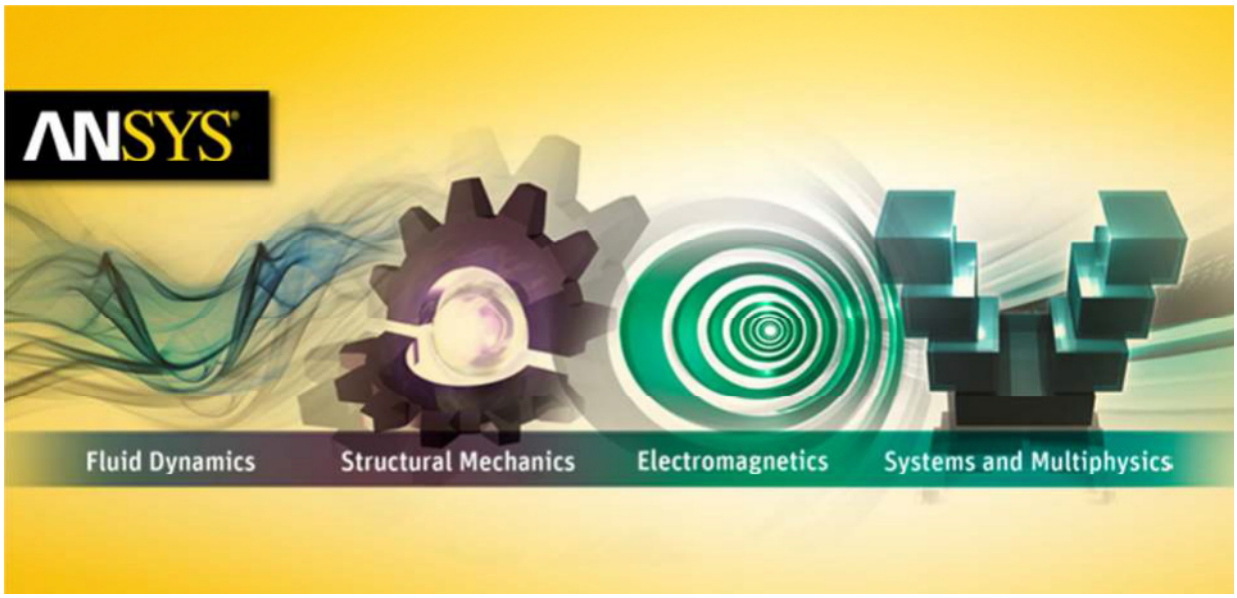

Circuit Design Training Manual - Low Noise Amplifier Part I

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1. Low Noise Amplifier Design

Low Noise Amplifier Design

This document shows how to use **Circuit Design** in the **ANSYS Electronics Desktop** to design a small signal 900 MHz low noise amplifier (LNA) using an s-parameter model of NEC BJT NE68133, including noise parameters. The document also shows how to synthesize matching networks using the built-in Smith Tool. Tuned circuits are connected to the input and output to provide matching, essential to finalizing the design of the low noise amplifier.

Prerequisite

To perform the training exercise, you need the relevant designs and the corresponding footprints available at the following location: **Examples>Circuit>Low Noise Amplifier**.

ANSYS Electronics Desktop

The ANSYS Electronics Desktop provides a comprehensive environment for designing and simulating various electronic components and devices. The following figure shows the ANSYS Electronics Desktop with **Circuit Design** included.

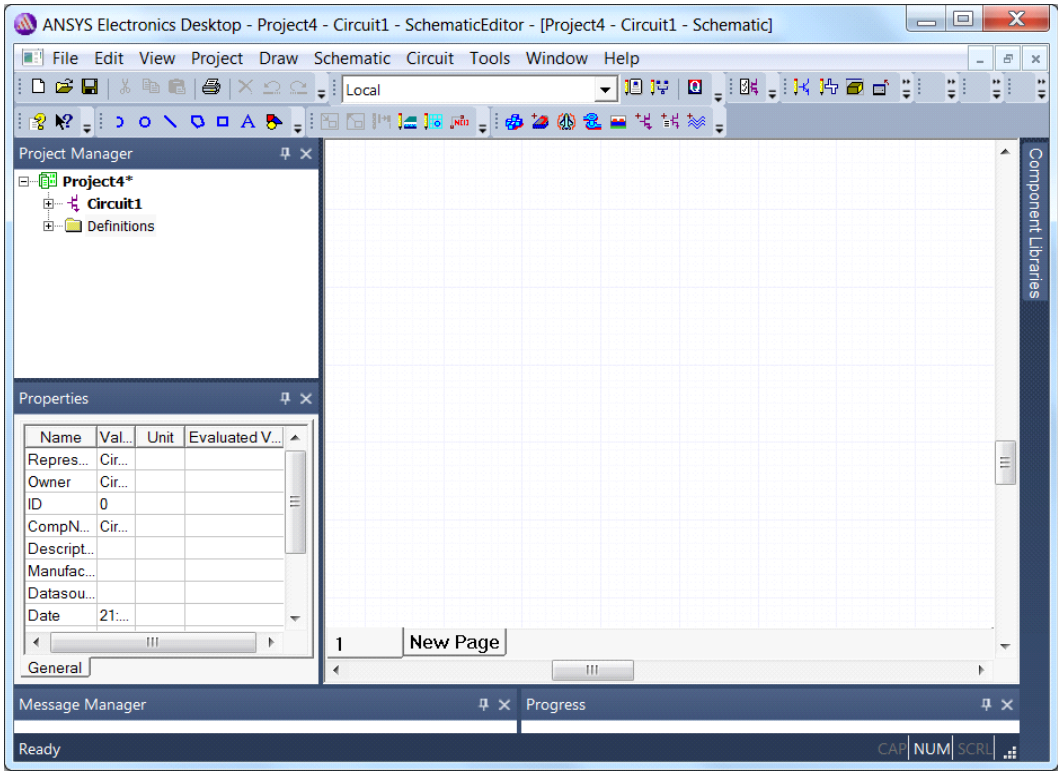


Figure 1. ANSYS Electronics Desktop

The Electronics desktop supports many design types listed below:

- HFSS
- HFSS-IE
- EM Design (HFSS 3D Layout or Planar EM)
- Circuit Design
- Circuit Netlist
- Filter Design
- Q3D Extractor
- 2D Extractor

All design types appear as icons on the toolbar or under the Project menu. The relevant design type for simulating LNA using an s-parameter model of NEC NE68133 BJT, is **Circuit Design**, which is illustrated in the following figure.

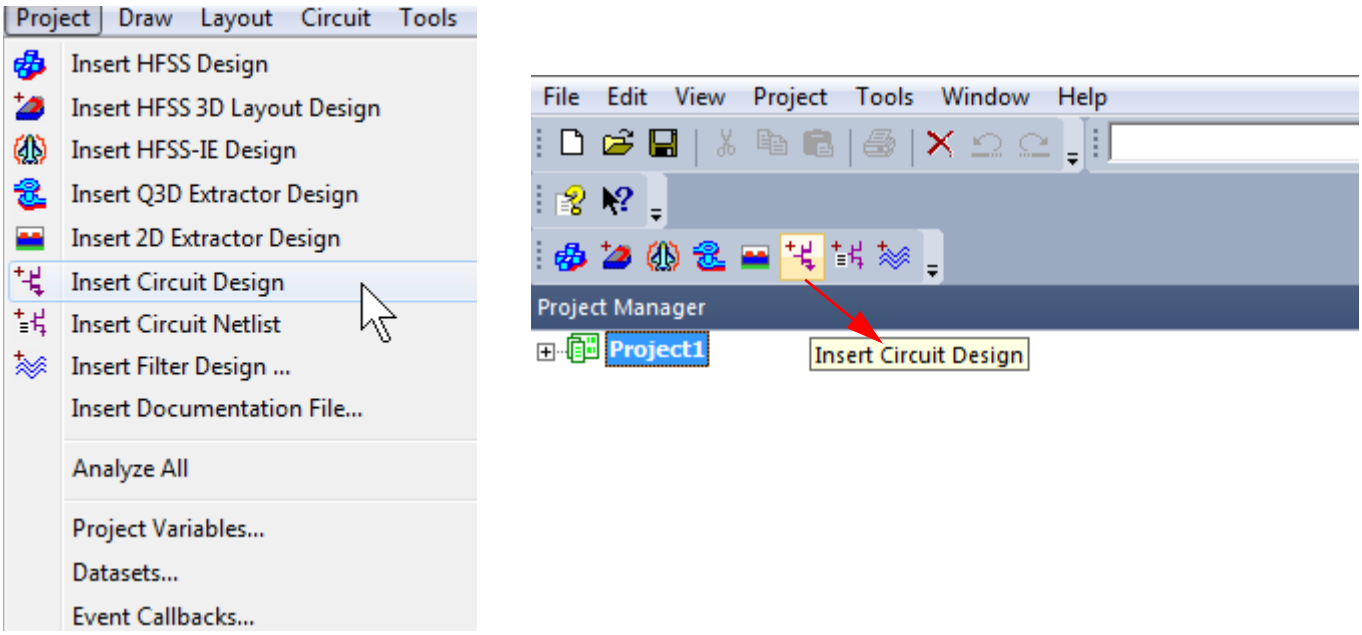


Figure 2. Circuit Schematic Level

Smith Tool

ANSYS Electronics Desktop provides the interactive Smith chart utility for designing amplifiers, oscillators, and matching networks, using linear analyses techniques. The Smith chart includes the following capabilities:

- Arbitrary grids for impedance, admittance, Q, VSWR, etc.
- Constant available gain and power gain circles.
- Constant noise circles.
- Stability circles.
- Circles of constant reflection for oscillator design.
- Bilateral mapping between source and load planes with gain mismatch circles.
- Ladder matching circuits using discrete and distributed elements.

Setting up the LNA Schematic

Set up the LNA schematic in the ANSYS Electronics Desktop as follows:

1. Go to **File > Open Examples > Circuits > Low Noise Amplifier**.
2. Select *LNA_SmithTool.aedt* and save the file in a different location other than the **Examples** folder.

The LNA schematic of the inserted design has the following circuit shown in Figure 1.The transistor in the schematic is an s-parameter file, including noise data at bias condition of Vcc = 2.5V and Ic = 3mA between 0.5 to 2 GHz.

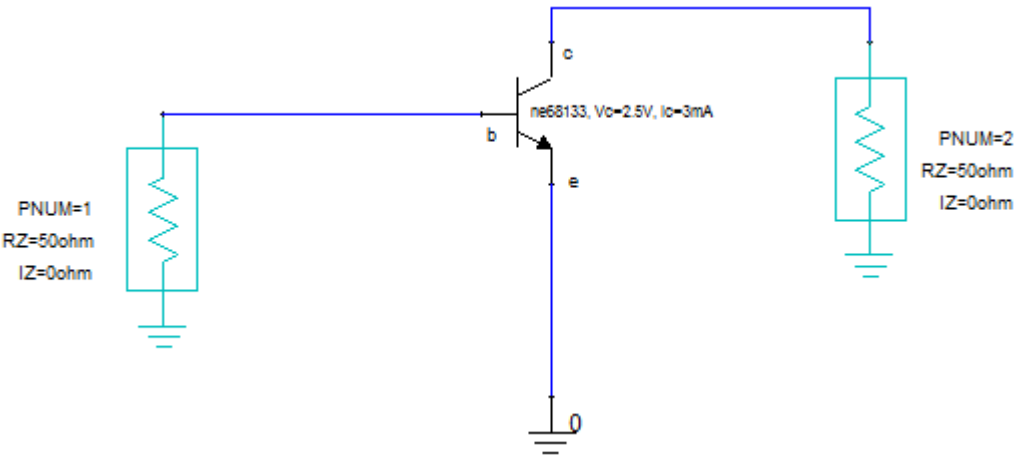


Figure 1. LNA Schematic

3. Double-click **Analysis** on the **Project Manager** window to check the settings in the Linear Network Analysis dialog box.

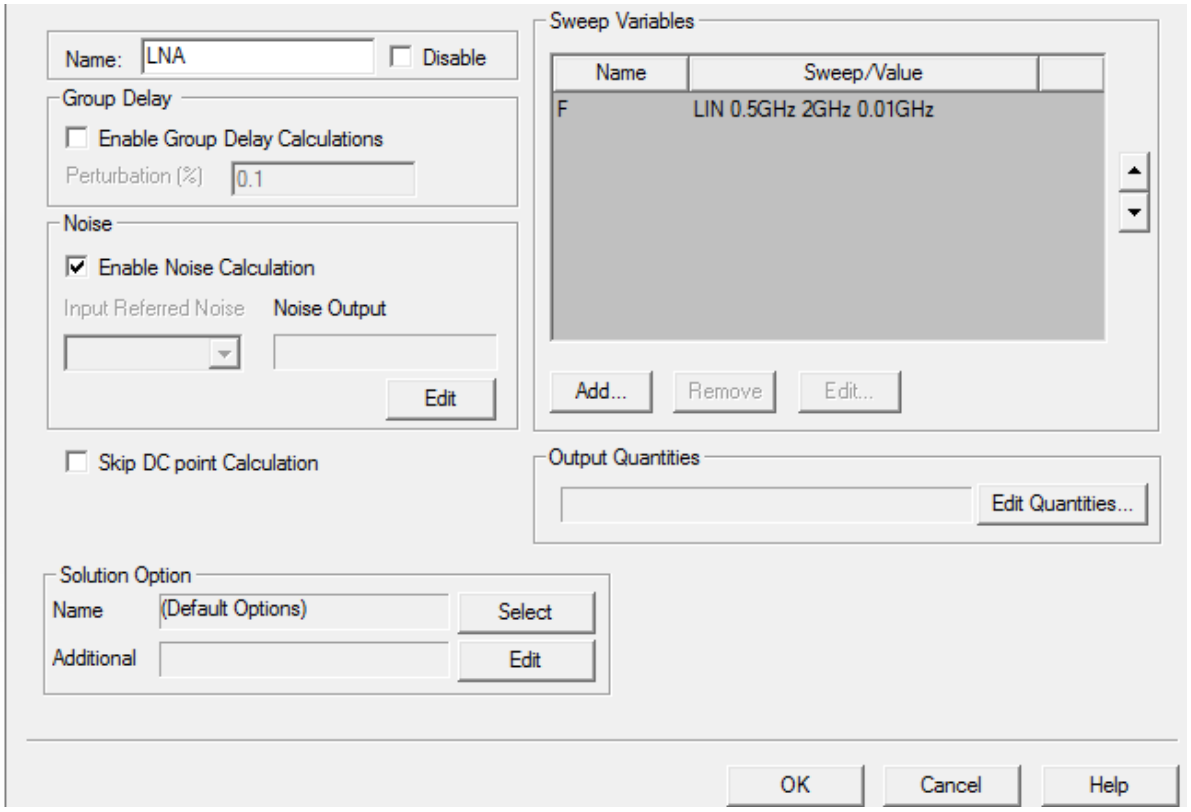


Figure 2. Linear Network Analysis dialog box

4 Right-click **LNA** under **Analysis** and select **Analyze** in the short-cut menu to start the simulation.

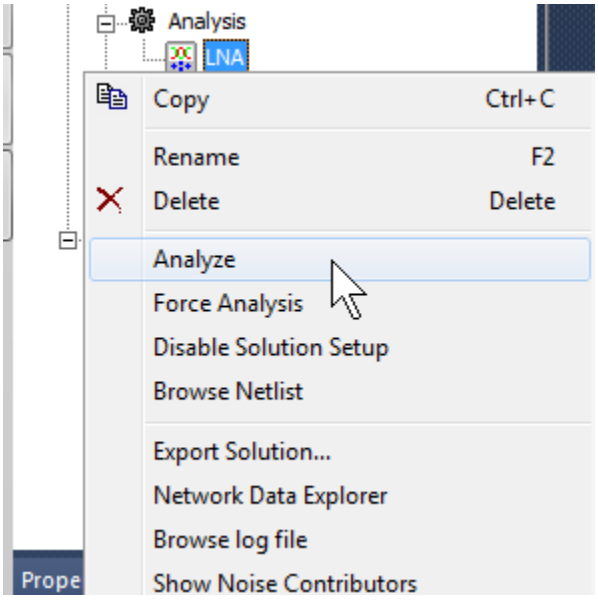


Figure 3. Analyze the design

Creating Smith Chart Reports

Generate Smith Chart as follows:

1 On the **Project Manager** window, right-click **Results** and select **Create Standard Report** > **Smith Chart**.

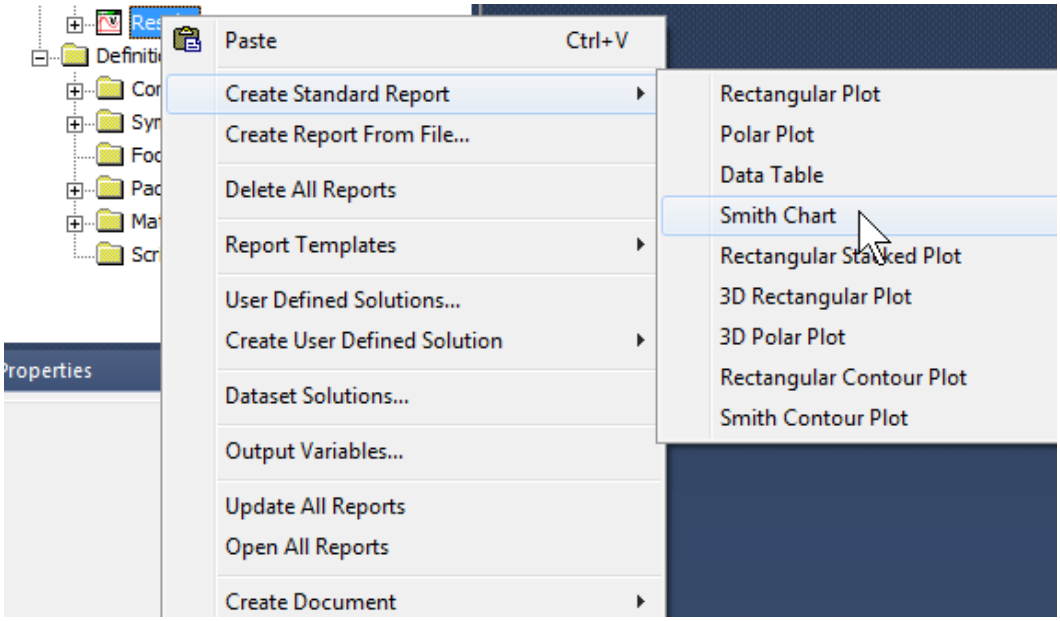


Figure 4. Create report

2 On the **Report** dialog box select the following options:

- **Category:** S parameter
- **Quantity:** S(Port1, Port1)
- **Function:** <none>

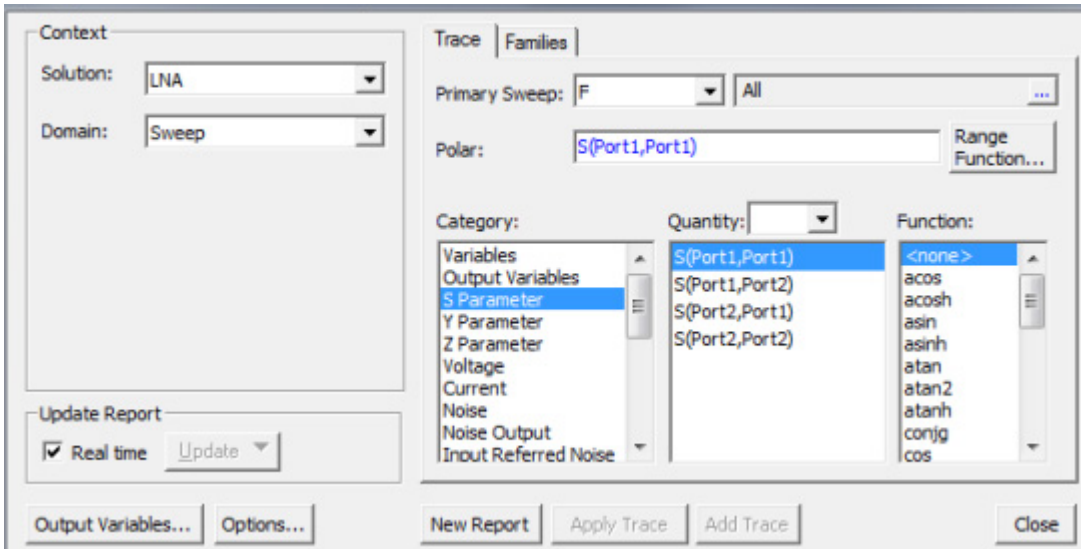


Figure 5. LNA New Report

3 Click the **New Report** button and then click **Close**.

The Smith Chart report is generated as shown below.

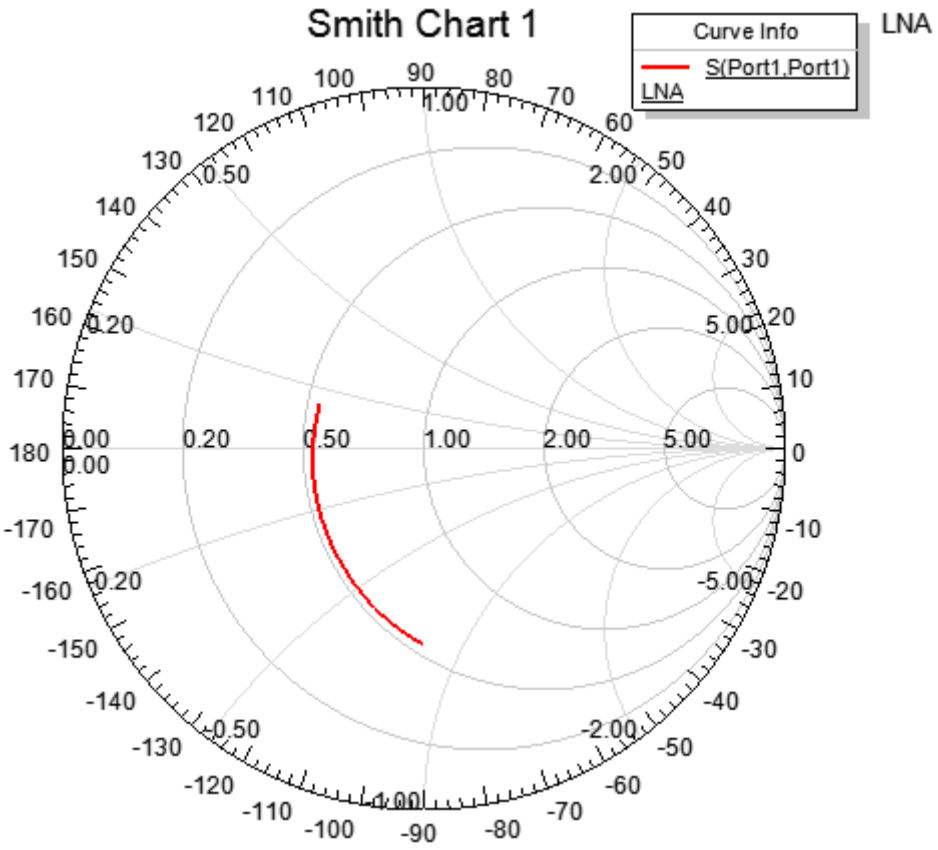


Figure 6. Smith Chart 1

Using the Smith Tool Utility

To access the Smith Tool utility, perform the following steps:

1. Double-click Smith Chart 1 under **Results** to make the plot active.

   This action updates the menu bar with the **Report2D** item.

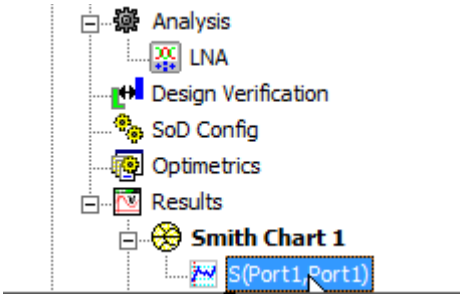


Figure 7. Selecting plot under Smith Chart

2. On the menu bar, go to **Report2D > Smith Tool**.

   The Smith Tool dialog box appears.

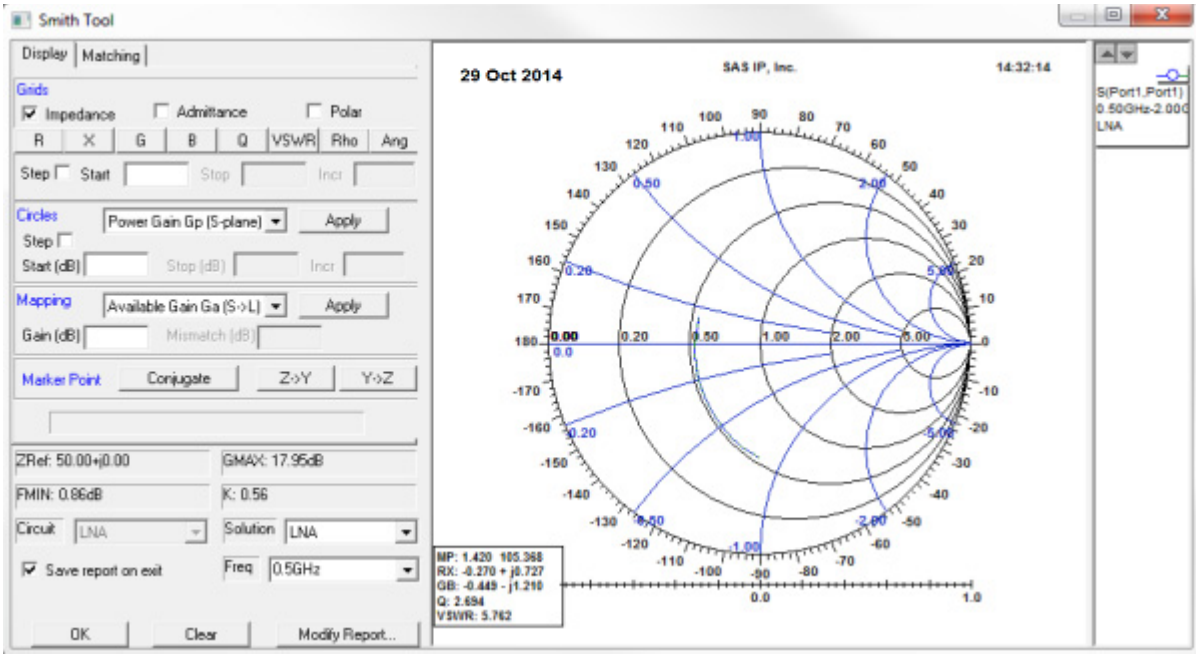


Figure 8. Smith Tool dialog box

Note Double-click inside the Smith Chart to open the **Contrast Properties** dialog box and select the desired color. Change other properties as needed.

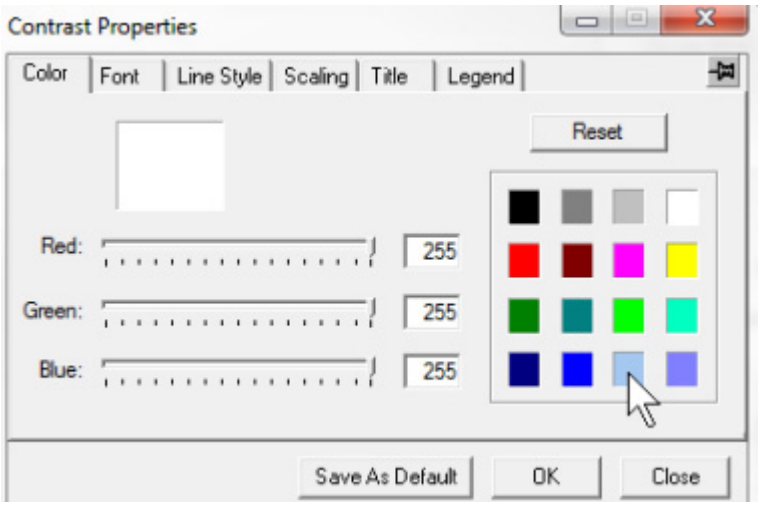


Figure 9. Contrast Properties dialog box

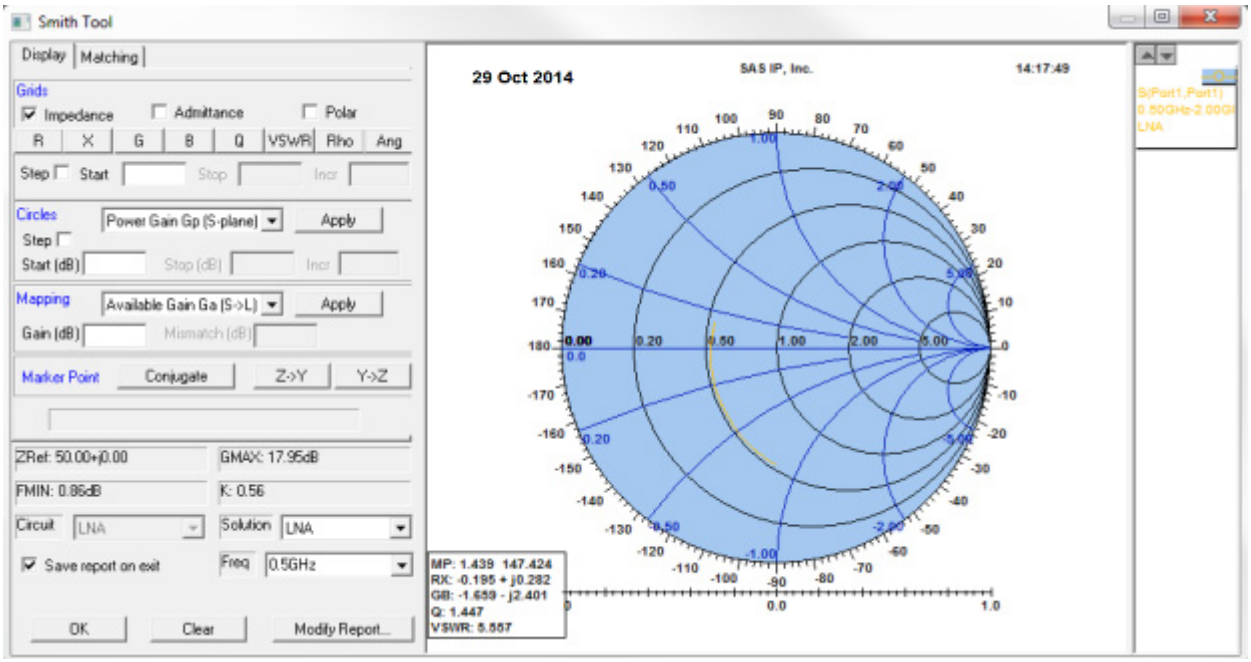


Figure 10. Smith Tool utility

The Smith Tool Utility contains several areas as described below:

- In the Grids area, draw constant R, X, G, B, Q, VSWR, and Rho circles on the plot.
- In the Circles area, draw Gain, Noise, and Stability circles.
- In the Mapping area, transform the responses from the source plane to the load plane and vice-versa.
- At the top of the dialog, there are tabs to switch between the Display portion of the dialog and the Matching portion.
- At the bottom of the dialog is information that is calculated from the device S Parameters:
  - Maximum Stable Gain
  - Minimum NF
  - stability factor

Stabilize Transistor

The followng settings are used to stabilize the transistor:

- Freq = 0.9 GHz
- Select **Stability K (S-plane)** from the **Circles** pull-down menu and click the **Apply** button.
- Select **Stability K (L-plane)** from the **Circles** pull-down menu and click the **Apply** button.
- Select the check box **Save report on exit**.

Click **OK**.

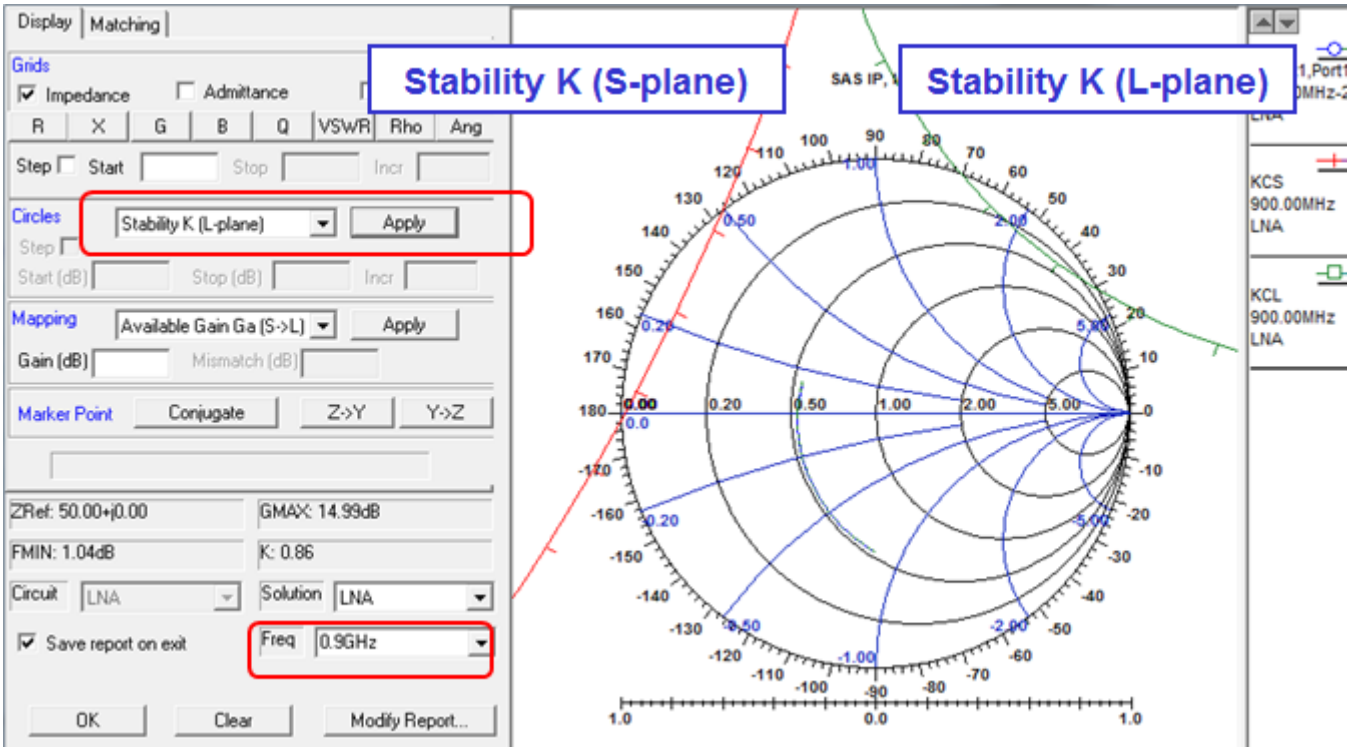


Figure 11. Red curve is Stability K (S-plane) and green is Stability K (L-plane)

Adding Emitter Degeneration Inductor

Perform the following steps to add an inductor between the emitter and Gnd:

1 Right-click the link between the emitter and Gnd, and select **Delete** from the short-cut menu.

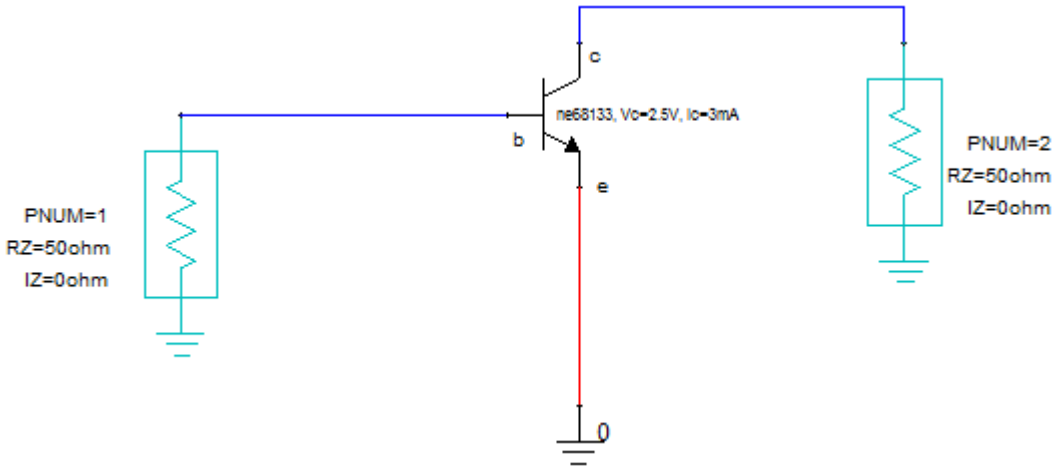


Figure 12. Selection highlighted in red

2 From the **Components** library, drag and drop the first inductor on the list **IND_:Inductor** into the schematic and press the **Esc** key.

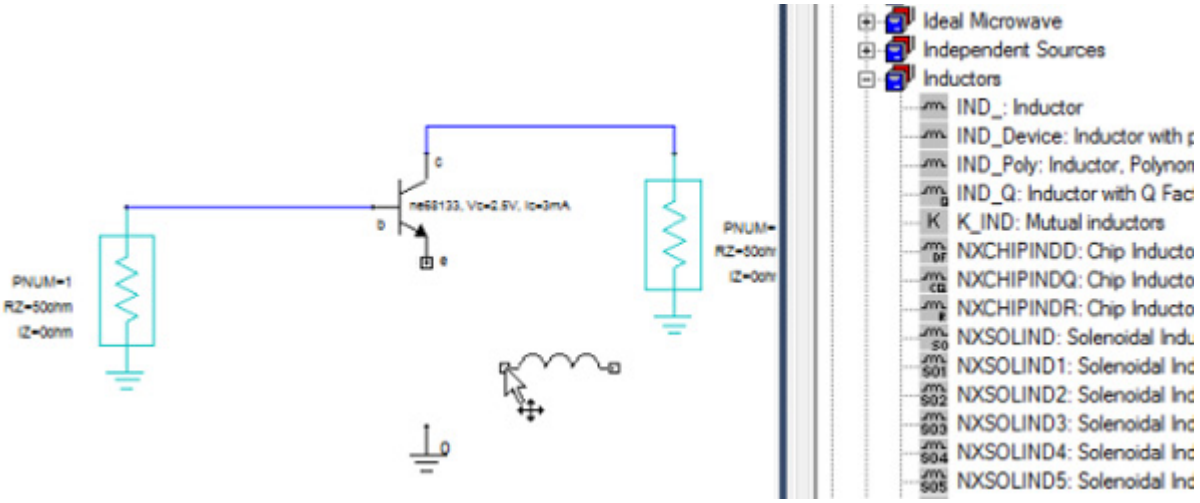


Figure 13. Adding inductor

3 Right-click the inductor symbol in the schematic and select **Rotate**, and connect the inductor between the emitter and Gnd.

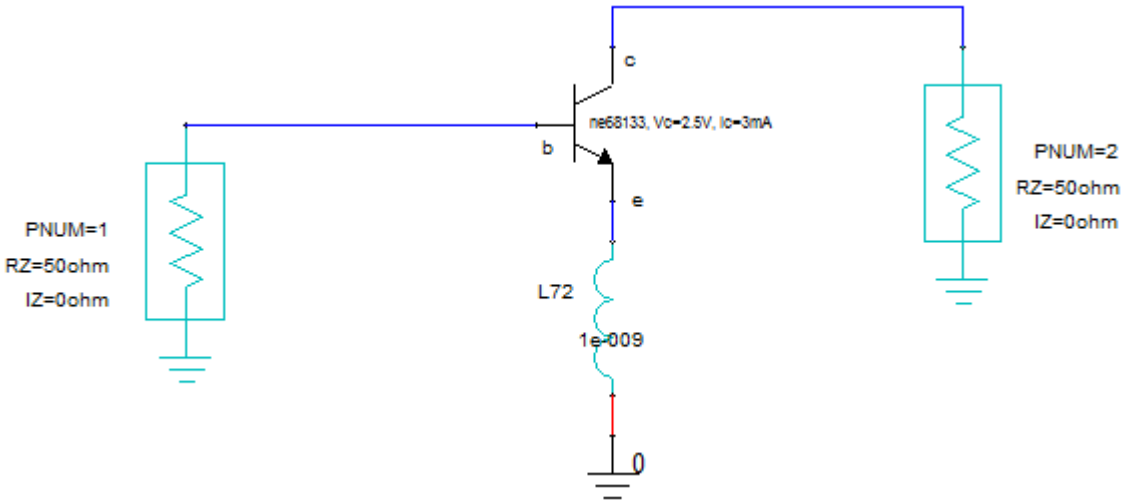


Figure 14. Inductor added

4 Double-click the inductor and set a local variable, L1, with value 0nH and add the appropriate unit, nH, in the unit field.

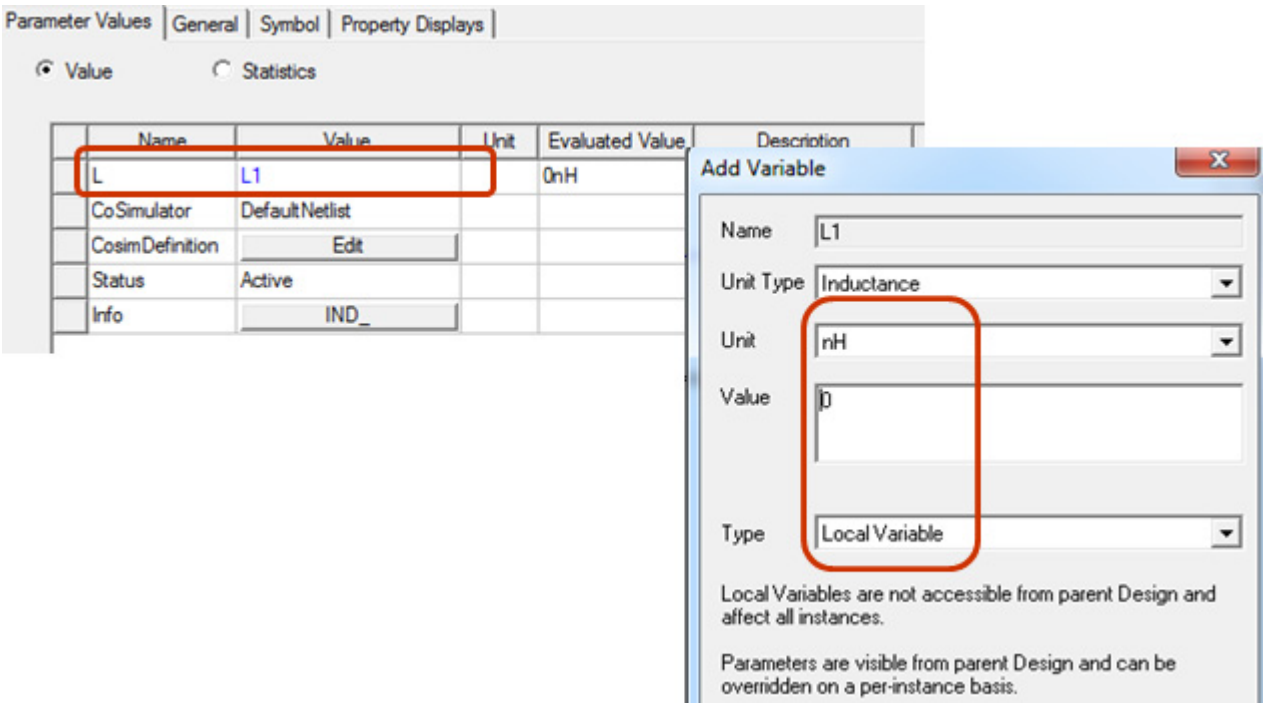


Figure 15. Local Variable

5 Analyze to run the simulation.

The Smith Chart is shown below.

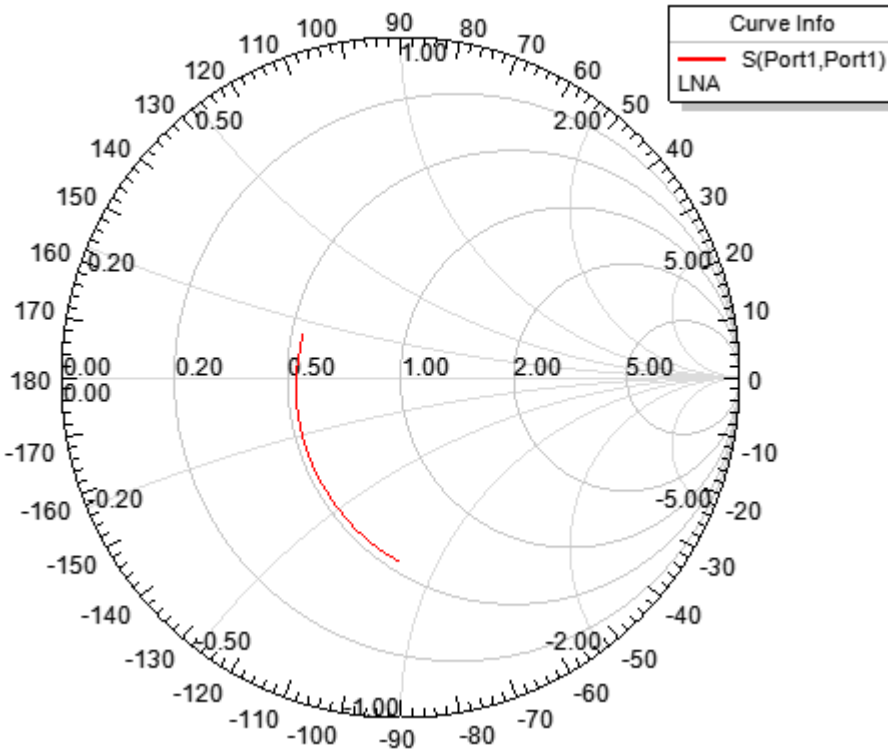


Figure 16. Smith Chart after simulation

Set Tuning Parameter

1 Right-click the **LNA** design in the **Project Manager** and select **Design Properties** from the short-cut menu.

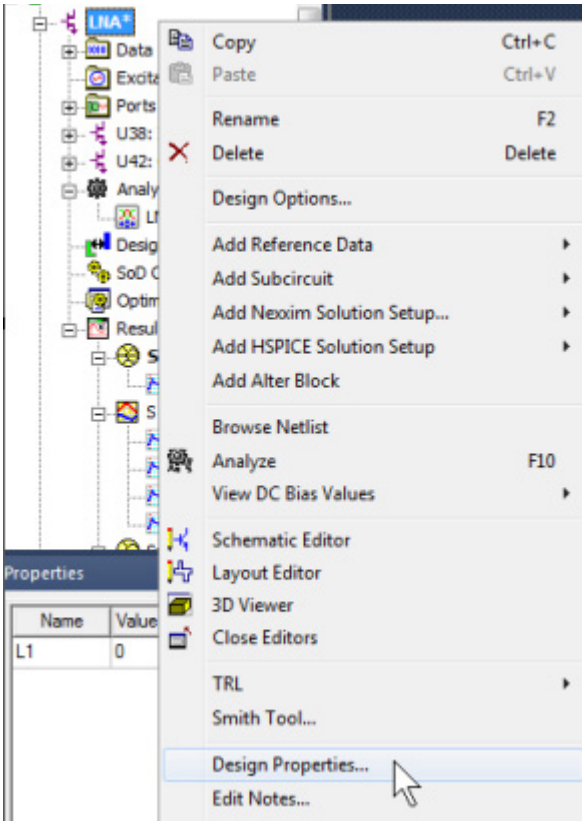


Figure 17. Design Properties selection

2 Select the **Local Variables** tab, and then select the **Tuning** option.

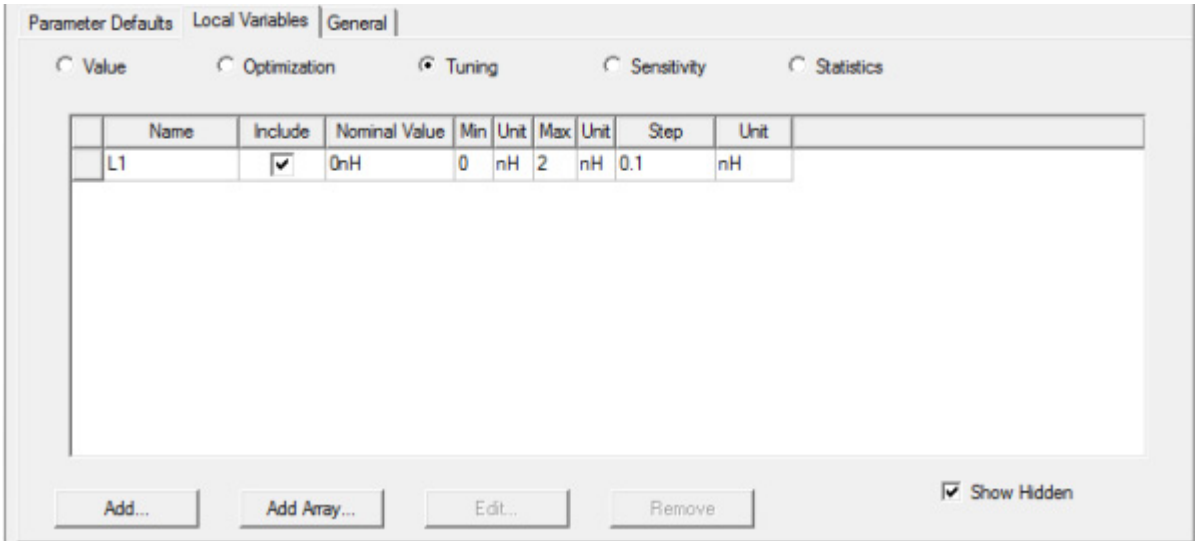


Figure 18. LNA Properties dialog

3 Select **Include** for L1 and set Min=0, Max=2nH, and Step=0.1nH and click **OK**.

4 Run the analysis (F10).

This tuning parameter is used for the inductor as described in the following section.

Tune Inductor

Ensure that the Smith chart generated by the Smith Tool utility is open and verify that the stability circles are visible.

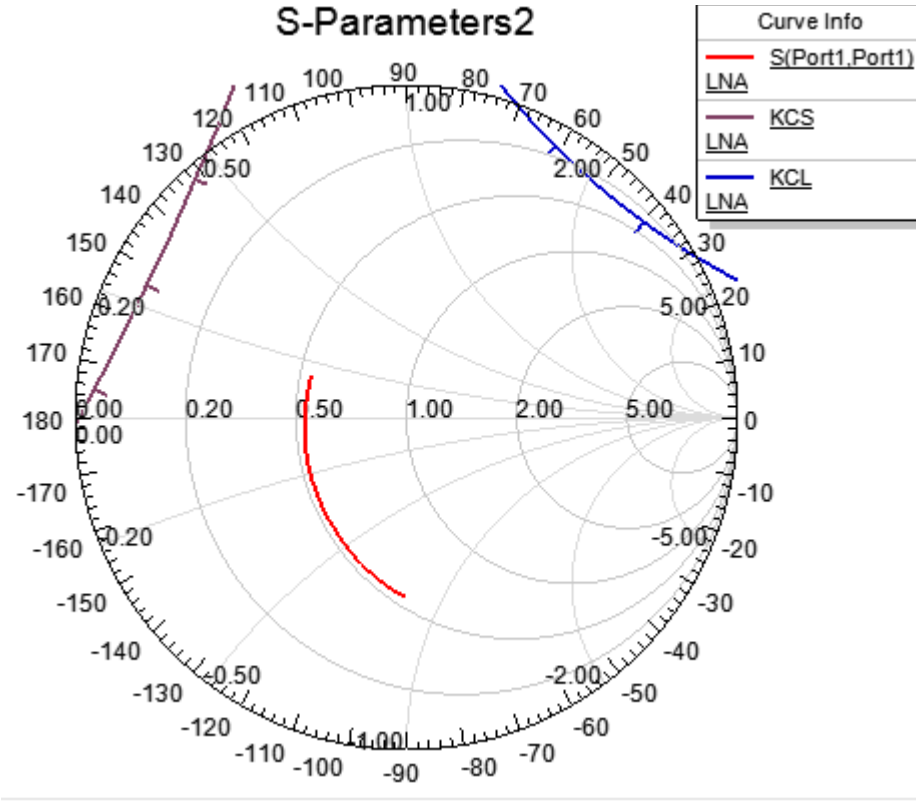


Figure 19. S-paramters plot

1 Right-click **Optimetrics** and select **Tuning** from the short-cut menu as shown in the following figure.

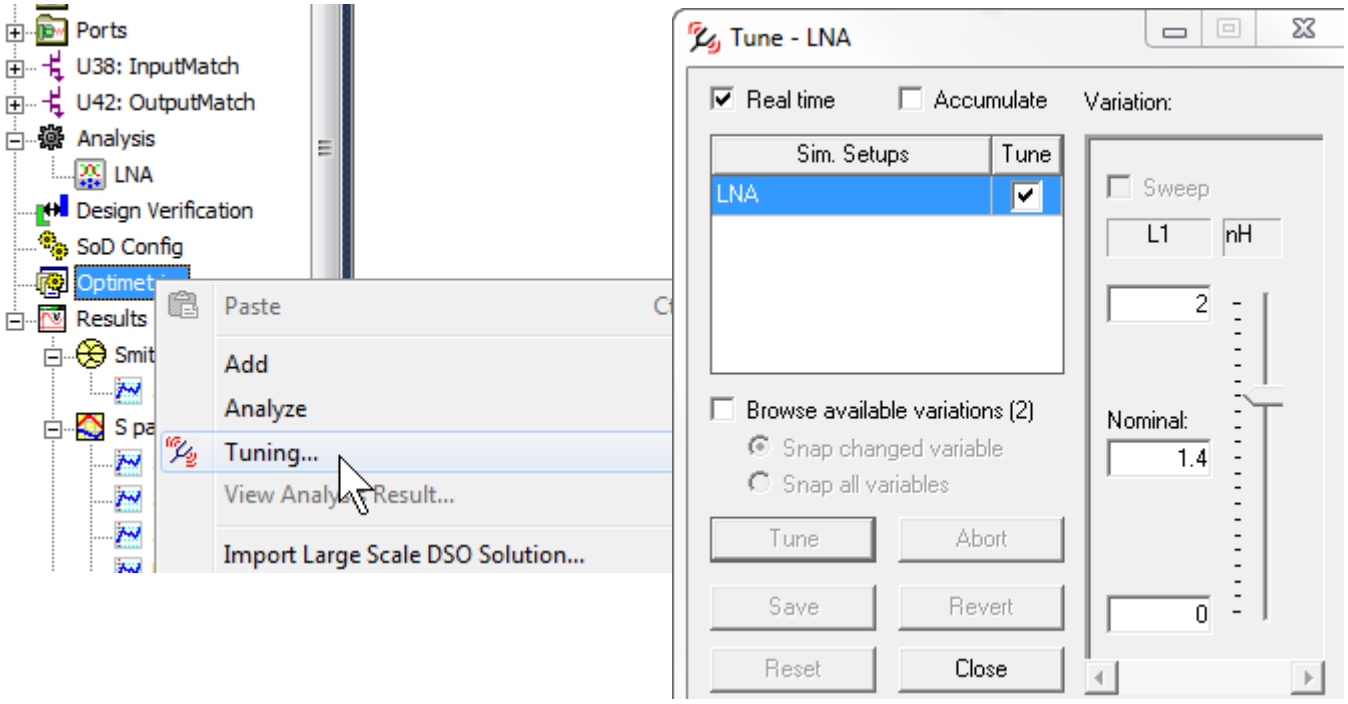


Figure 20. Tuning

2 Deselect the option **Browse available variations** and tune the inductor value until the stability circles move outside the Smith Chart (L~1.4nH) and click **Close**.

3 Click **OK** in the **Apply Tuned Variation** dialog box and analyze the design.

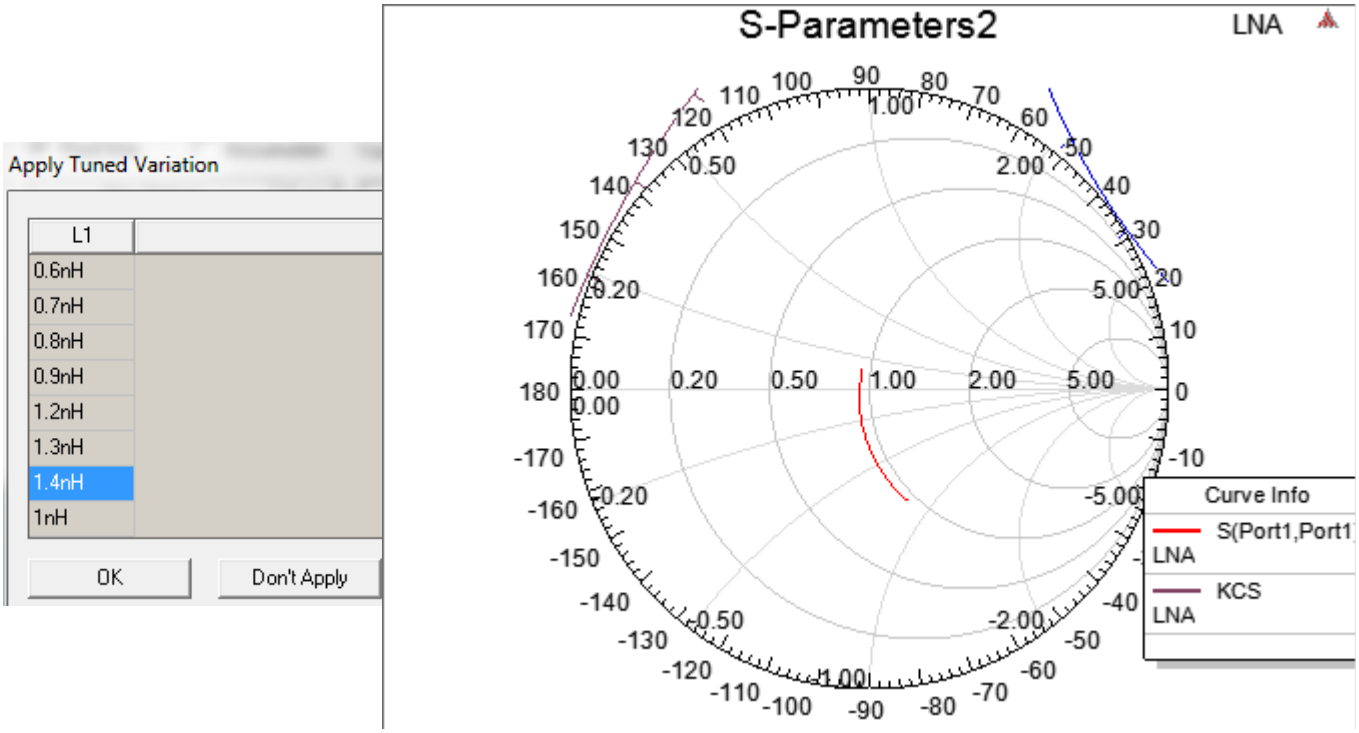


Figure 21. Tuning pushes the stability circles outside the Smith Chart

Matching Circuit

1. Select the Smith Chart to make it active.
2. From the menu bar, select **Report2D > Smith Tool** to load the Smith Tool utility.
3. Set **Freq** to 0.9 GHz.

Note At 0.9 GHz, K>1, Gmax is 12.69dB, Fmin is 1.02 dB.

4. Select **Stability K (S-plane)** and click **Apply**.
5. Select **Stability K (L-plane)** and click **Apply**.
6. Deselect the **Save report on exit** option.

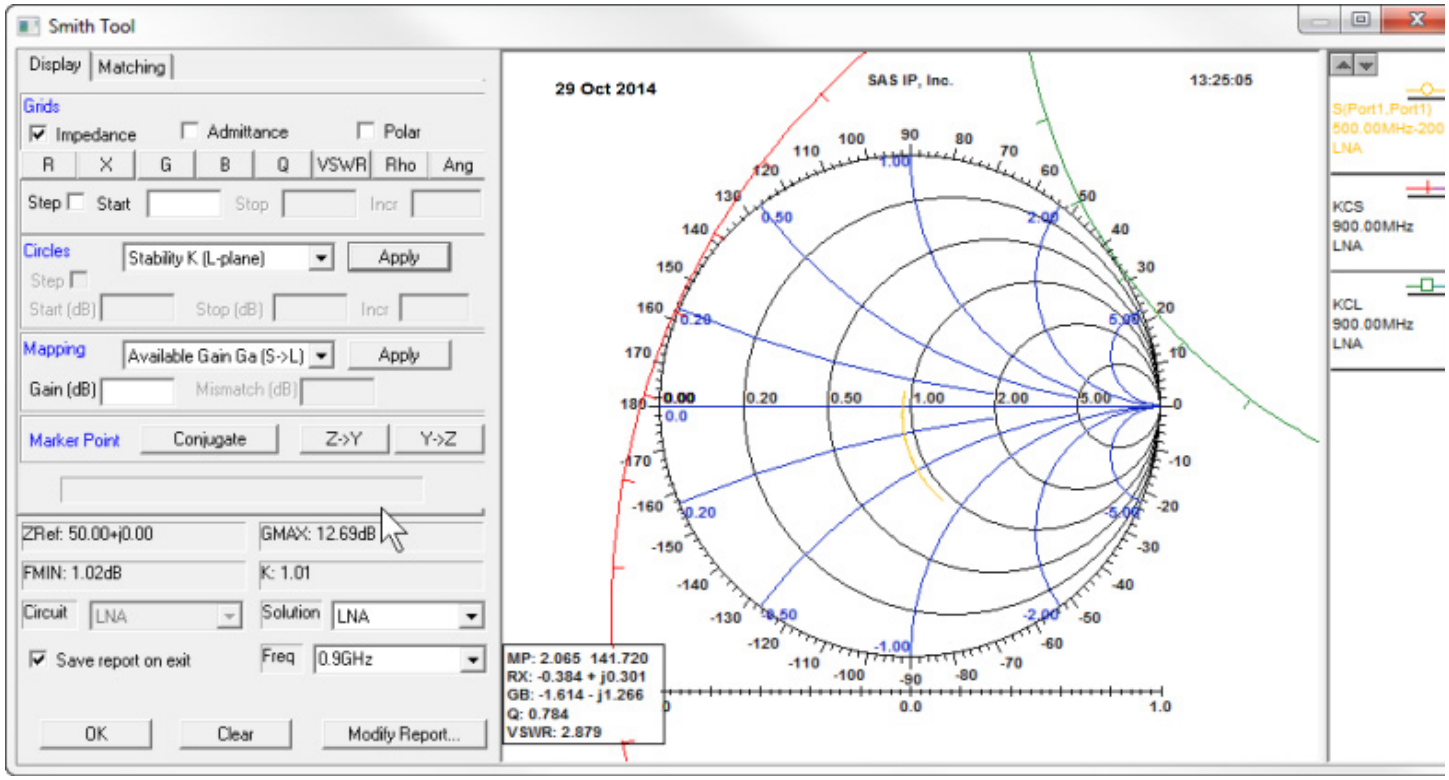


Figure 22. Smith Tool (KCS in red and KCL in green)

Add Constant Gain/Noise Circles

1. Select **Available Gain Ga (S-Plane)** from the **Circles** pull-down menu.
2. Enter 12.25 in the **Start** field and click **Apply**.
   A 12.25dB gain circle appears.

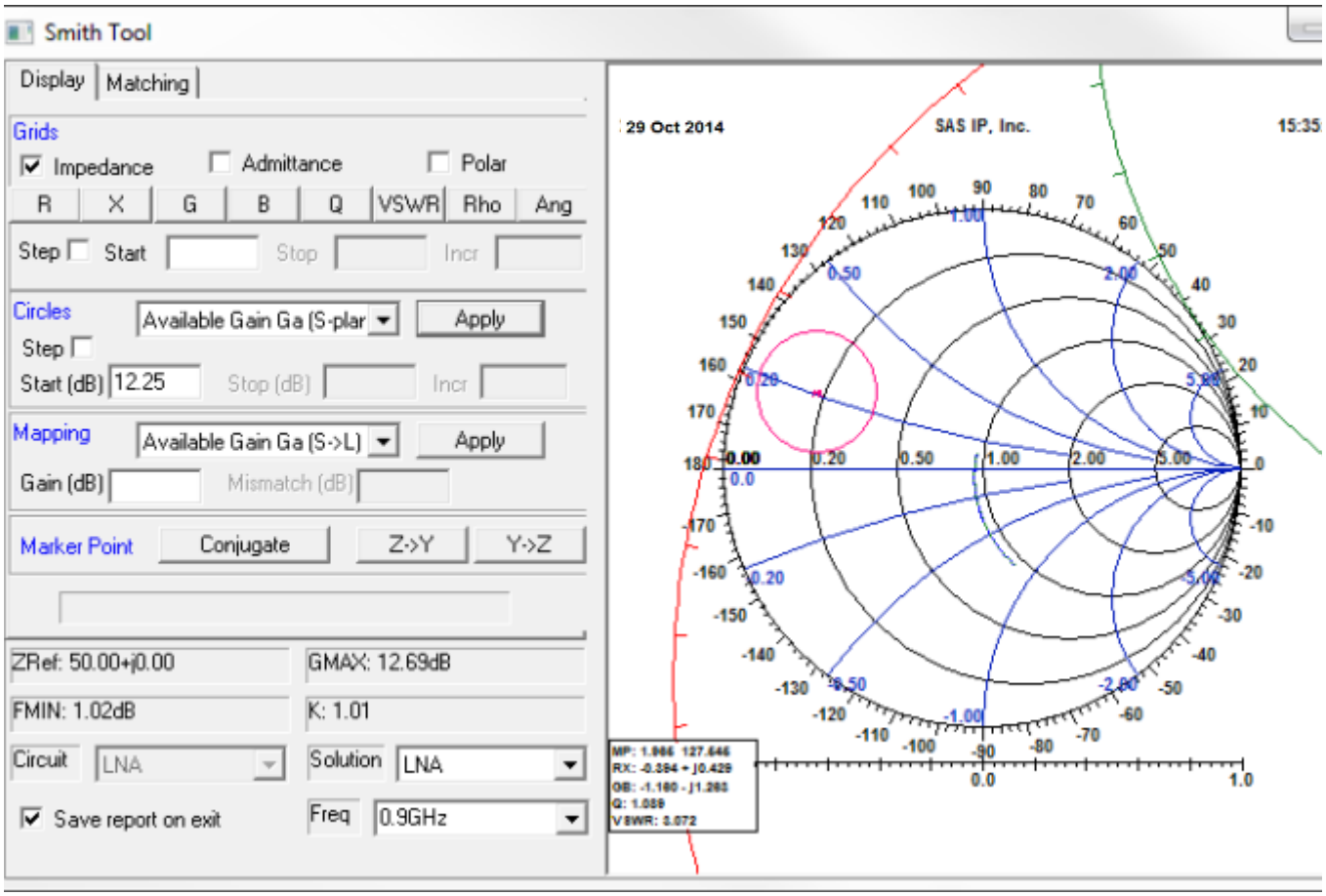


Figure 23. 12.25 dB Gain circle (in pink)

3. Select **Noise** and enter 1.5 dB, and click **Apply**.
   A 1.5dB noise circle appears.

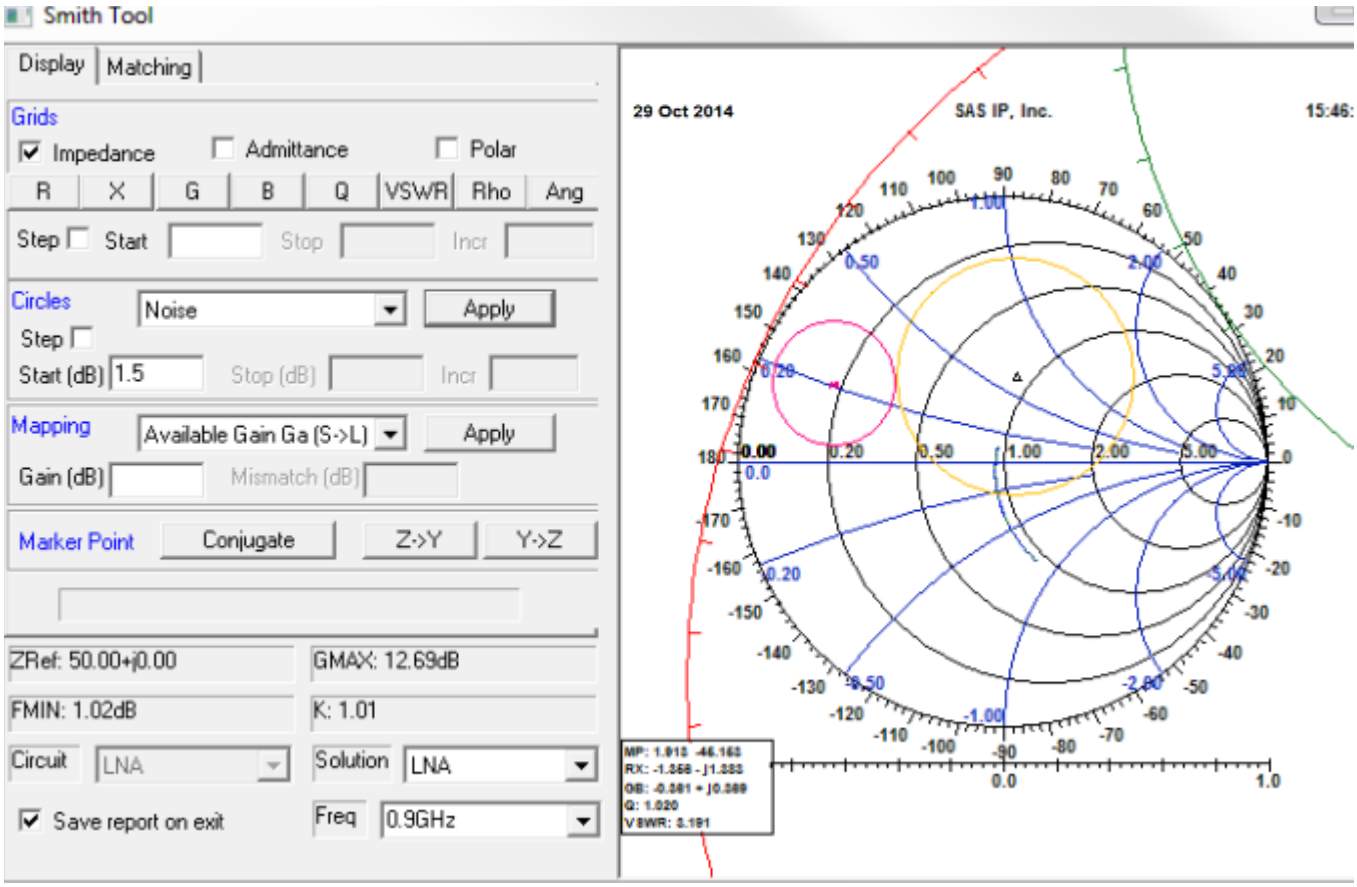


Figure 24. 1.5 dB noise circle in yellow.

Smith Tool - Drawing Aids and Matching Tab

1. Enter 1 in the **Start** field of section **Grids** and click **G** to plot the constant circle of real part 1 for the admittance.
2. Click **R** in section **Grids** to plot constant **R** circle.
3. Move the cursor to point P and click **R** to display constant real part circle for the impedance located a point P (where Gain and Noise circles touch).
4. Click on the **Matching** tab on the **SmithTool** dialog box.

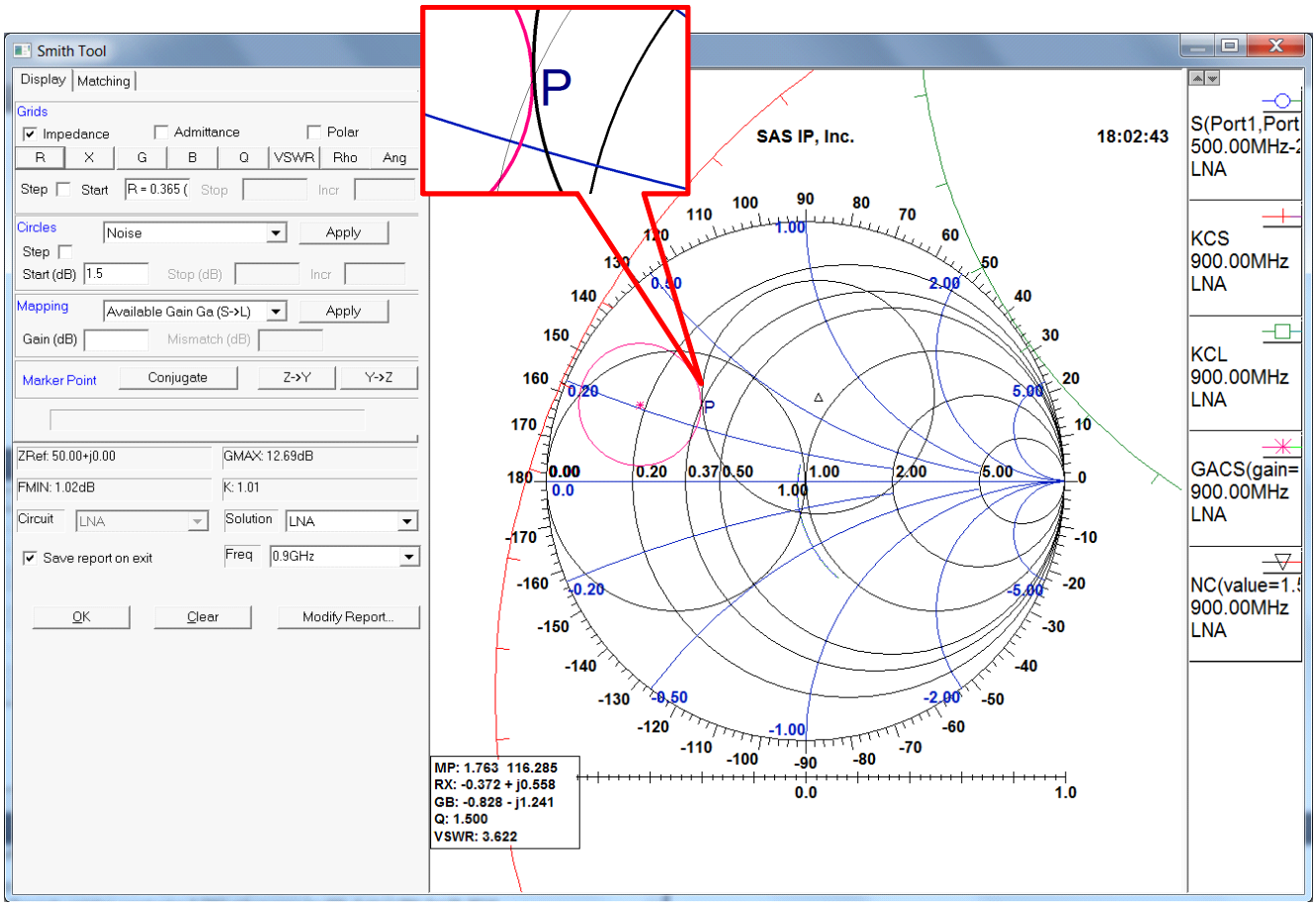


Figure 25. Smith Tool (Grid Settings)

For the input matching circuit, move from 50 Ohms at the center of the chart to the point P.

5 Click the **New Match** button.

The cursor immediately jumps to the center of the Smith chart.

6 Without moving the mouse, click again to place the “crosshair” at the center i.e. 50 Ohms.

The ten element buttons in the dialog become active. These are the elements available for use in the matching circuit, representing both lumped and distributed components.

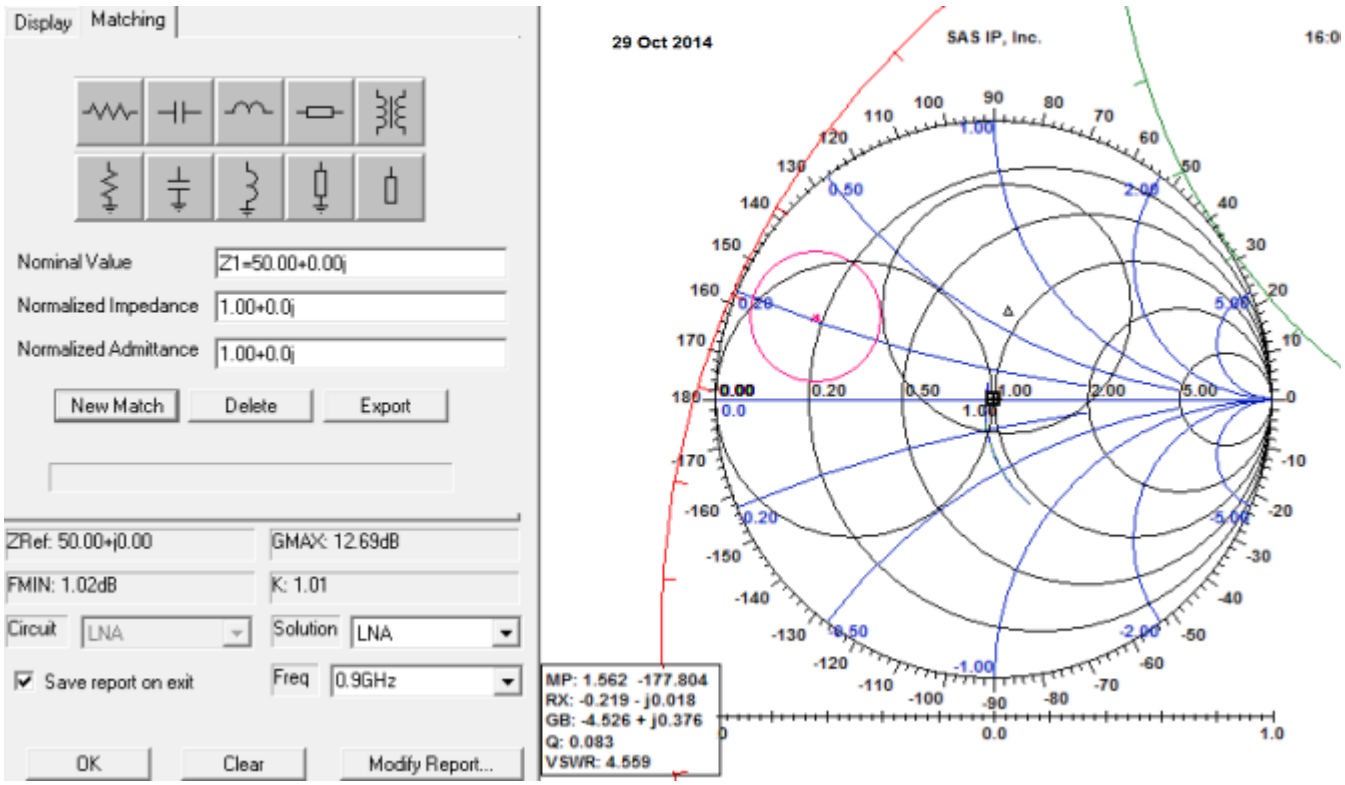


Figure 26. Matching Tab of the Smith Tool.

Input Matching Circuit

1. Click the **Shunt L** button in the dialog.

   A small "tail" appears on the R = 1 circle.
2. Click the tail and drag it to the constant R circle added earlier (approximately R = 0.36).
3. Click the **Series C** button in the dialog.

   Again, a tail appears from the last point.
4. Drag this tail to the point P to complete the match.

   The approximate values for the matching elements should be: L = 6.7nH, C = 19.5pF

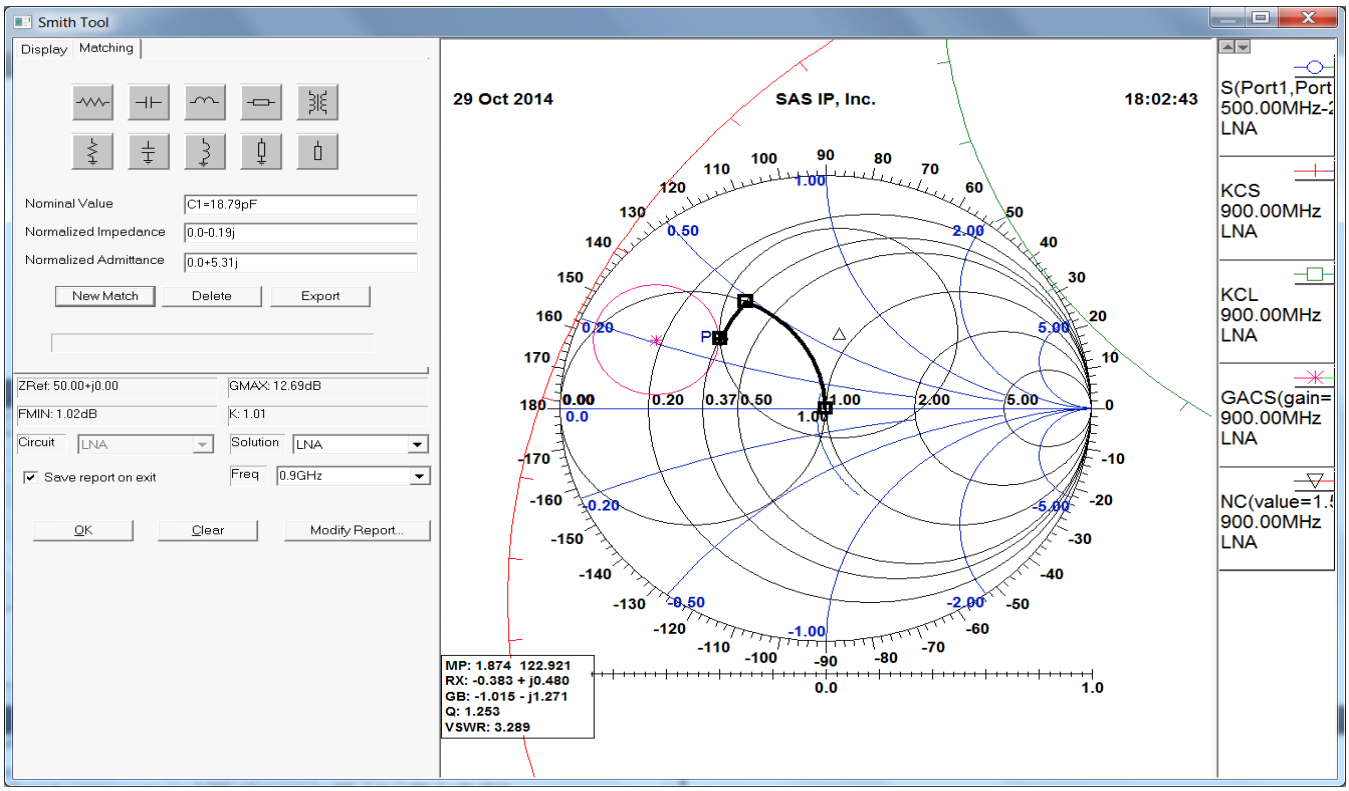


Figure 27. Input matching circuit

5 Click the **Export** button to write the subcircuit for the input matching circuit.

6 Click **OK** on the message dialog box to confirm that the subcircuit is created.

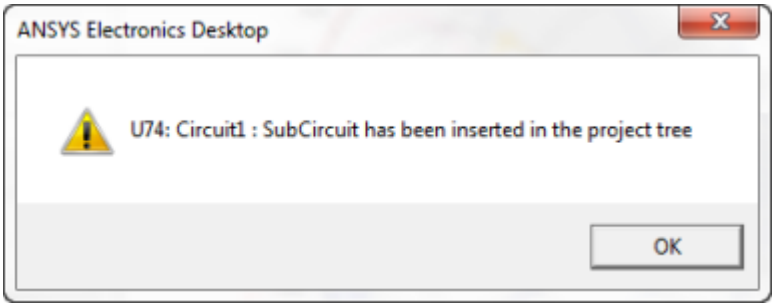


Figure 28. Message dialog

Smith Tool - Source/Load Mapping

1 Take the point used for our input match and transform it into the load plane.

2 Go to **Display** tab and in the **Mapping** section of the dialog, make sure that **Available Gain Ga S->L** is selected.

3 In the **Gain (dB)** box, enter 12.25, which is the same gain value that was used to determine point P, and click **Apply**.

4 Re-analyze by clicking **Yes** when the message dialog box appears.

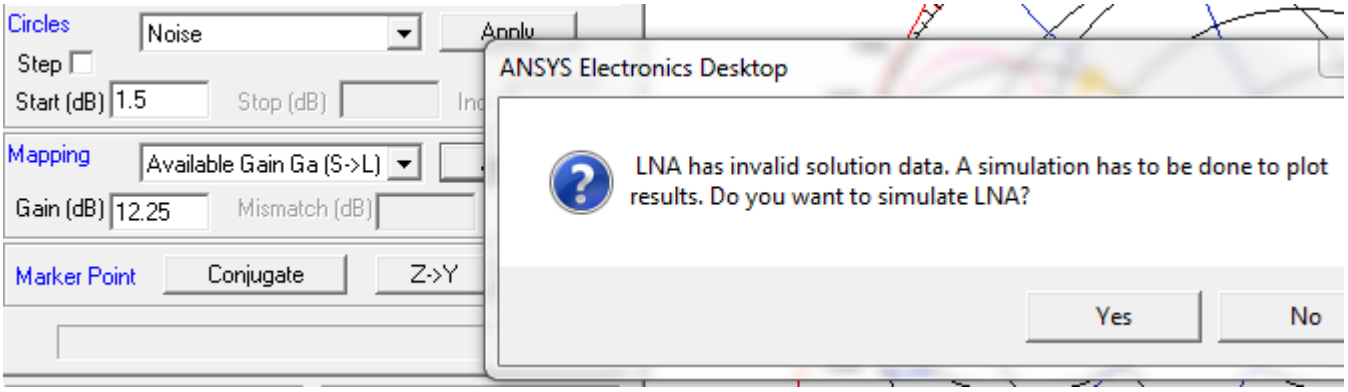


Figure 29. Message dialog

A second circle appears; it represents the source plane gain circle mapped into the load plane.

5 Move the cursor on the source plane to point P.

6 Click point P.

A new point appears on the load plane circle representing the same point, but in the load plane, as shown above. This point is called Q in the figure below.

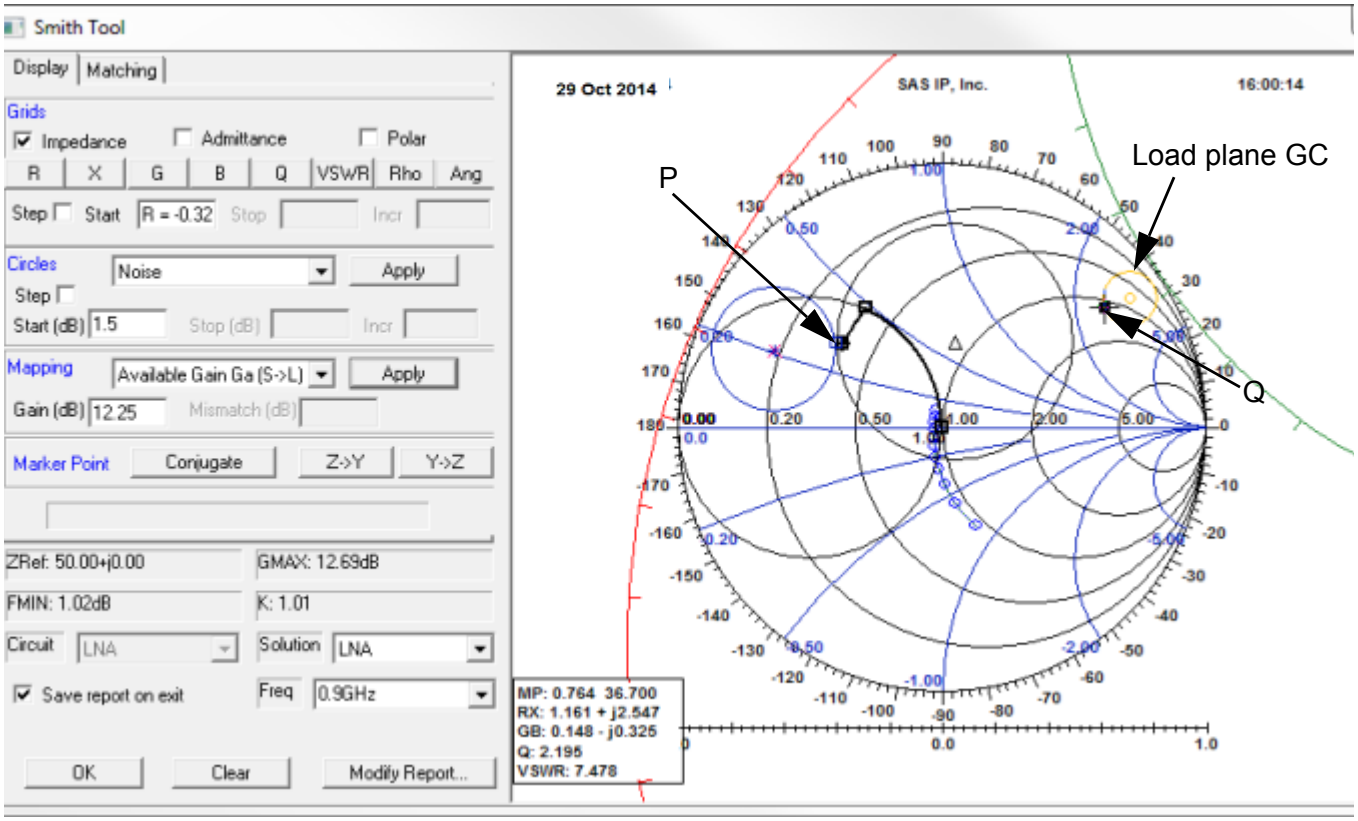


Figure 30. Source/Load Mapping

SmithTool - Complex Conjugation

To complete the output match, take point Q in the load plane and conjugate it. Use the conjugated point, Q*, to begin the output match. Click **Conjugate** and click point Q.

This creates a point Q* with the equal real part and opposite imaginary part.

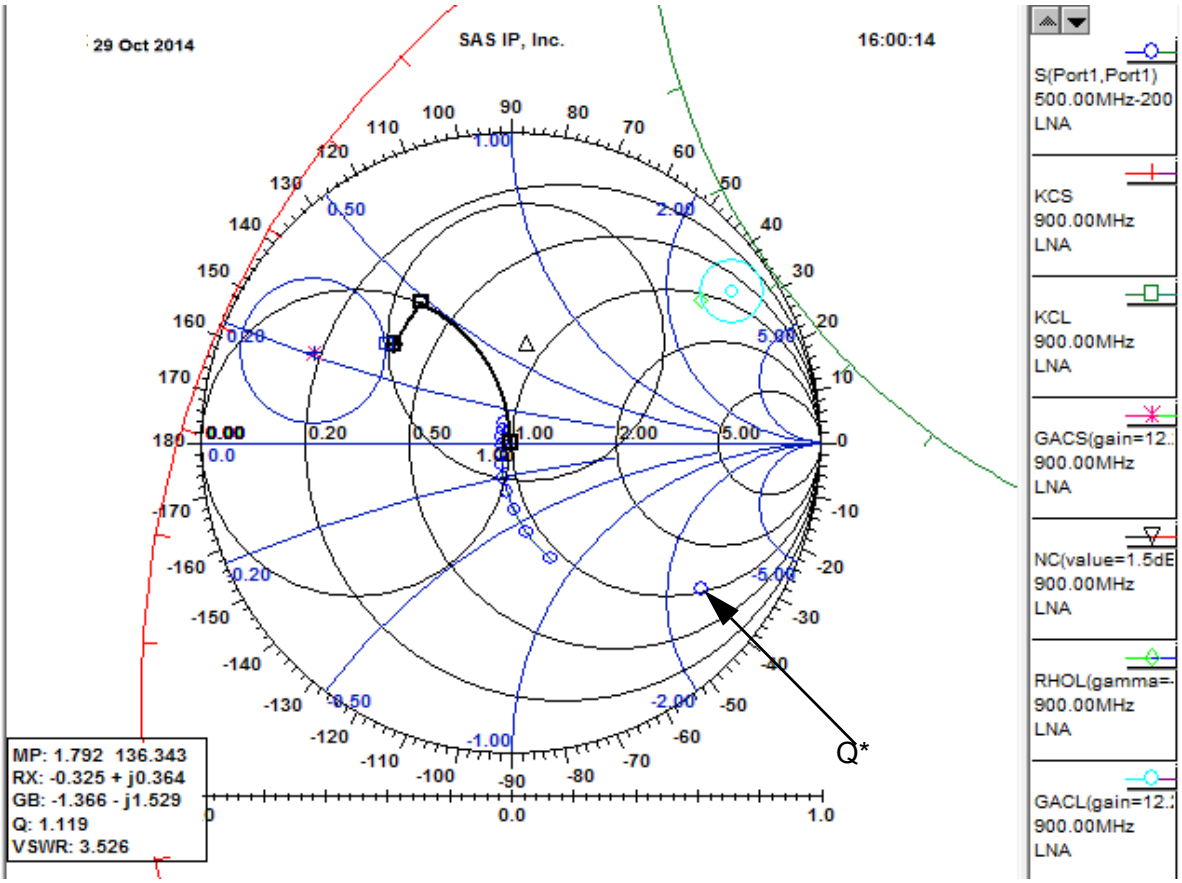


Figure 31. Conjugate

Output Matching Circuit

1. Click the **New Match** button.

   The cursor jumps to the Smith chart.
2. Click on the point Q* to start the match.
3. Click on the shunt **L** button with the icon. 
4. Drag its tail up to the R = 1 circle.
5. Click on the series **C** button with the icon. 
6. Drag its tail down to the center of the chart.

   Approximate values are: L = 13.1nH, C = 1.45pF
7. Click the **Export** button to write the Subcircuit for the output matching circuit

   A window message pops up to confirm that the Subcircuit is created, click **OK**.
8. Click **Clear** and **OK**.

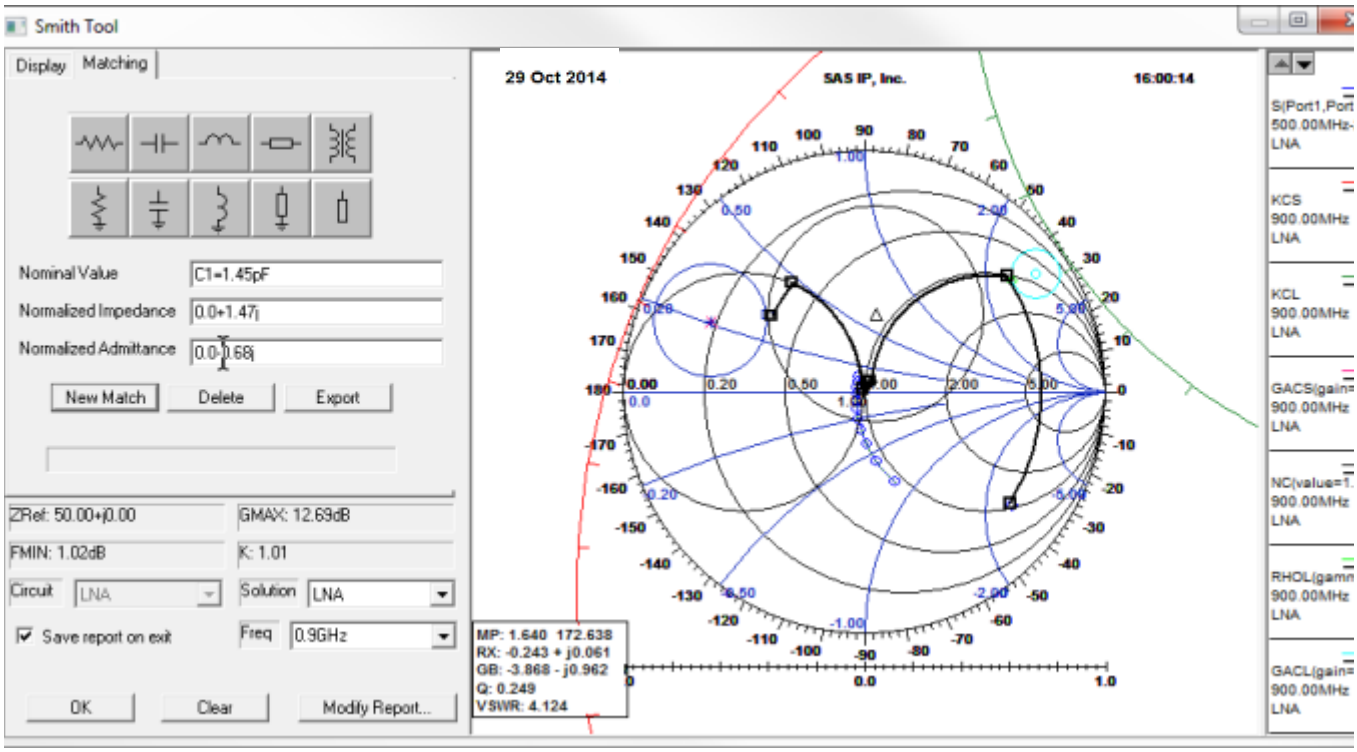
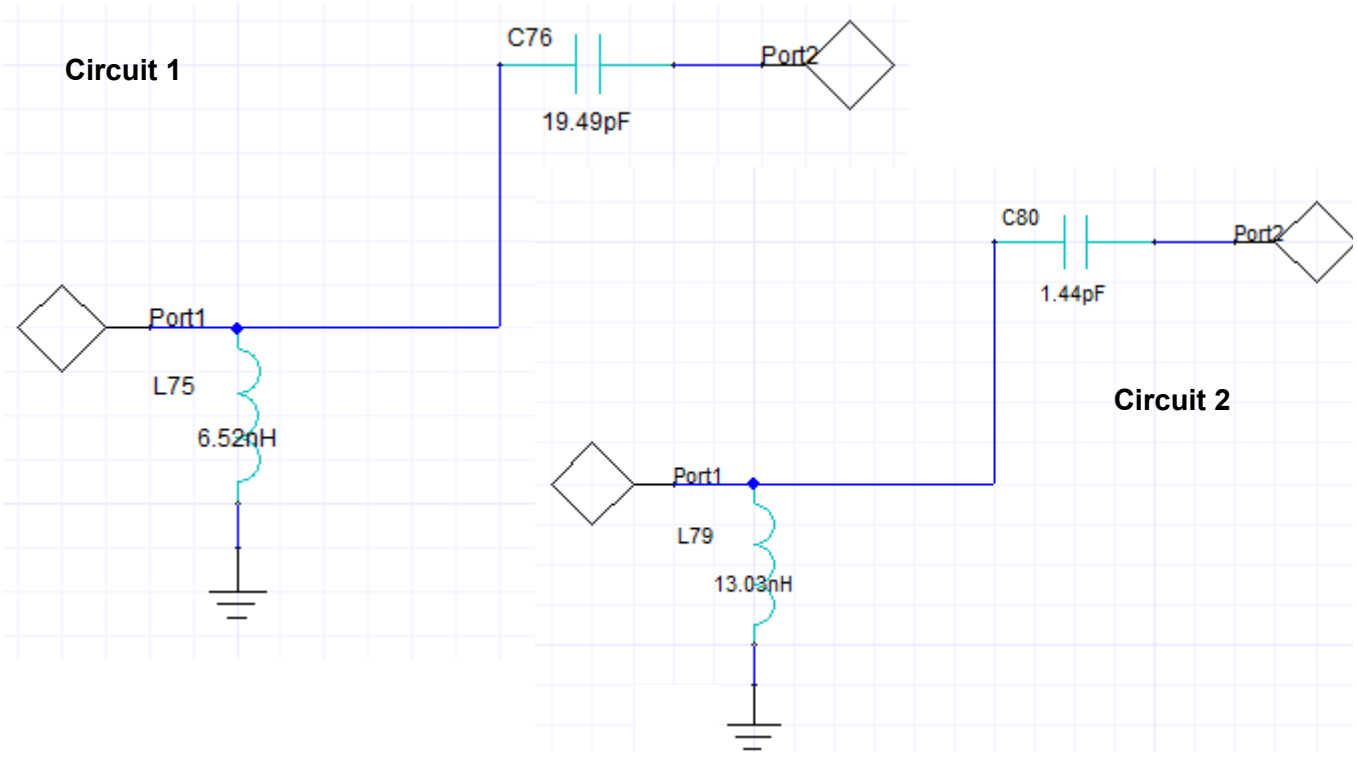


Figure 32. Output matching circuit

Building the Amplifier

Sub-Circuit Circuit1 is InputMatch and Sub-Circuit Circuit2 is the OutputMatch. Connect the sub-circuits on the schematic as shown to complete the LNA.



Completed Amplifier

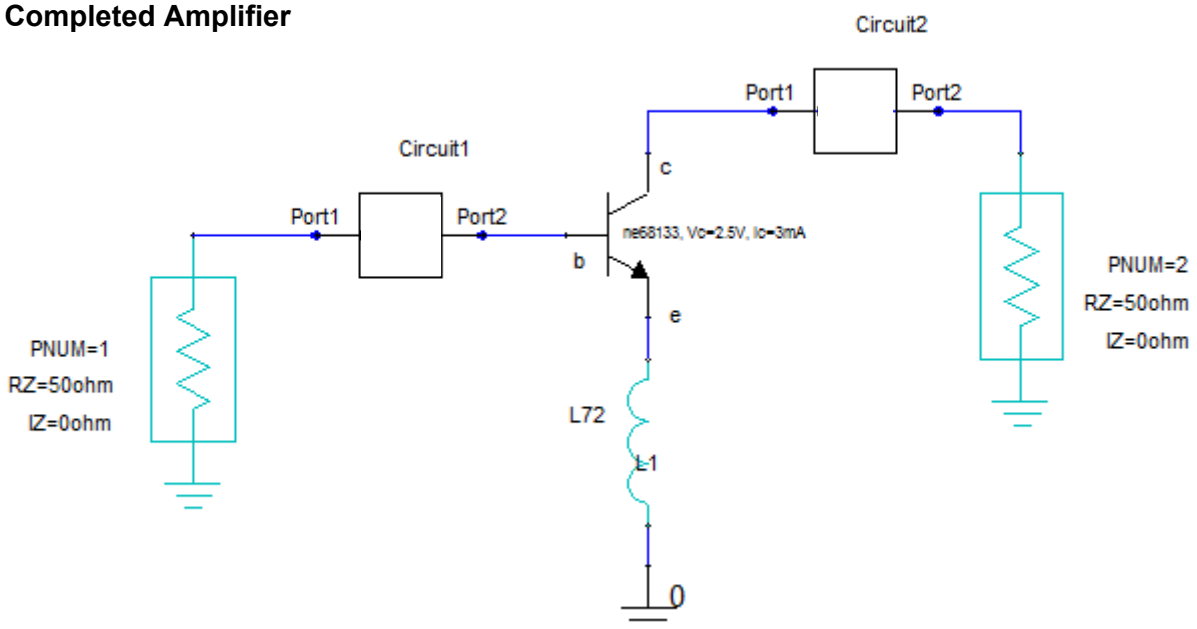


Figure 33. Building the Amplifier

Verifying Amplifier Performance

1. Run the analysis.
2. Create a new rectangular graph with the following traces: dB(S11), dB(S22), dB(S21), and additionally add dB(NF)
3. Right-click on the graph and select **Marker > Add X Marker**.
4. Move **X Marker** to 0.9GHz or modify **Marker Properties** Xvalue to 0.9GHz.
5. Design goals of 12.25dB gain and 1.5dB NF should have been met.
6. Save the current project as **LNAMatch**.

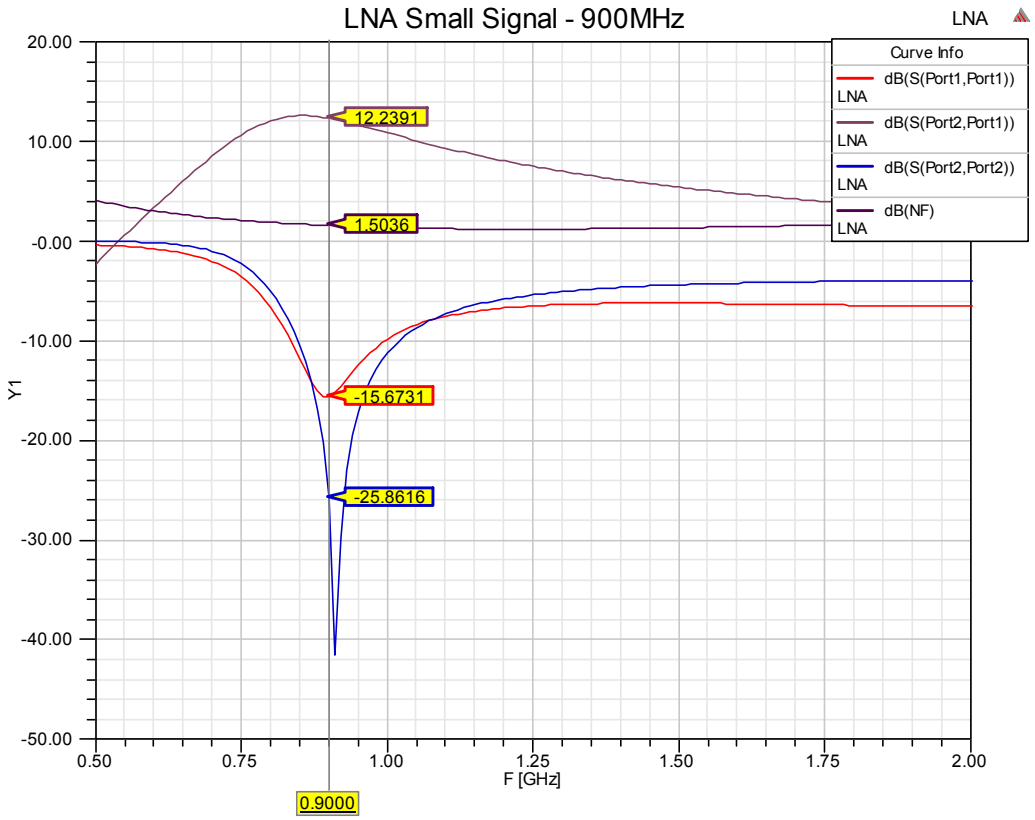


Figure 34. Results