

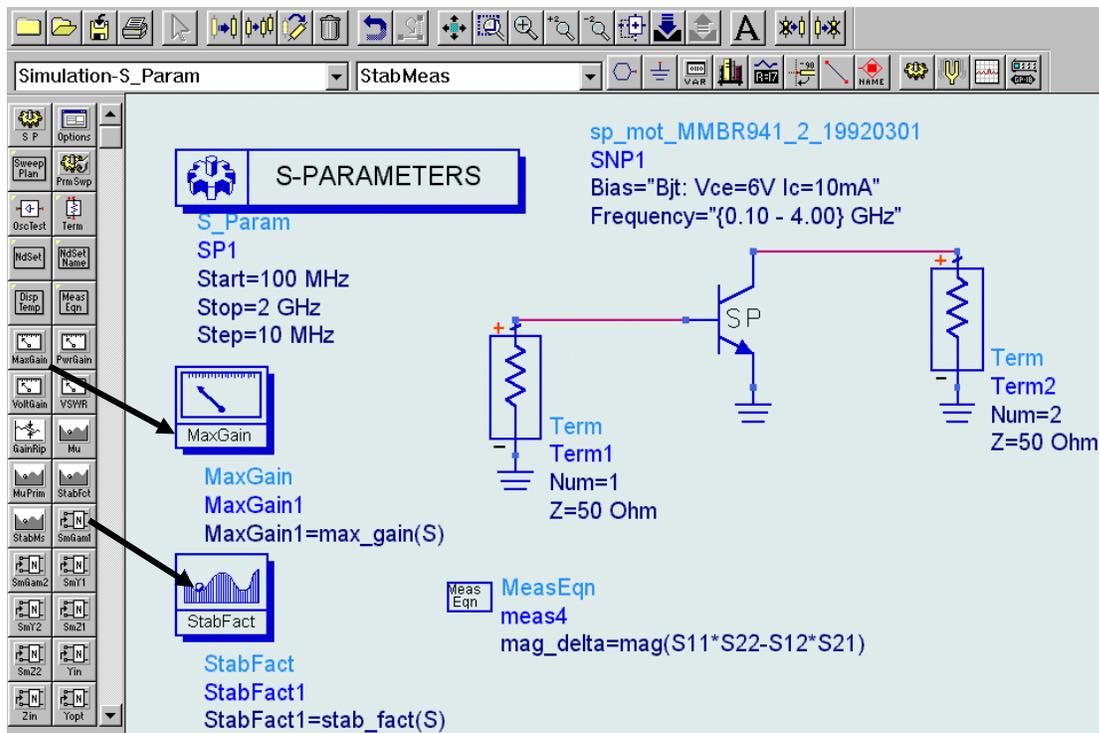
ADS Tutorial Stability and Gain Circles ECE145A/218A

The examples in this tutorial can be downloaded from xanadu.ece.ucsb.edu/~long/ece145a as the file: stab_gain.zap

The first step in designing the amplifier with the S parameter method is to determine whether the transistor is unconditionally stable or potentially unstable. This can be easily estimated using the K stability factor and delta. The amplifier will be unconditionally stable if:

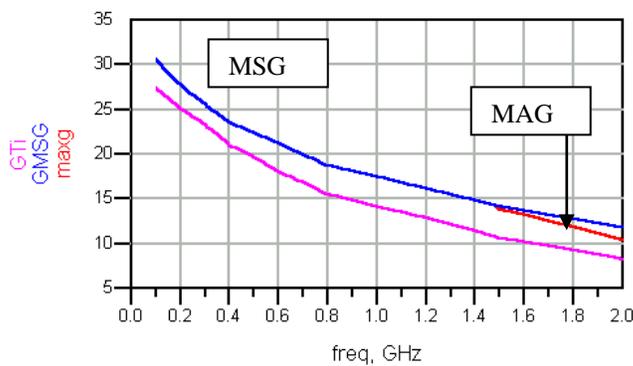
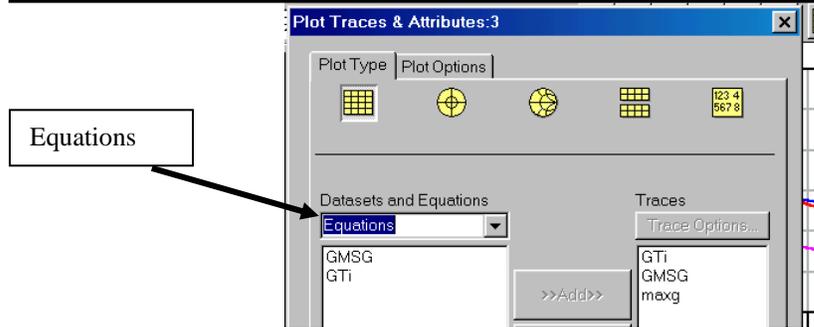
$$K > 1 \text{ and } \text{mag}(\Delta) < 1.$$

These factors are easily calculated using Measurement Equations in the ADS schematic panel. K is pre-programmed in as StabFact which can be selected from the S-parameter palette on the left. Delta can be programmed yourself using a blank MeasEqn. The maximum available gain (MAG) and maximum stable gain (MSG) can also be calculated using the MaxGain function.



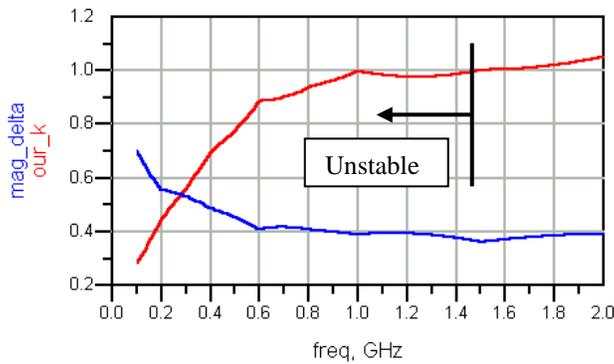
When swept over a range of frequencies, it can be clearly seen where the device will be unconditionally stable (above 1.5 GHz for this example). Note that the user-defined equation capability of the display panel can be used to also calculate and plot MSG and the intrinsic transducer gain, G_{ti} , the transducer gain when both Γ_S and $\Gamma_L = 0$. In the regions where $K < 1$, the max_gain function plots MSG. When unconditionally stable, it plots MAG.

ADS tip: When you want to plot from your user-defined equations, you need to select the equations dataset in the plotting panel.



Eqn GMSG=10*log(mag(S21)/mag(S12))

Eqn GTi=20*log(mag(S21))



Next, you could check (as the book suggests) to see if the device is unilateral. (this is rarely the case). Evaluate the Unilateral Figure of Merit, U, at the design frequency using a Measurement Equation. Let's choose 500 MHz for our example.

```

Meas Eqn MeasEqn Unilateral Figure of Merit
meas1
U=(mag(S12)*mag(S21)*mag(S11)*mag(S22))/((1-(mag(S11))**2)*(1-(mag(S22))**2))

Meas Eqn MeasEqn
meas2 UFM_minus=10*log(1/((1+U)**2))
Meas Eqn MeasEqn
meas3 UFM_plus=10*log(1/((1-U)**2))
  
```

Show the result in a table in the display panel.

freq	U	UFM_minus	UFM_plus
500.0MHz	0.137	-1.114	1.278

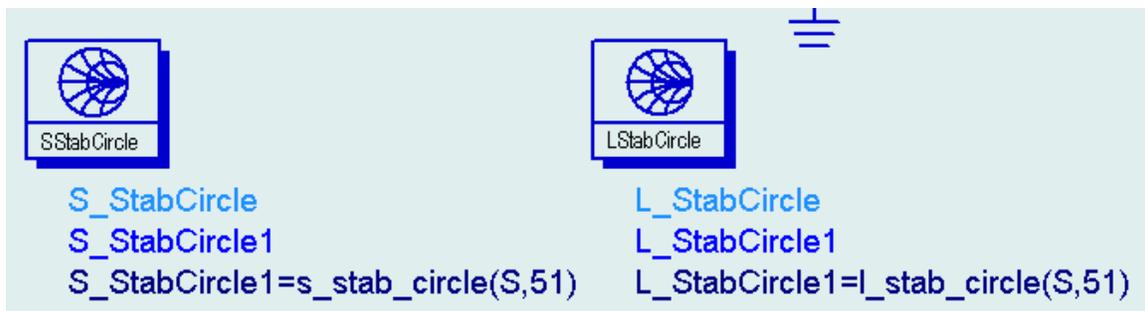
Here, we see that at 500 MHz, the device is clearly not unilateral. The unilateral approximation would have an error of over 1 dB.

Bilateral design. If the device is unconditionally stable at the design frequency, then the input and output can be conjugately matched as shown in Section 3.6 of Gonzalez (and Sect. 11.3 of Pozar) and the maximum available gain can be obtained. Γ_{MS} and Γ_{ML} can be determined uniquely. The input and output VSWR would = 1 in this case. This would be applicable for this device in the region where $K > 1$. The conjugate match reflection coefficients can be calculated on ADS using the Smgam1 and Smgam2 measurement equation icons in the S-parameter palette.

However, at 500 MHz, we find that $K = 0.75$. We must take into account stability as well as gain. It is wise to design the amplifier for less than the maximum stable gain, MSG, to allow margin for stability. We have 2 choices on how to proceed with the design.

1. We could continue with the design for a bilateral amplifier if the source and load plane stability circles do not contain Γ_S or Γ_L . This is possible only if we can meet the required gain specifications while still avoiding the unstable regions.
2. We could add stabilization resistors to the device to force unconditional stability. Then, we would be less constrained in our choices of Γ_S or Γ_L , but if we over-stabilize the device, we may again find that we can't meet the required gain specifications.

So, let's look at the device first for stability. Stability circles should be calculated. This is done by using the LStabCircle and SStabCircle functions.



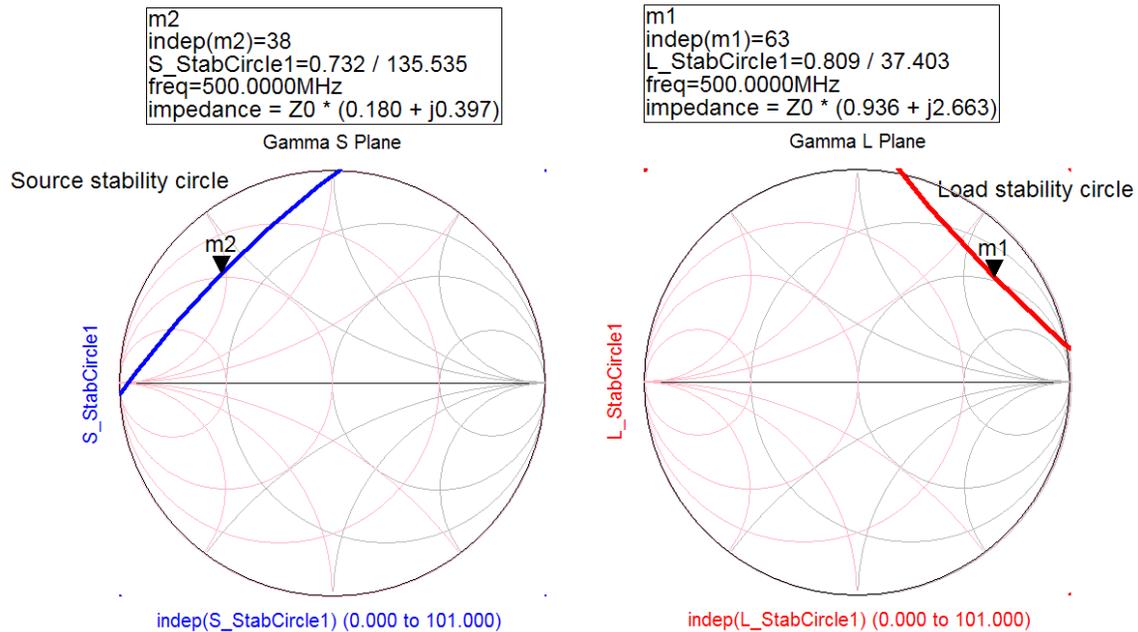
The screenshot shows two icons from the ADS S-parameter palette. The left icon is labeled 'SStabCircle' and the right icon is labeled 'LStabCircle'. Below each icon are the function names and their corresponding equations:

```

S_StabCircle
S_StabCircle1
S_StabCircle1=s_stab_circle(S,51)

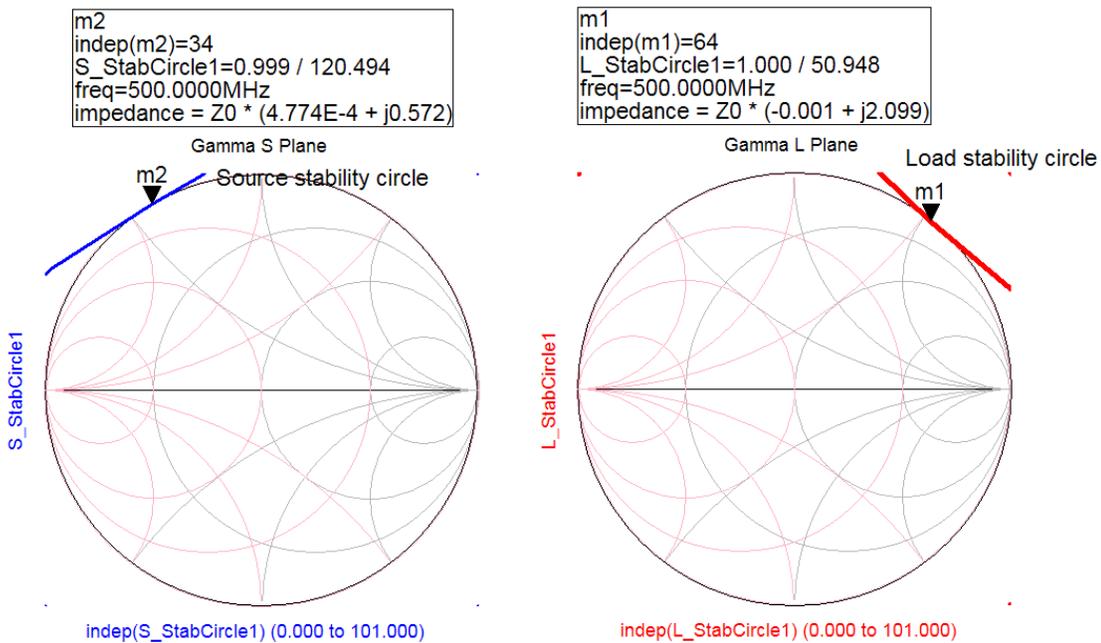
L_StabCircle
L_StabCircle1
L_StabCircle1=l_stab_circle(S,51)

```



Examining the stability circles, we see that it would be relatively easy to resistively stabilize this transistor and make it unconditionally stable at 500 MHz. A series resistance of $0.18(50) = 9\Omega$ at the input or a shunt resistor of $1/(0.117*0.02) = 430\Omega$ at the output will push the source or load circles outside the Smith chart at this frequency. Of course, after designing the matching networks, we must check the amplifier later over a wider frequency range for stability. We might need to modify the stabilization approach, but if resistance is included in the matching network appropriately, it is often possible to improve stability without sacrificing gain at the design frequency..

So, let's take approach #2 and see how effective a shunt 430 ohm resistor on the output of the transistor will be. From the figure below, we see that it provides stability on the load plane and nearly unconditional stability on the source plane (again, remember, this is at a single frequency).



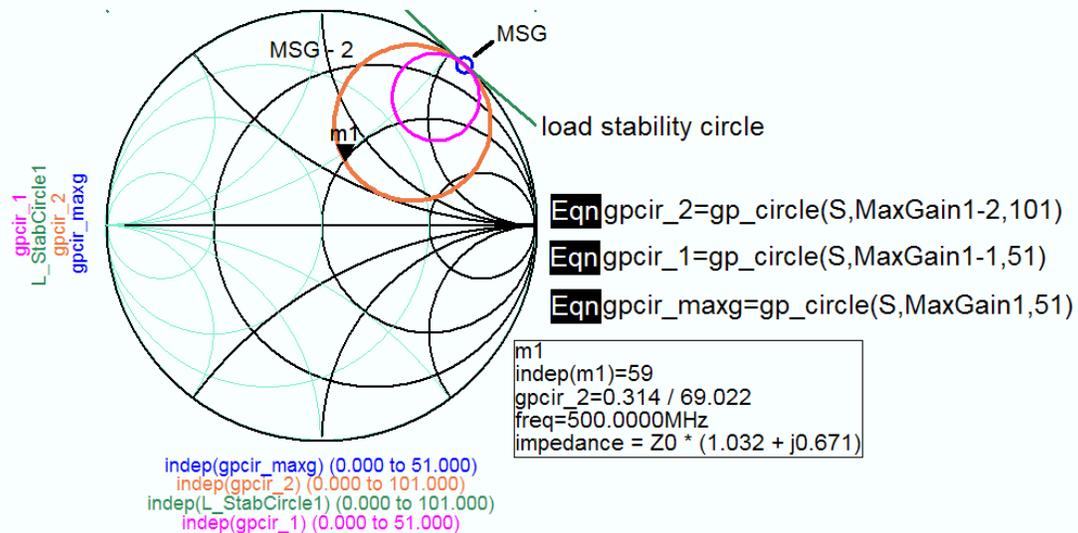
Now, we can proceed with designing the input and output matching networks. In the bilateral case, we need a systematic design method, because changes in Γ_S will affect Γ_{OUT} and changes in Γ_L will affect Γ_{IN} . Γ_L is the load reflection coefficient presented to the device. The operating power gain, G_P , provides a graphical design method suitable for bilateral amplifiers. Gain circles can be calculated that show contours of constant operating power gain. G_P is useful since it is independent of the source impedance; the gain circle represents the gain that would be obtained if a magic genie adjusted $\Gamma_S = \Gamma_{IN}^*$ for each value of Γ_L on the circle. Then, $G_P = G_T$, ie. the operating power gain equals the transducer gain.

I have found it more convenient to calculate the operating power gain circles on the data display rather than on the schematic. On the data display, you can change the gain values without having to re-simulate the amplifier. Use the Eqn function to write gain circle equations. The syntax is: `gp_circle(S, gain, # points on circle)` where S is the S-parameter matrix. Let's illustrate.

In the example below, a table is used to display frequency, maximum stable gain (MSG), the stability factor, k, and the magnitude of delta. The gain circles are at MSG (MaxGain1 in this case), and 1 and 2 dB below MSG. A marker is placed on the -2 dB circle. Γ_L can be read off the display as magnitude = 0.290 with angle = 71.7 degrees. If the input is conjugately matched (and stable), then the gain should be $MSG - 2 = 20.4$ dB.

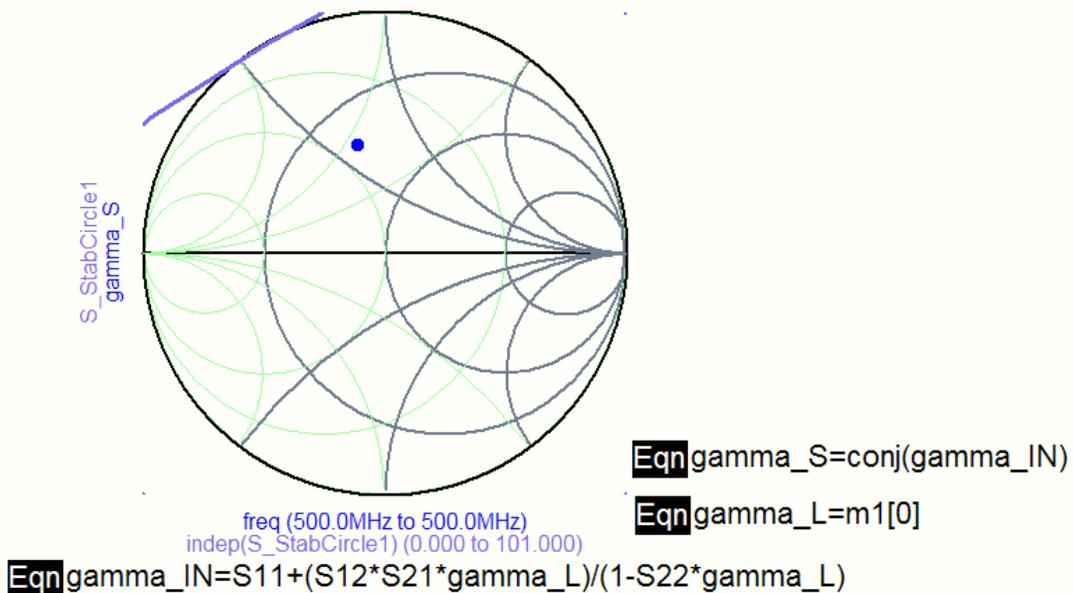
The load stability circle is also shown. The load impedance can be chosen away from this circle to maximize stability. We see that $k < 1$, but not significantly so.

freq	mag_delta	StabFact1	MaxGain1
500.0MHz	0.386	0.999	22.442

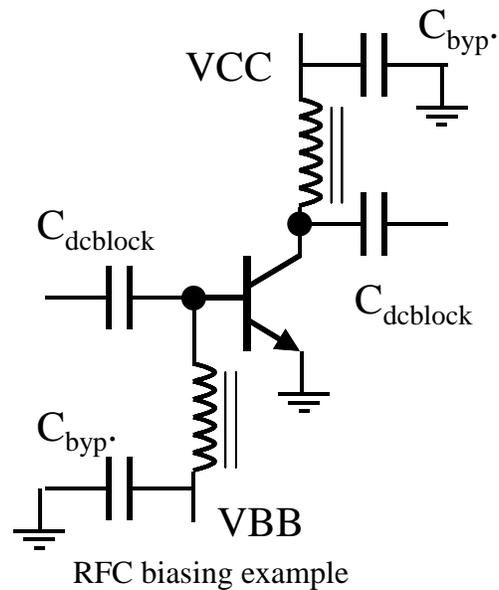


Next, calculate the input reflection coefficient for your choice of Γ_L and make sure it is stable. To do this, plot the source plane stability circle and compare with Γ_S . We can see that this choice will be stable at the design frequency.

gamma_IN	gamma_S	gamma_L
0.465 / -104.339	0.465 / 104.339	0.314 / 69.022

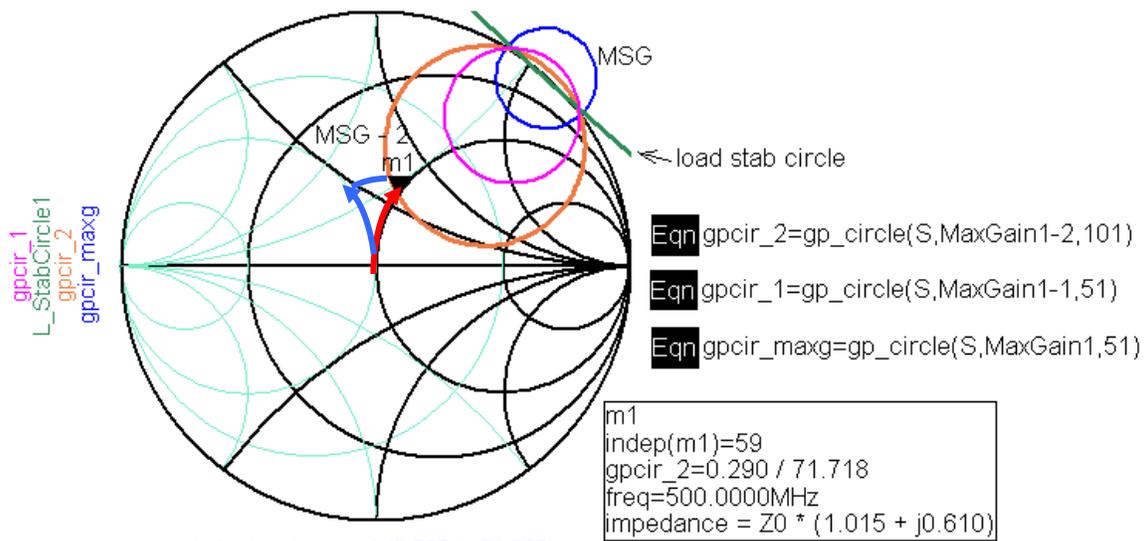


Biasing and matching network design. The next step in designing the amplifier will be the implementation of the input and output matching networks such that they provide reflection coefficients Γ_S and Γ_L as determined above. This can be done using the Smith chart. In general, there may be several solutions possible using lumped or distributed L networks. In selecting a design, you need to consider how you will bias the amplifier. You have 2 choices: bias with RF chokes and blocking capacitors or bias through the matching network elements.



Consider the load plane.

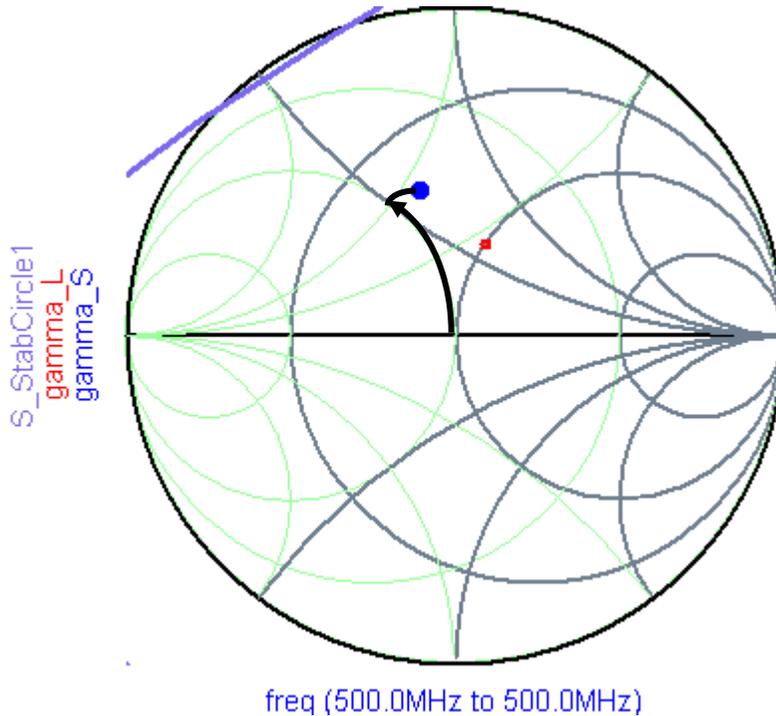
freq	mag_delta	StabFact1	MaxGain1
500.0MHz	0.391	0.979	22.442



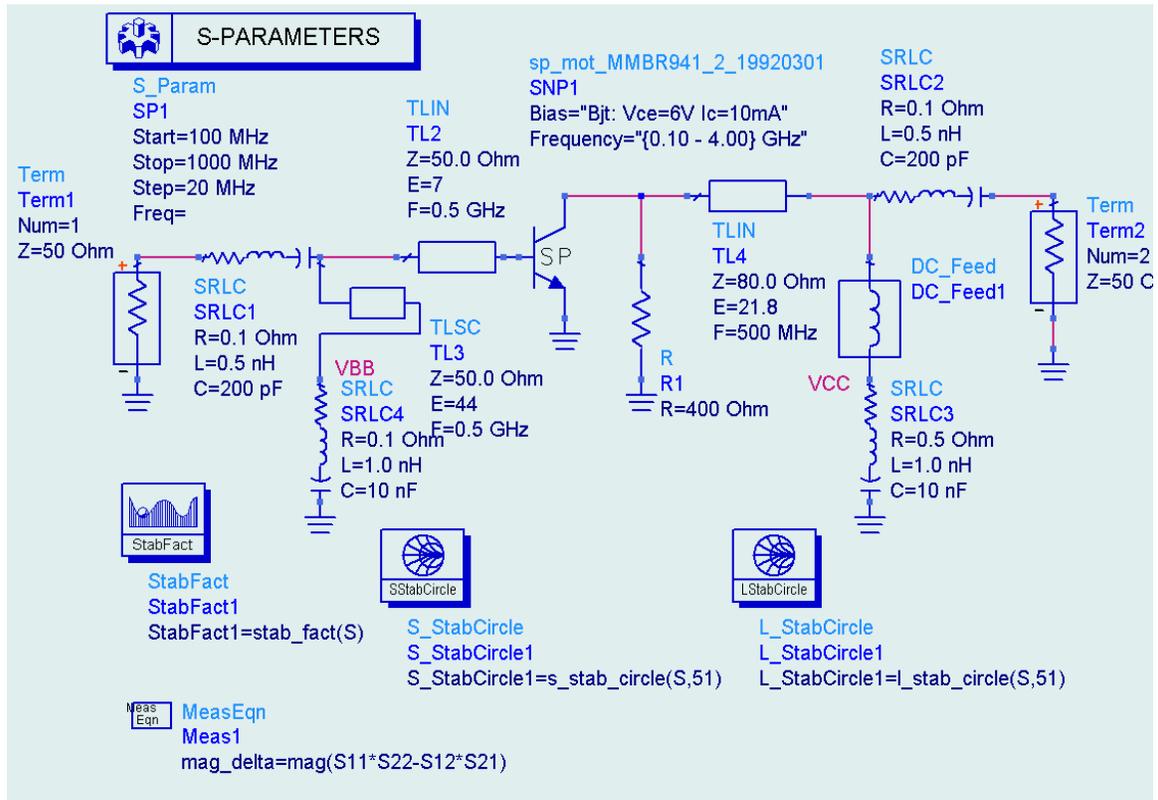
The marker is on the -2 dB operating power gain circle and represents our choice of Γ_L . Notice that we have many options for Γ_L as long as we keep a respectable distance from the load stability circle. As shown above, if we choose Γ_L at the location of m1, we are nearly on the unit constant resistance circle ($r=1$). Adding an inductance (red arrow) in series with the 50 ohm load will place us at Γ_L . The series inductance could be implemented with a lumped inductor (if feasible) or a series transmission line of high impedance. This approach will require an RFC or a $\lambda/4$ high Z_o line for biasing.

Alternately, a series – shunt matching network could be used. This approach is shown in blue arrows. A series 50 ohm transmission line connects the collector to a shunt shorted stub or an inductor. This stub can also serve as our bias port if we are careful to provide appropriate bypass capacitance for the power supply and DC blocking where needed.

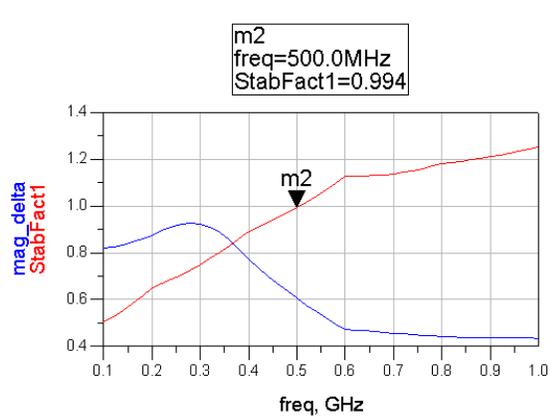
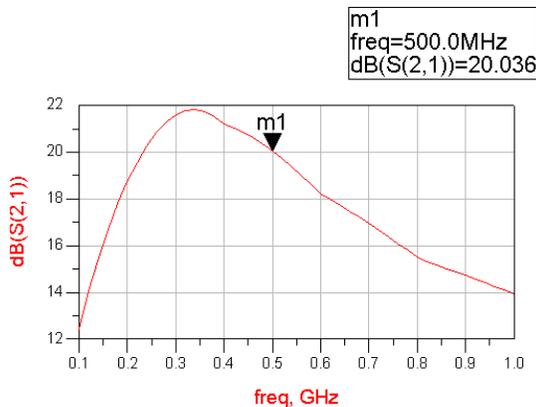
We can use the same idea for the source plane: add shunt inductance, moving up the $g=1$ circle. Then add a series 50 ohm transmission line until you reach Γ_S . This is the impedance that must be provided to the input to match Γ_{IN} .



The complete circuit looks like this:



Checking the results, we find that it does meet the expected gain of 20 dB but is potentially unstable at frequencies below 500 MHz.

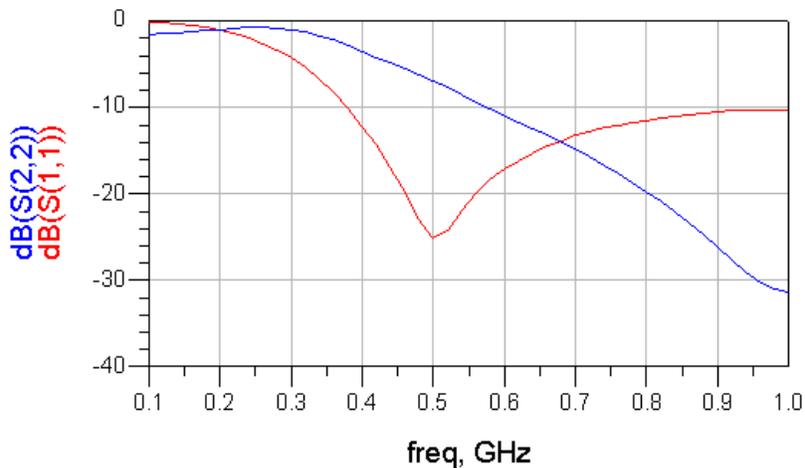


Note that the capacitors needed for bypassing and DC blocking have been modeled with equivalent networks. The DC blocking capacitors at the input and output have been designed to be series-resonant at the operating frequency. Further improvements in accuracy for design purposes could be obtained by using the MLIN microstrip physical line models with bends and tees as needed. When RF chokes are used for biasing instead

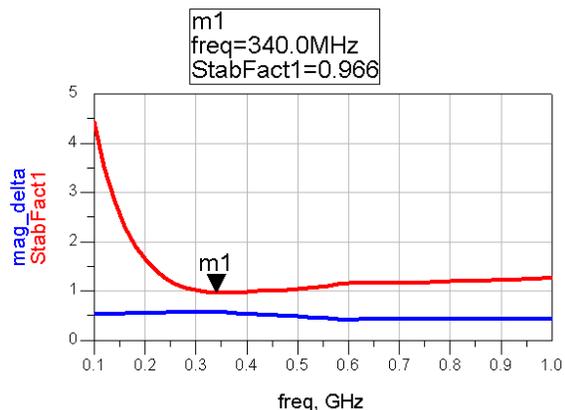
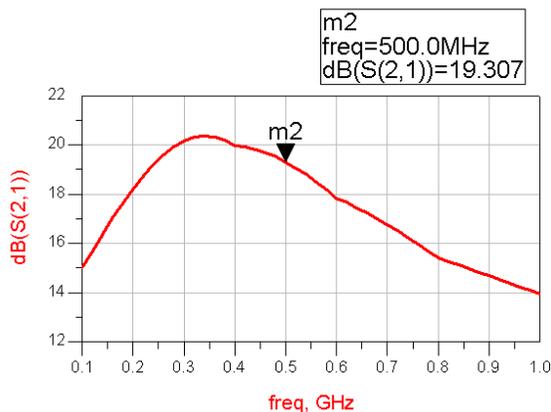
of the matching network approach, you should model the RFC as an equivalent RLC network and determine stability of the amplifier over a wide frequency range as well.

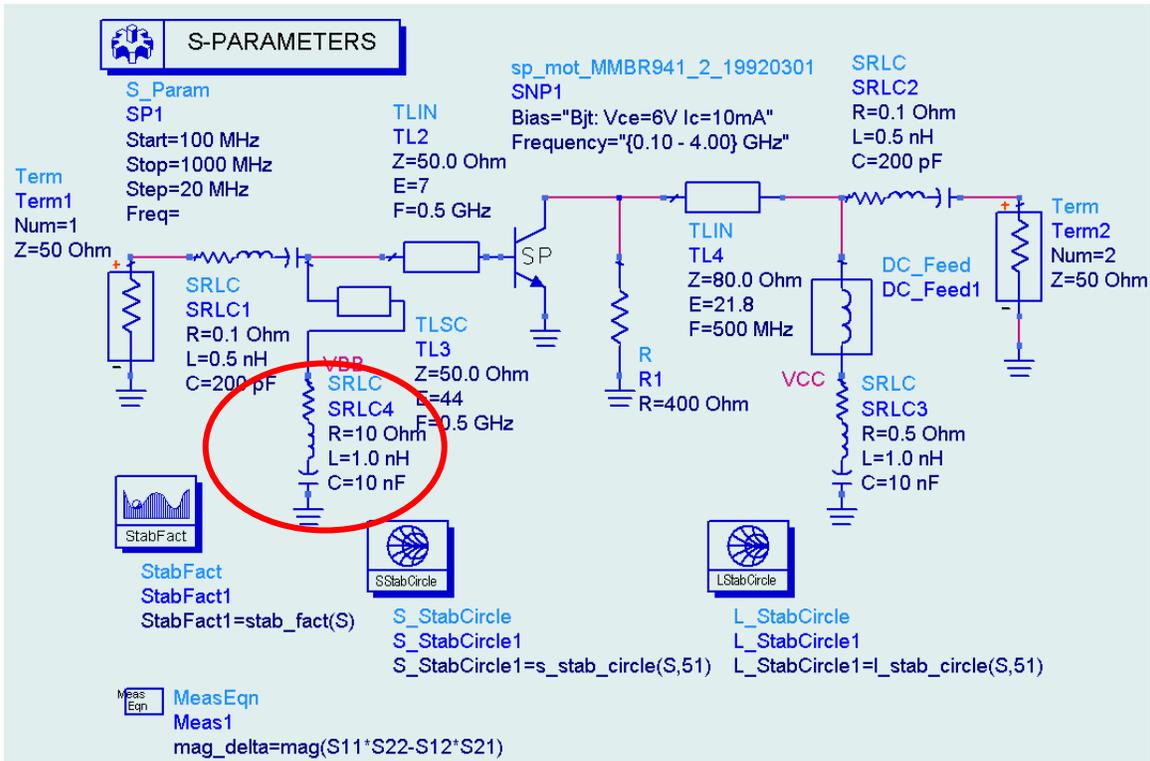
If you want to have a successful design on the first attempt, you must include equivalent circuit models for all of the components which will sensitively affect the performance.

Wideband Stability. We must also guarantee that the amplifier is stable not only at the design frequency but everywhere else as well. To do this, we will sweep the frequency over a wide range (100 MHz to 1 GHz) and look at k , S_{11} and S_{22} . We noted already that $k < 1$ below 500 MHz. The magnitude of S_{11} and S_{22} are < 1 , thus stability is not in great danger. Nevertheless, we must modify the circuit to prevent $k < 1$ to any significant extent.



We could try a different Γ_L and test again. But, we may be able to solve the problem directly by adding losses to the input match. Notice that the input matching network has a shunt line that will become a short circuit at low frequencies. The device may become unstable as we approach $\Gamma_S = 1$. So, add some small series resistance to the shunt stub to modify the low frequency behavior. Fortunately, this works in this case. Adding 10 ohms in series with the input stub costs about 0.7 dB of gain, but keeps k acceptable at all frequencies. The worst case is now $k = 0.966$ at 340 MHz.

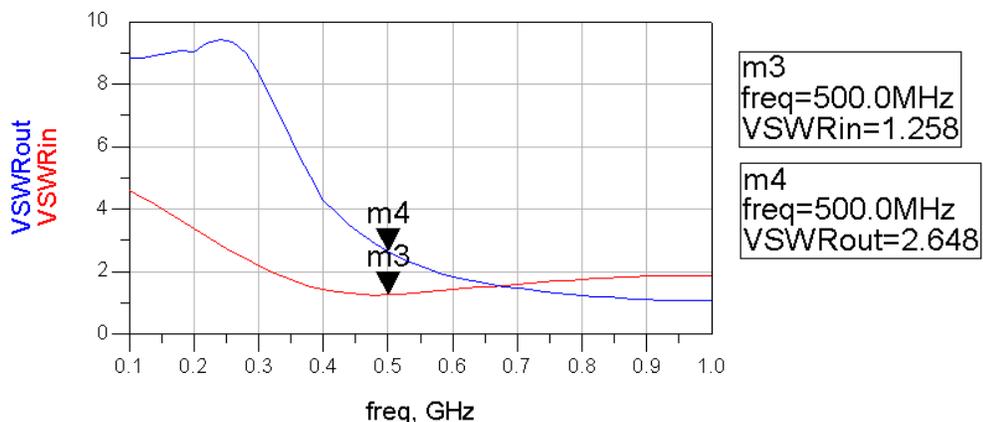




Other alternatives for stabilization would include modifying the stabilizing resistor at the output of the device using the stability circle technique at 300 MHz. You can see that the wideband stabilization of an amplifier can involve some effort in design.

What about input and output VSWR? We can see that there is a good match at the input, which we expected because Γ_S was a conjugate match. However, the output VSWR is high. This occurred because we intentionally mismatched the output (gave up 2 dB of gain) in order to make the design less sensitive to component variations and provide an extra margin of stability.

Eqn $VSWR_{out}=vswr(S22)$ **Eqn** $VSWR_{in}=vswr(S11)$



A suitable bias control circuit will now be needed to maintain the correct V_{CE} and I_C values for the amplifier. Note that constant V_{BE} or constant I_B designs are not acceptable because of the exponential temperature dependence of I_C on V_{BE} and because of the large temperature coefficient of β (0.7%/degree C).