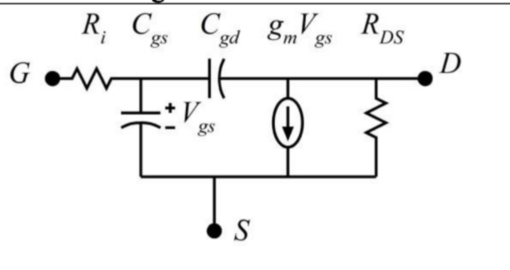
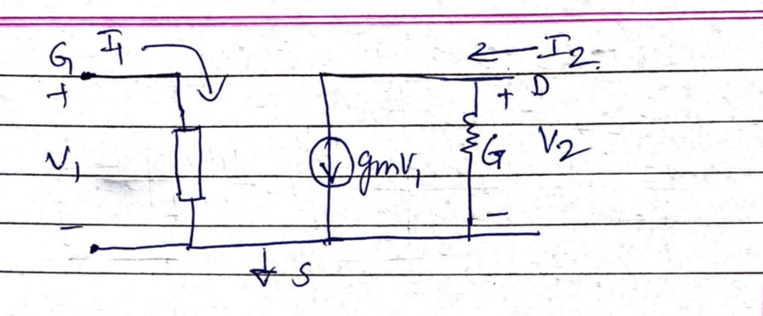
Problem 1: Shown is a highly simplified small-signal model of a MOSFET. Ri=0 Ohms, gm=200 mS, Rds=75 Ohms, Cgs=100 fF, Cgd=0 fF The source is grounded.



a) Compute by hand the four Y-parameters as a function of frequency.
b) create a 2-port circuit of this device in ADS. Simulate using the provided gain_testbench, and make plots of the real and imaginary parts of the 4 Y-parameters. Use linear scales for both axes.

1 a)



$I_1 = j\omega C_{gs} V_1$

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

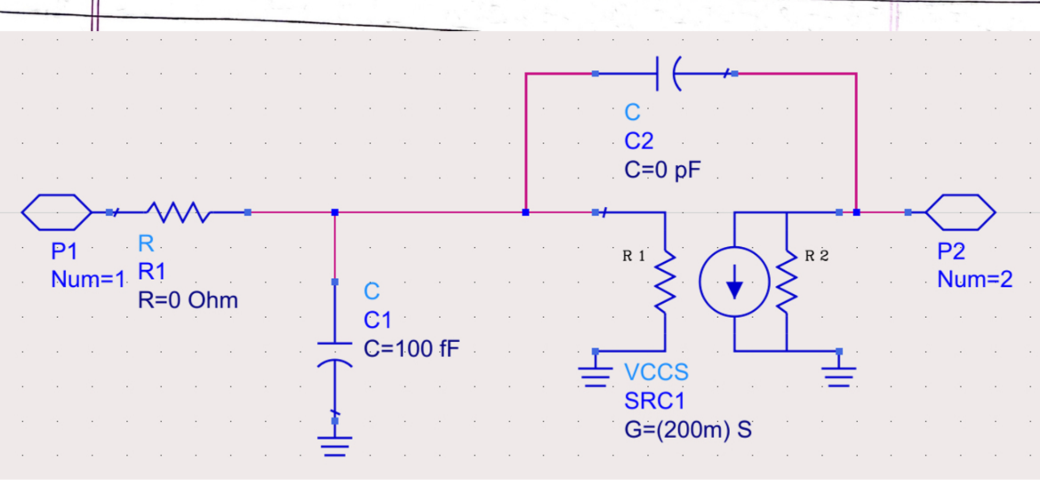
$Y_{11} = \frac{I_1}{V_1}\Big|_{V_2=0} = j\omega C_{gs}$

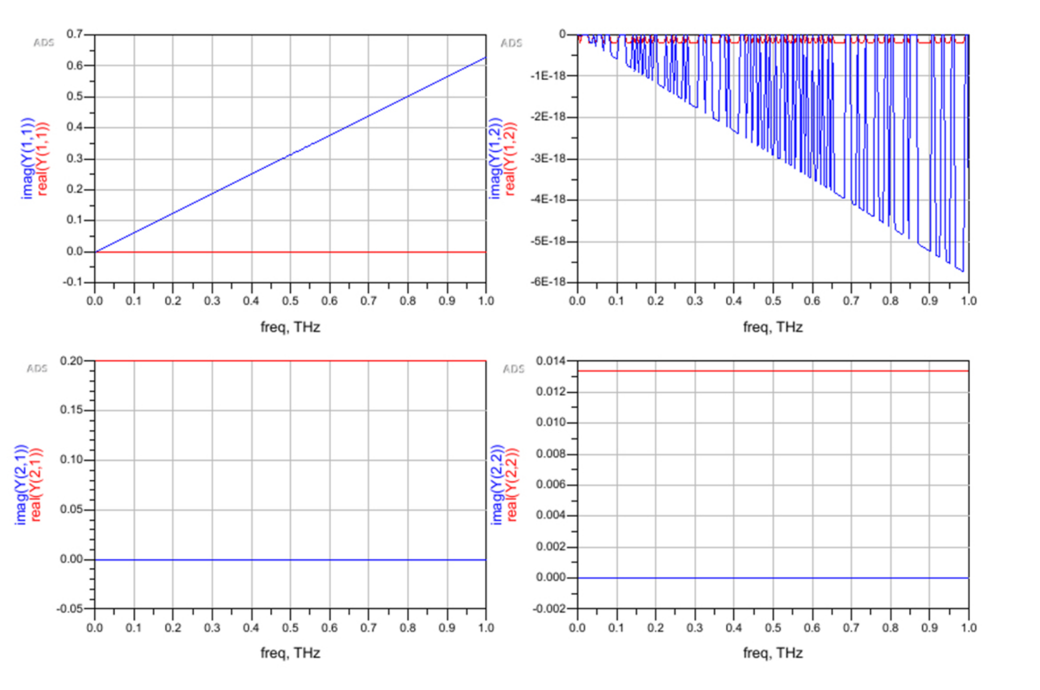
$Y_{12} = \frac{I_1}{V_2}\Big|_{V_1=0} = 0$

$Y_{21} = \frac{I_2}{V_1}\Big|_{V_2=0} = g_m$ no current through res.

$Y_{22} = \frac{I_2}{V_2}\Big|_{V_1=0} = G$ only current through res.

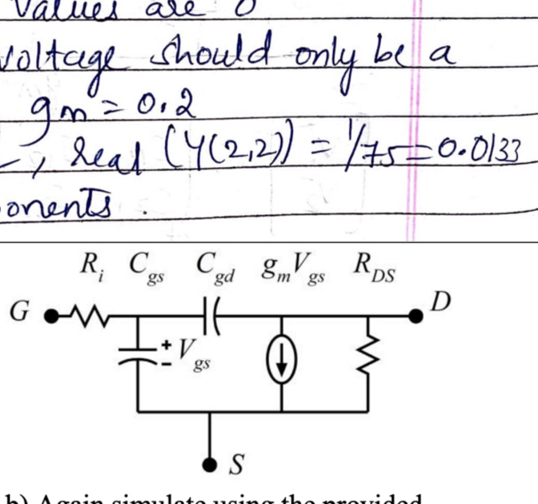
$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} j\omega C_{gs} & 0 \\ g_m & G \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$





Y_{11}: The value is purely imaginary, which is expected for $y_{11} = j\omega C_{gs}$ at 1THz, $Y_{11} \approx j(2 \cdot \pi \cdot 1\times10^{12} \cdot 100\times10^{-15})$ $\approx = 0.628$, which matches the graph
Y_{12}: Both real & imag. Values are 0
Y_{21}: only real, since voltage should only be a function of gm, $g_m = 0.2$
Y_{22}: Since $R_L = 75\Omega$, real $(Y(2,2)) = 1/75 = 0.0133$
No im() components.

Problem 2 **(218A only)**: Now set Ri=0 Ohms, gm=200 mS, Rds=75 Ohms, Cgs=100 fF, Cgd=5 fF The source is grounded.

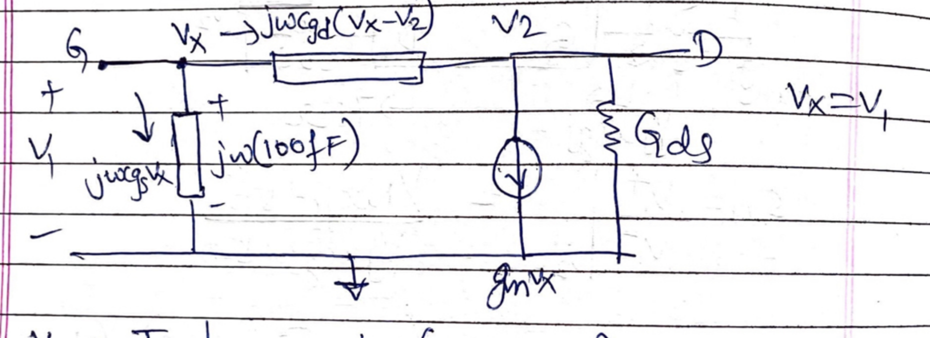


a) Again compute the 4 Y-parameters (real and imaginary parts) by hand. Use numerical approximations so that all four of these are written as polynomials in $(j\omega)^n$, and truncate the polynomials to 2nd order in $(j\omega)$. Comment about how the effects of the various circuit elements show up in the Y parameters.

b) Again simulate using the provided gain_testbench, and make plots of the real and imaginary parts of the 4 Y-parameters.

This is an elementary introduction to device model extraction: S-parameters are measured of a transistor, converted to Y-parameters, and compared to that of a model.

2a.



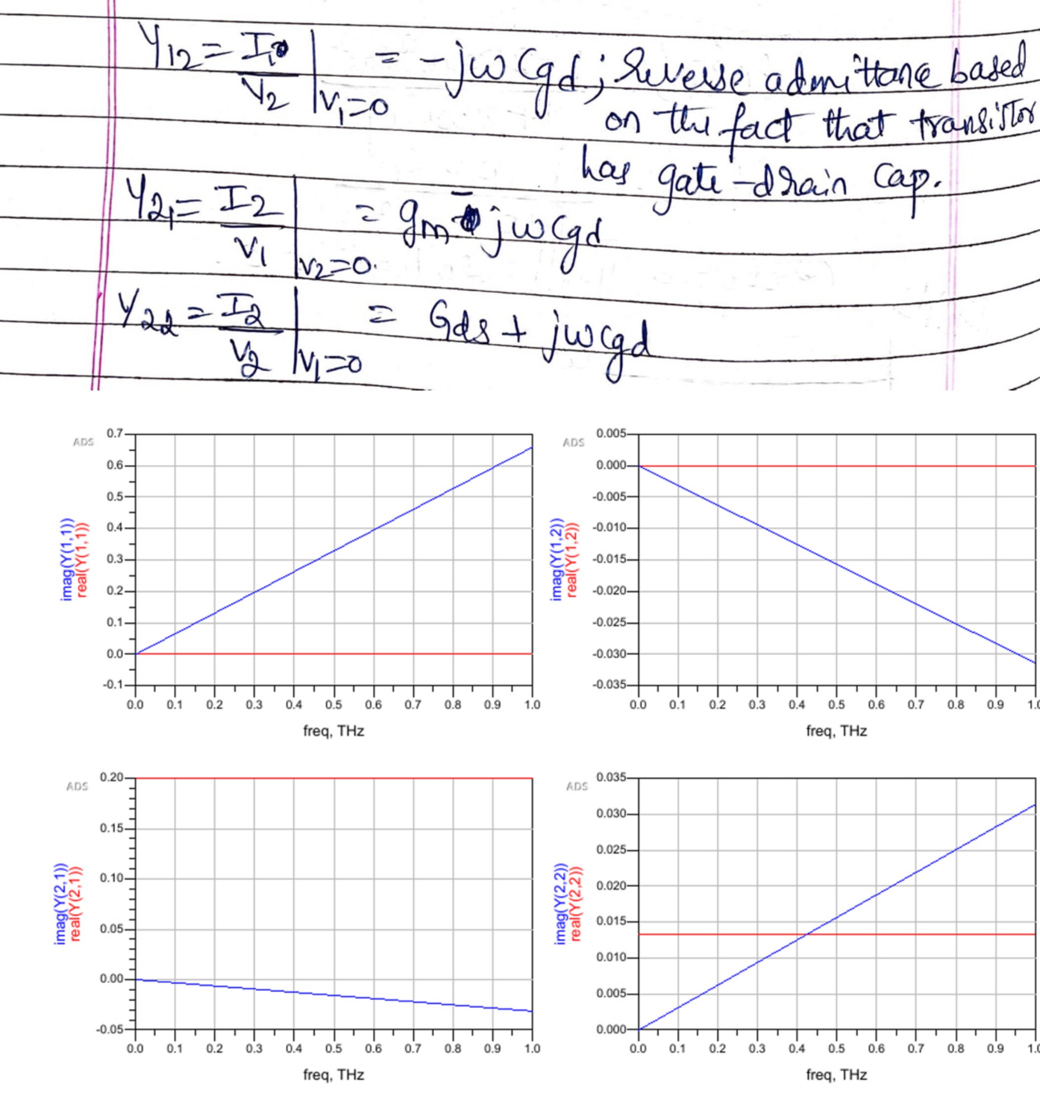
$V_x = V_1$

$Y_{11} = \frac{I_1}{V_1}\Big|_{V_2=0} = j\omega(C_{gs} + C_{gd})$

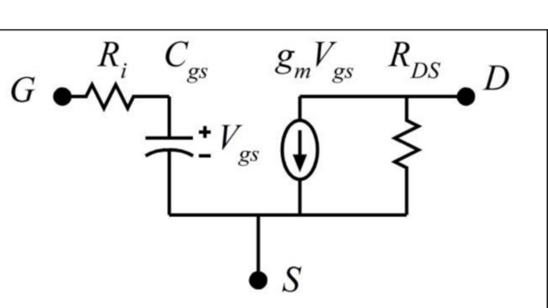
$Y_{12} = \frac{I_1}{V_2}\Big|_{V_1=0} = -j\omega C_{gd}$; Reverse admittance based on the fact that transistor has gate-drain cap.

$Y_{21} = \frac{I_2}{V_1}\Big|_{V_2=0} = g_m - j\omega C_{gd}$

$Y_{22} = \frac{I_2}{V_2}\Big|_{V_1=0} = G_{ds} + j\omega C_{gd}$



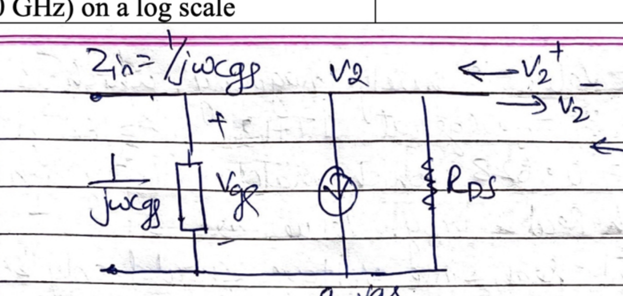
Problem 3: Ri=0 Ohms, gm=200 mS, Rds=75 Ohms, Cgs=100 fF. The source is grounded.



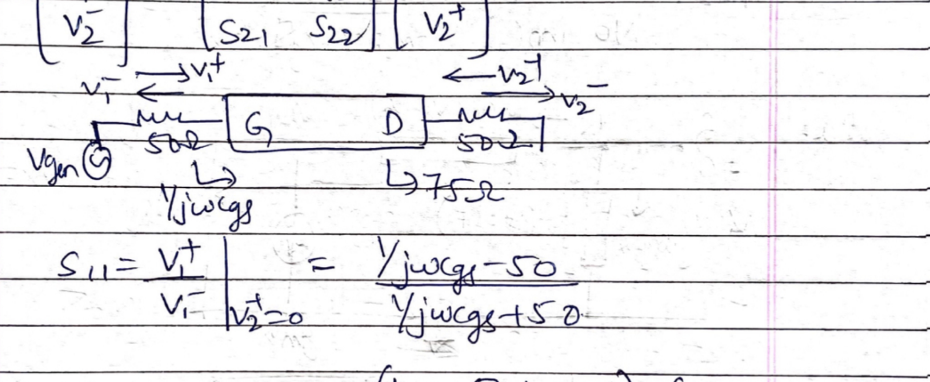
a) Compute by hand the four S-parameters. Make a hand sketch of dB magnitude of S11 and S21 vs frequency on a log scale (DC-300 GHz)
b) Simulate using the provided gain_testbench, and make plots of dB magnitude of S11 and S21 vs frequency (DC-300 GHz) on a log scale

Please also make plots on the Smith chart of S11 and S22, and polar plots of S21 and S12.

3



$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}$$



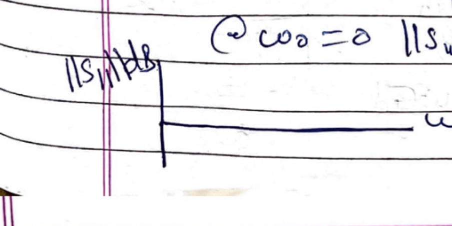
$S_{11} = \frac{V_1^+}{V_1^-}\Big|_{V_2^+=0} = \frac{1/j\omega C_{gs} - 50}{1/j\omega C_{gs} + 50}$

$= \frac{(1 - 50 j\omega C_{gs})(1 - 50 j\omega C_{gs})}{(1 + 50 j\omega C_{gs})(1 - 50 j\omega C_{gs})}$

$Re\{S_{11}\} = \frac{1 - 2500\omega^2 C_{gs}^2}{1 + 2500\omega^2 C_{gs}^2}$

$Im\{S_{11}\} = \frac{-j\,100\,\omega C_{gs}}{1 + 2500\omega^2 C_{gs}^2}$

@ $\omega_0 = 0$ $\|S_{11}\| = 20\log(1) = 0$.



$S_{12} = \frac{V_1^+}{V_2^-}\Big|_{V_1^-=0} = 0.$

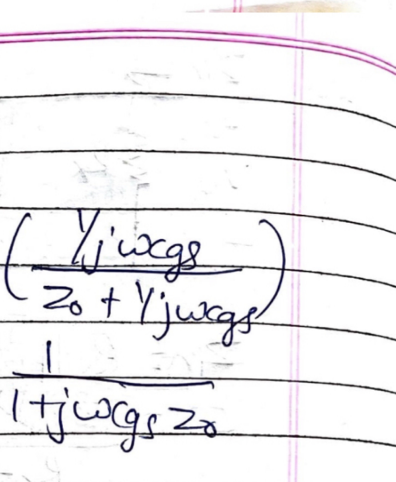
$S_{21} = \frac{V_2^-}{V_1^+}\Big|_{V_2^+=0}$ $V_{gs} = V_1\left(\frac{1/j\omega C_{gs}}{Z_0 + 1/j\omega C_{gs}}\right)$

$= \frac{2V_{out}}{V_1}$ $= \frac{1}{1 + j\omega C_{gs} Z_0}$

$V_{out} = -g_m V_{gs} R_{ds}$
$= -g_m R_{ds}\left(\frac{1}{1 + j\omega C_{gs} Z_0}\right) V_1$

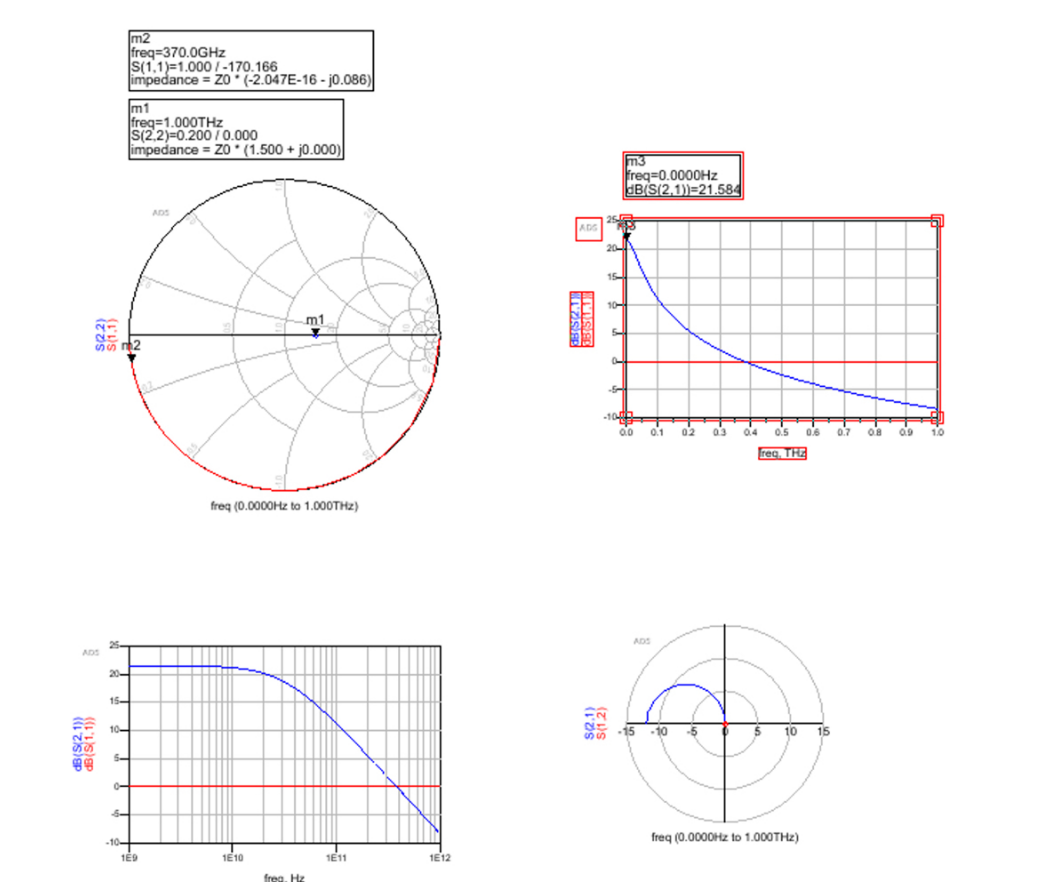
$\frac{V_{out}}{V_1} = \frac{-g_m R_{ds}}{1 + j\omega C_{gs} Z_0}$

$\frac{2V_{out}}{V_1} = \frac{-2 g_m R_{ds}}{1 + j\omega C_{gs} Z_0}$

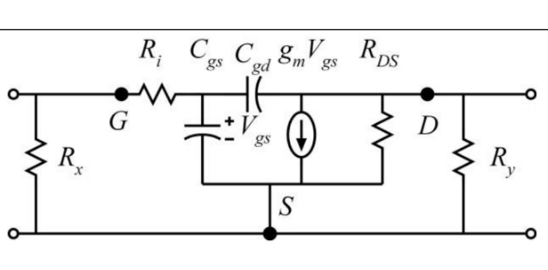


$S_{22} = \frac{V_2^+}{V_2^-}\Big|_{V_1^+=0} = \frac{Z_{out} - Z_0}{Z_{out} + Z_0} = \frac{75 - 50}{75 + 50} = 0.2$

$$\begin{bmatrix} V_1 \\ V_2^- \end{bmatrix} = \begin{bmatrix} \frac{1 - 2500\omega^2 C_{gs}^2 - 100 j\omega C_{gs}}{1 + 2500\omega^2 C_{gs}^2} & 0 \\ \frac{-2 g_m R_{ds}}{1 + j\omega C_{gs} Z_0} & 0.2 \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}$$

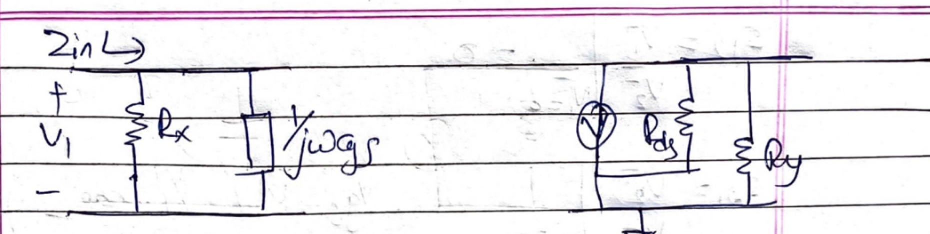


Problem 4: (please DO work this problem) Simple common-source amplifier (bias networks are not shown) Ri=0 Ohms, gm=200 mS, Rds=75 Ohms, Cgs=100 fF.
a) Compute the values of Rx and Ry necessary to give 50 Ohm input and output impedance. (b) the circuit is then to be used in a 50 Ohm system, i.e. with 50 Ohm generator and load. Compute by hand all four S-parameters.



(c) Explain precisely how S11, S22, S21 relate to gain, input and output impedance.

4a



$Z_{in} = R_x \| 1/j\omega C_{gs} = 50\Omega$

$50 = \frac{R_x \cdot 1/j\omega C_{gs}}{R_x + 1/j\omega C_{gs}}$

$R_x(1 - 50 j\omega C_{gs}) = 50.$

$R_x = \frac{50}{1 - 50 j\omega C_{gs}}$ @ low freq. $\omega = 0$. $R_x = 50$ ohms.

$Z_{out} = R_{ds} \| R_y = 50$:

$50 = \frac{75 R_y}{75 + R_y} \Rightarrow R_y = 150\Omega$

b) $Z_{in} = 50\Omega$, $Z_{out} = 50\Omega$

$S_{11} = 0$ Small because impedance is matched

$S_{12} = \frac{V_1^+}{V_2^-}\Big|_{V_1^-=0} = 0.$

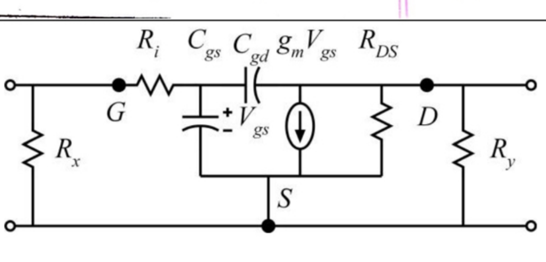
$S_{21} = \frac{V_2^-}{V_1^+}\Big|_{V_2^+=0} = \frac{2V_{out}}{V_{gen}}$ $V_{gs} = V_{gen}\left(\frac{50}{100}\right)$

$\frac{V_{out}}{V_{gs}} = -g_m Z_0 \Rightarrow \frac{V_{out}}{V_{gen}} = -\frac{1}{2} g_m (R_{ds} \| R_L)$

$S_{21} = \frac{2V_{out}}{V_{gen}} = -g_m(R_{ds} \| R_L)$. @ low freq.
$= -6$

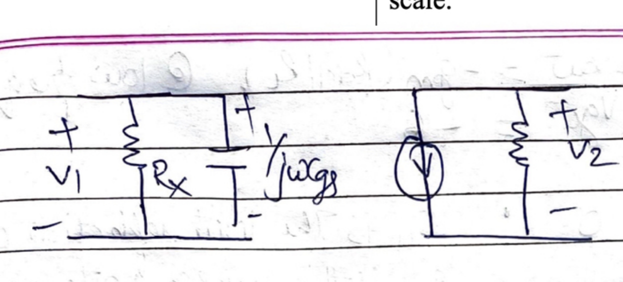
$S_{22} = 0$: S_{11} is the input reflection coefficient
S_{12} is the reverse voltage gain of ckt
S_{21} is the forward voltage gain of ckt
S_{22} is the output reflection co-efficient

Problem 5: Simple common-source amplifier (bias networks are not shown) Ri=0 Ohms, gm=200 mS, Rds=75 Ohms, Cgs=100 fF.
Using the values of Rx and Ry from above (a) Compute by hand S21 and S11 as a function of function of frequency. Identify specifically the 3-dB bandwidth and the low-frequency value of S21.



(b) Simulate using the provided gain_testbench, and make plots of dB magnitude of all 4 S-parameters vs frequency (DC-300 GHz) on a *dB and log frequency* scale.

5a.



$S_{11} = \frac{Z_{in}|_{Z_L=Z_0} - Z_0}{Z_{in}|_{Z_L=Z_0} + Z_0}$ $Z_{in} = R_x \| \frac{1}{j\omega C_{gs}}$
$= \frac{R_x}{1 + j\omega C_{gs} R_x}$

$= \frac{\frac{R_x}{R_x j\omega C_{gs} + 1} - 50}{\frac{R_x}{R_x j\omega C_{gs} + 1} + 50}$

$= \frac{R_x - R_x 50 j\omega C_{gs} - 50}{R_x + 50 R_x j\omega C_{gs} + 50}$

$= \frac{-2500 j\omega C_{gs}}{100 + 2500 j\omega C_{gs}}$

$S_{21} = \frac{2V_{out}}{V_{gen}}$

$V_{out} = -g_m V_{gs}(R_{ds} \| R_y \| Z_0)$.

$V_{gs} = V_{gen}\left(\frac{\frac{R_x}{R_x j\omega C_{gs} + 1}}{\frac{R_x}{R_x j\omega C_{gs} + 1} + 50}\right)$

$\frac{V_{gs}}{V_{gen}} = \frac{50}{100 + 2500 j\omega C_{gs}} = \frac{1}{2 + 50 j\omega C_{gs}}$

$\frac{V_{out}}{V_{gs}} = -g_m(R_{ds} \| R_y \| Z_0) = 5$

$\frac{2V_{out}}{gen} = 2\,\frac{5}{2 + 50 j\omega C_{gs}}$

$$\boxed{S_{21} = \frac{10}{2 + 50 j\omega C_{gs}}}$$

@ low freq, $S_{21} = 13.97$ dB.
To find -3dB point, look for $\|S_{21}\| = 10.97$dB