(8) Return to parameters in (1) and find freq where MAG = 10 dB

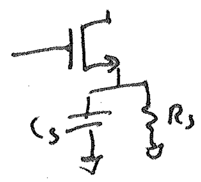
Examination of ADS plotted calculations shows $f = 126\,\text{GHz}$

Set $f_{Bragg} = 126\,\text{GHz}$.

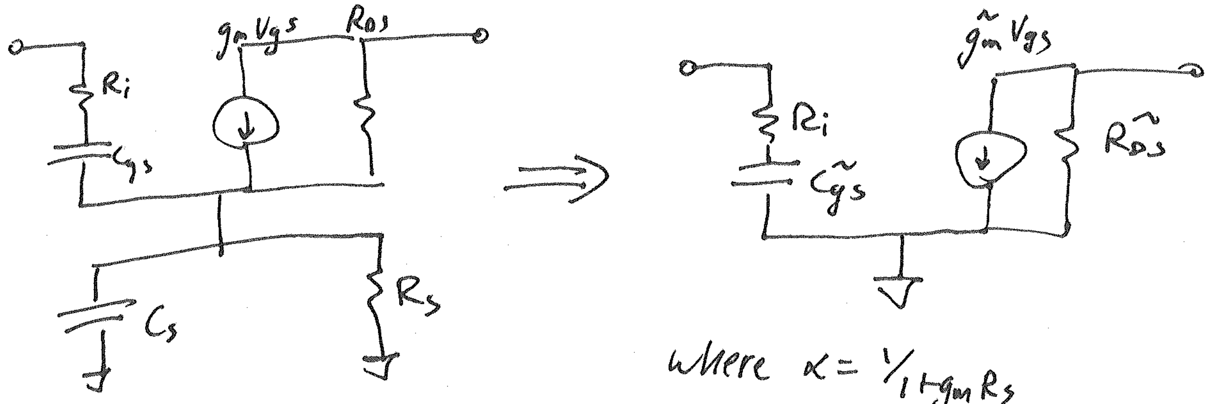
Now with source generation $C_s + R_s$

set $G_{11} = G_{22}$, find C_s / C_{gs}

Then design transmission lines.



where $R_s C_s = C_{gs}/g_m$



where $\alpha = 1/(1+g_m R_s)$

$\tilde{C}_{gs} = \alpha C_{gs}$

$\tilde{g}_m = \alpha g_m$

$\tilde{G}_{DS} = \alpha G_{DS}$

$G_{11} = Re(Y_{11})$

$Y_{11} = \left(R + \frac{1}{j\omega C}\right)^{-1}$

$= j\omega C \left(\frac{1}{1 + j\omega RC}\right)$

$\cong j\omega C(1 - j\omega RC)$

$\underline{G_{11} = Re(Y_{11}) = \omega^2 \tilde{C}_{gs}^2 R}$,

Note: $\frac{1}{1+x} \cong 1 - x + \cdots$

for small x, $x \ll 1$

since $R \ll \frac{1}{j\omega C}$ we can do this

Clearly (since $V_{in} = 0$), $\underline{G_{22} = \tilde{G}_{DS}}$

Set these equal & solve for C_s/C_{gs}

$$\omega^2 \tilde{C}_{gs}^2 R_i = \tilde{G}_{DS}$$

$$\omega^2 \frac{C_{gs}^2}{(1+g_m R_s)^2} R_i = \frac{G_{DS}}{(1+g_m R_s)}$$

$$\omega^2 C_{gs}^2 R_i = G_{DS}(1+g_m R_s)$$

$$\omega^2 C_{gs}^2 \frac{0.5}{g_m} = g_m/8\,(1+g_m R_s)$$

$$\omega^2 C_{gs}^2 \frac{4}{g_m^2} = 1 + \frac{C_{gs}}{C_s}$$

$$\omega^2 \left(\frac{g_m}{2\pi f_T}\right)^2 \frac{4}{g_m^2} = 1 + \frac{C_{gs}}{C_s}$$

$$\left(\frac{2 f_{Bragg}}{f_T}\right)^2 - 1 = \frac{C_{gs}}{C_s}$$

$R_i = 0.5/g_m$, $G_{DS} = g_m/8$

$R_s = \frac{C_{gs}}{C_s g_m}$

$C_{gs} = g_m/2\pi f_T$

$\omega^2 = (2\pi f_{Bragg})^2$

$$\frac{C_{gs}}{C_s} = 0.5876, \quad \boxed{\frac{C_s}{C_{gs}} = 1.702}$$

Set $f_{Bragg} = 126\,GHz$ & $Z_0 = 50\,\Omega$

$50 = \sqrt{L/C}$, $L = \tilde{C}_{gs} 50^2$

and $f_{Bragg} = \frac{1}{\pi\sqrt{L\tilde{C}_{gs}}} = \frac{1}{\pi 50 \tilde{C}_{gs}} = \underline{126pH}$

so $\tilde{C}_{gs} = \frac{1}{\pi 50 f_{Bragg}} = \underline{50.5fF = \tilde{C}_{gs}}$

<u>Other parameters</u>

- $\tilde{C}_{gs} = \frac{C_{gs}}{1+g_m R_s} = \frac{C_{gs}}{1+C_{gs}/C_s}$; $C_{gs} = \tilde{C}_{gs}\left(1+\frac{C_{gs}}{C_s}\right)$

  $\underline{C_{gs} = 80.17fF}$

- $g_m = 2\pi f_T C_{gs}$

  $\underline{g_m = 0.1007}$

- $R_i = 0.5/g_m$

  $R_i = 4.96$

- $R_{DS} = 8/g_m$

  $R_{DS} = 79.4$

- $C_s = C_{gs} \times \left(\frac{C_s}{C_{gs}}\right)$

  $\underline{C_s = 136.4fF}$

$\alpha = \frac{1}{1+g_m R_s} = 0.63$

$\tilde{g}_m = \alpha g_m = 0.063$

$\tilde{R}_{DS} = R_{DS}/\alpha = 126$

Choose N so f_{3dB} due to gate loss is @ $f_{Bragg} = 126\,GHz$

$$A_g = \omega^2 R_i \tilde{C}_{gs}^2 \frac{Z_0}{2} \Big|_{f=126GHz} = 0.1982$$

$$N = \frac{3 \ln 10}{20 A_g} = ~~1.61~~ \; 1.73$$

Choose $N=2$, @ f_{3dB} $\quad -3 = \frac{20}{\ln 10}\left(-N \omega_{3dB}^2 R_i \tilde{C}_{gs}^2 \frac{Z_0}{2}\right)$

$$f_{3dB} = \sqrt{\frac{3 \ln 10}{20 (R_i \tilde{C}_{gs}^2 \frac{Z_0}{2}) 4\pi^2}} = 119\,GHz,$$

which is a bit below f_{Bragg}

And we expect low-freq gain to be:

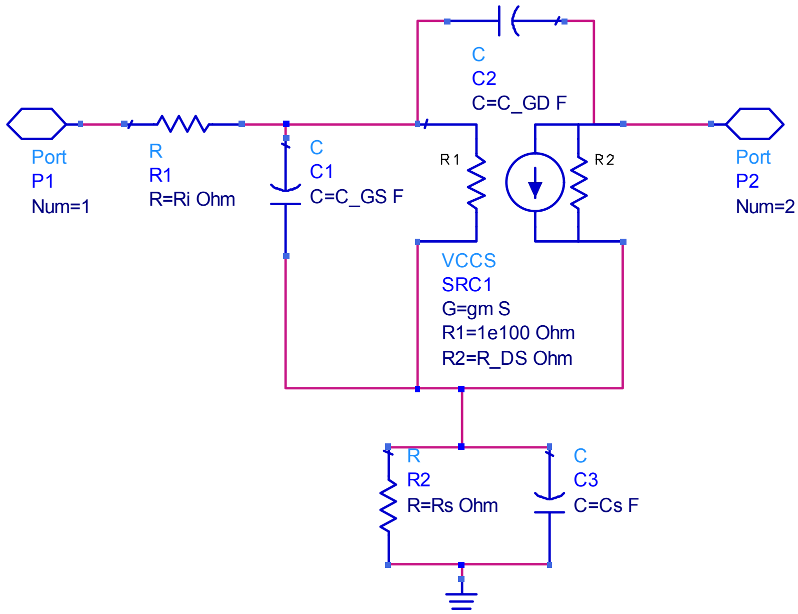
$$A_D = \frac{Z_0}{2 \tilde{R}_{DS}} = 0.2$$ *Note: same as A_g @ 126 GHz because $G_{11} = G_{22}$ there

$$S_{21}(f=0) = 20 \log\left(\tilde{g}_m N \frac{Z_0}{2} \exp(-N A_D)\right)$$
$$= 6.5\,dB$$

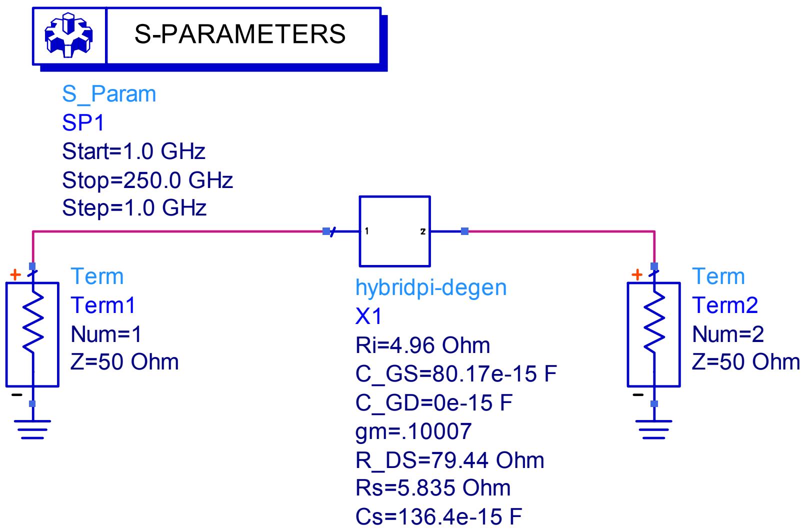
Because Drain Loss is frequency dependent we expect f_{3dB} in simulation to be somewhat lower than 119 GHz

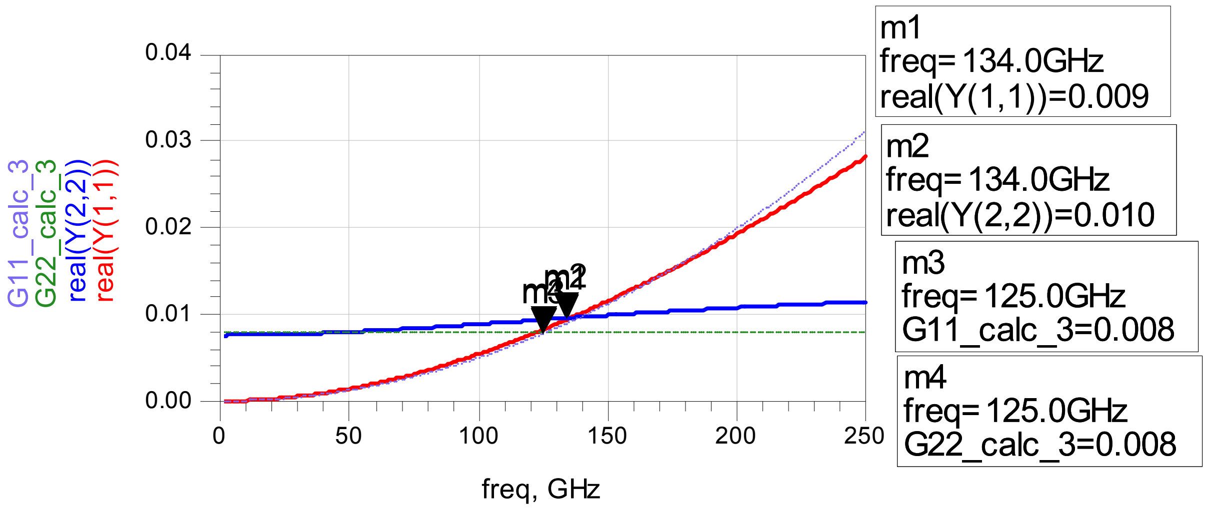
<u>Problem #8</u>

Parameterized degenerated transistor:



Circuit to check G11 and G22:



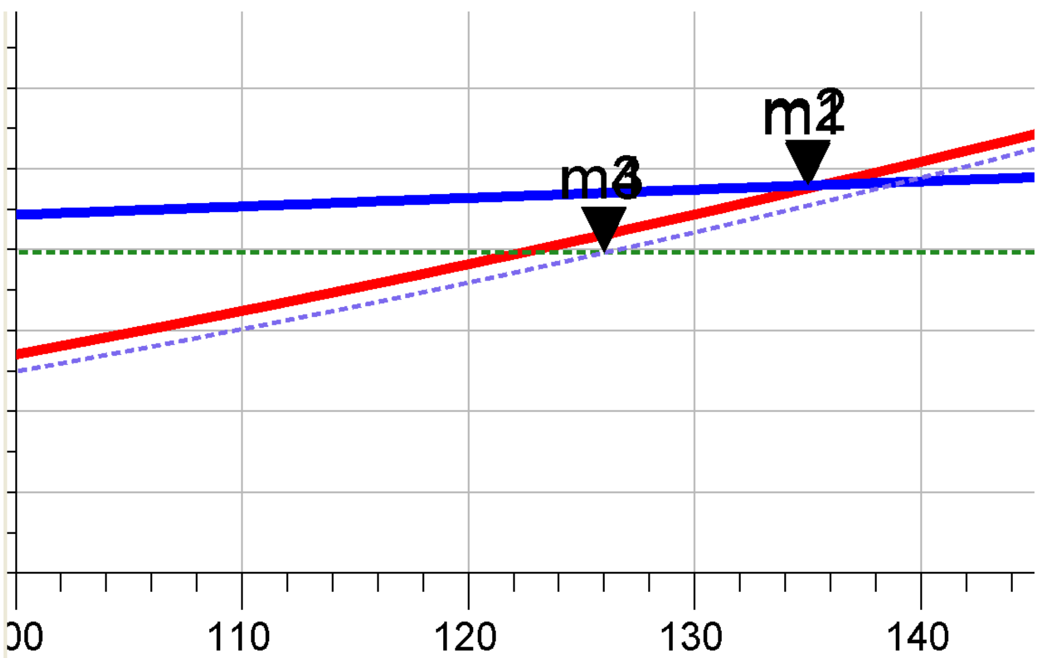


Eqn w = 2*pi*freq

Eqn G22_calc_3=((1/79.4)/(1+.1007*5.835))*freq/freq

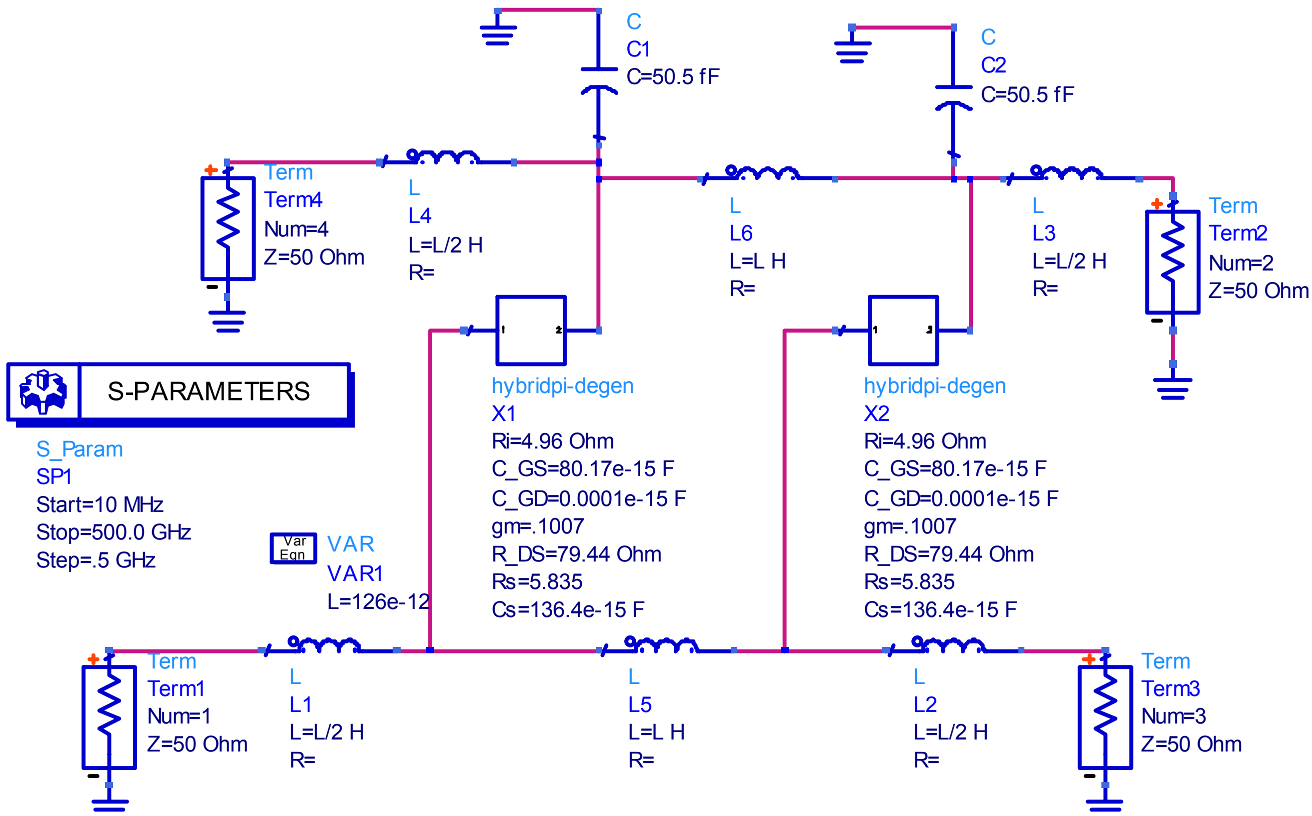
Eqn G11_calc_3=(2*pi*freq*80.17e-15/(1+.1007*5.835))**2*4.96

Zoomed in on intersection:

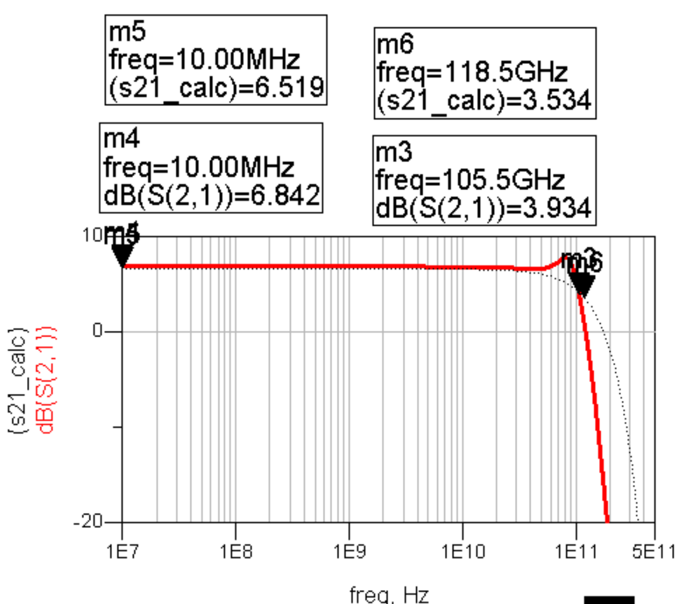


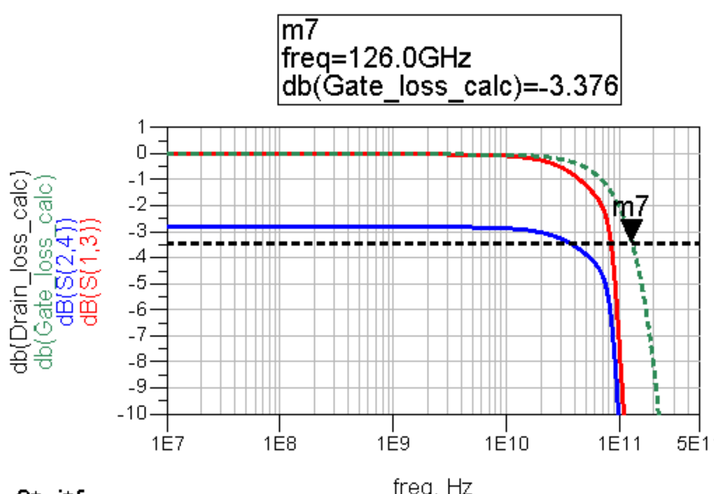
The main discrepancy is the frequency dependence of G22 caused by the source degeneration. The design model G11 and G22 (dotted lines) intersect at 126Ghz as intended, but since G22 is increasing, their actual simulated intersection is at 134GHz.

Full amplifier:



Results:





Eqn w = 2*pi*freq

Eqn s21_calc = 20*log(2*.063*25*(exp(-2*Ag)*exp(-2*Ad)))

Eqn Ag = w**2*4.96*(50e-15)**2*25

Eqn Ad = 25/126

Eqn Gate_loss_calc = exp(-2*Ag)

Eqn Drain_loss_calc = exp(-2*Ad)*freq/freq

We can see above that the low frequency gain is consistent between simulation and calculation. There are discrepancies between calculated loss and simulated loss, the gate transfer response rolls off faster than the calculations suggest, in part because of the cutoff frequency of the line itself. The drain line frequency response also indicates a frequency dependence at higher frequencies because of the source degeneration, which results in the amplifier having a lower 3dB bandwidth than we expected, at 105GHz instead of 118 GHz.

We also observe that the loss on the gate and drain lines is equal at 126GHz, the frequency at which G11=G22.