Sample HW solution

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EE215C Homework 1

Problem 2:

1:15
2:35

(a)

Current mirror provides I=2.5mA for M1. I applied I=2.5mA with an ideal current source and by sweeping the W1 from 20uM to 100uM I found voltage at input node. Next I change I to 2.6mA and repeat the same steps. This gives me Delta V for different W1 values and since delta I = 0.1mA and resistance is 50 ohms, I selected the W1 that has delta V equals to 5mV.

$$I_1 = 2.5mA, I_2 = 2.6mA \Rightarrow \Delta I = 0.1mA$$

$$R_{in} = \frac{1}{g_m + g_{mb}} = 50\Omega$$

$$\Rightarrow \Delta V = R_{in} \times \Delta I = 5mV$$

The data resulted from simulation shows W1 is around 43uM to 46uM. Next, I select W1=43uM and W1=46uM and run DC simulation and extract the gm and gmb. The results are as following:

$$W_1 = 40\mu M \Rightarrow g_m = 15.99mS, g_{mb} = 2.91mS, \Rightarrow R_{in} = \frac{1}{(15.99 + 2.91)\times 10^{-3}} = 52.91$$

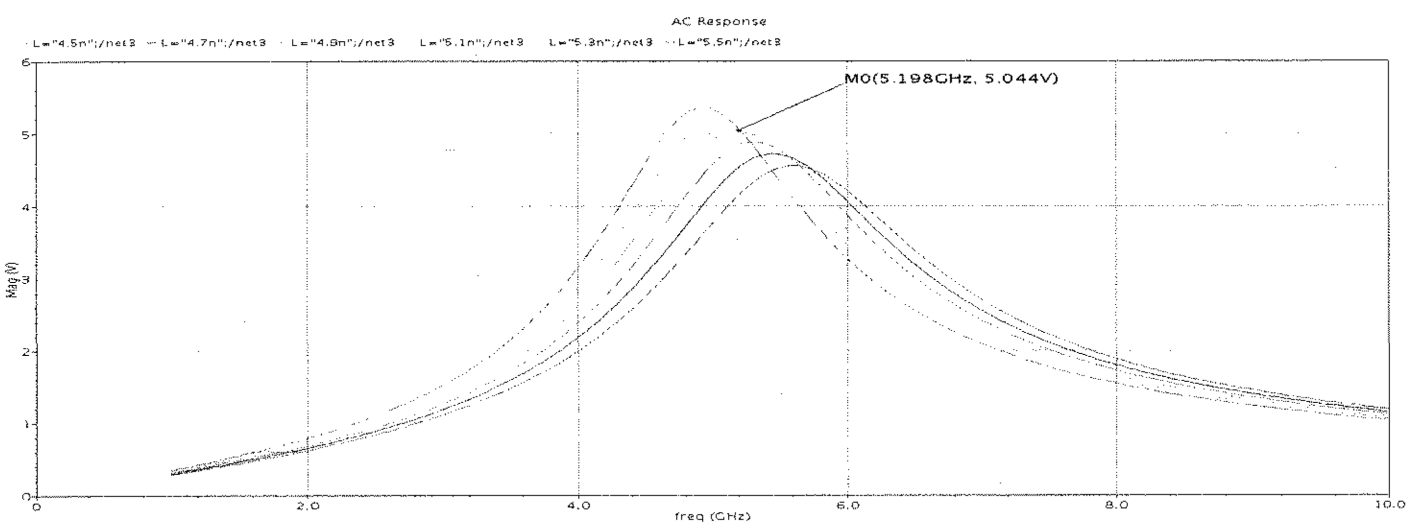
$$W_1 = 43\mu M \Rightarrow g_m = 16.88mS, g_{mb} = 3.063mS, \Rightarrow R_{in} = \frac{1}{(16.88 + 3.063)\times 10^{-3}} = 50.14\Omega$$

Therefore the Width for M1 is 43uM.

(b)

$$Q = \frac{R_P}{L\omega} = 4 \Rightarrow R_p = 4\times 2\pi \times 5.2GHz \times L = L\times 130.7G\Omega$$

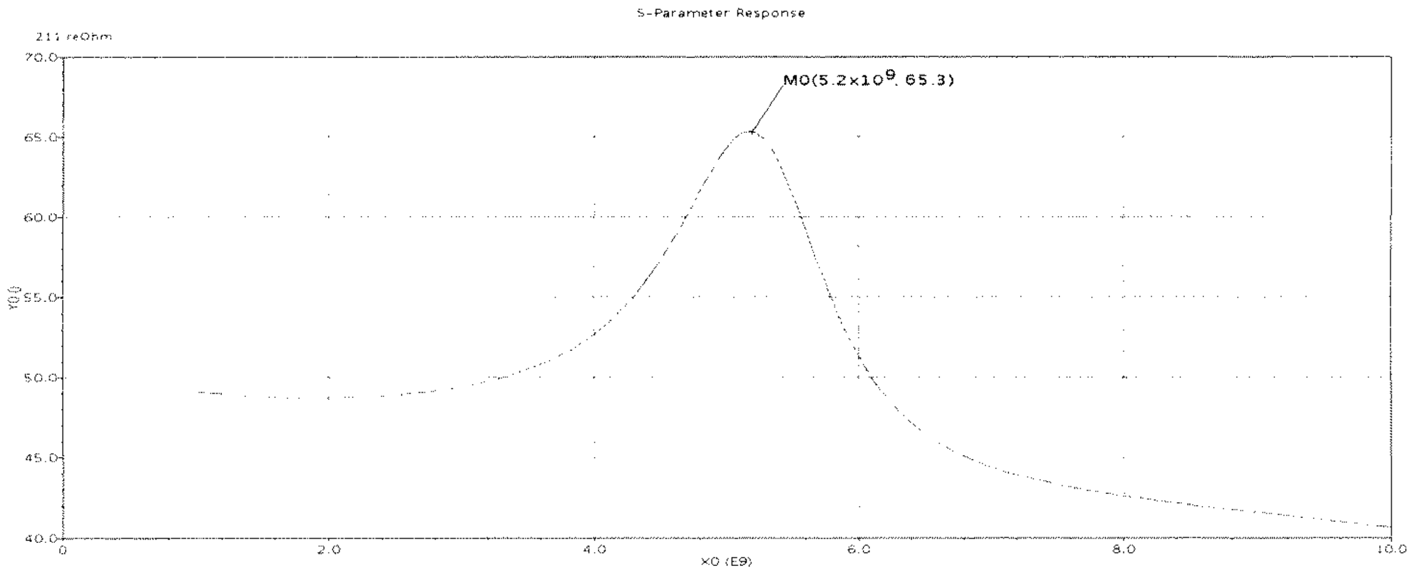
Cp is 10fF for each nanohenry of inductance so Cp is 10L fF for L nanohenry. Using the inductor model and running the AC simulation while sweeping the L value we found the family of plots as below:



As the plots show the resonance frequency at 5.2GHz happens for L=5.1nH.

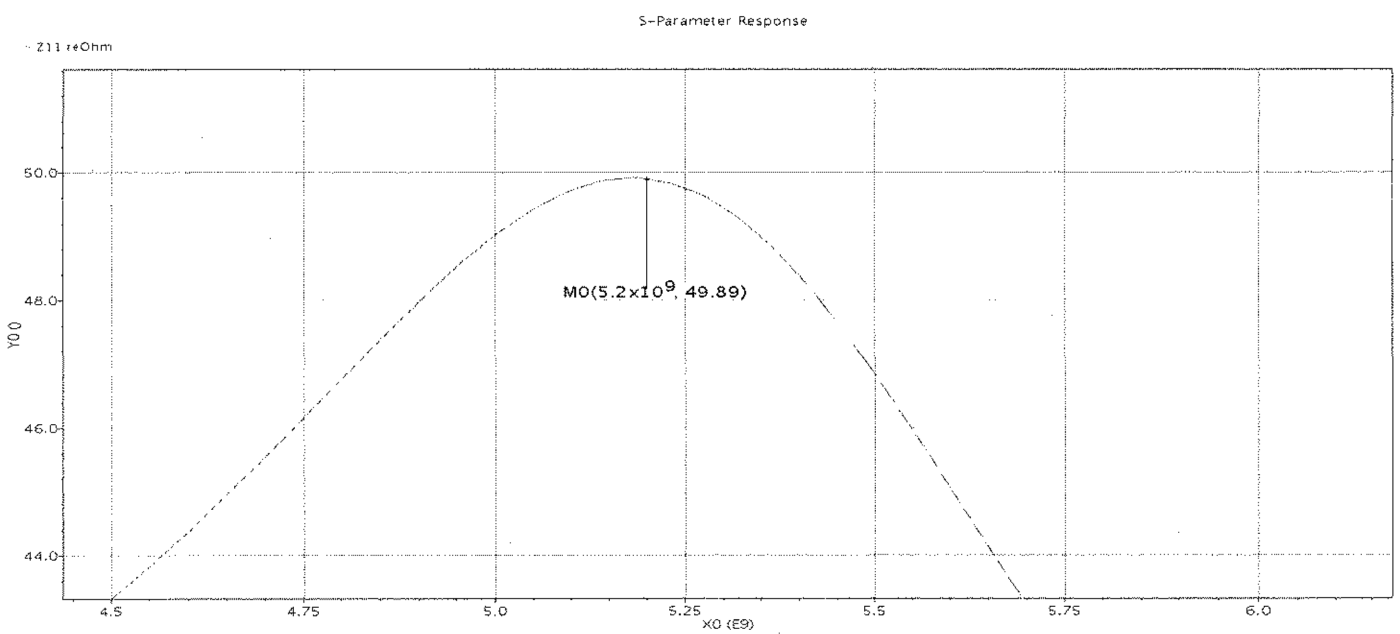
(c)

For this part I used the S-parameter analysis on cadence and Plot the real part of input impedance while sweeping the frequency from 1kHz to 100MHz. The following graph shows the result. At DC (i.e. the low frequency) the resistance is 50 ohms as expected. At resonant frequency f=5.2GHz the resistance equals to 65.3 ohms.



The reason for this is that as we use the non-ideal inductor model there exists an internal resistance for inductor. At low frequency this resistance gets shorted by inductor but at resonance frequency this appears as a pure resistance at Drain of M1 and therefore the input resistance increases.

$$R_{in} = \frac{1 + \frac{R_D}{r_o}}{\frac{1}{r_o} + g_m + g_{mb}}$$ At DC RD is zero and Input resistance is $(gm+gmb)^{-1}$ but at resonance frequency RD is not zero and therefore input resistance is higher. Adjusting the Width of M1 to get the input resistance as 50 ohms results that resonance frequency change too, therefore by adjusting the width to W1=65 uM we need to adjust the L to 4.1nH so that we get resonance frequency equal to 5.2 GHz and resistance of 50 ohms. The results are shown below:

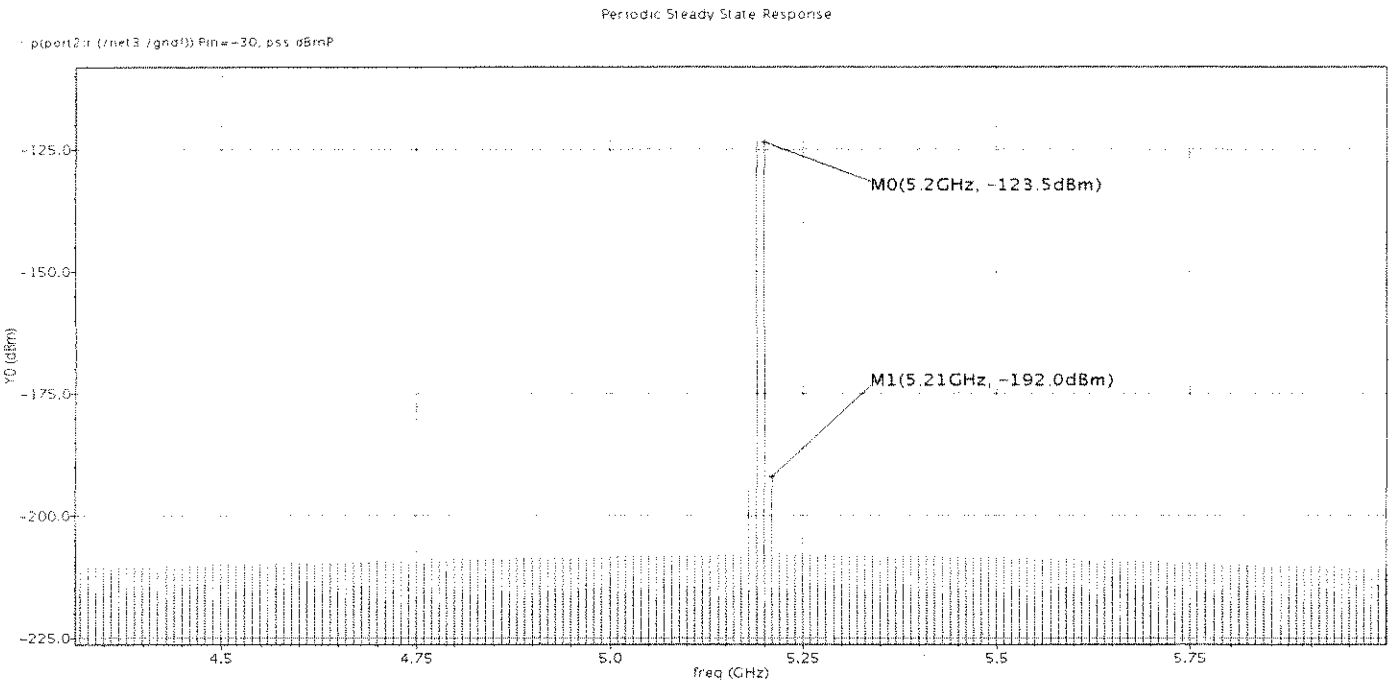


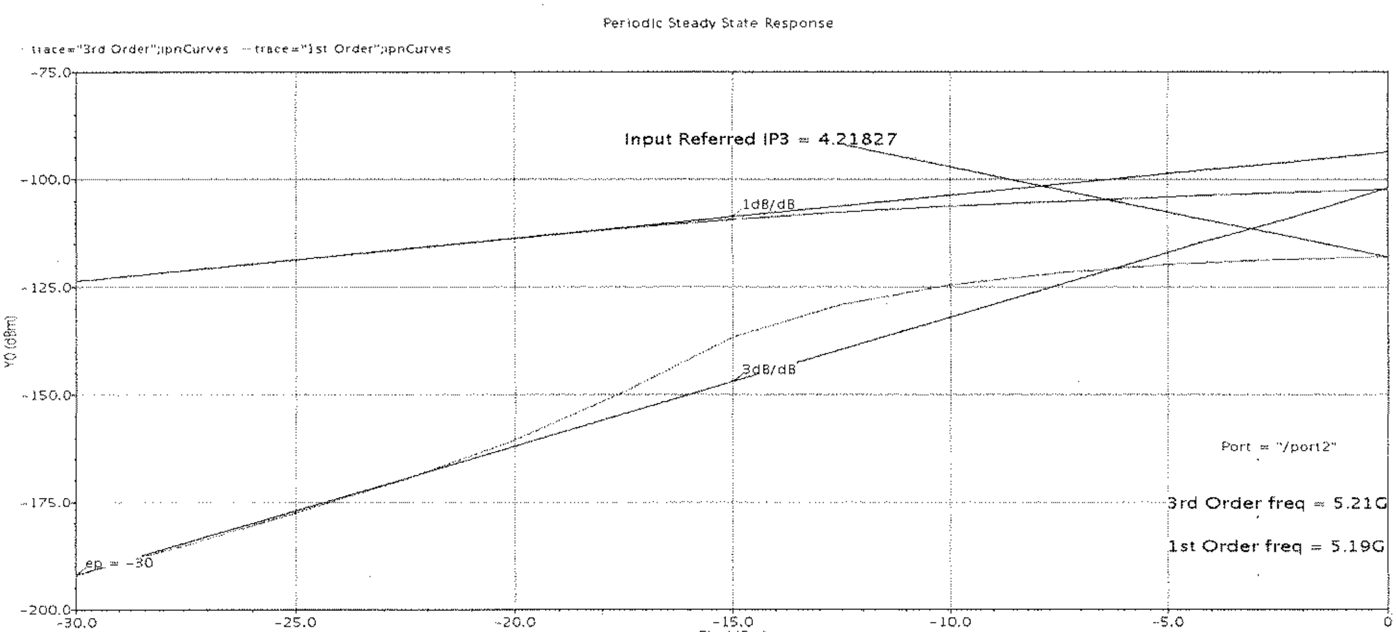
(d)

Using PSS analysis and applying two tones at 5.19GHz and 5.2GHz with Pin = -30dBm, I plot the output Power in dBm and calculate the differenc between them, and find IIP3 in dbm from shortcut method. I also used the IPN curve method of input power extrapolation and find the same result. The plots are shown below:

$$\Delta P\big|_{dB} = (-123.5dBm) - (-192dBm) = 68.5dB \Rightarrow \Delta P\big|_{dB}/2 = 34.25$$

$$IIP_3\big|_{dBm} = \frac{\Delta P\big|_{dB}}{2} + P_{in}\big|_{dBm} = 34.25 - 30 = 4.25dBm$$



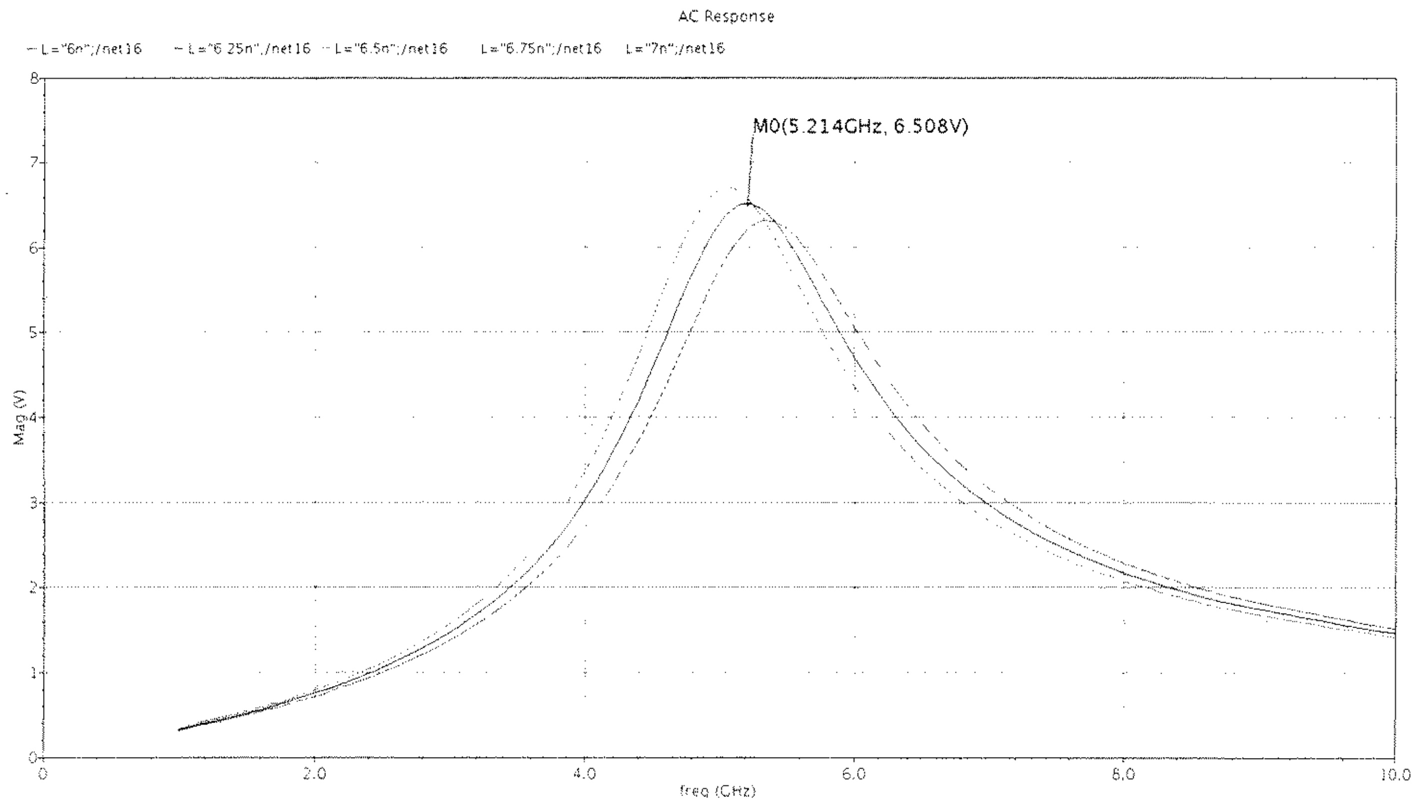


<u>IIP3 = 4.25dBm</u>.

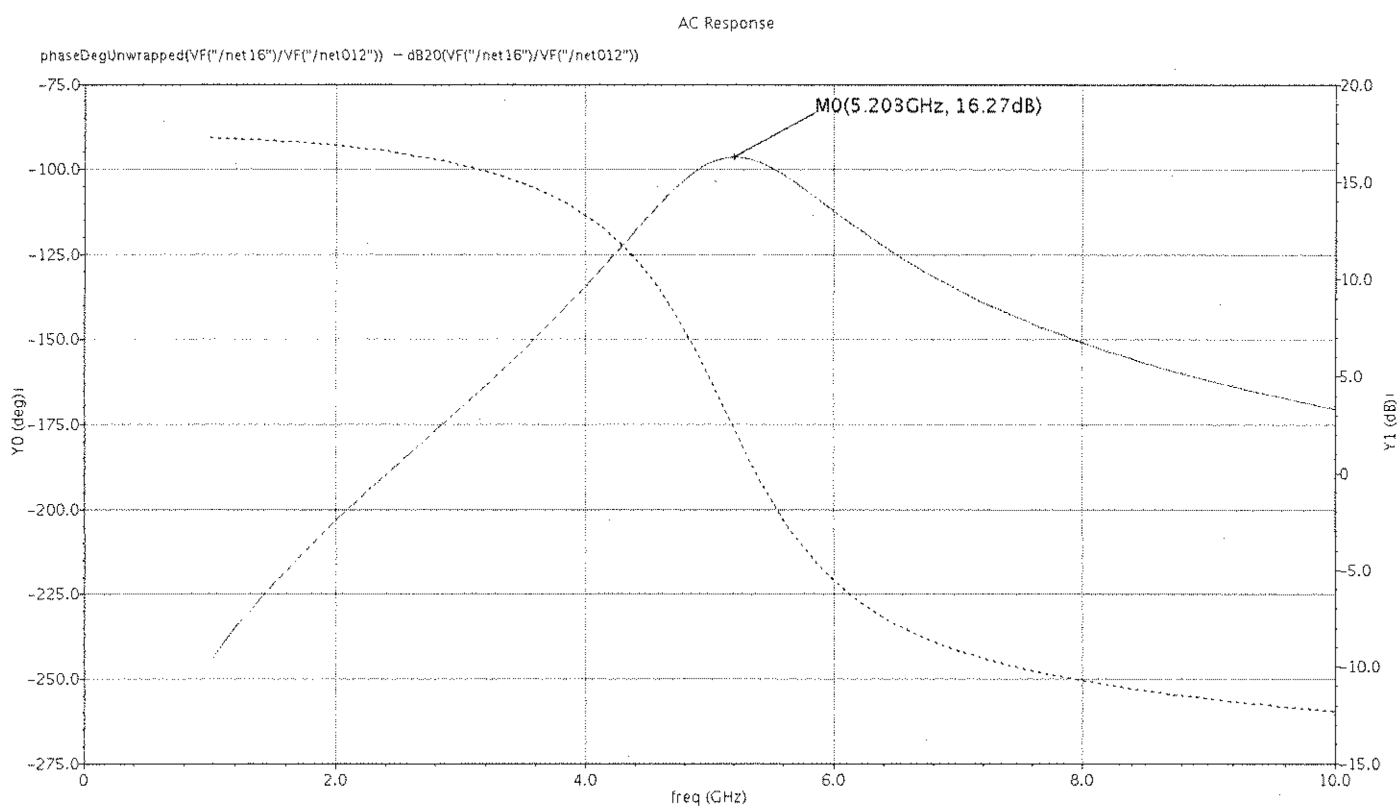
The Voltage gain from AC simulation at 5.2GHz equals to <u>19.36dB = 9.3</u>

(e)

Following the same method as part b at first iteration I found that L2 is between 6nH and 7nH, by second simulation and sweeping L2 from 6nH to 7nH we found <u>L2=6.25nH</u>



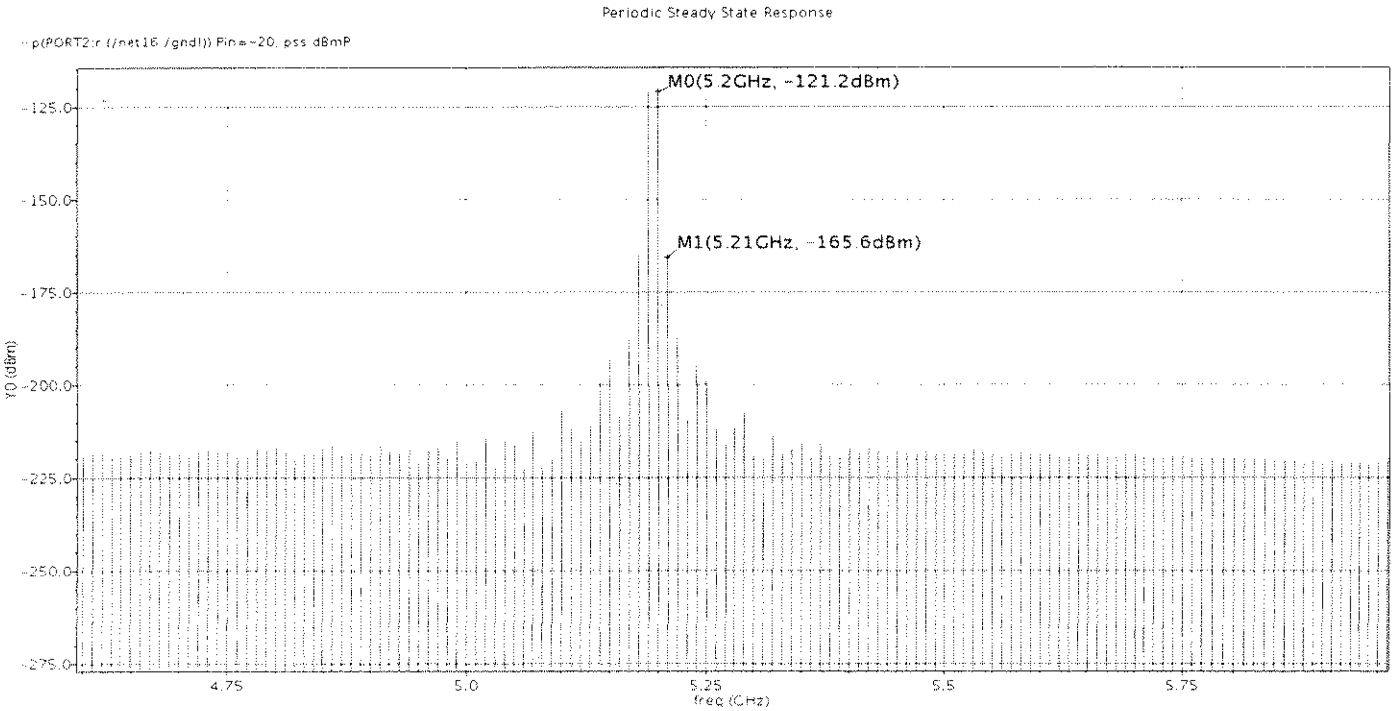
The voltage gain from AC simulation was found as: <u>16.27dB</u>

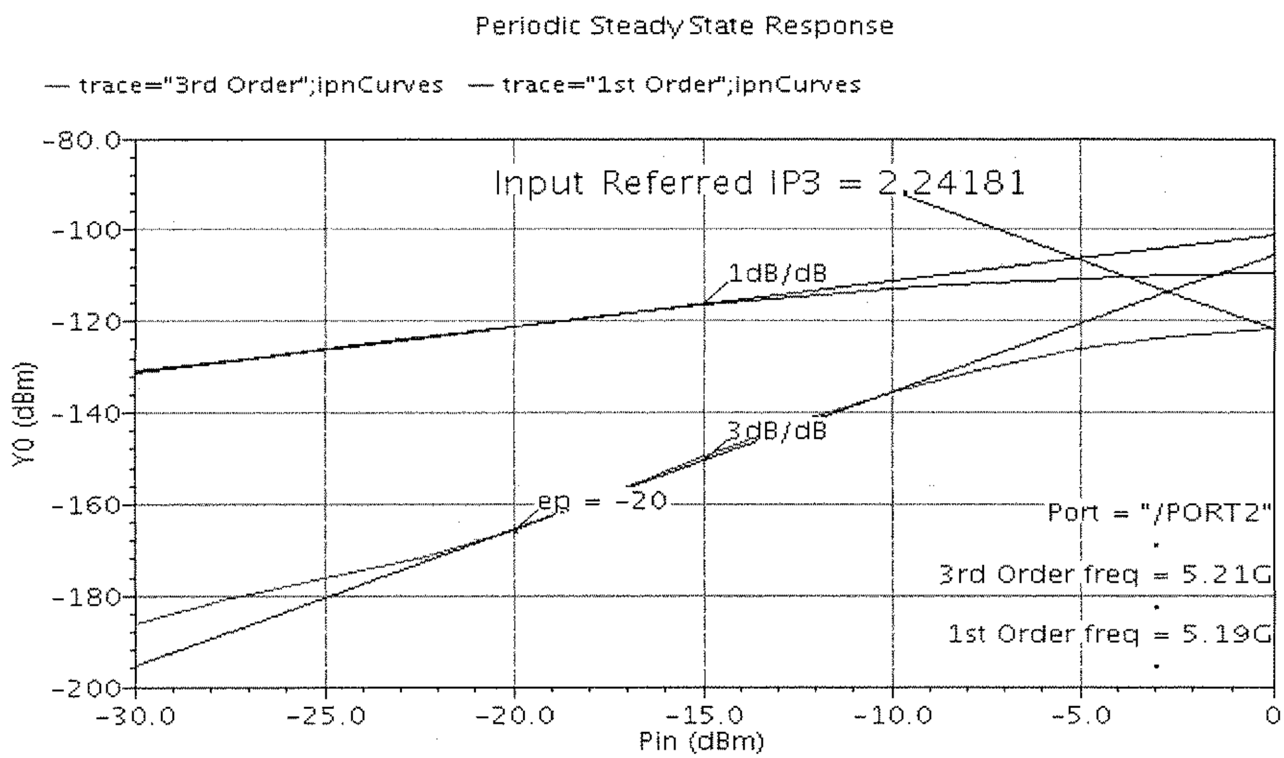


Using same method for calculating IIP3 I found the following results:

$$\Delta P\big|_{dB} = (-121.2dBm) - (-165.6dBm) = 44.4dB \Rightarrow \Delta P\big|_{dB}/2 = 22.2dB$$

$$IIP_3\big|_{dBm} = \frac{\Delta P\big|_{dB}}{2} + P_{in}\big|_{dBm} = 22.2 - 20 = 2.2dBm$$





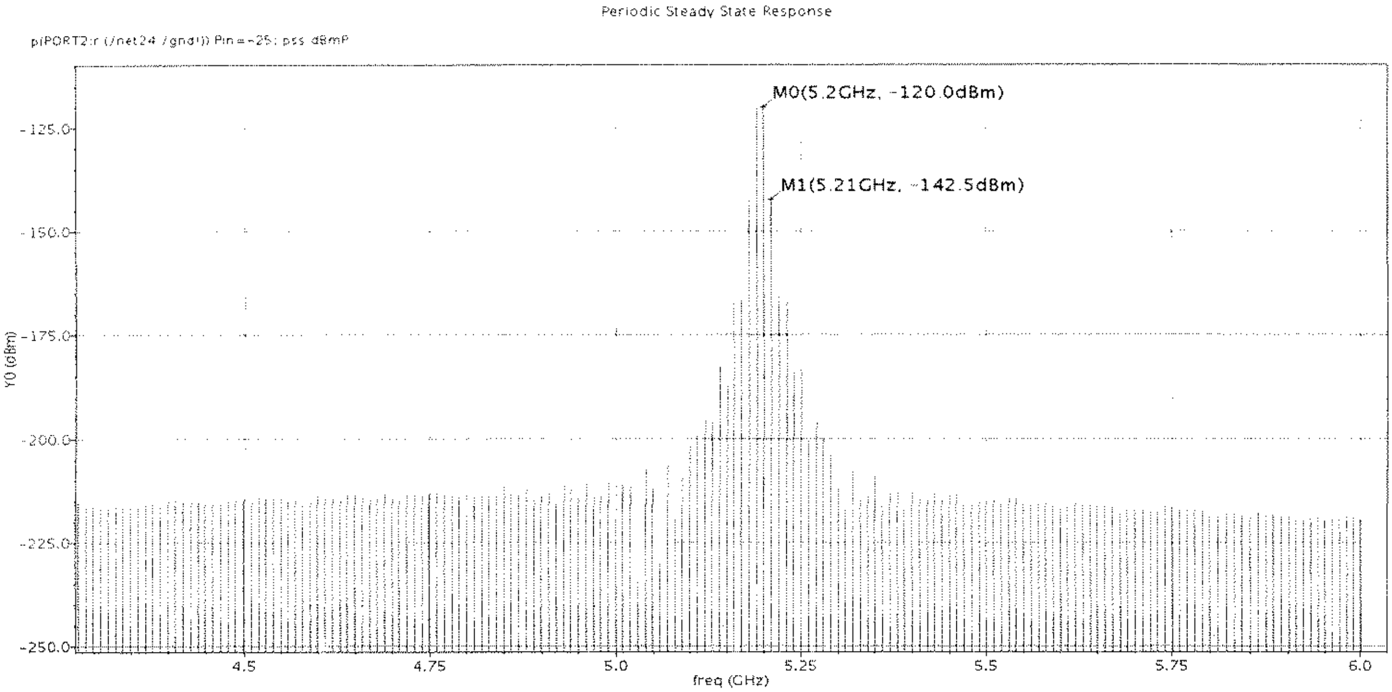
<u>IIP3 = 2.2 dBm</u>

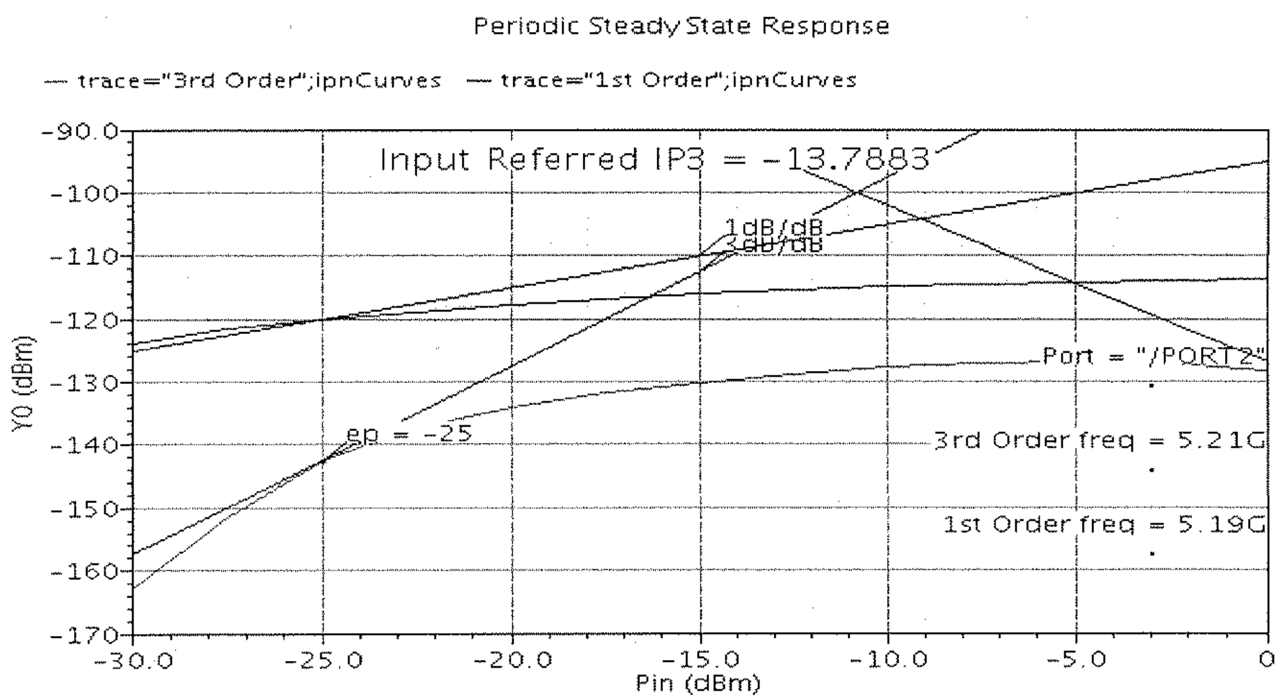
(f)

By placing the second amplifier as the load of the first amplifier the resonance frequency changes to 4.6GHz which is a result of change in the load of the first amplifier As a result a I changed the value of L1 to have the resonance frequency equal to 5.2GHz while kept all other parameters (i.e. W1, L2) fixed.

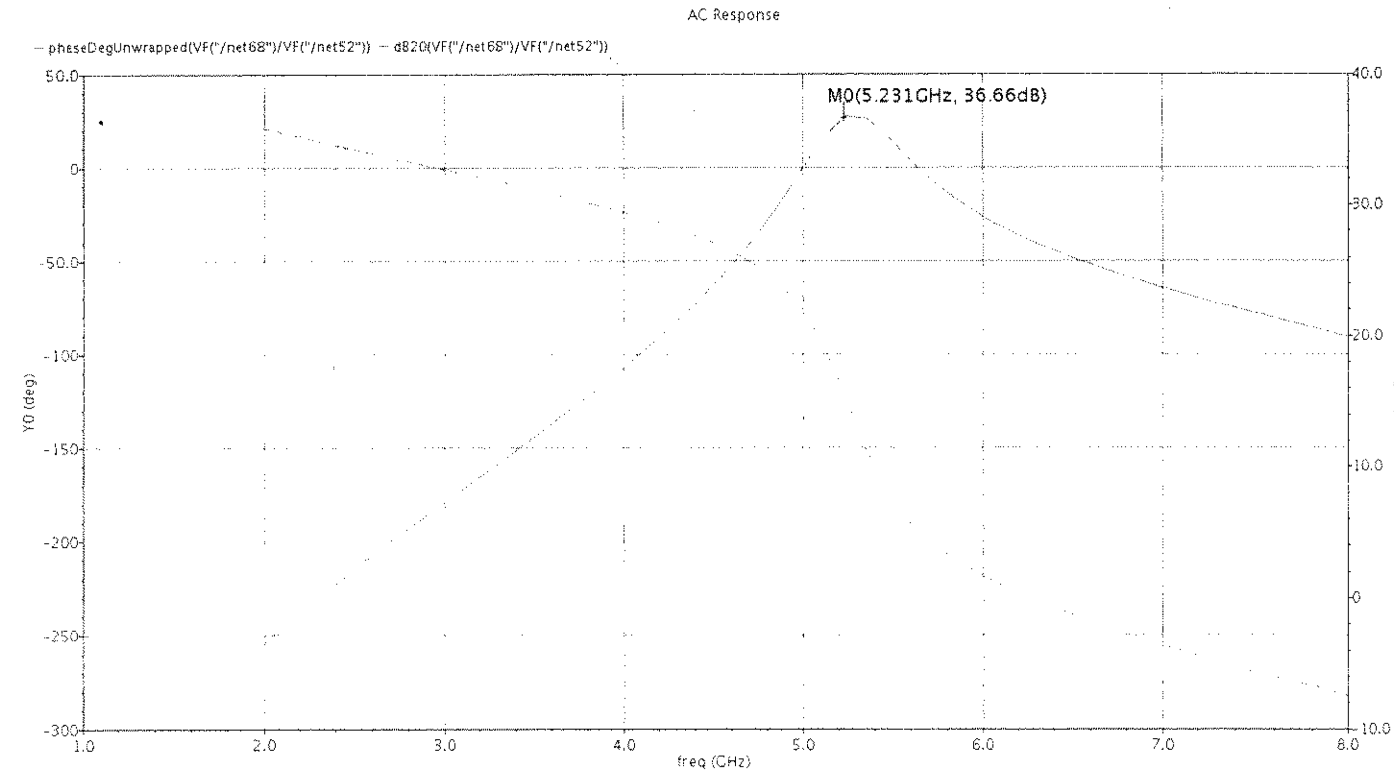
$$\Delta P\big|_{dB} = (-120dBm) - (-142.5) = 22.5dB \Rightarrow \Delta P\big|_{dB} / 2 = 11.25$$

$$IIP_3\big|_{dBm} = \frac{\Delta P\big|_{dB}}{2} + P_{in}\big|_{dBm} = 11.25 - 25 = -13.75dBm$$





<u>**IIP3 = -13.78 dBm**</u>



<u>**And the overall Voltage gain is: 36.66 dB which matches to the gain of stage 1 in dB + gain of stage 2 in dB.**</u>

In order to use equation (2.46) we have to change the dBm and dB values of IIP3's and Voltage gain to real numbers.

$$\Rightarrow = 4.25dBm \Rightarrow AIP_{3-1} = (632mV)\times 10^{\frac{4.25}{20}} = 1030.9mV$$

$$IIP_{3-2} = 2.2dBm \Rightarrow AIP_{3-2} = (632mV)\times 10^{\frac{2.2}{20}} = 814.2mV$$

$$\alpha = 19.36dB = 10^{\frac{19.36}{20}} = 9.3$$

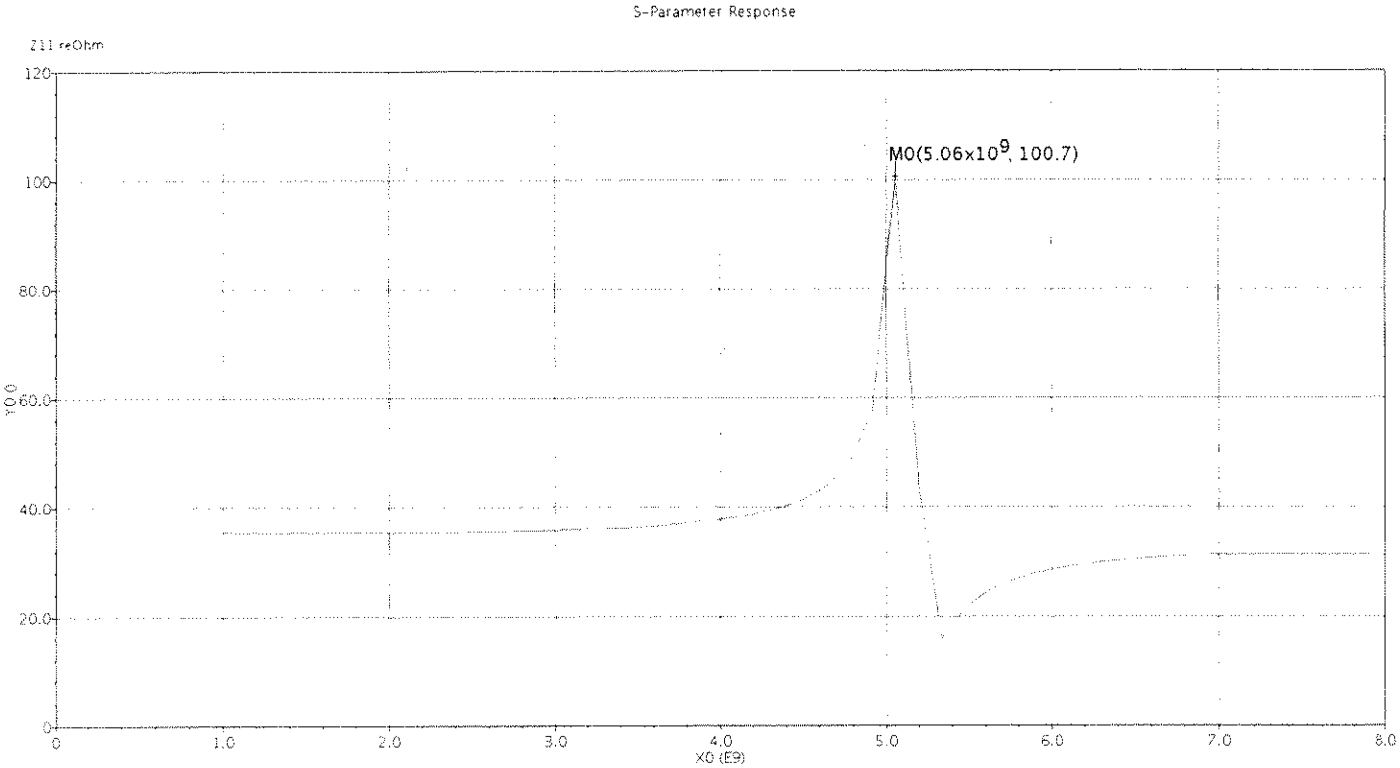
$$\frac{1}{A_{IP3}^2} = \frac{1}{A_{IP3-1}^2} + \frac{\alpha^2}{A_{IP3-2}^2} = \frac{1}{(1.0309V)^2} + \frac{(9.3)^2}{(0.8142V)^2} \Rightarrow A_{IP3} = 87.24mV$$

$$\Rightarrow IIP_3 = 20\times\log\left(\frac{87.24mV}{632mV}\right) = -17.20dBm$$

The result from the simulation and calculation are close but they don't match exactly, the reason could be a result of neglecting the effect of IM2 of the first amplifier which will increase the IM3 at the output of the second stage and also changing the value of L each times we want to match the resonant frequency to 5.2GHz. Nevertheless, the amount of error is not huge and this shows the simulation was successful.

(g)

From the plot below, it can be seen that the input resistance changes by a significant amount. It is now almost 100 ohms. This is because there is now a much larger load on the first stage, thus affecting the input impedance. Also, the adjustments in the inductor model to achieve resonance at 5.2GHz will have some effect on the input impedance.



(h)

The second stage limits the IIP3 because of the large gain in the first stage.

1).

a) using eq (4.28): $NF = \frac{\overline{V_{n,out}^2}}{A^2} \cdot \frac{1}{4kTR_S}$

$$NF_1 = \frac{\overline{V_{n,amp}^2} + 4kTR_S A^2}{A^2} \times \frac{1}{4kTR_S} \Rightarrow \overline{V_{n,amp}^2} = (NF_1 - 1) \times 4kTR_S A^2$$

$$\Rightarrow NF_{tot} = \frac{\overline{V_{n,amp}^2} + 4kT(R_S \parallel R_P)A^2}{(\frac{1}{2}A)^2} \times \frac{1}{4kTR_S} = \frac{(NF_1 - 1)4kTR_S A^2 + 4kT\frac{R_S}{2}A^2}{(\frac{1}{2}A)^2} \times \frac{1}{4kTR_S} = 4NF_1 - 4 + 2$$

$$\Rightarrow \boxed{NF_{tot} = 4NF_1 - 2}$$

b) Here the first stage is a loss stage with the gain of ½.

Fris's equation: $NF_{tot} = 1 + (NF_1 - 1) + \frac{NF_2 - 1}{A_{P_1}}$

$$\Rightarrow NF_{tot} = 1 + (2 - 1) + \frac{NF_1 - 1}{(\frac{1}{2})^2} = 4NF_1 - 4 + 2 = \boxed{4NF_1 - 2}$$