

Interpolation with Markers in the MSA

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In the MSA, graph markers can be placed by double-clicking on the graph, which places the marker at indicated selected frequency on the nearest trace. A marker can also be placed by using MouseOver—holding down the left mouse button while moving the mouse to the desired location, and then pressing the key for the desired marker. It is possible that the pixel at which the double-click or key press occurred does not correspond to the frequency of an actual data point, but rather lies between two adjacent points.

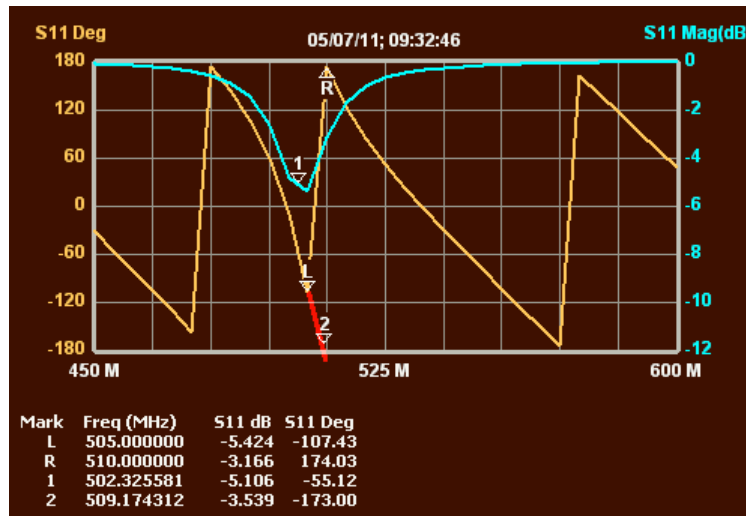
In Spectrum Analyzer modes, the location will be rounded to the nearest whole step. This is done because a spectrum may consist of many discrete signals, with nothing between them, and it may not make sense to try to examine a location between two data points.

In VNA modes, however, such rounding does not occur. Data for the in-between point is interpolated from the neighboring actual data points. The rationale is that the response does not typically “disappear” between data points in VNA modes, and the in-between response generally has some relationship to the response at the neighboring points. This is useful if, for example, you want to locate the point where the phase crosses zero or 180 degrees, but there is no actual data point whose phase equals the target value. Of course, such interpolation is not perfect, but is generally a good approximation.

There are a couple of possibly confusing aspects involving this interpolation, which we discuss here. Note that, if desired, it is possible to avoid interpolated markers by placing the marker and then adjusting it with the “+” or “-” buttons, which will move the marker to integral step numbers.

Phase Wrap-Around and Interpolation

Figure 1 shows a simulated scan of a parallel LC circuit located at the end of a coax cable (the coax was added to make phase change faster).



**Figure 1—Parallel Resonant Circuit
(Red line was added with Photoshop.)**

For the moment, ignore the blue line (magnitude). Phase (orange) declines toward minus 180 degrees. When it passes that level it wraps around to the top. For example, -186 degrees would be graphed as 174 degrees. This repeated wrap-around creates the sawtooth effect that is common in phase graphs.

Markers L and R mark two adjacent points where such a wrap-around takes place. In the graphing process, the adjacent points are connected by a line, but the orange line from L to R is very misleading. It suggests that phase between those points crosses zero degrees. In reality, the path taken from L to R follows the red line; the phase declines slightly past minus 180 degrees to about -186 degrees, which is equivalent to 174 degrees.

Marker 2 shows such a frequency between L and R. If we hadn't drawn the red line, marker 2 would appear to float in mid-air. We might have expected that marker 2 would touch the orange line somewhere between L and R, but as noted above that line is completely bogus. Proper interpolation follows the red line from L to R, and the MSA software is smart enough to locate marker 2 that way.

The same issue arises when using *MouseOver*, whose markers would also follow the path of the red line. Note that the ideal way to draw the graph would be to have the orange line follow the red line to the bottom of the graph, and then resume at the top of the graph and continue on to R, with no line connecting the bottom and top of the graph. However, most people are used to seeing these graphs drawn as shown in orange in Figure 1. The

Appendix shows another way around this issue, by using a graph range far greater than 360 degrees.

If the “floating” marker is visually confusing, one solution is to place it on the blue magnitude line. The phase value will still be properly interpolated, but the marker will look less strange.

Smith Chart Interpolation

The foregoing describes the first possibly confusing aspect of interpolation between adjacent points. A similar but possibly more confusing issue arises with the Smith chart. Figure 2 shows the Smith chart corresponding to Figure 1.

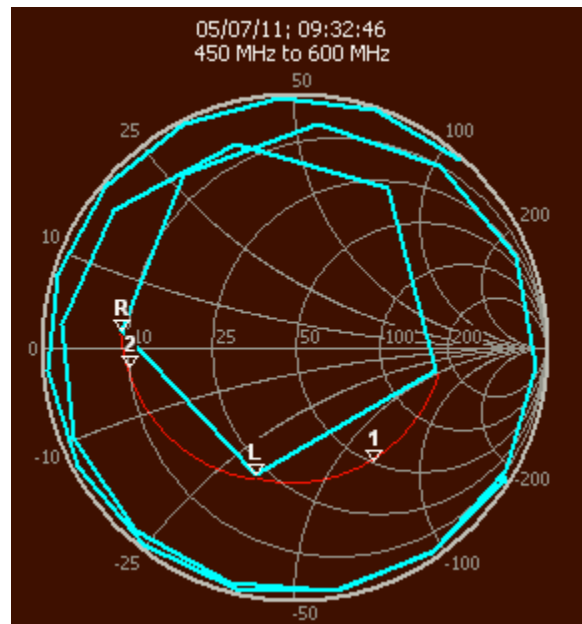


Figure 2—Smith Chart for Scan of Figure 1

The Smith chart of Figure 2 contains a lot of circular action. This is caused by the repeated wrap-around of phase shown in Figure 1. In this case, though, the transition from near -180 to near +180 is made smoothly by clockwise crossing of the left half of the horizontal axis. So we don't have discontinuities at the wrap-around points.

The centermost “circle”, on which R and L are located, is the typical resonance loop, which moves rapidly clockwise as the frequency increases. It has flattened sides because the number of steps is relatively low so large changes occur between steps. We did this to illustrate a point, but it is also common in real scans for the transition through resonance to be fast enough that the resonance loop is noticeably “piecewise linear”, even if the remainder of the graph is smooth.

All these markers are at the same locations as they were in Figure 1. Note that L and R are adjacent points, connected by a blue line. Markers 1 and 2 float outside the resonance

loop, without touching it. They are approximately located on the red arc. If we had a higher resolution scan, we would expect the graph to approximately follow that red line. Not only does this placement of markers 1 and 2 more accurately reflect reality than if they were placed on the blue graph, but it also corresponds to their S_{11} values on the main graph.

This approach to interpolation does not always work well. See Figure 3.

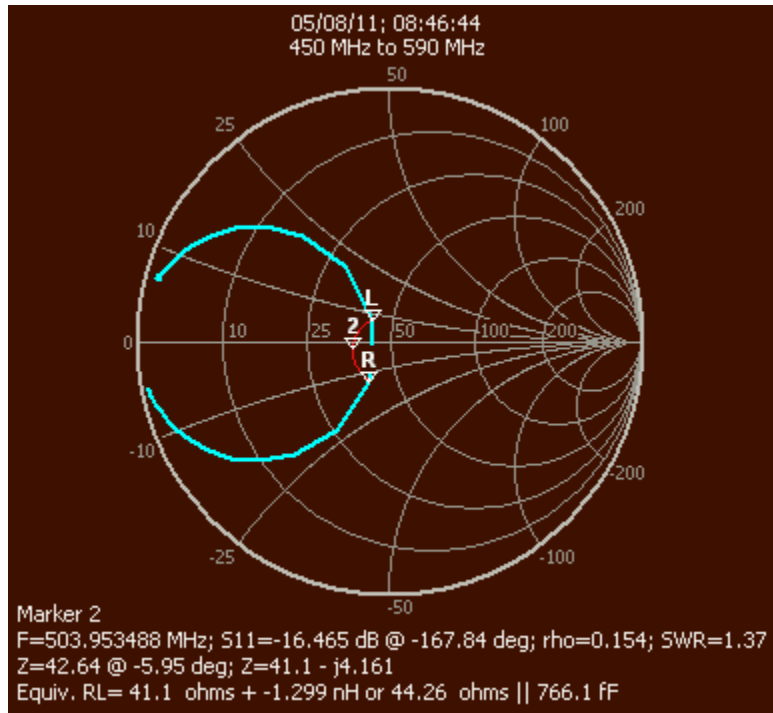


Figure 3—Interpolation Gone Awry

L and R are adjacent scan points. Marker 2 is between them.

In Figure 3, the arc on which interpolation is done goes the wrong way. A natural projection of the resonant loop would have put marker 2 very near 50 ohms. Note that the reflection coefficient (distance from center) for L and R are approximately the same, and the interpolation ends up with a similar value at marker 2. (The red arc is approximately a constant-rho arc.) This is exactly the way interpolation of S_{11} would be done on the regular graph—if two adjacent points had $|S_{11}|$ values of -16 dB, points in-between would be graphed with that same value.

Figure 3 illustrates nearly the worst-case scenario, involving large point-to-point changes near the center of the Smith chart. Note that this is the area where S_{11} reaches a minimum, and would correspond on the regular graph to the bottom of an S_{11} dip. Everyone is already familiar with the fact that if you want to accurately locate the bottom of a notch, you need to use enough scan points to get high resolution of that area. So this Smith chart interpolation glitch is just another manifestation of the need for high resolution at notches.

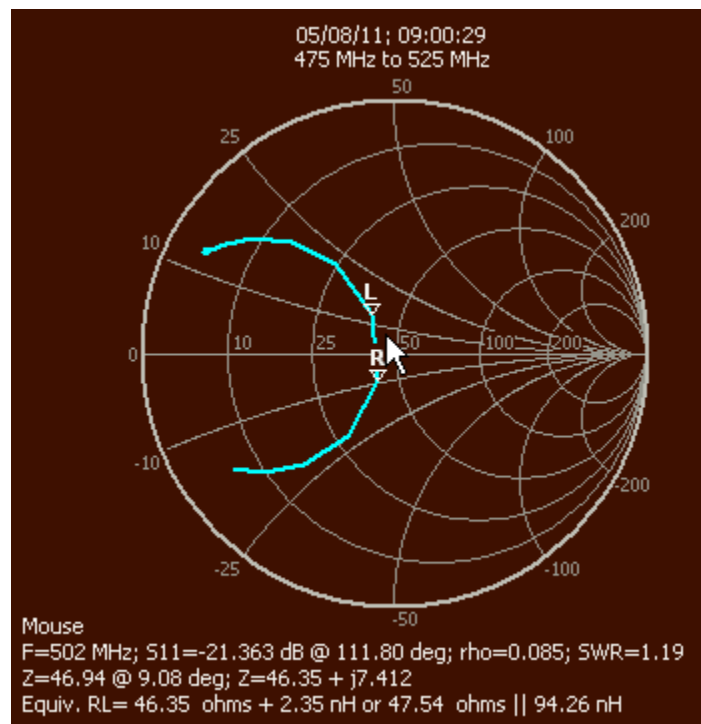
There is no perfect way to do interpolation. We could simply interpolate along the line connecting L and R on the Smith chart. However, that would give different results from what we get on the main graph, which creates confusion. Even when the difference is small, it is disconcerting to have a marker on one graph show a value of -30 dB and the same marker on another graph show -30.05 dB. With a reasonable number of scan points (we used no more than 30 points for the above graphs), these interpolation glitches are normally not significant, and of course they never exist if markers are placed at whole step numbers (i.e. actual data points).

(Prior to MSA version 116-4k, Smith chart interpolation would have placed all markers on the blue graph line. This avoided floating markers, but did not locate the markers in a position that corresponded to their S_{11} values, as shown in the main graph or at the bottom of the Smith Chart.)

There is an additional issue involving Smith chart interpolation, that also arises from trying to produce the same values as the regular graph would display. Below the chart are shown S_{11} and various related values, such as impedance. Each of those is separately interpolated from the neighboring data points. Because the relationship between S_{11} and impedance is not linear, there is a difference between interpolating S_{11} and then calculating impedance from the result, and calculating impedance at neighboring points and then interpolating. This means that for markers not located at actual data points, the values at the bottom of the chart are not entirely consistent: if you calculated impedance from the displayed S_{11} value, you might get a different value than is actually displayed for impedance. But the displayed values will match what you would see on the regular graphs of S_{11} and impedance, which was deemed to be a higher priority.

Doing Your Own Interpolation on the Smith Chart

There is a way to get reasonably accurate results even if your scan does not have enough points in the area of interest. Figure 4 shows the same graph as Figure 3, with the MouseOver cursor shown.



**Figure 4—Similar to Figure 3, using MouseOver instead of Marker 2
(The screen-capture program Greenshot was used to capture
the mouse cursor along with the graph.)**

In Figure 4, a bit of human intelligence was used to estimate a point through which the resonance loop would pass. With the left mouse button down, the mouse was moved to that location, shown by the cursor arrow. The data for that point is displayed at the bottom of the graph. Note that there is no particular frequency associated with any point on the Smith chart, so to get frequency-dependent data (frequency itself and the final line of the listed data) it is necessary to specify a frequency, which is done through menu Options→Mouse Frequency. By this method, it is sometimes possible to much more accurate information than is obtained by placing a marker between data points.

In this case, unlike interpolation with markers, S_{11} is determined at the indicated points and all other values are calculated from that S_{11} . This means that all the displayed values are perfectly consistent with one another.

(One might think that the software could automatically estimate the desired frequency from the nearest graph point to the mouse location. In Figure 4 that is true, but in general, due to the tendency of Smith chart graphs to cross themselves, it is difficult to automatically determine what frequency the user is interested in. Therefore, the frequency must be entered manually when using MouseOver on the Smith chart. But you need not enter frequency if all you are interested in is non-frequency-dependent data, such as S_{11} and impedance.)

APPENDIX—ANOTHER SOLUTION TO PHASE WRAP-AROUND

The sawtooth graphs typically produced for phase are choppy and make it appear that there is a lot of phase action going on, when all that is happening is a gradual decrease in phase value. One solution is to specify a broader range for phase values, as shown in Figure A1.

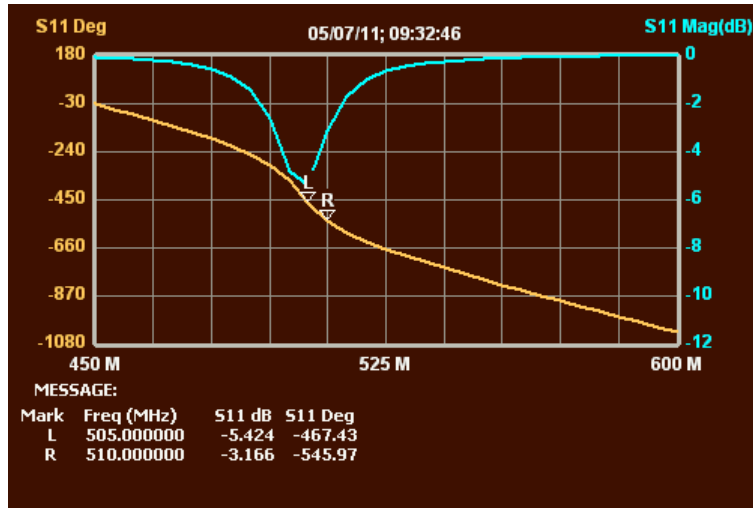


Figure A1—A Continuous Graph of Phase

Figure A1 shows the same data as Figure 1, but the phase range is extended down to minus 1080 degrees. This eliminates any wrap-around, and shows a smooth decline in phase, with a bit more rapid descent in the area of resonance. Markers L and R are at adjacent points; if we placed a marker between them it would be located on the orange line, with no chance of floating.

This type of graph is also useful to show the total cumulative phase delay. For example, while 1080 degrees and 360 degrees may be mathematically equivalent, there is a difference between a filter with 360 degree phase delay and one with 1080 degrees phase delay, as the latter is likely to be much more temperature sensitive. Whatever percentage phase delay is caused by a given temperature change will represent three times as many phase degrees in the filter with the larger phase change.