}{\cancel{Y_0}\,\frac{1-|\Gamma_s|^2}{\cancel{|1+\Gamma_s|^2}}} \cdot 4 Y_0^{\cancel{2}} \frac{|\Gamma_{opt}-\Gamma_s|^2}{\cancel{|1+\Gamma_s|^2}\,|1+\Gamma_{opt}|^2}$$

$$F = F_{min} + \frac{4 R_n Y_0 \, |\Gamma_{opt}-\Gamma_s|^2}{(1-|\Gamma_s|^2)\,|1+\Gamma_{opt}|^2}$$

FOR FIXED F, THIS IS AN EQ FOR A CIRCLE OF Γ_s PLANE.

$$N = \text{NOISE FIG PARAM} = \frac{|\Gamma_S - \Gamma_{opt}|^2}{1 - |\Gamma_S|^2}$$

$$= \underbrace{\frac{F - F_{min}}{4R_n Y_0} |1 + \Gamma_{opt}|^2}$$

FOR FIXED F THIS IS CONSTANT

$$(\Gamma_S - \Gamma_{opt})(\bar{\Gamma}_S - \bar{\Gamma}_{opt}) = N(1 - |\Gamma_S|^2)$$

$$\Gamma_S \bar{\Gamma}_S - (\Gamma_{opt}\bar{\Gamma}_S + \bar{\Gamma}_{opt}\Gamma_S) - \Gamma_{opt}\bar{\Gamma}_{opt} = N(1 - |\Gamma_S|^2)$$

$$\Gamma_S \bar{\Gamma}_S \cancel{(N+1)} - \frac{(\quad)}{(N+1)} - \frac{\Gamma_{opt}\bar{\Gamma}_{opt} - N}{N+1} = 0$$

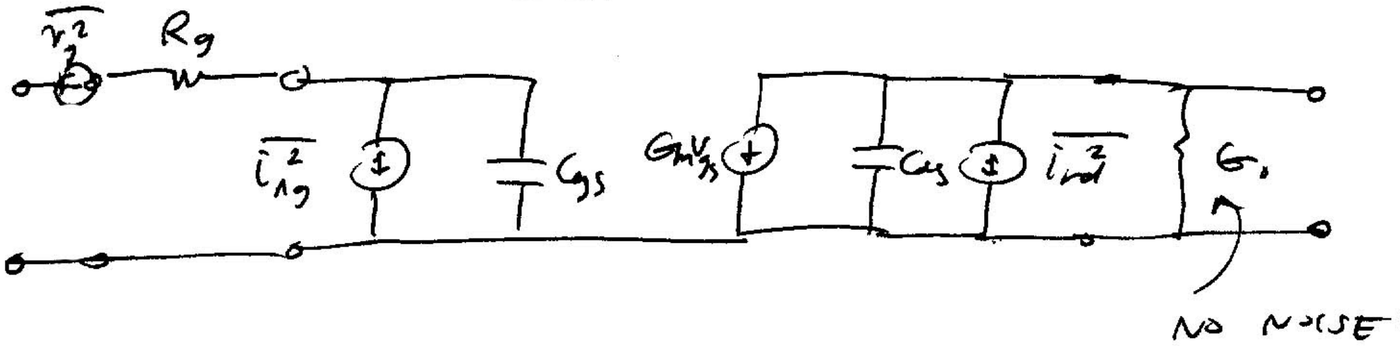
$$\Gamma_S \bar{\Gamma}_S - \frac{(\Gamma_S \bar{\Gamma}_{opt} + \Gamma_{opt}\bar{\Gamma}_S)}{N+1} + \frac{\Gamma_{opt}\bar{\Gamma}_{opt}}{(N+1)^2} = \frac{|\Gamma_{opt}|^2 - N}{N+1} + \frac{|\Gamma_{opt}|^2}{(N+1)^2}$$

$$\cancel{x^2 + \alpha y^2 +} (X + \alpha Y) = X^2 + \alpha^2 Y^2 + 2\alpha X Y$$

$$\left| \Gamma_S - \frac{\Gamma_{opt}}{N+1} \right| = \underbrace{\frac{\sqrt{N(N+1 - |\Gamma_{opt}|^2)}}{N+1}}_{\text{RADII}}$$

CENTER

FET NOISE MODEL



$$\overline{i_{ng}^2} = 4kT\delta \frac{\omega^2 C_{gs}^2}{5 g_{do}}$$

$$\overline{i_{nd}^2} = 4kT\gamma g_{do}$$

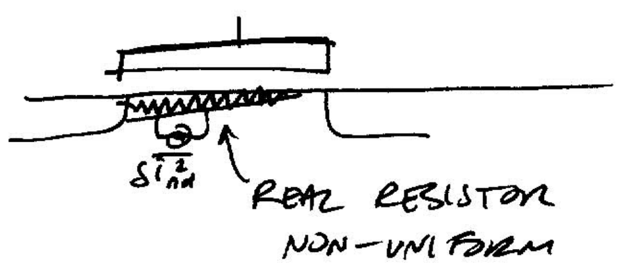
$\gamma \approx 2/3 - 1.33$

$\delta \sim 1.33 - 4$

$$c = \frac{\langle i_{ng}, i_{nd} \rangle}{\sqrt{\overline{i_{ng}^2}\;\overline{i_{nd}^2}}} \cong j\,0.4$$

LONG CH. NQS CALC

WHERE DOES NOISE COME FROM?



g_{do} IS CHANNEL CONDUCTANCE

$$g_{do} \propto \frac{I_{ds}}{V_{dsat}} \cong \frac{\frac{1}{2}\mu C_{ox}\left(\frac{W}{L}\right)(V_{gs}-V_T)^2}{(V_{gs}-V_T)}$$

$$= \frac{1}{2} g_m$$

A

WHEN DEVICE IS IN TRIODE : (V_{DS} SMALL)

$$I_D = \mu C_{ox}\left(\frac{W}{L}\right)\left((V_{GS}-V_T)V_{DS} - \frac{V_{DS}^2}{2}\right)$$

$$g_{d0} = \frac{\partial I_D}{\partial V_{DS}} \cong \mu C_{ox}\left(\frac{W}{L}\right)(V_{GS}-V_T)$$

IN SATURATION:

$$I_D = \mu C_{ox}\left(\frac{W}{L}\right)\frac{1}{2}(V_{GS}-V_T)^2$$

$$g_m = \frac{\partial I_D}{\partial V_{GS}} = \mu C_{ox}\left(\frac{W}{L}\right)(V_{GS}-V_T)$$

$$g_m \approx g_{d0}$$

IN REALITY $\alpha \triangleq \frac{g_m}{g_{d0}}$ DROPS SINCE

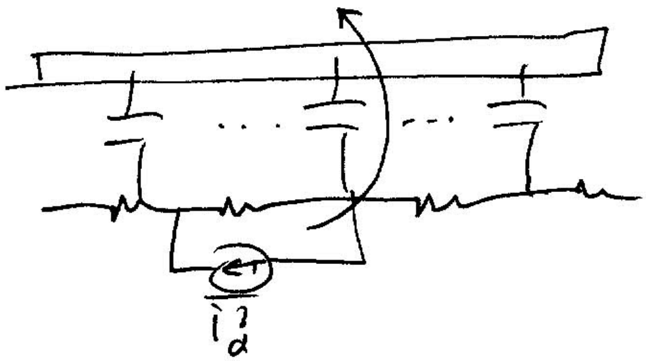
$$g_m = f(V_G, V_D)$$

THERMAL NOISE $\propto$ G_{CH} $\propto$ g_{ds0} $\propto$ g_m

$$\overline{i_d^2} = 4kT\gamma g_{d0} = 4kT\gamma\frac{g_m}{\alpha}$$

$$= 4kT\left(\frac{\gamma}{\alpha}\right)g_m$$

WHERE DOES GATE NOISE COME FROM?



DRAIN NOISE LEAKS INTO GATE THROUGH C_{gs}. AS FREQ INCREASES, THIS GATE CURRENT INCREASES. GATE CURRENT IS THUS CORRELATED TO DRAIN NOISE:

$$\frac{\overline{i_{ng}^2}}{\Delta f} = 4kT\,\delta\,\frac{\omega^2 C_{gs}^2}{5\,g_{d0}} \qquad \left| \quad \langle i_{ng},\, i_{nd} \rangle = 4kT\,\frac{1}{6}\,j\omega C_{gs} \right.$$

EQUIV GATE NOISE VOLTAGE

$$\frac{\overline{v_g^2}}{\Delta f} = 4kT\,R_{eq}$$

$$R_{eq} \stackrel{?}{=} \text{INPUT RESISTANCE}$$

$$= \frac{1}{5}\,\frac{1}{g_m}$$

ACTUAL VALUE IS $\frac{4}{3} R_i$

CLOSE TO 1!

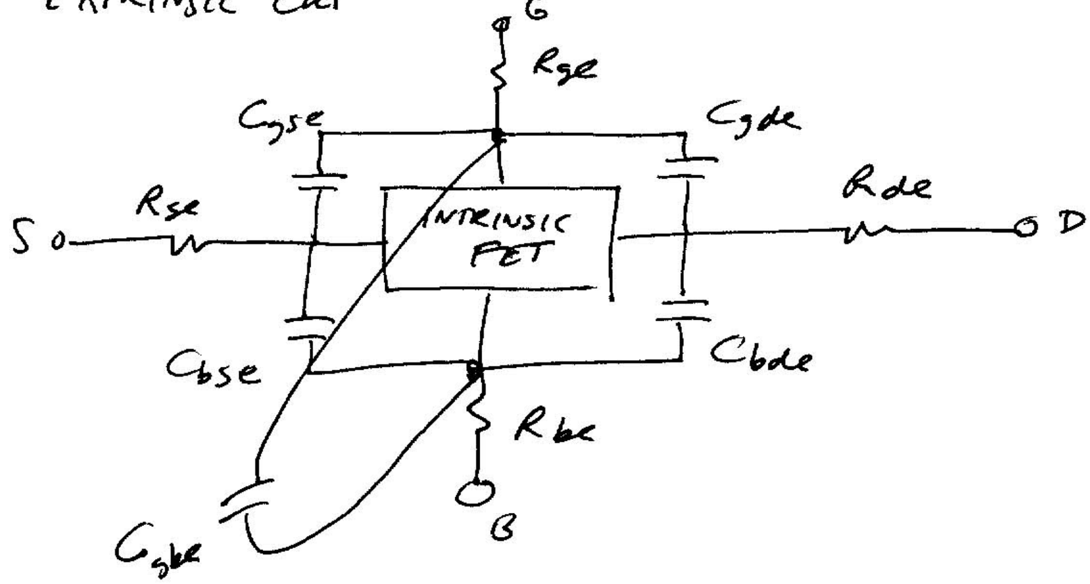
C

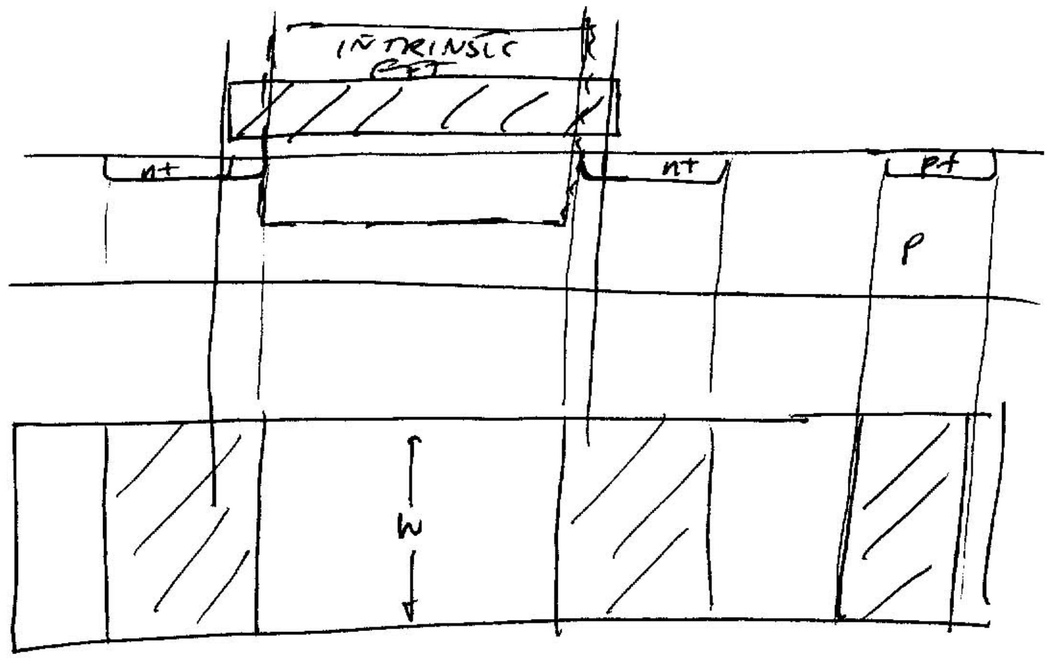
LECT 19 4/10 A

SMALL SIGNAL EQ CIRCUIT FOR FETS

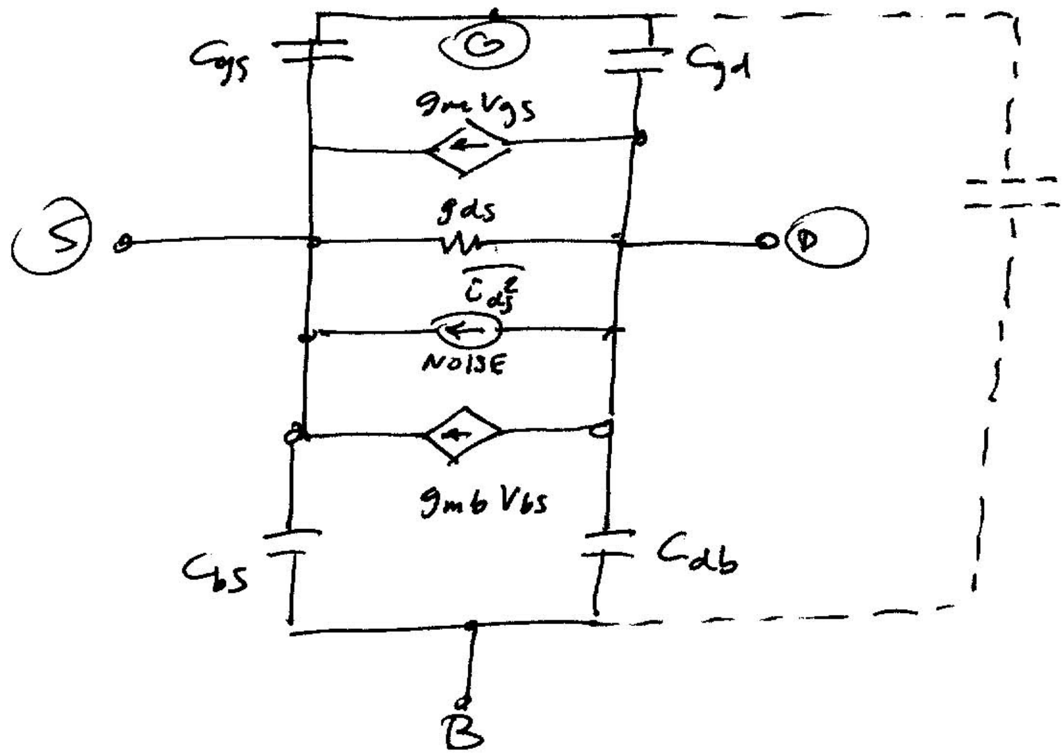
MEDIUM FREQ (RF) 4 TERMINAL DEVICE

EXTRINSIC CKT





SIMPLE INTRINSIC MODEL (QUASI-STATIC)



NOISE : IN SAT $\overline{i_{ds}^2} = 4KT \left[\frac{2}{3} \underbrace{\frac{W}{L} \mu C_{ox} (V_{GS} - V_T)}_{g_{sd0}} \right]$

$\gamma = 2/3$

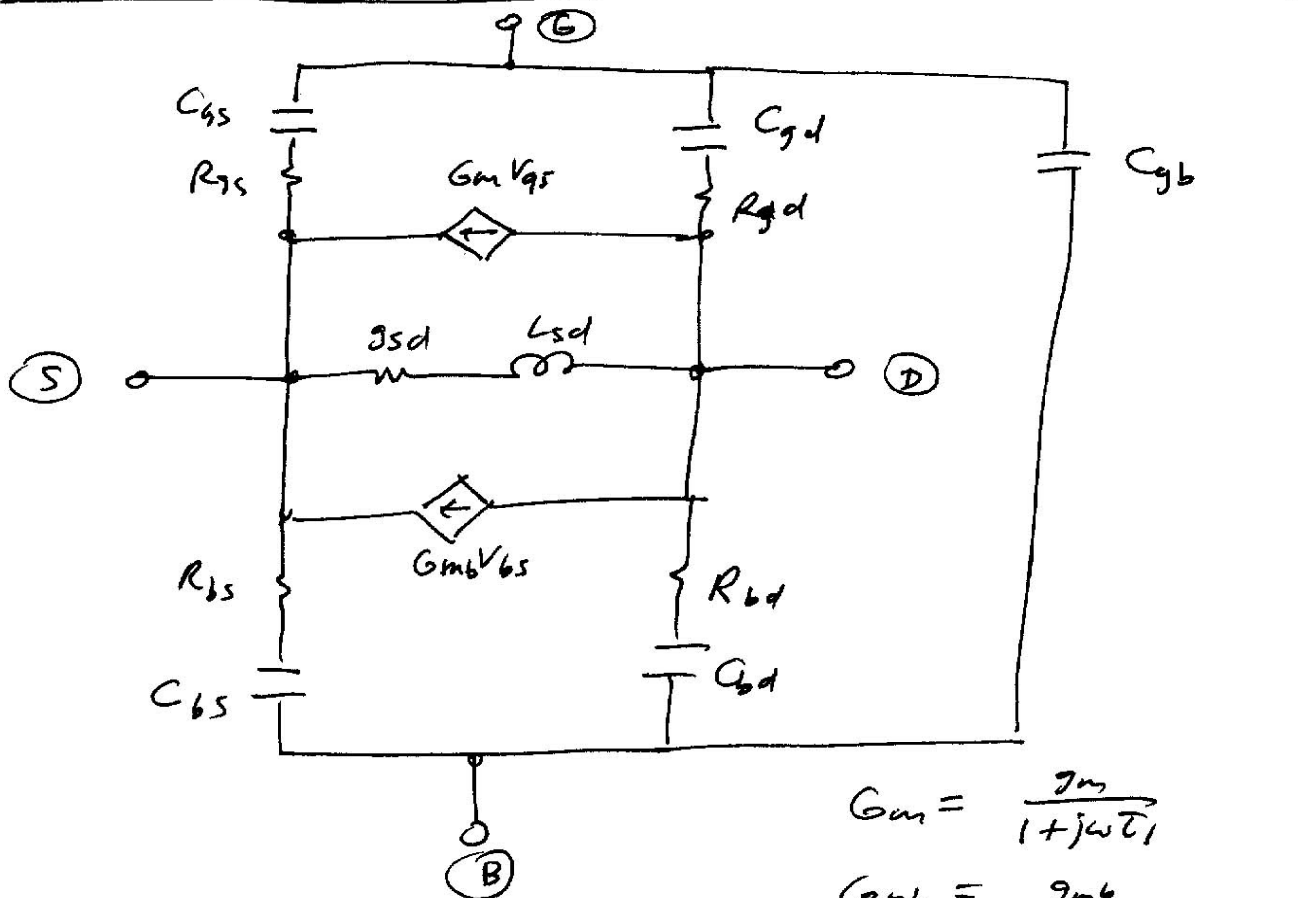
g_{sd0} CH CONDUCTANCE FOR $V_{DS} = 0$

FOR SHORT CHANNEL DEVICES γ IS LARGER DUE TO DISTRIBUTED EFFECTS. HOT ELECTRON EFFECTS MAY ALSO CONTRIBUTE $\gamma \sim 2-3$ REPORTED.

INPUT REFER NOISE : $\overline{V_n^2} = \frac{\overline{i_{ds}^2}}{g_m^2}$

FLICKER NOISE : LF NOISE IMPORTANCE ESP. FOR OSCILLATORS DUE TO NOISE UP-CONVERSION

NON-QUASI-STATIC MODEL (TSIVIDIS MOS TRANSISTOR)



$$G_m = \frac{g_m}{1 + j\omega\tau_1}$$

$$G_{mb} = \frac{g_{mb}}{1 + j\omega\tau_1}$$

$$L_{sd}\, g_{sd} = \tau_1$$

IN SATURATION THIS MODEL SIMPLIFIED TO

$$C_{gs} = \tfrac{2}{3} C_{ox}$$

$$R_{gs} = \frac{1}{5 g_m}$$

$$R_{bs} = \frac{1}{(\alpha_1 - 1)\, g_m 5}$$

$$C_{bs} = (\alpha_1 - 1)\, \tfrac{2}{3} C_{ox}$$

$$C_{gb} = \frac{\alpha_1 - 1}{3\alpha_1} C_{ox}$$

$$\tau_1 \simeq \frac{1}{3.75\,\omega_0}$$

$$\omega_0 = \frac{\mu (V_{GS} - V_T)}{\alpha L^2}$$

$$\alpha \simeq 1 + \frac{\gamma}{2\sqrt{\phi_0 + V_{SB}}}$$

BODY EFFECT COEFF

SP IN STRONG INV

MODEL VALID $\simeq \omega_0$

NOTE $\omega_0 = \omega_T$ (NO VELOCITY SAT)

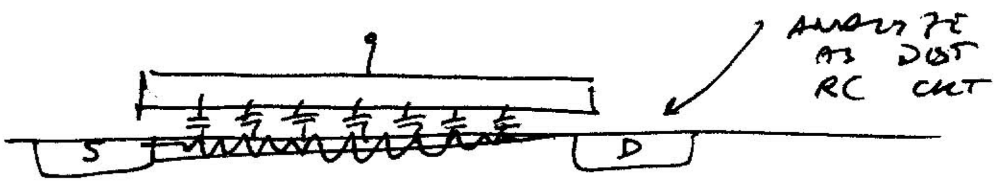
$$\omega_T = \frac{|v_d|_{max}}{L} \quad \text{VELOCITY SAT.}$$

E.G. $|v_d|_{max} \simeq 10^7$ cm/s

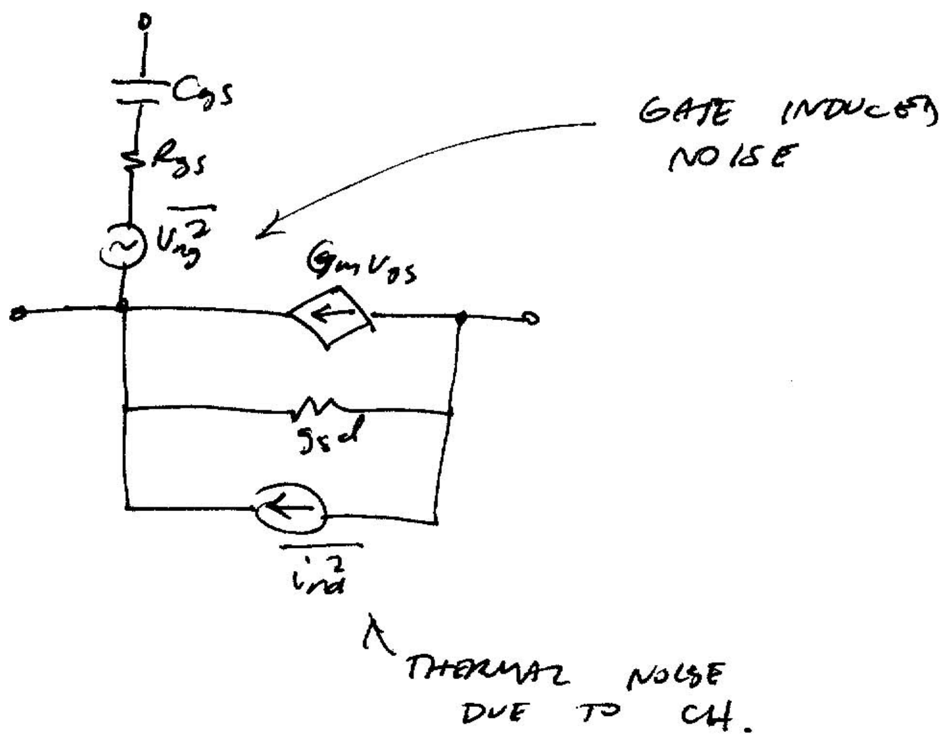
$L \simeq 0.1\mu$

$\rightarrow \quad \omega_T = 160\,GHz \times 2\pi$

CHANNEL RESISTANCE PLAYS AN IMPORTANT ROLE IN NON-QUASI-STATIC MODEL



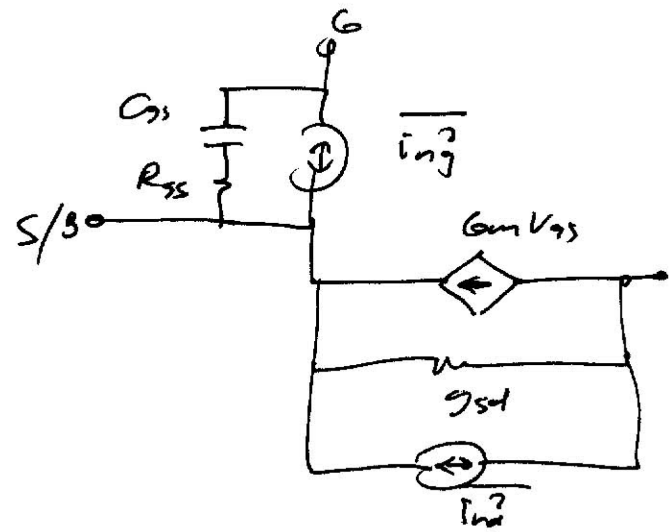
NOISE



$$\overline{v_{ng}^2} = 4KT\left(\frac{4}{3} R_{gs}\right)$$

INTUITIVE RESULT IS $4KT\,R_{gs}$

COMMON-WAY IS TO REPRESENT AS NORTON EQ.



$$\overline{i_{ng}^2} = 4KT\left(\frac{4}{3} R_{gs}\right) \omega^2 C_{gs}^2$$

THIS NOISE IS CORRELATED WITH THE DRAIN NOISE

$$\langle i_{ng}, \overline{i_{nd}} \rangle = 4KT \frac{1}{6} j\omega C_{gs}$$