ECE 166 – Microwave Circuits and Systems
Homework #5– Friday December 3, 2021 - In the Review Session
(Low-Noise Amplifier Design, High-Gain Amplifier Design)
Counts as 1.5Hwks

You will be designing a low noise and a high gain amplifier using the Avago ATF 34143 amplifier. This is a high-performance GaAs amplifier with a NF_{min} of 0.1-0.3 dB at 500 MHz to 3 GHz (all for 20 cents, amazing!). *All simulations and plots are to be done in ADS.* The S-parameters are given on the website.

Note: ADS can plot many of these parameters for you. See ECE 166 website.

1) Using the S-parameters for <u>3 V, 20 mA</u> bias (page 7 in the data sheet), calculate and plot at 0.1-10 GHz:
   a) S-parameters (for S_{21}, you can plot $S_{21}/10$ so that it is mostly in the Smith Chart).
   b) The unilateral coefficient (U), and the upper and lower bounds of the gain in dB (centered at 0 dB). In which frequency region is the unilateral approximation valid?
   c) The Stability Factor, k and Δ. In which frequency region is the transistor unconditionally stable?
   d) The maximum transducer gain in dB (MSG or MAG depending on k) that can be attained using this device. Compare with S_{21}. This is basically Fig. 23 in the data sheet.

2) Using the S-parameters at 3 V, 20 mA, and the noise parameters, design a <u>low-noise amplifier</u> *at 2.5 GHz* for WLAN base-stations. Clearly write Gamma(opt), Gamma(s), Gamma(out), Gamma(in) and Gamma(l) *at 2.5 GHz*, the matching networks used (ideal components but with Q=40 for the inductor and Q=100 for the capacitor), and the simulated S-parameters and noise figure (plot from 0.1-5 GHz). Use LC matching. Label the gain, the output match level (must be good), the input match level (should not be *that* good but OK), and the noise figure at 1-4 GHz. <u>Check that the LNA is stable at all frequencies</u> by plotting the input and output stability circles, and Gamma(s) and Gamma(l) (again, ADS does this automatically). Make sure that Gamma(s) and Gamma(l) do not enter the un-stable regions at their respective frequencies. Make sure that S_{11} and S_{22} for the entire amplifier are < 1 at all frequencies (for stability). Clearly plot the S-parameters and NF of the entire amplifier. Clearly state how you stabilized it.

3) Using the same S-parameters at 3 V, 20 mA, <u>design a high-gain amplifier at 5.5 GHz</u>. You will see that the transistor is still not stable but U is ~ 0.1, and that one can use a unilateral gain approximation. However, the transistor is greatly unstable at < 4 GHz and your wonderful design at 5.5 GHz may lead to oscillations at lower frequencies. Make sure to avoid the bad regions on the Smith chart for both Gamma(s) and Gamma(l). Clearly show the LC matching networks used (ideal components but with Q=40 for the inductor and Q=100 for the capacitor). Plot the S-parameters and NF of the amplifier from 1 to 10 GHz (but check stability at all frequencies). Clearly state how you stabilized it. What is the achieved gain at 5.5 GHz as compared to the unilateral gain?

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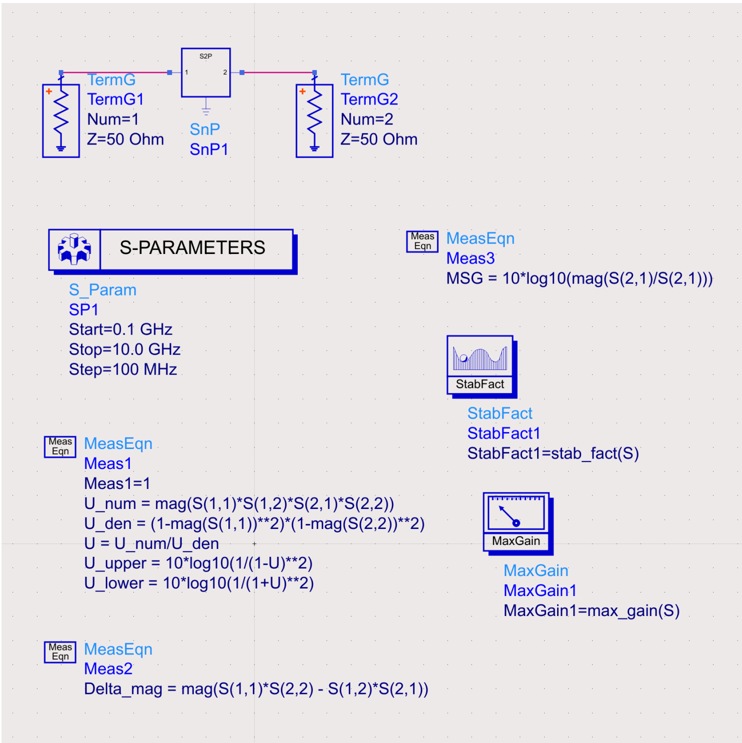
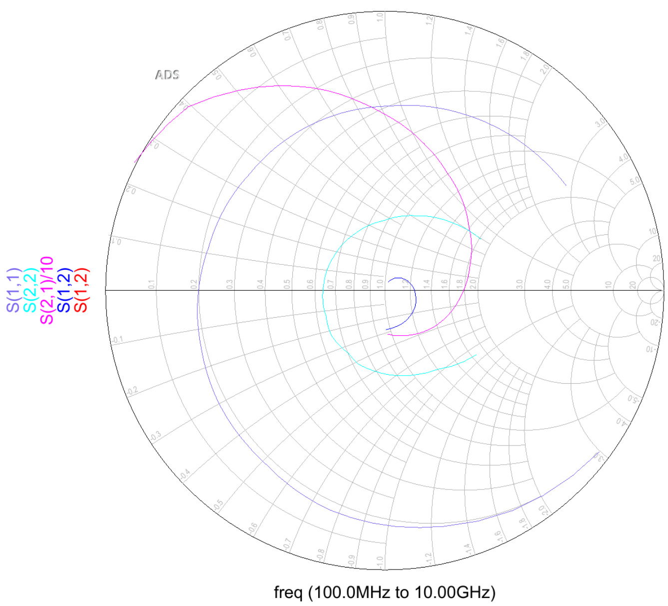
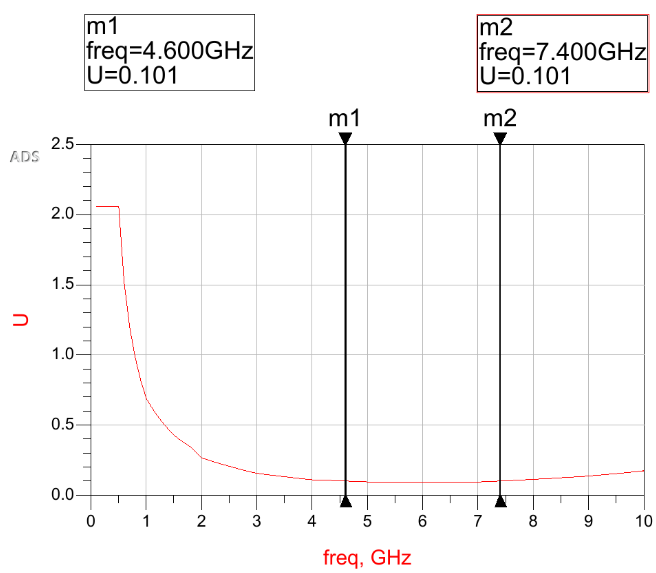
Problem 1

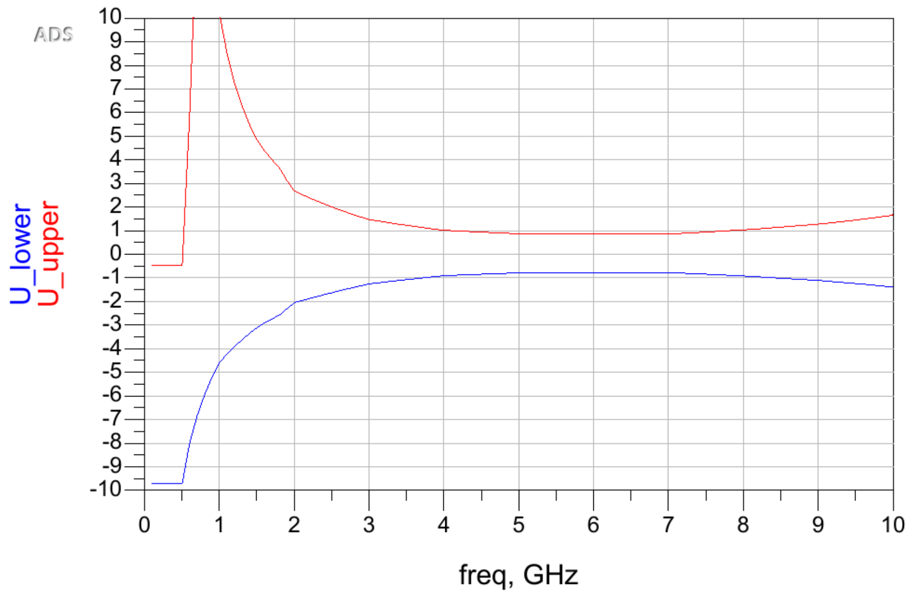


a)


ADS
S(1,1)
S(2,2)
S(2,1)/10
S(1,2)
S(1,2)
freq (100.0MHz to 10.00GHz)

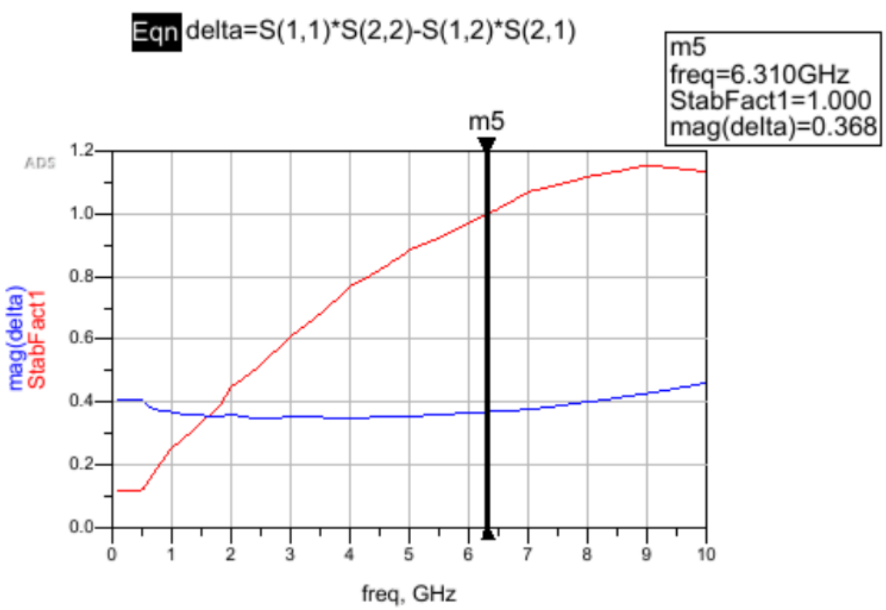
b)


m1
freq=4.600GHz
U=0.101
m2
freq=7.400GHz
U=0.101
m1
m2
ADS
2.5
2.0
1.5
1.0
0.5
0.0
U
0 1 2 3 4 5 6 7 8 9 10
freq, GHz



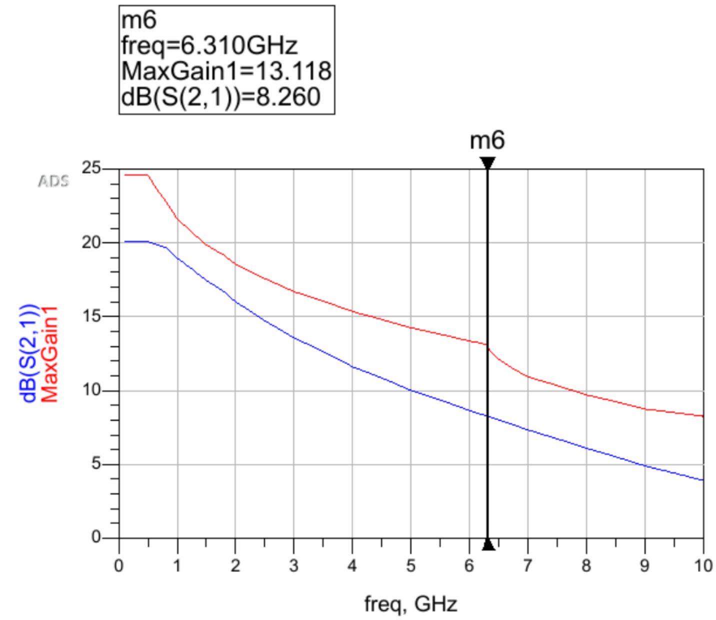
The unilateral approximation is valid when u < 0.1, which is frequency range 4.6 GHz - 7.4 GHz. This is when the effect of S12 can be ignored.

c)



The amplifier is unconditionally stable when |k| > 1, |delta| < 1.

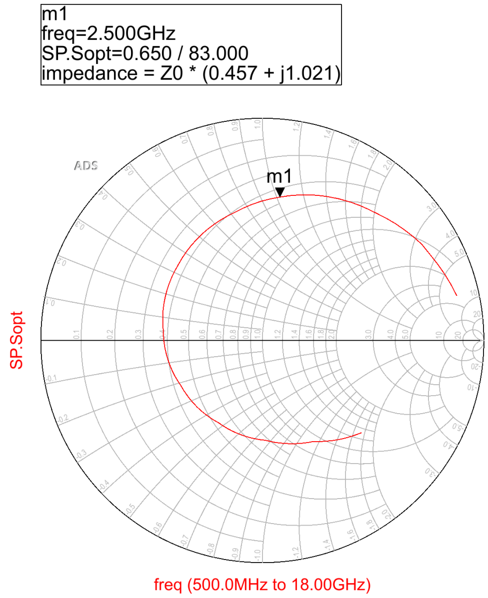
d)



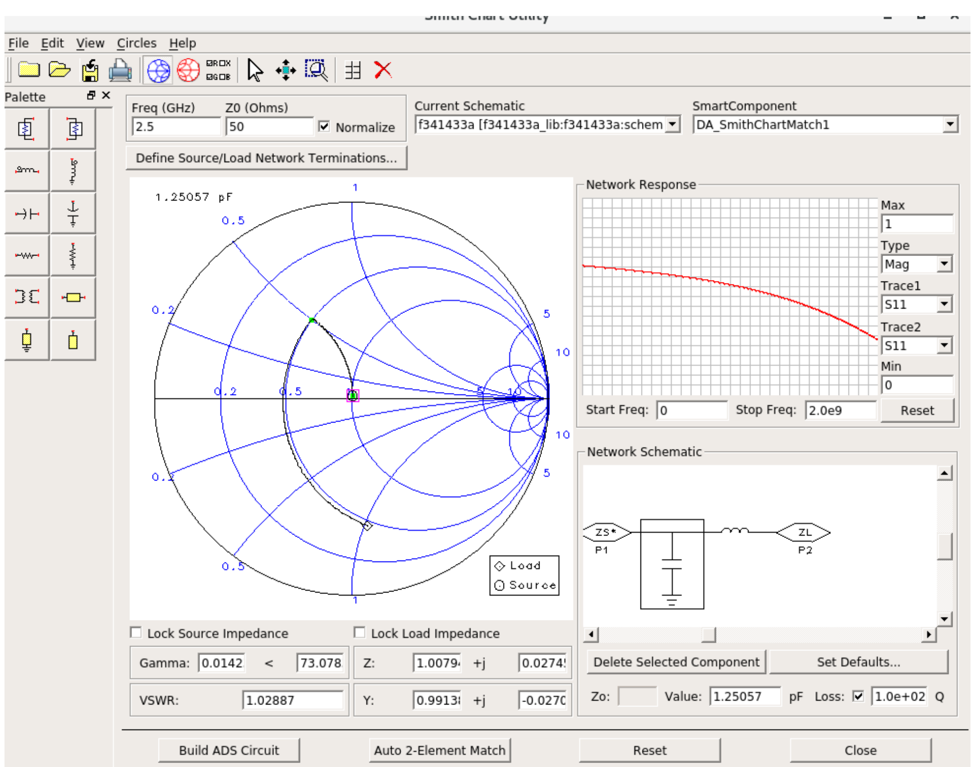
Frequencies lower than 6.31 GHz are unstable. Higher frequencies are stable.

<u>Problem 2: Low-Noise Amplifier</u>

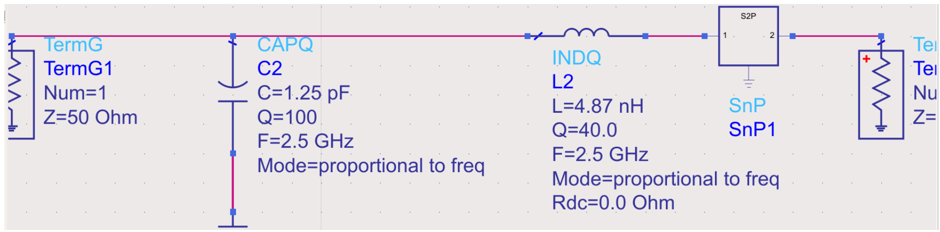
Finding gamma opt for the ATF-34143 at 2.4 GHz:



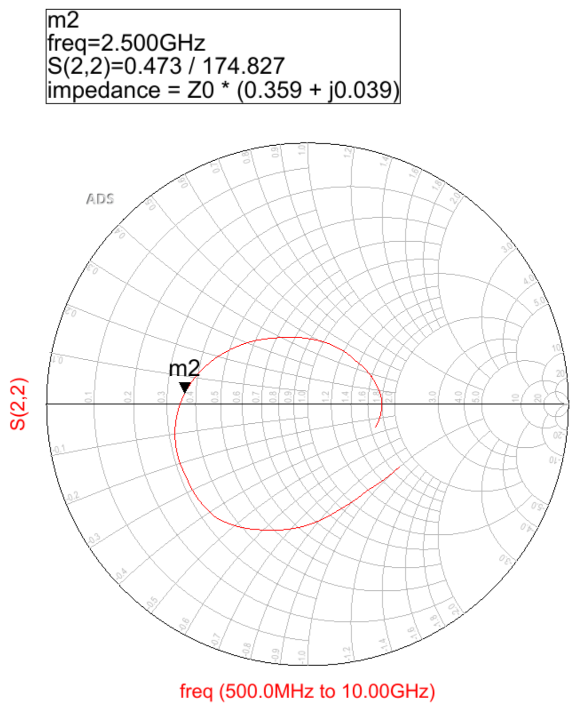
The above shows the Zs that correspond to gamma_opt. Below, the smith chart is used to match Zs* to Zo. For Q(ind) = 40 and Q(cap) = 100, L = 4.87 nH and C = 1.25 pF.



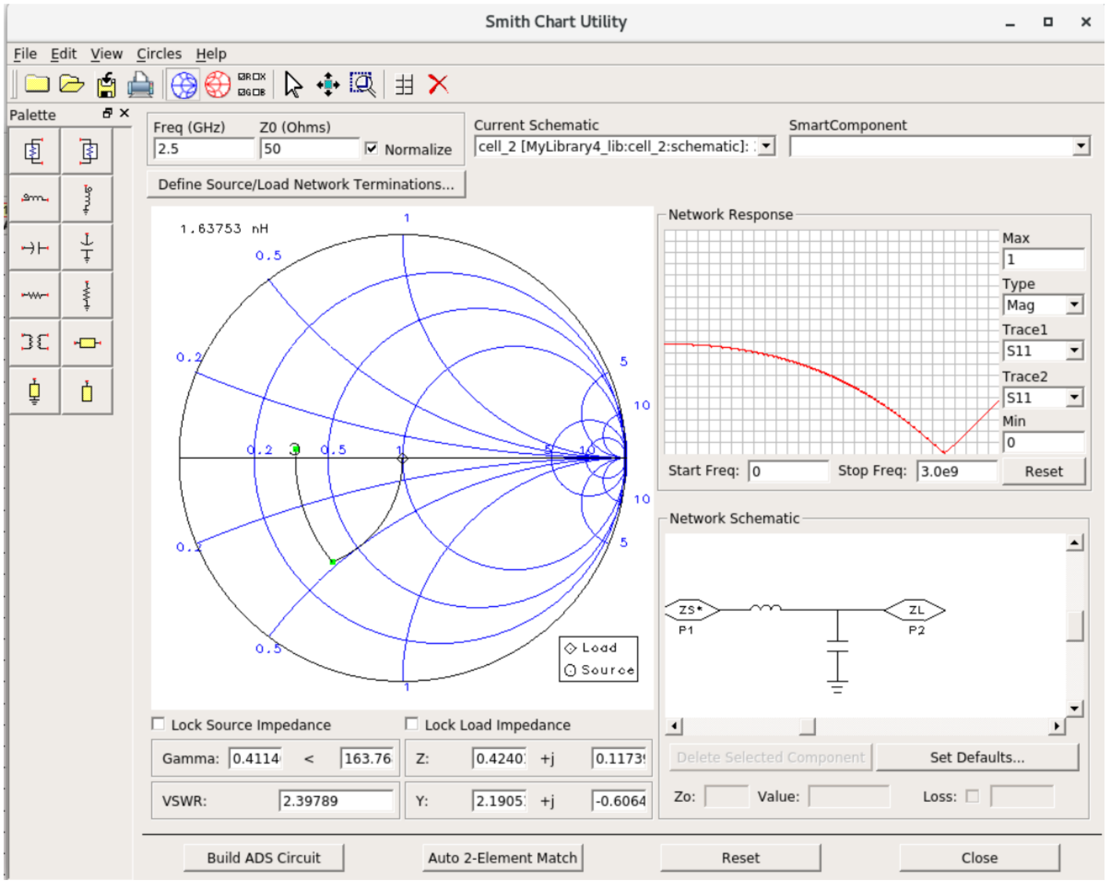
The circuit now looks like:



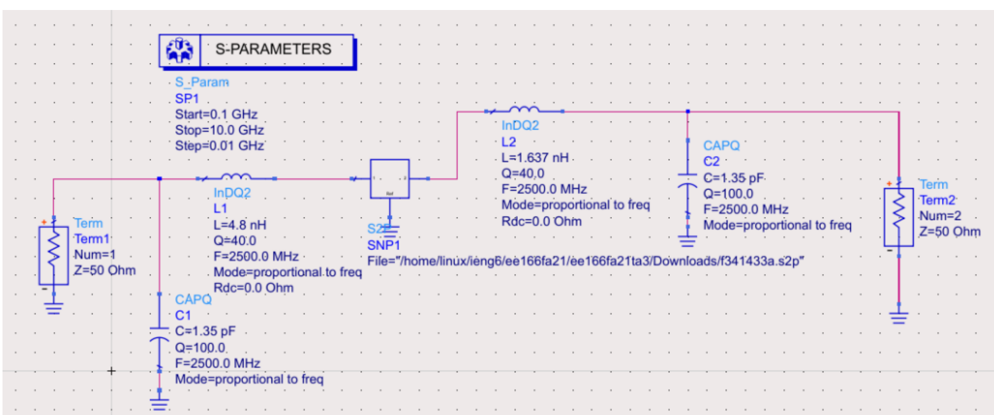
Next, we need to design a matching network for the output. Finding Gamma(out) and the corresponding Zout:



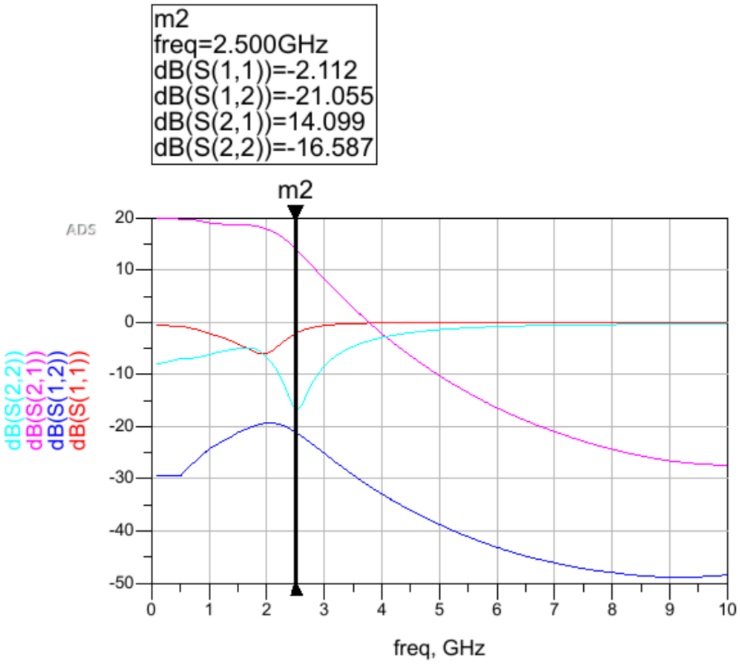
Matching Zout* to Zo with finite Q's included, we get L = 1.637 nH, C = 1.735 pF



Final circuit is now:

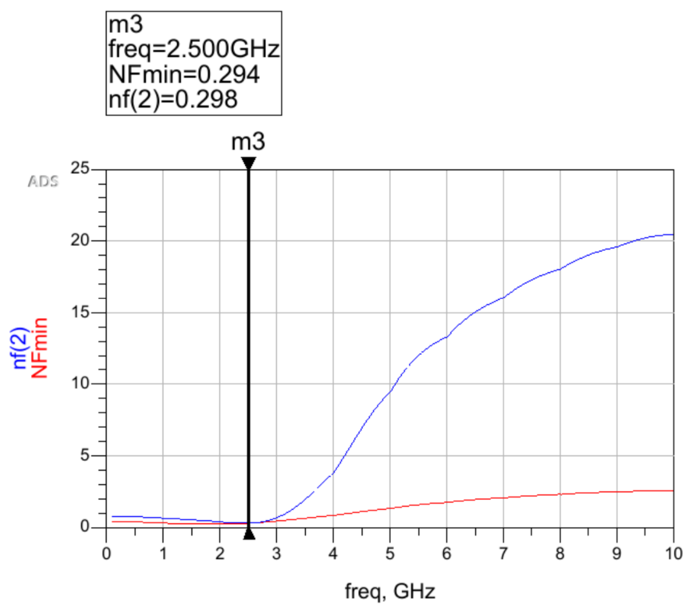


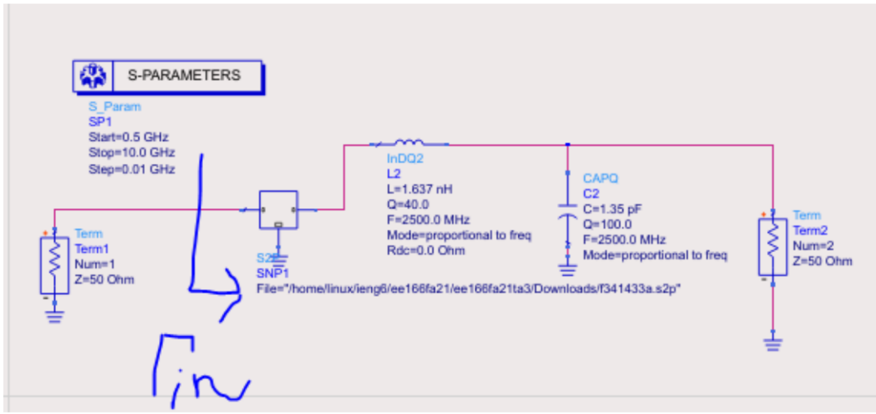
The S-parameters are:

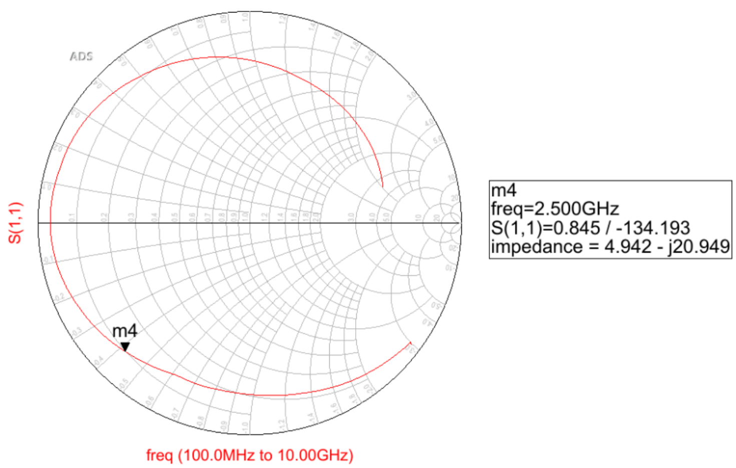


This is close to what the data sheet parameters are, so the amplifier is correctly designed. S21 is the gain, 14 dB at 2.5 GHz which agrees with Ga on the datasheet. The output match level is S22 @2.5GHz = -16.59 dB. The input match level is S11 @2.5GHz = -2.11 dB.

NF:





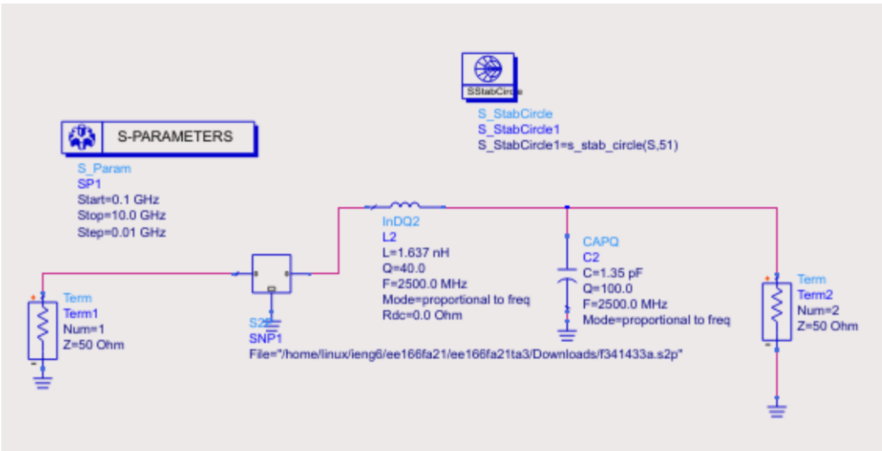


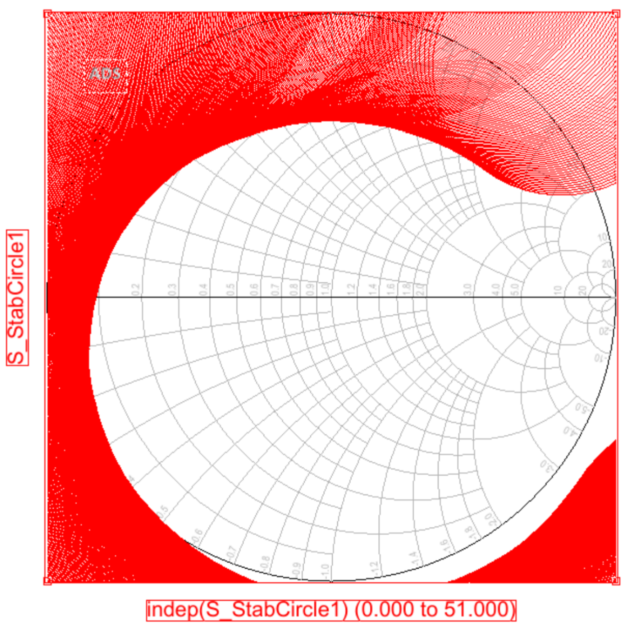
Above is gamma_in @2.5GHz. Gamma_l is the conjugate of gamma_out, which was measured earlier. Therefore, gamma_l is 0.489exp(-1i*174deg). We now know gamma_in, gamma_out, gamma_l, and gamma_opt.

Now, we need to check that the LNA is stable at all frequencies.

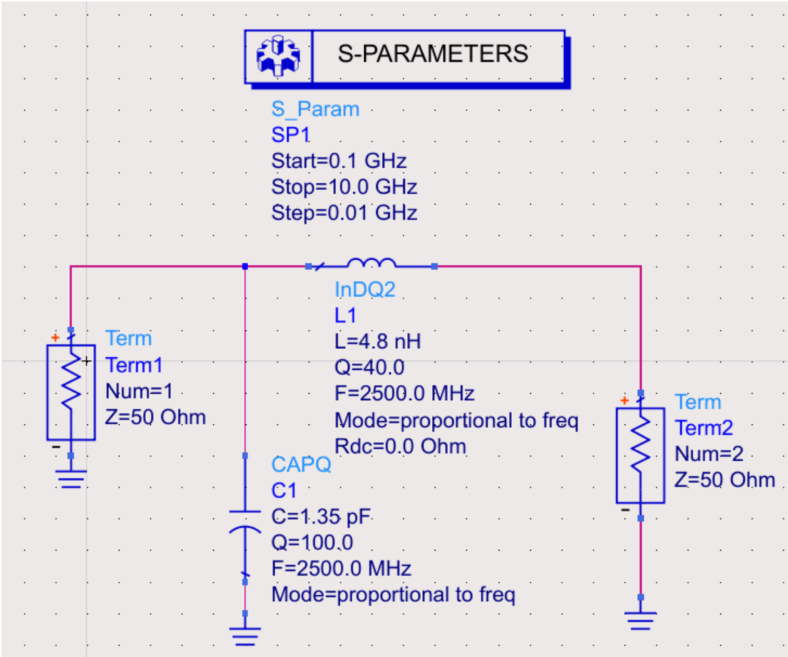
Stability Adjustments

A source stability circle is generated to find the region where gamma_s will be stable.

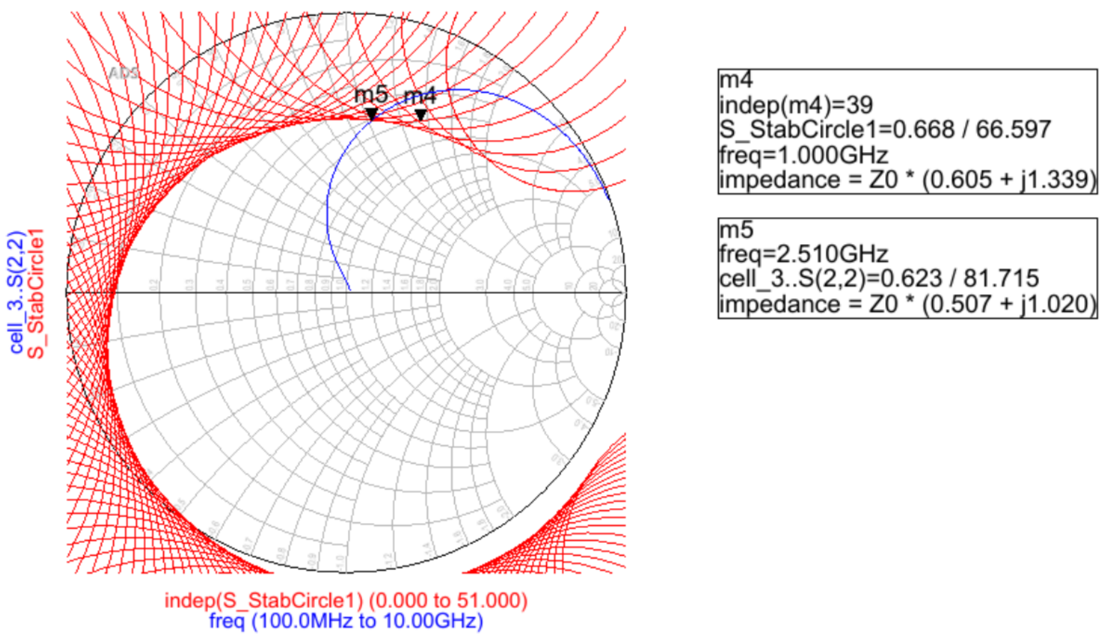




For stability, the S22 curve of the input matching network must not intersect at the same frequency of the red region above.

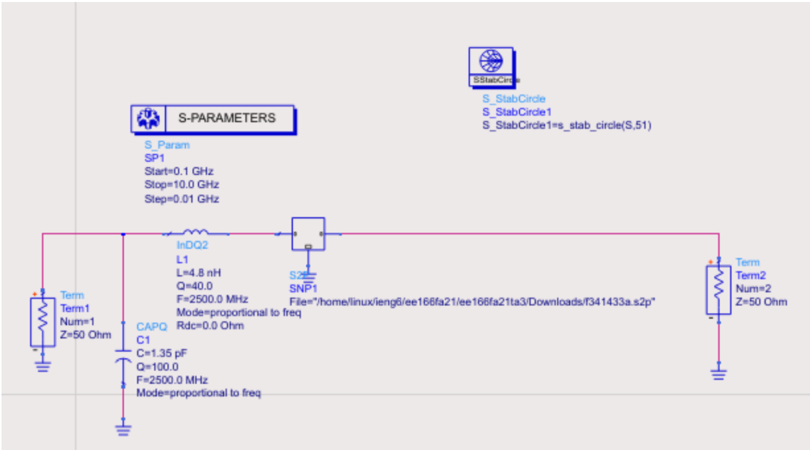


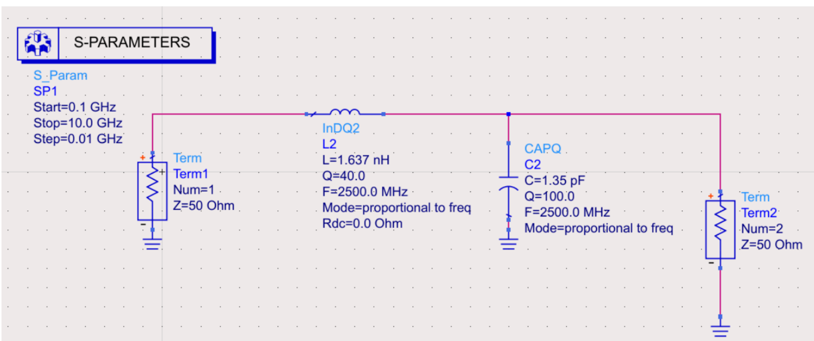
Plotting with less curves to make it more clear:

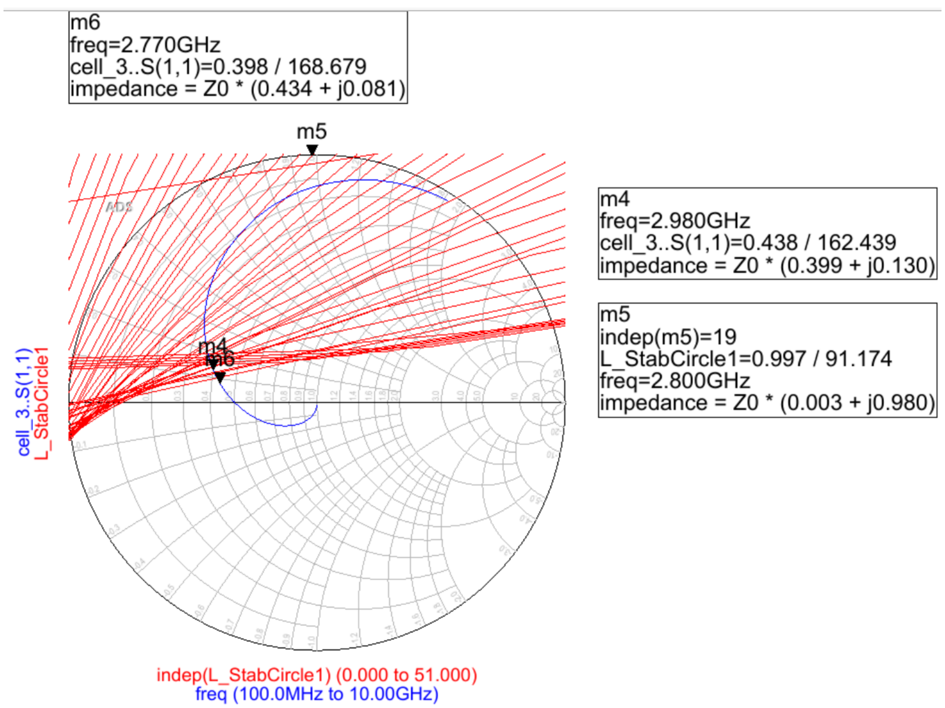


The red curve which intersects with m5 is the highest frequency of the stability circle. This is much lower than the S22 circle frequencies in that region, so it will be conditionally stable. This is different from unconditionally stable, in which all the red circles would be outside the smith chart. This only happens when k>1.

Doing the same for the output network, we use L_StabCircle to generate load stability circles.

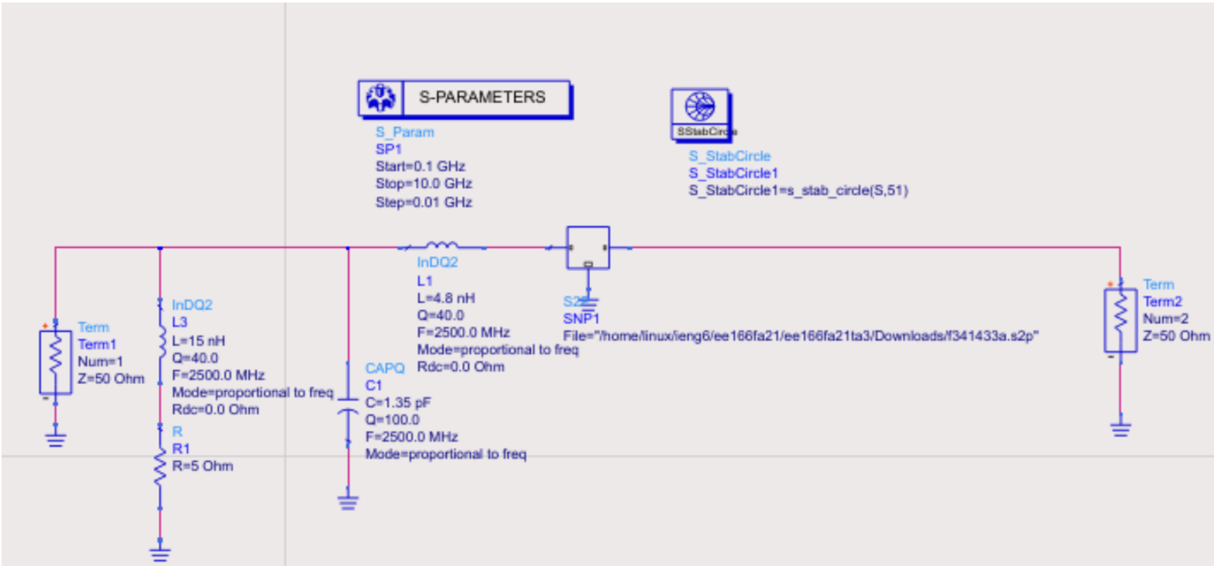




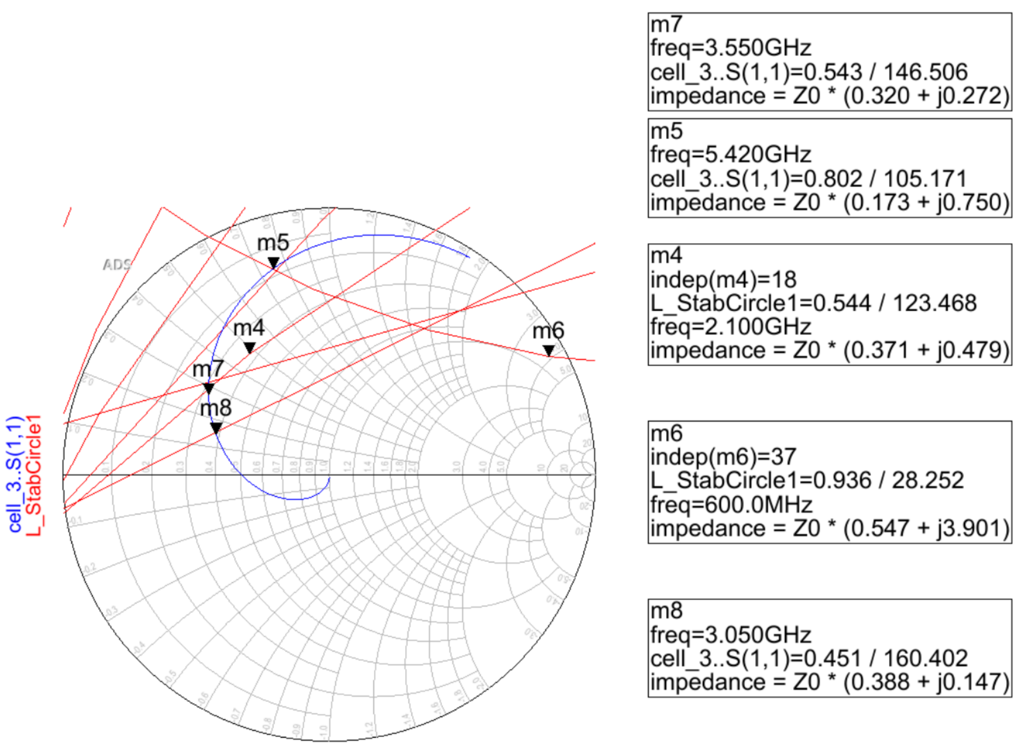


This is clearly unstable because some of the curves are very close to each other in frequency on their intersection.

To fix this, we introduce a large shunt inductor in series with a small resistor.

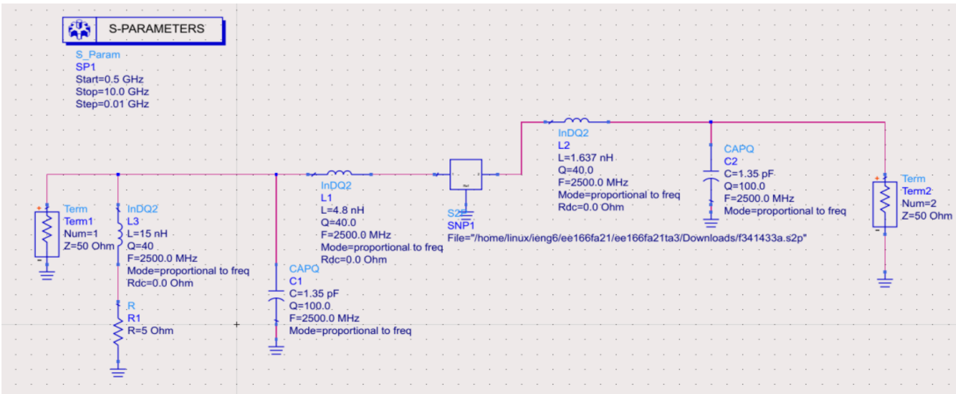


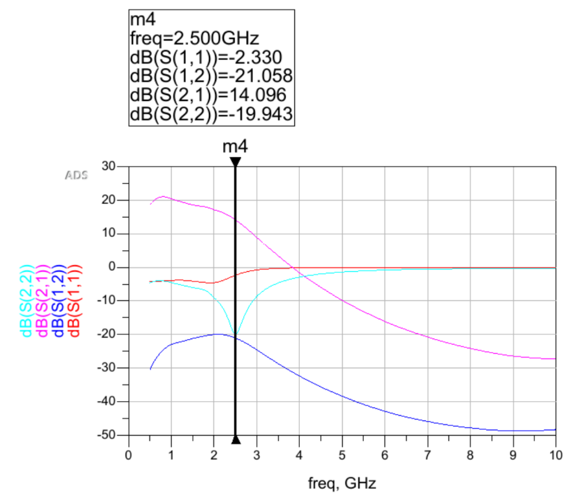
Taking a look at the stability circles again:



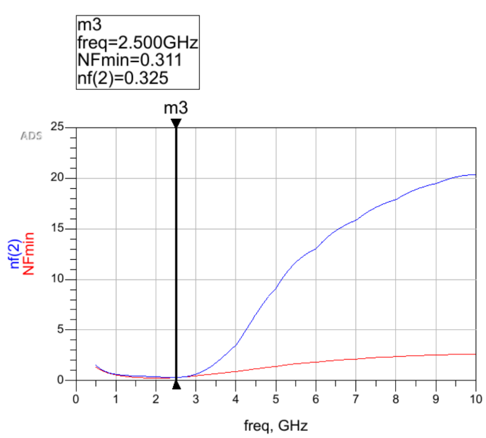
The amplifier is now clearly conditionally stable, as there is plenty of headroom in frequency between the red curves and blue curves.

Now, we will plot the S-parameters again to see what effect the stability adjustments had. This effect should be negligible. The final circuit is below:





The noise figure is slightly worse because of the addition of a resistor, but it is still within acceptable range. The amplifier design is complete.



Problem 3: High-Gain Amplifier

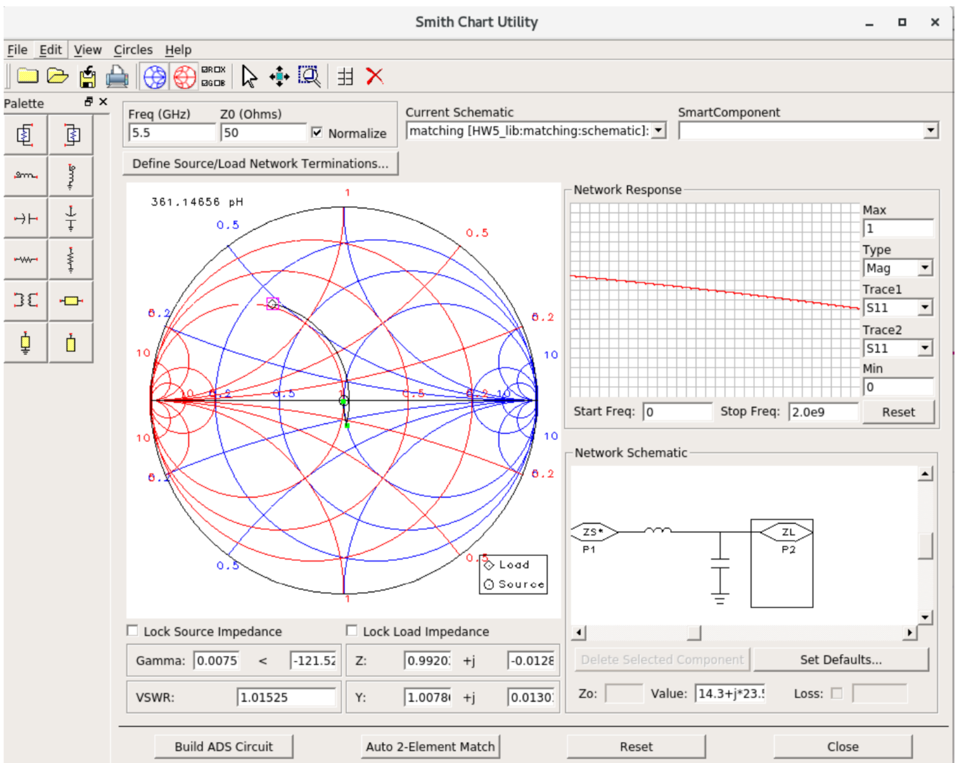
The S parameters of the amplifier @5.5GHz are below:

freq	S(1,1)	S(1,2)	S(2,1)	S(2,2)	u
5.500 GHz	0.645 / 126.500	0.122 / -28.000	2.936 / 5.500	0.225 / 132.000	0.094

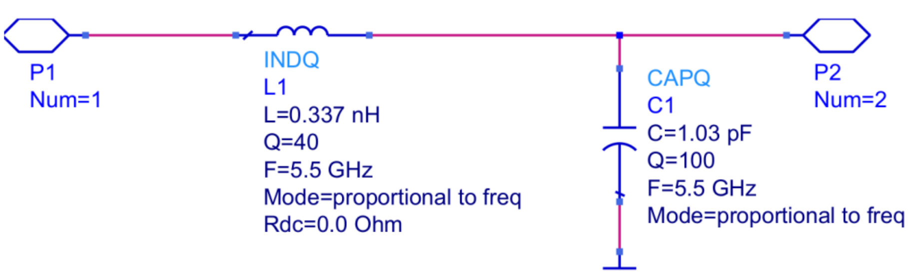
Eqn u = (mag(S(1,1))*mag(S(2,1))*mag(S(1,2))*mag(S(2,2)))/((1-pow(mag(S(1,1)),2))*(1-pow(mag(S(2,2)),2)))

u is around 0.1, so we can use the unilateral approximation for matching:
Gamma_s = S(1,1)* and Gamma_l = S(2,2)*

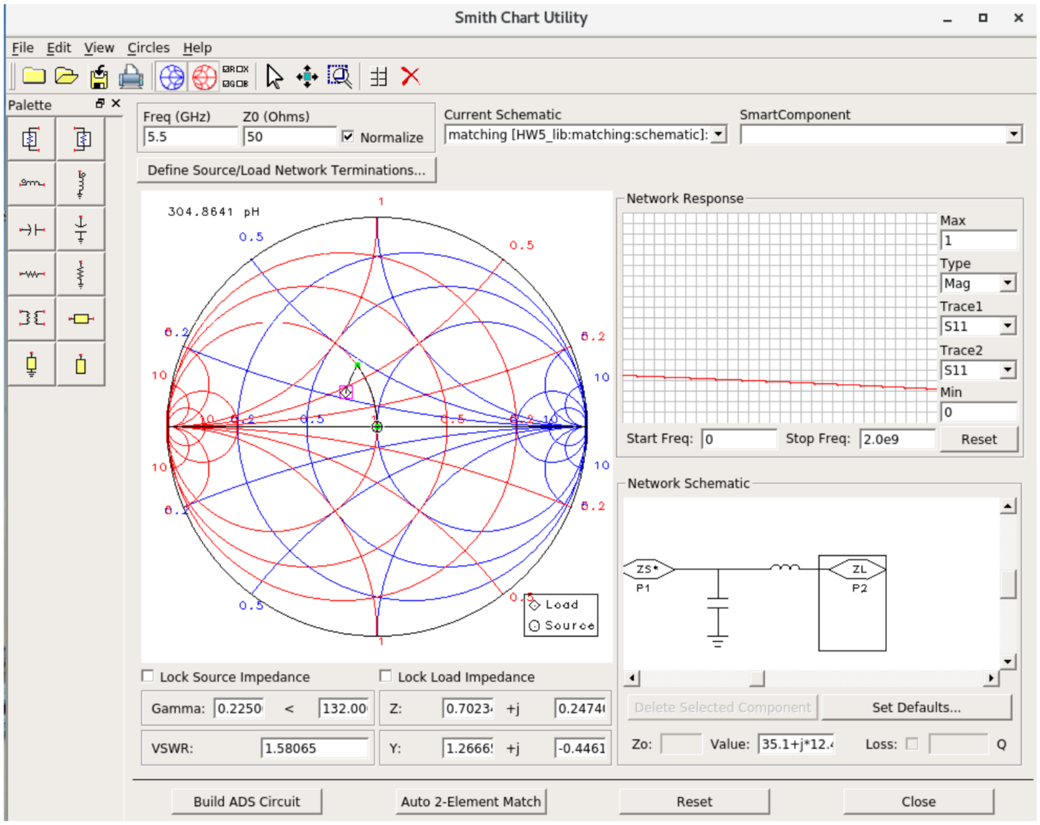
Matching gamma_s with S(1,1):



We get the matching network for the source below:

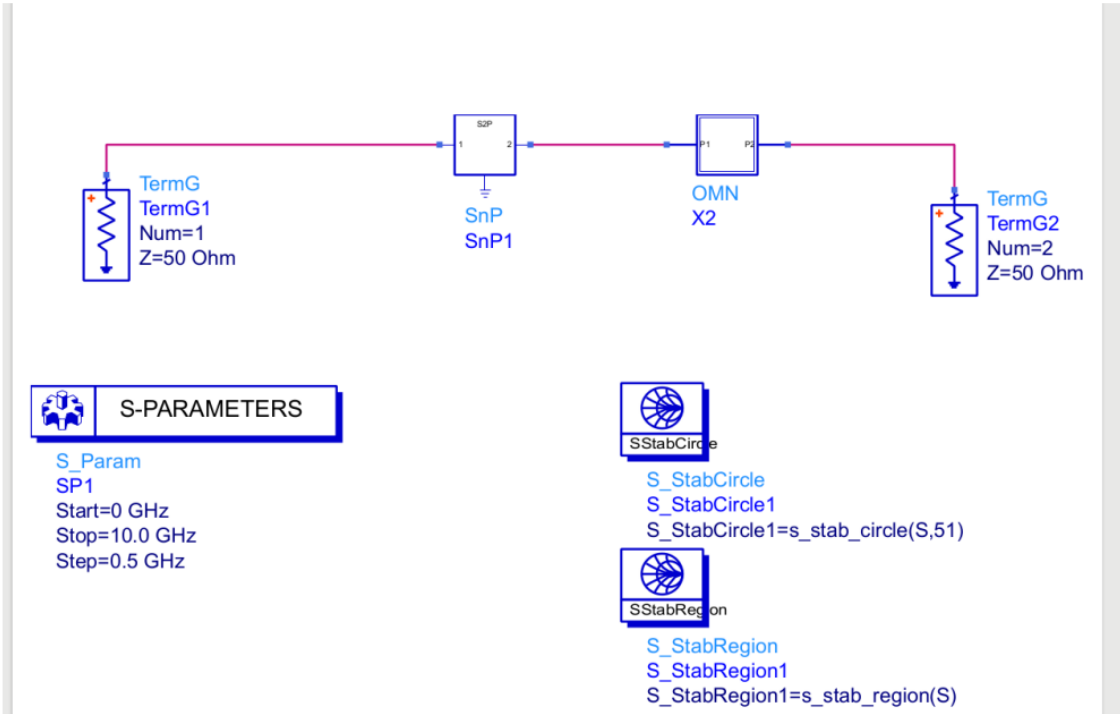


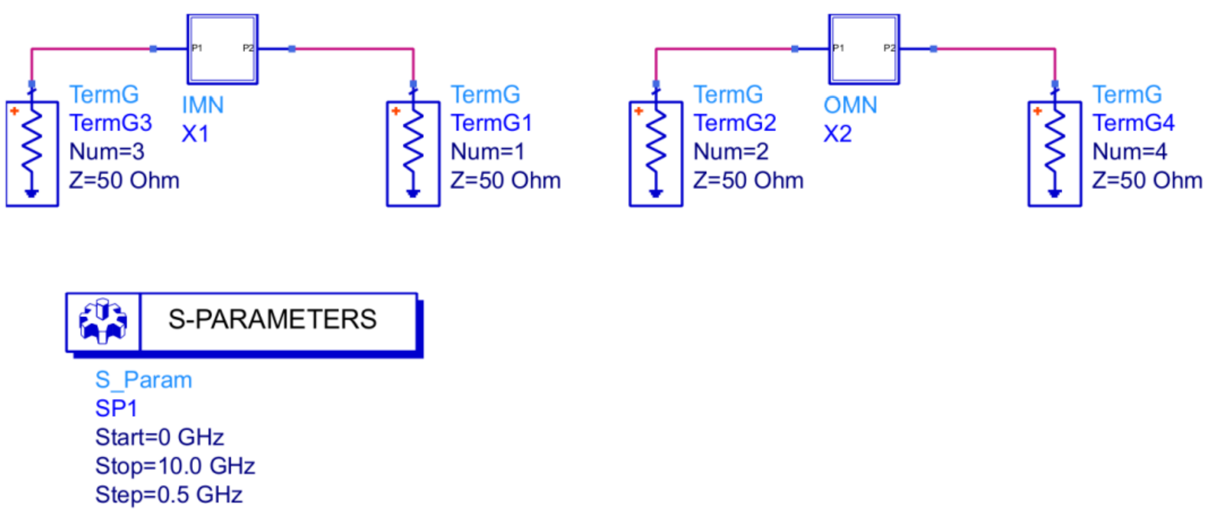
Next we match gamma_l to get the load matching network:

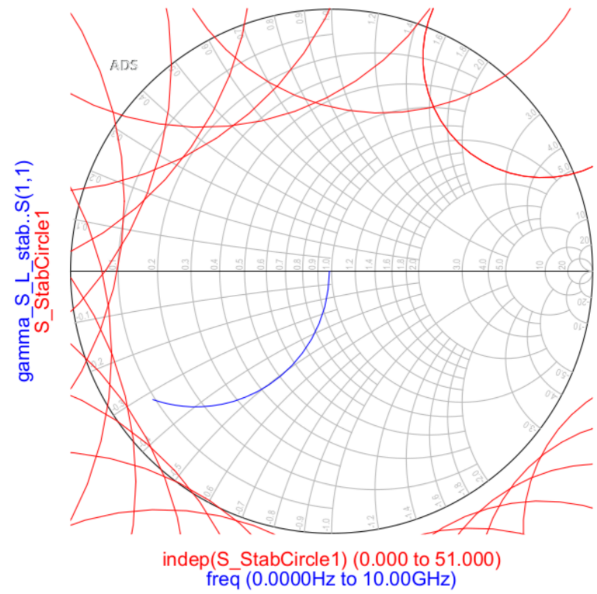


Now, we look at the the stability for 0.1GHz to 10GHz.

First, the s stab circles for gamma_s:

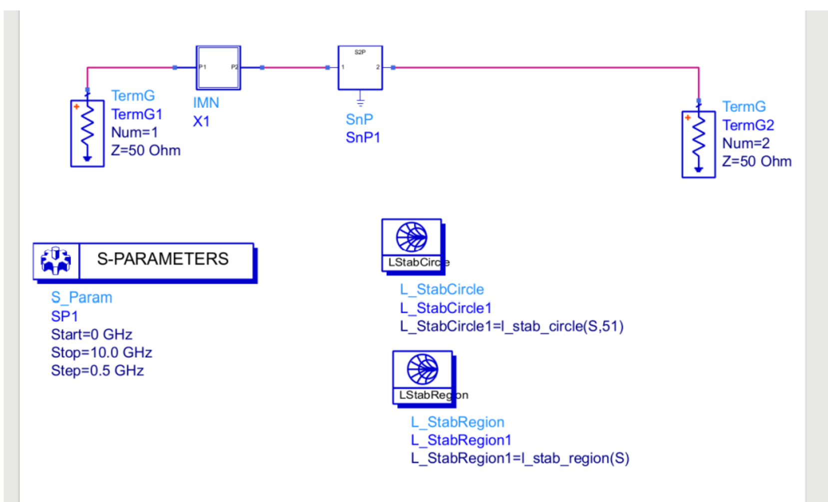


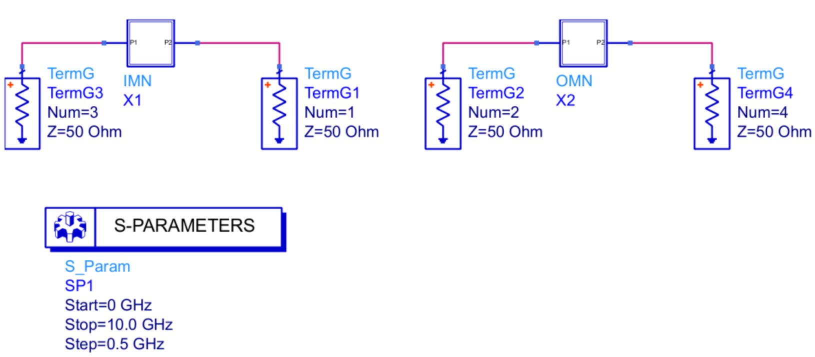


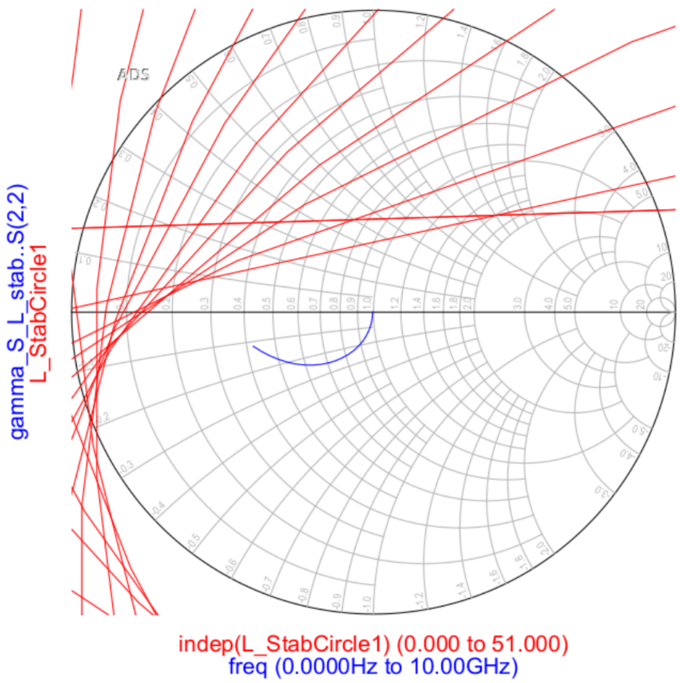


The network is stable for gamma_s.

Now, the l stab circles for gamma_l:

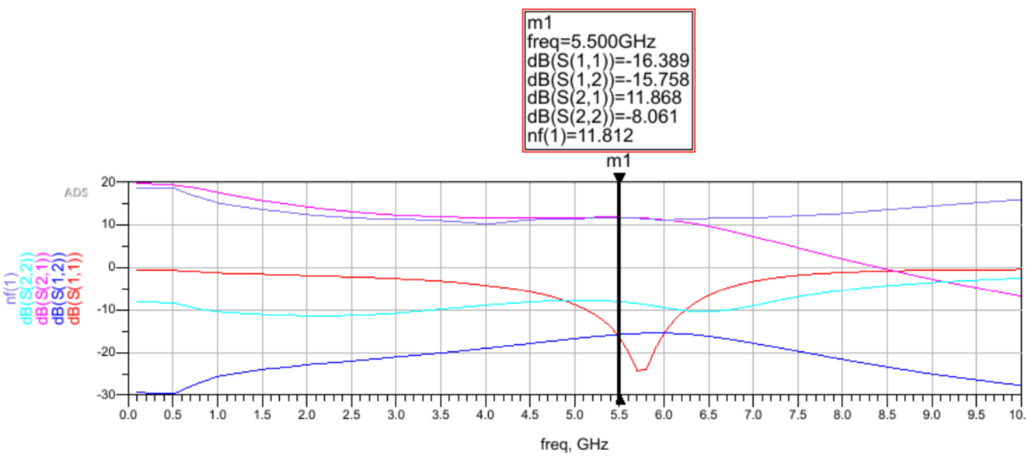






Gamma_l is also stable.

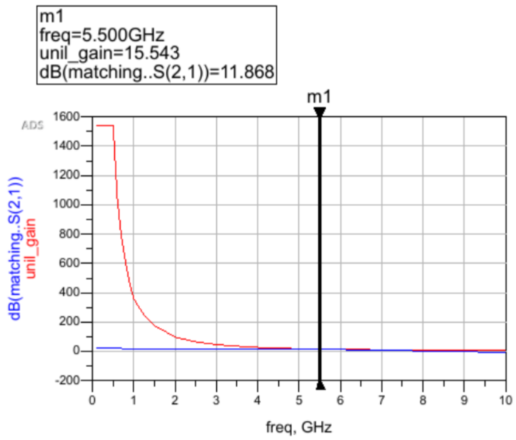
Below is the NF and gain comparison to the unilateral approximation:



We can see that this is not designed for low noise and for matching since we are using a non-ideal inductor and capacitor. It is not a perfect match for S11 and S22.

Comparing the gains:

Eqn unil_gain = pow(mag(S(2,1)),2) / (((1 - pow(mag(S(1,1)),2))*(1 - pow(mag(S(2,2)),2)))) using the S paramters of the amplifer before matching



It is 4dB lower than max unilateral gain.