A Walk Through the MSA Software
# Vector Network Analyzer Reflection Mode
12/12/09

This document is intended to familiarize you with the basic features of the MSA and its software, operating as a Vector Network Analyzer in Reflection mode, without the need for you to have the MSA hardware. All that is necessary is that you have installed the software per Scotty's instructions. It is assumed that you have done the Walk-Through of the MSA in Spectrum Analyzer Mode. It may also be helpful to have performed the Walk-Through for Transmission Mode.
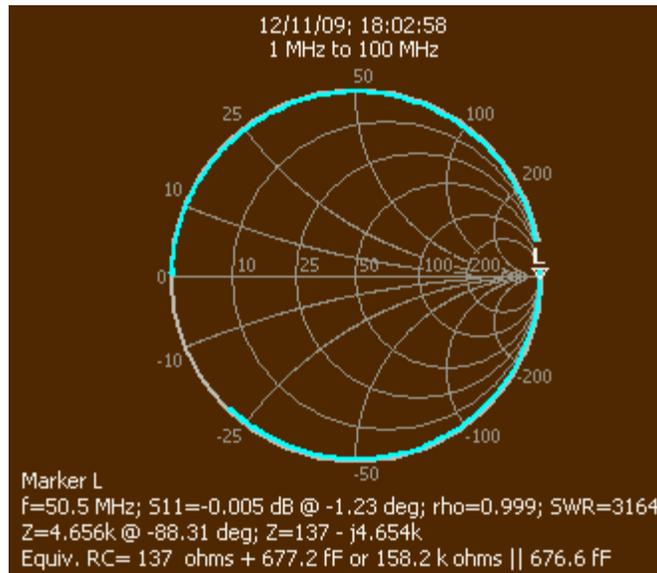
Basic Operation in Reflection Mode

1. To start the program, double-click the icon for the MSA software. Warning: You may resize the MSA graph window or the Smith chart window, but you must be sure the scan is halted (click Halt) before doing so. **Resizing while a scan is in progress has a 50-50 chance of crashing the program, due to a Liberty Basic bug.**

2. Select menu Mode→VNA Reflection. The software will switch to VNA Reflection mode, in which it would normally measure the reflection coefficient of a device, which when expressed in dB is usually referred to as the S-Parameter S_{11}. Here we will operate with simulated data. There is no need to worry about Final IF filters or Video filter settings, but normally in Reflection mode you would use a Final IF filter in the 2-10 kHz range and set the Video filter to Mid or Narrow.

3. Click Halt. Double-click under the frequency axis to open the Sweep Parameters window. Select a start frequency of 1 MHz, a stop frequency of 100 MHz, and a number of steps/sweep equal to 200. In the Data Mode box, select item 5 (Simulated RLC/coax). Close the window.

4. Because you have selected to graph simulated data, a window will be presented allowing you to select the type of coax and the RLC components to use for the simulation. To start, we want to simulate a parallel LC circuit. Check the Inductance and Capacitance checkboxes, and uncheck the Resistance box. In the RLC area, select Parallel and enter 100n for the Inductance value, and 100p for the Capacitance value. For Transmission Line Connection, select "None". We are now simulating a parallel combination of 100 nH and 100 pF, attached directly to a theoretical bridge at one end and grounded at the other. Click OK to close the window.

5. Double-click on the numeric labels for the each axis and select Trace Width of 2; then close the window. Click Restart and then Halt At End. The

**MSA will complete one sweep and halt. The graph will look something like this:**
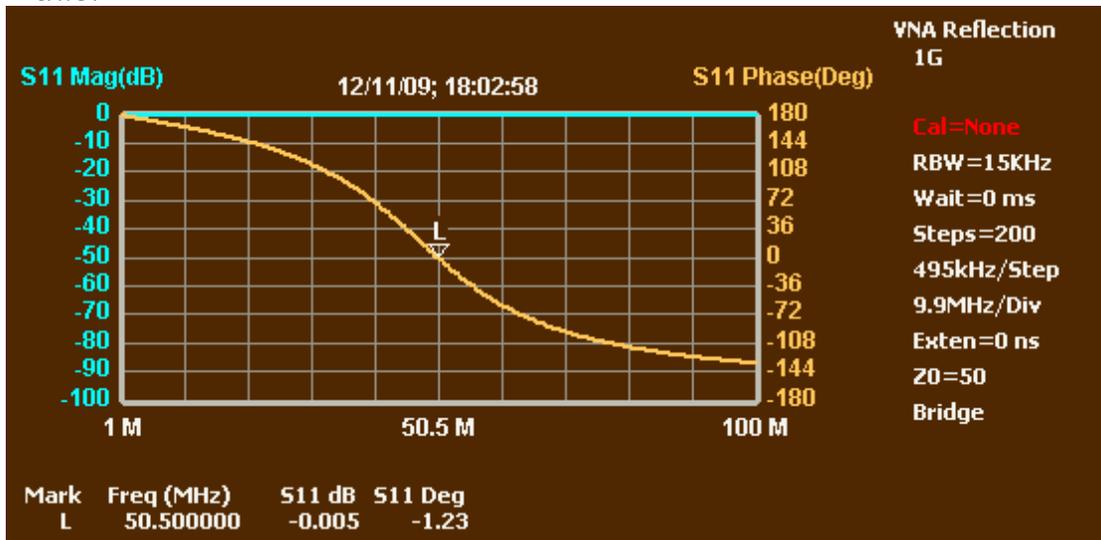
6. **Your axes may be reversed. These scans were produced with the primary axis set to 1 (using Setup→Primary Axis). The "L" marker actually won't be there yet. Select the L marker, or "None" and double-click where the phase graph crosses zero. Then use the marker "+" or "-" button to move the marker as close as possible to zero phase.**

7. **The LC circuit starts at low frequency looking like an inductor of very low impedance. That means S_{11} of 0 dB at 180 degree phase—100% inverted reflection. Gradually, the capacitive reactance cancels out the inductive reactance. The phase decreases, but we still have a net pure reactance, so the reflection is still 100% and S_{11} is still 0 dB. At marker L, we reach resonance, where the capacitive and inductive reactances cancel each other, creating infinite impedance. Well, almost infinite. The inductance and capacitance each have some resistance (based on the specified Q), so at marker L, S_{11} is -0.005 dB, rather than being exactly 0 dB. Beyond resonance, the LC combination is a net capacitance, still with S_{11} near 0 dB, but phase approaching -180 degrees.**

8. **The Smith Chart will look something like this:**

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12/11/09; 18:02:58
1 MHz to 100 MHz
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Marker L
f=50.5 MHz; S11=-0.005 dB @ -1.23 deg; rho=0.999; SWR=3164
Z=4.656k @ -88.31 deg; Z=137 - j4.654k
Equiv. RC= 137 ohms + 677.2 fF or 158.2 k ohms || 676.6 fF

9. **The Smith chart is a polar graph of reflection coefficient. Here, the graph starts at the left of the chart. The beginning is marked by a slightly enlarged dot. In addition, Smith chart graphs always move in a clockwise direction (not necessarily in a perfect circle), which helps identify the starting point. As noted above, the reflection of the LC circuit is always near 100%, so the graph follows the Smith Chart boundary, where the reflection coefficient is 1. It starts at the left side, where impedance is near zero, and reaches marker L (resonance), where impedance is theoretically infinite. At that point, the LC combination becomes a net capacitance, so it follows the lower boundary of the Smith chart. By 100 MHz, the end of the graph, it is just below –j25 ohms.**

10. **Normally, a reflection mode measurement is preceded by a calibration scan, to allow the MSA to record the strength and phase of the signal transmitted with a direct connection from TG out to MSA in. However, this is not required for simulated data.**

Other Graphs

1. **Open the Sweep Parameters window and click OK. In the window that opens, select a coax type of None. In the RLC area, select Series, Inductance and Resistance; deselect Capacitance. For the inductance, specify a value of 100n. For resistance, specify 20. This represents a 100 nH inductor in series with a 20 ohm resistor, attached to a theoretical bridge at one end and grounded at the other. Click OK to close the window. Click Restart and then Halt At End. If the L marker is not still showing, double-click somewhere on the graph to place it. The graph will look something like this:**
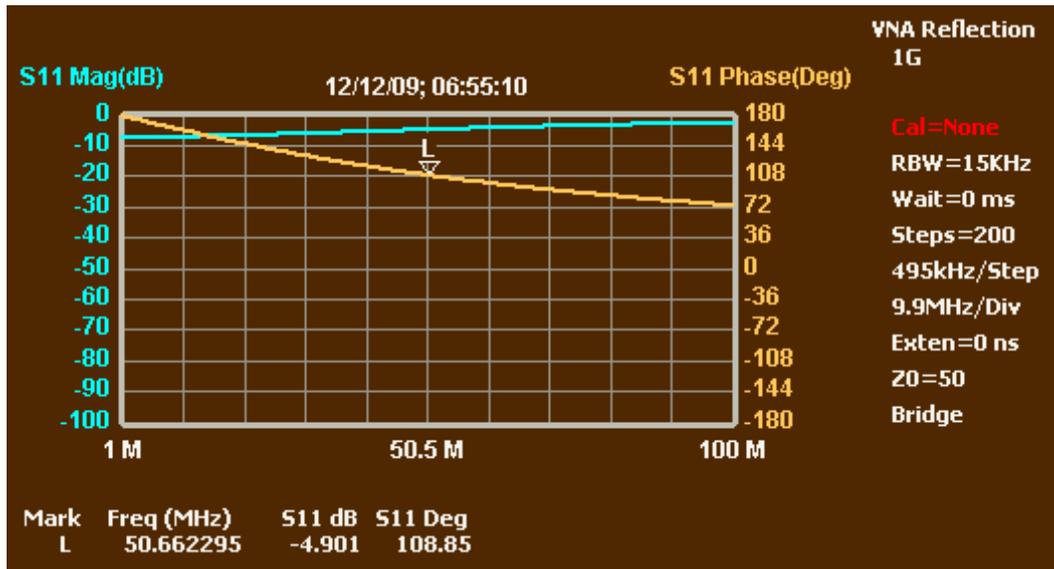
As the frequency increases, the RL combination looks more and more like a pure inductor with high impedance, so S_{11} magnitude heads toward 0 dB (reflection coefficient of 1) and the phase heads toward zero. The trajectory is more interesting to view on the Smith Chart:
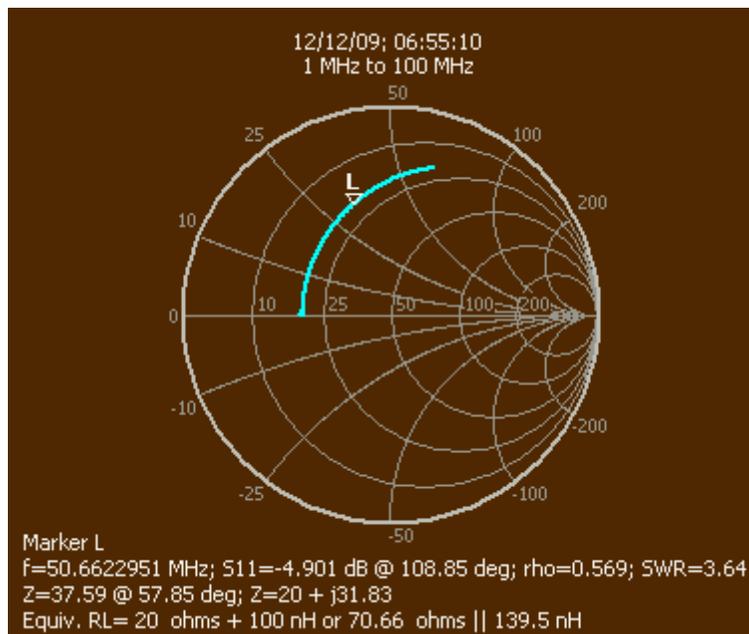
2. Notice that at the bottom of the Smith chart all sorts of information is displayed for the L marker frequency. In the bottom line, the equivalent circuit is stated, first as series and then as parallel. The series values exactly match the values specified for the simulation.

3. Double-click in the area of the numeric labels of the left axis. The Y-axis window will open. For Graph Data, select Series Inductance, and click auto-scale. Close the window. Do the same for the right axis, but select Series Resistance for Graph Data. The graph will look something like this (the marker was cleared for this image):
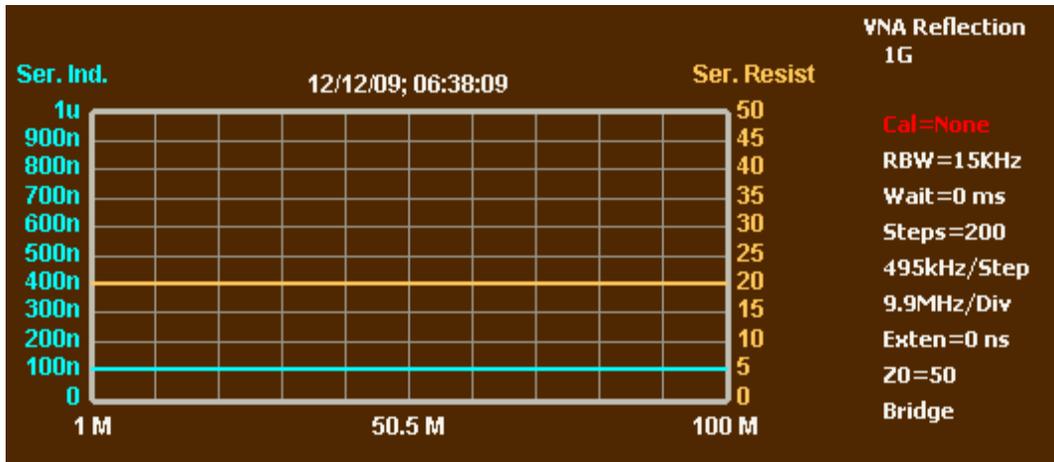
4. **This graph is fairly dull because the component values are absolutely fixed. Open the sweep parameters window and click OK, to open the window for specifying the simulated components. Deselect the resistance, and change the inductor Q value to 10. Click OK to close the window, then click Restart and Halt At End. The graph will look something like this:**
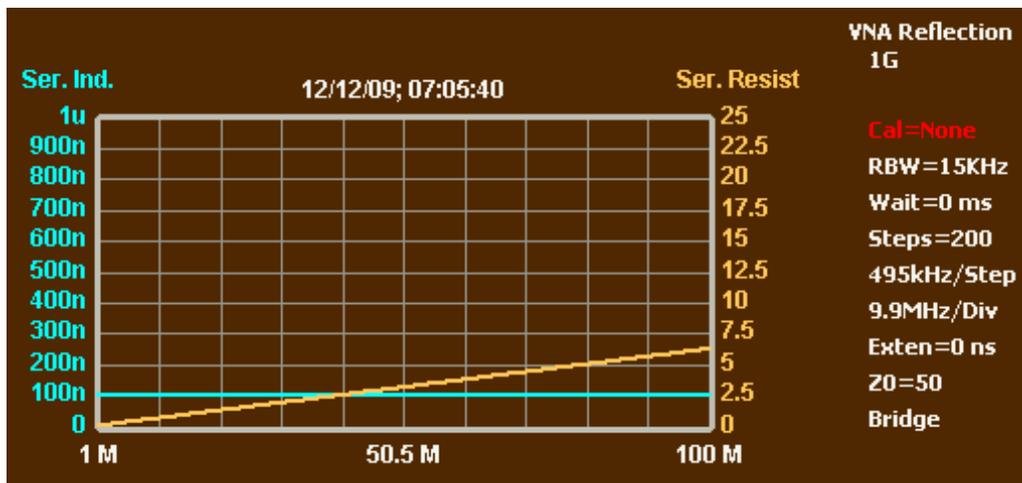
5. **The inductance is still flat at 100 nH, but the resistance now increases with frequency. Double-click on the inductance axis to open the Y-axis window and select Series Reactance for Graph Data. If the L marker is not present, place it somewhere on the graph. The graph will look something like this:**
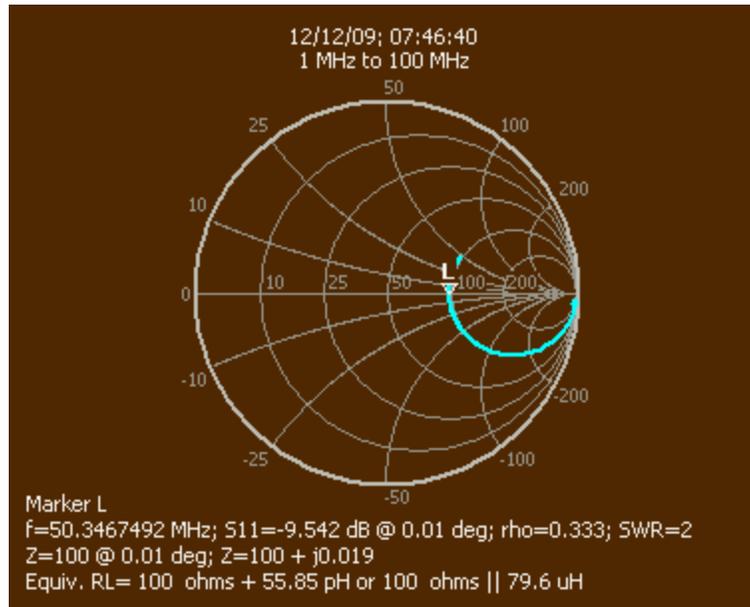
The chart shows:

VNA Reflection
1G

Ser. React.   12/12/09; 07:05:40   Ser. Resist

Cal=None
RBW=15KHz
Wait=0 ms
Steps=200
495kHz/Step
9.9MHz/Div
Exten=0 ns
Z0=50
Bridge

Mark	Freq (MHz)	Xs	Rs
L	57.803279	36.32	3.632
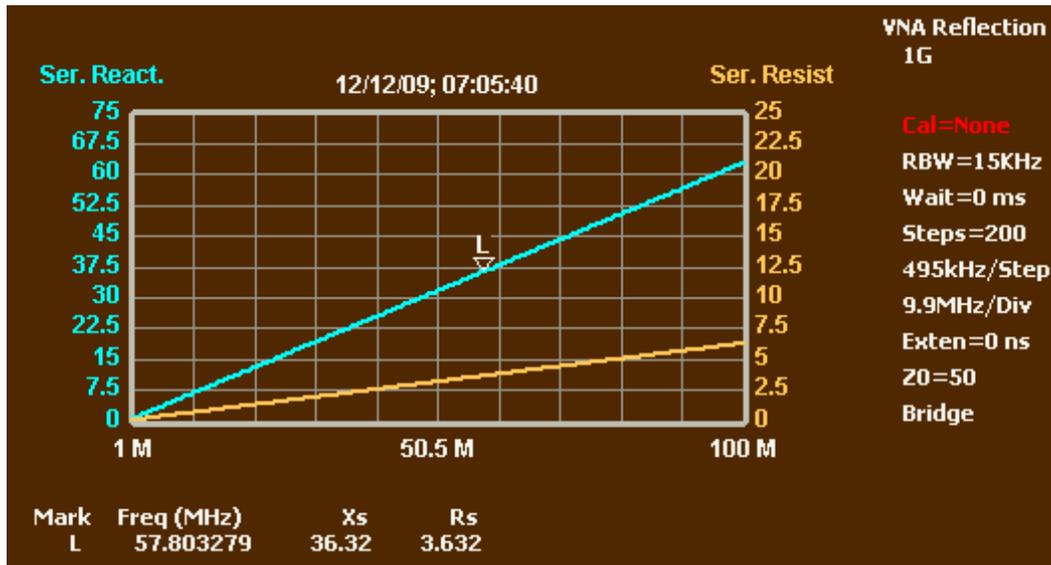
6. The information for marker L shows that the resistance is one-tenth the reactance, which is what it means to specify that the inductor Q equals 10.

7. There are other graphs to choose from. The last graph above shows the components of impedance. You can also choose to graph impedance magnitude and angle. You can graph parallel inductance and resistance, which will accurately show the equivalent parallel circuit at each frequency. However, modeling a series combination as a parallel combination is generally not useful. We started out by graphing S_{11} magnitude and angle, with the magnitude in dB, but we could instead graph the magnitude as a ratio, which is the reflection coefficient magnitude. The reflection coefficient magnitude, not expressed in dB, is often referred to as rho, and its angle as theta, and they are listed under those names. Theta is actually the same as the S_{11} angle, but it is listed as a separate graph for convenience.

RLC Analysis

1. If you did not get here by performing all the steps above, go back and perform the first three steps under Basic Operation. Otherwise, just select menu Mode→VNA Reflection. This will recreate the windows and reset the graph types to S_{11} magnitude and phase. Click Halt.

2. Open the Sweep Parameters window and click OK. In the window that opens, select Series, Resistance, Inductance and Capacitance. Enter 100 for resistance, 100n for inductance and 100p for capacitance. Be sure the Q values are large (e.g. 10000). For Transmission Line Connection, select None. Click OK to close the window. Click Restart and then Halt At End. The regular graph will show the phase crossing zero near 50 MHz, which identifies the point of resonance. Place a marker at that zero-crossing point. The Smith chart will show a trajectory that follows the circle representing resistance of 100 ohms, with the L marker at the point

where the curve crosses the horizontal center line (representing pure resistance):

12/12/09; 07:46:40
1 MHz to 100 MHz

Marker L
f=50.3467492 MHz; S11=-9.542 dB @ 0.01 deg; rho=0.333; SWR=2
Z=100 @ 0.01 deg; Z=100 + j0.019
Equiv. RL= 100 ohms + 55.85 pH or 100 ohms || 79.6 uH

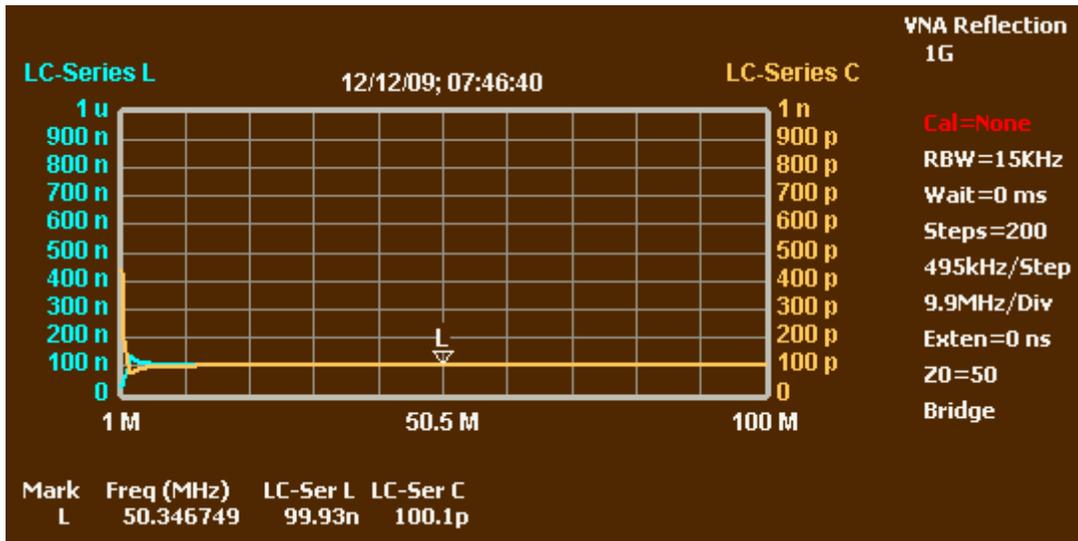3. **Select menu Functions→RLC Analysis. In the window that opens, select the box to indicate that the components are in series, and click Analyze. The window will display the following:**

F=50.5 MHz; R=100 ohms; L=99.91 nH; C=100.1 pF; Qu= 0.317

-Freq   +Freq

4. **The displayed values are close to the simulated values, but don't match exactly because they are based in part on the resonant frequency, which can only be determined exactly with an infinite-precision scan. The values are displayed for the sweep step closest to the resonant frequency. RLC analysis in Reflection mode does not actually require that the scan include the resonant frequency, but makes use of that information if it is present.**

5. **Close the RLC Analysis window. The regular graph will have been changed to look like this:**

7

The following data appears on the instrument display:

LC-Series L	12/12/09; 07:46:40	LC-Series C	VNA Reflection 1G

LC-Series L axis: 1u, 900n, 800n, 700n, 600n, 500n, 400n, 300n, 200n, 100n, 0

LC-Series C axis: 1n, 900p, 800p, 700p, 600p, 500p, 400p, 300p, 200p, 100p, 0

X axis: 1 M, 50.5 M, 100 M

Right panel:
Cal=None
RBW=15KHz
Wait=0 ms
Steps=200
495kHz/Step
9.9MHz/Div
Exten=0 ns
Z0=50
Bridge

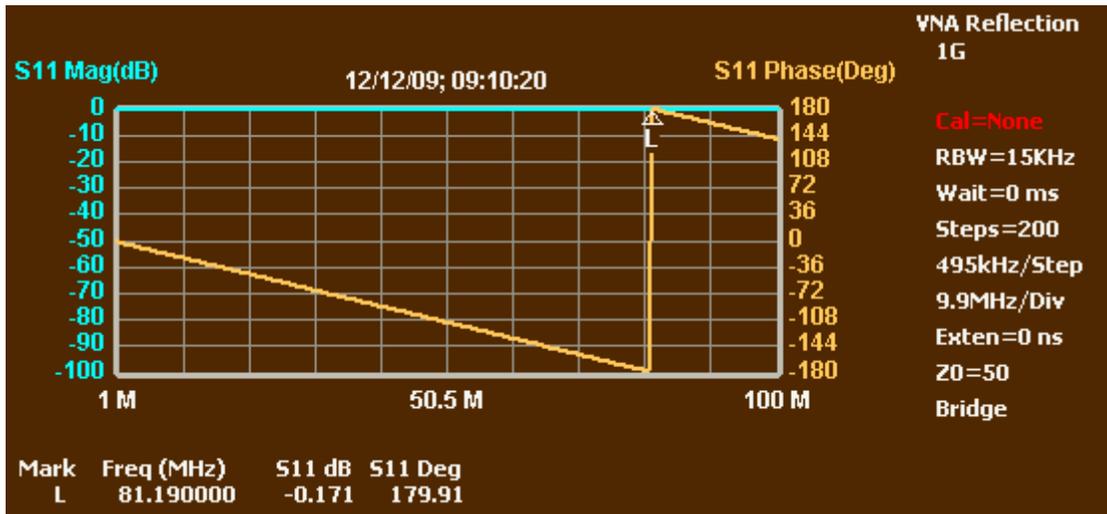| Mark	Freq (MHz)	LC-Ser L	LC-Ser C
L	50.346749	99.93n	100.1p

6. **The L marker has been placed at the resonant frequency. The graph data consists of LC-Series L and LC-Series C; here one is mostly on top of the other. These are the L and C values for the RLC model created in RLC analysis. This is the same as the data displayed within RLC Analysis, but simultaneously shows all frequencies. For various reasons, the graph can be distorted at the very ends.**

7. **The graphs of LC-Series L and LC-Series C are specially created by RLC Analysis, and are listed among the graph choices in the Y-axis window. They will survive until a Restart. They differ from the normal series or parallel L and C graphs. The latter represent the net inductance of the components, and cannot separate a reactance into L and C components.**

8. **Double-click on the LC-Series L axis labels to open the Y-axis window. Select Series Capacitance as the Graph Data. In doing so, notice that at the bottom of the list, which normally ends with "None", three graphs have been added by RLC Analysis. Be sure auto-scale is not selected, and set the graph range from -10 nF to 10 nF. Close the Y-axis window. Place a marker somewhere left of resonance and another somewhere right of resonance. The graph will look like this:**
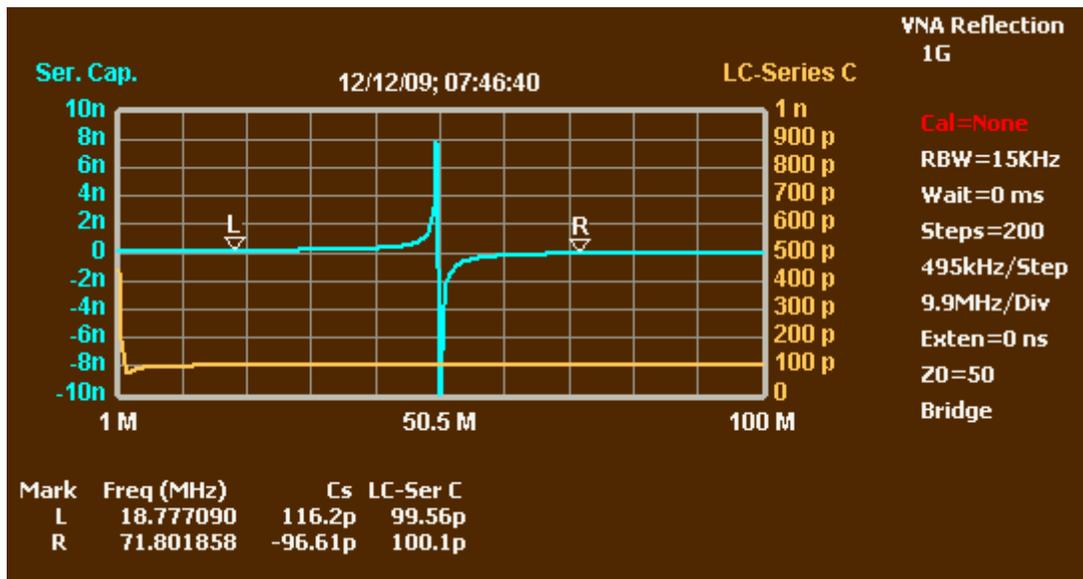
9. This graph illustrates the difference between LC-Series C and Series Capacitance. Series capacitance is the capacitance value that would produce the net LC reactance at any frequency. Below resonance (L marker) it is a positive value that rises as it approaches resonance, because the net series LC impedance is declining. As it passes resonance it switches from a large positive value to a large negative value. A capacitor value of –C actually represents an inductance that would produce a reactance equal to the negative of the reactance produced by capacitance C. This means a large negative capacitance represents a small inductor value. So at resonance the series LC combination switches from acting like a large capacitor to acting like a small inductor. As the frequency increases, the combination will gradually be dominated by the 100 nH inductor, as though the capacitor were not even there. LC-Series C, however, accurately identifies the actual capacitor value at all frequencies, and remains level near 100 pF.

Coax Parameters

1. If you did not get here by performing all the steps above, go back and perform the first three steps under Basic Operation. Otherwise, just select menu Mode→VNA Reflection. This will recreate the windows and reset the graph types to S11 magnitude and phase. Click Halt.

2. Open the Sweep Parameters window and click OK to open the simulation data window. Deselect Resistance, Inductance and Capacitance. Select RG-58C as the Transmission Line Connection, and enter a length of 2. The MSA will now simulate two feet of unterminated RG-58C. Click OK to close the window. Click Restart and Halt At End. The graph will look like this:

The image displays a VNA Reflection plot with the following details:

- **S11 Mag(dB)** axis on left: 0, -10, -20, -30, -40, -50, -60, -70, -80, -90, -100
- Date/time: 12/12/09; 09:10:20
- **S11 Phase(Deg)** axis on right: 180, 144, 108, 72, 36, 0, -36, -72, -108, -144, -180
- X-axis: 1 M, 50.5 M, 100 M

Right side panel:
- VNA Reflection 1G
- Cal=None
- RBW=15KHz
- Wait=0 ms
- Steps=200
- 495kHz/Step
- 9.9MHz/Div
- Exten=0 ns
- Z0=50
- Bridge

Mark	Freq (MHz)	S11 dB	S11 Deg
L	81.190000	-0.171	179.91

3. **Place the L marker as shown, where the phase is close to +/- 180 degrees. This is the point of quarter-wavelength resonance of the open coax stub. The marker will also appear on the Smith chart at the left end of the horizontal center line, indicating a pure resistance near zero ohms, so the open coax is looking like a direct short.**

4. **Select menu Functions→Coax Parameters. In the window that opens, enter a length of 2 feet. Click Analyze. Then click Analyze Z0. Enter 1G as the value of the termination resistor. (Normally, you might at this point terminated the coax with 50 ohms and enter that value. But with simulated data you can't do that.) Close the window in which you entered the termination value. The display will look like this:**

☑ Length   [2]   ☑ feet ☐ meters
☐ Velocity Factor (0-1)

F= 81.149501 MHz; Len= 2.000 ft; VF=0.660; A0= 4.27

Z0 Real= 50.1; Z0 Imag= 0.0

5. **F is the resonant frequency. Len is the length you entered. VF is the velocity factor. A0 is the cable loss in dB per hundred feet. Both the real and imaginary parts of Z0 (characteristic impedance) are shown. The real part came out close to 50 ohms. Had we been able to use a termination resistor in the 25-100 ohm range, the Z0 calculation would have been more accurate, and a small imaginary component would likely have been shown.**

6. **Click Done. Open the Sweep Parameters window and click OK. In the window that opens, select Resistance and enter 50 ohms. Change the coax length to 50,000. This will simulate an extremely long coax terminated in 50 ohms. Click OK to close the window.**

7. **Click Restart and Halt At End. When the sweep stops, open the Y-axis window for the left axis and change the Graph Data to Series Resistance. Deselect Autoscale and close the window. Open the Y-axis window for the right axis and change the Graph Data to Series Reactance. Deselect Autoscale and enter Top Ref=0 and Bot Ref=-5. Close the window. The graph will look like this:**
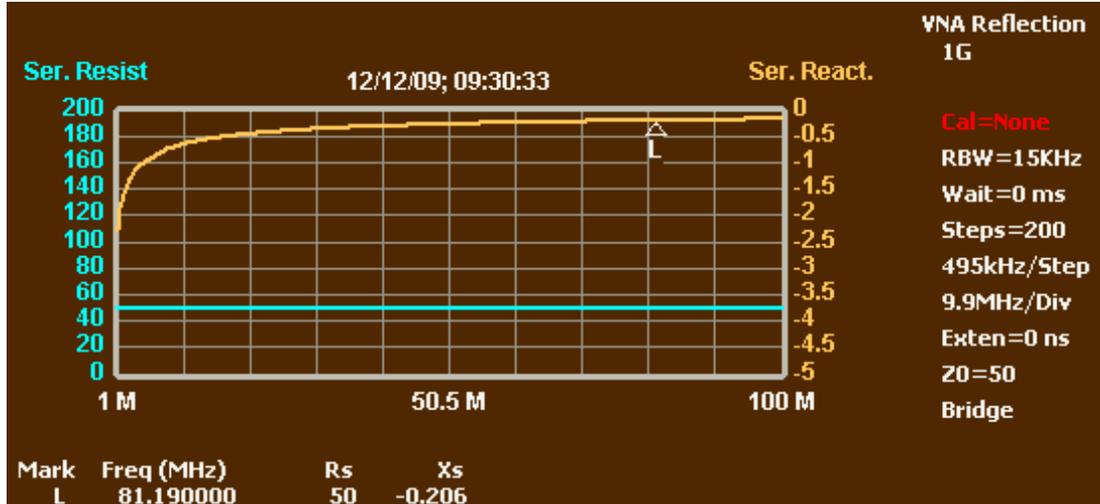
8. **Place the L marker near 81.1 MHz, the frequency at which Z0 was determined above. The input impedance of an extremely long coax cable is very close to its Z0, especially if it is terminated with a value even remotely close to Z0. So the actual Z0 of this coax at 81.1 MHz is 50–j*0.2. The imaginary part is created by the cable losses and is typically ignored. However, the graph shows that at very low frequencies the imaginary part becomes significant. It can't be seen on this graph, but at low frequencies the real part actually increases slightly. (There are many flavors of RG-58, and there is no guarantee that any particular product labeled RG-58C will exactly match the simulated coax.)**