Measuring Impedance With Return Loss Bridge

Sam Wetterlin

11/29/08

In a separate document titled "Manual Return Loss Measurements", I describe how a return loss bridge (a/k/a reflection bridge) can provide a scalar measurement of return loss. The purpose of this document is to describe how such measurements can be used to get a respectable estimate of the impedance of a device.

When we try to convert the return loss measurement into impedance, we find that an infinite number of impedances can produce any given magnitude of return loss. In fact, the possible impedances form a circle on the impedance plane. Figure 1 shows the possible impedances that produce a return loss of 15 db.

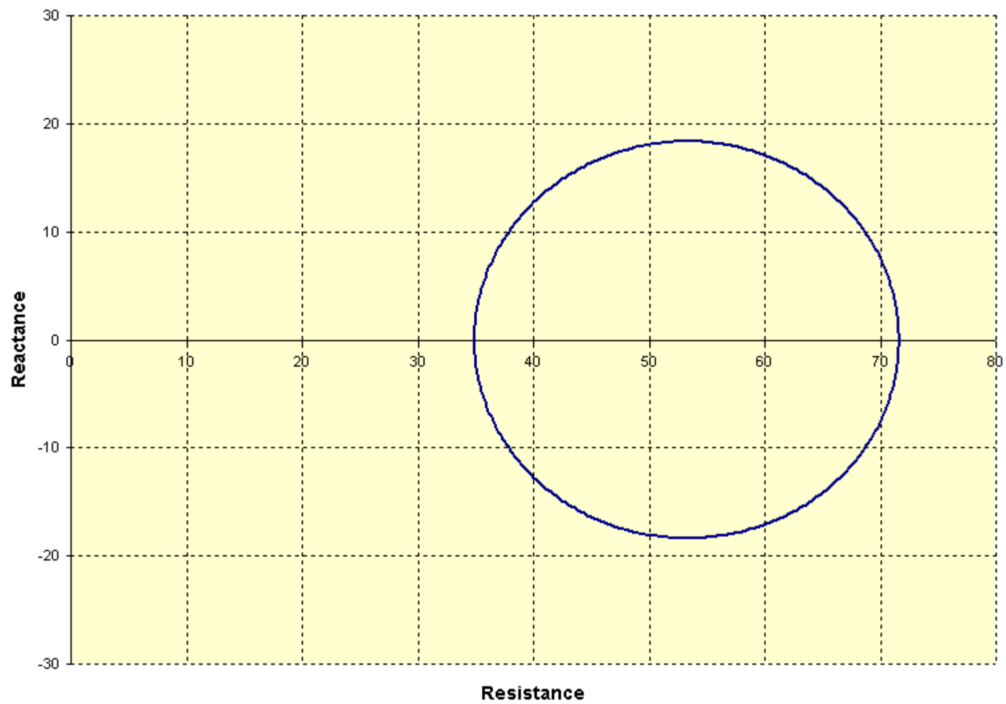


Figure 1—The circle of impedances that produce return loss of 15 db

Each such impedance would produce a different phase of reflection coefficient, but the phase is technically not a part of return loss, and in any event a straightforward measurement with a return loss bridge measures only the magnitude of a reflection, not its phase. Therefore, we have no basis on which to choose which of the many possible impedances is responsible for our measured return loss.

Suppose we take a second measurement after adding a series 5 ohm resistance to our device under test ("DUT"), and measure return loss of 14.5. Impedances which would create that return loss when put in series with a 5-ohm resistor are added to our graph as the orange circle in Figure 2.

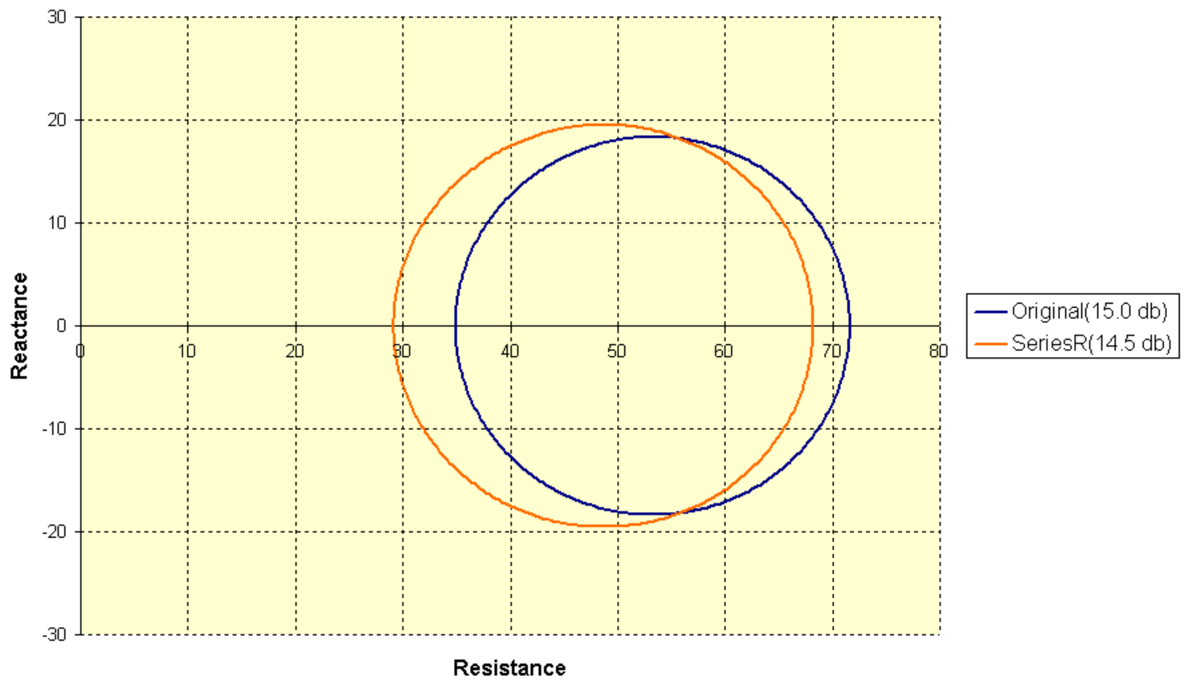


Figure 2—By taking a second measurement, we add a second circle to Figure 1. The device impedance must lie on both circles.

Our actual DUT impedance must lie on both circles in Figure 2, so it must be located at one of the two intersection points. Both those points have the same value of resistance, so we now know the DUT resistance. They also have the same magnitude of reactance, but one has positive reactance (inductive) and the other has negative reactance (capacitive).

If the reactance were small enough, we might decide to treat it as zero, in which case we have completely determined the DUT impedance with two measurements. Otherwise, we need one more measurement to determine the sign of the reactance. So we make a third measurement, using a series 0.01uf capacitor instead of the series resistor, and get return loss of 10 db. (Our measurements are at 1 MHz.) This gives us the third (green) circle in Figure 3.

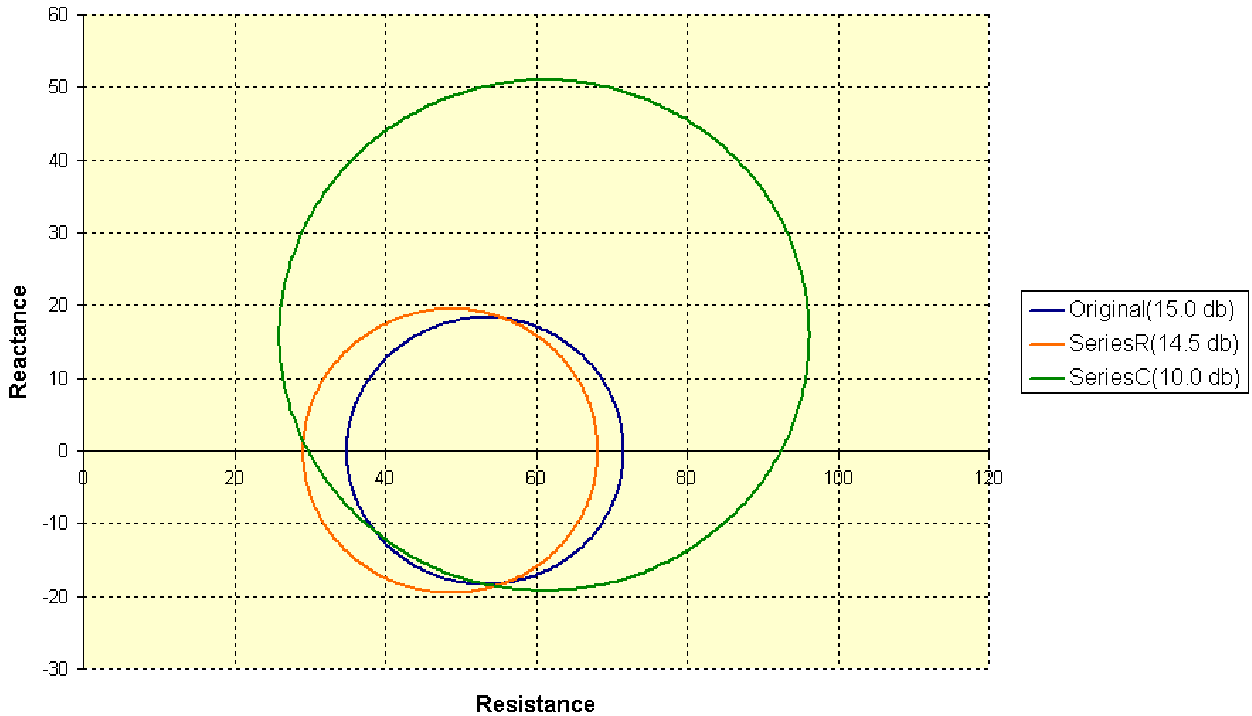


Figure 3—A third measurement with a series capacitor produces the green circle.

The DUT impedance must lie on all three circles, which means that, of the two possible impedances previously identified, it is the one with negative reactance. These graphs were all produced by entering the return loss measurements and the resistor and capacitor values into a spreadsheet, so the actual value of the intersection point can be identified by holding the mouse over that point. In this case, the impedance is 54-j18, which at 1 MHz corresponds to a 54 ohm resistor in series with an 8.8 nf capacitor.

We have therefore seen how scalar measurements can be used to determine impedance, which is a vector quantity. In actual practice, when we add series components to make the impedance shifts, we would like to get significant shifts in return loss, so that small errors in measuring return loss do not significantly affect our results. Our series 5 ohm resistor produced a shift in return loss of only 0.5 db, so a larger resistor would have been better. If the DUT impedance had been much smaller, 5 ohms would be a good value to use. If the DUT impedance is very large, a much larger resistor would be needed. Because we don't know the DUT impedance in advance, it may take a couple of trials to get the right resistor value. But if we have available resistors of 10, 49.9 and 150 ohms, we can handle a broad range of DUTs.

Similarly, the series capacitor should be selected to provide a significant shift in return loss. This is a little more complex because the capacitor impedance depends on frequency, so if we want to make measurements at widely separated frequencies we may have to change capacitors.

Note that if either the series resistor or series capacitor produces a significant return loss shift, the fact that the other does not do so becomes a bit less important. We just have to remember that if the three circles do not perfectly intersect at a single point, so we must triangulate between them, we should place the most faith in the circle with the most dramatic shift.

EXTREME IMPEDANCE VALUES

Impedances below 10 ohms or above 250 ohms present special challenges. We can use a slightly different approach for such impedances, but we should expect that our final determination of impedance will have more error when the DUT has such extreme values.

Large and small impedances have small return losses. If we can measure the return loss within a few tenths of a db, this does not present a major problem until the return loss becomes extremely small, such as below 1 db (e.g. resistances below 3 ohms or above 900 ohms). But if our bridge does not have an excellent open/short value (i.e, a few tenths of a db), but does have good directivity, we can improve accuracy by modifying the DUT to put the modified return loss above 20 db, where measurement accuracy will be good and even relatively large errors in return loss translate into small errors in impedance. The accuracy of measurement by this method will depend entirely on the directivity of the bridge, which should be at least 45 db.

For small impedances, the appropriate modification is to add a precision 49.9 ohm resistor to the DUT before doing all our measurements, and then subtract 49.9 ohms from our calculated impedance to get the actual DUT impedance. We can probably measure impedances as low as 1 ohm by this method, but for such small impedances we should probably assume an error of 0.5 ohms.

As an alternative, we could use a transformer to increase the DUT impedance, and then adjust our calculated impedance to account for the transformer ratio. It would be a good idea to test the transformer with known impedances to determine the frequency range in which the transformer makes a good transformation with minimal loss and without adding excessive parasitics.

Large impedances also have small return losses, and present problems similar to those of small impedances. In addition, when we add our series components to the DUT to make multiple measurements, we actually make the return loss smaller, so it may be difficult to cause the significant shift in return loss that we would like.

For large impedances, the appropriate way to modify the DUT is to add a parallel resistor. A 100 ohm parallel resistor will bring impedances of 250-1000 ohms into the range of 71-91 ohms, where measurement accuracy would be good. If the measured impedance is c +jd, and the parallel resistor is R, then the actual DUT impedance is a + jb, where

$$b = \frac{R^2 d}{(R - c)^2 + d^2}$$

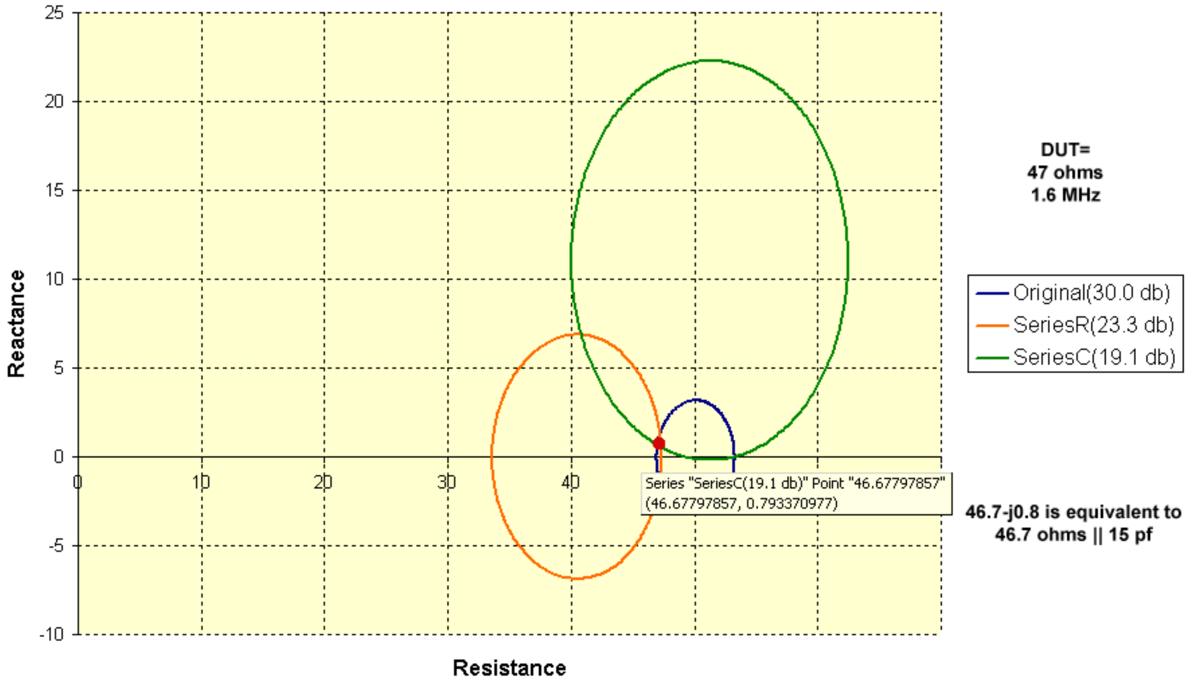
$$a = \frac{Rc - bd}{R - c}$$

This calculation can be done in the same spreadsheet used to graph the circles shown above. Of course, when you do the calculation to remove the effect of the parallel resistor, the result will be fairly sensitive to the measured impedance of the modified DUT, so any measurement error gets magnified, especially for the highest impedance DUTs. Still, there should be an overall increase in accuracy by this method.

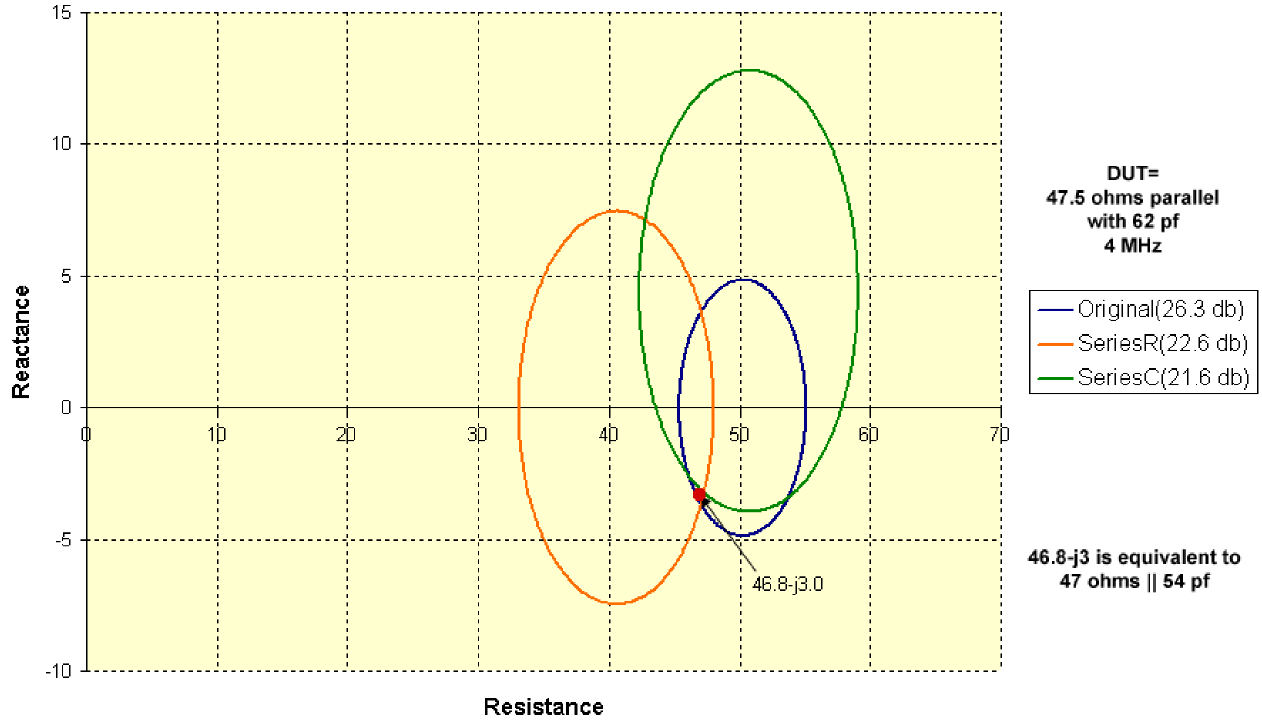
A transformer could also be used for large impedances, but this is complicated by the need for the transformer winding attached to the DUT to have much larger impedance than the DUT itself. This likely requires hand-wound transformers with a lot of windings, which may limit the frequency range in which the transformer will be satisfactory.

SOME ACTUAL TESTS

The following tests were conducted using a 10 ohm resistor for the resistive shift and a 9 nf capacitor for the capacitive shift, unless otherwise specified. After completing the tests, I realized that 1 nf would have been better, but 9 nf is what I already had mounted in a DC block, so I used that.

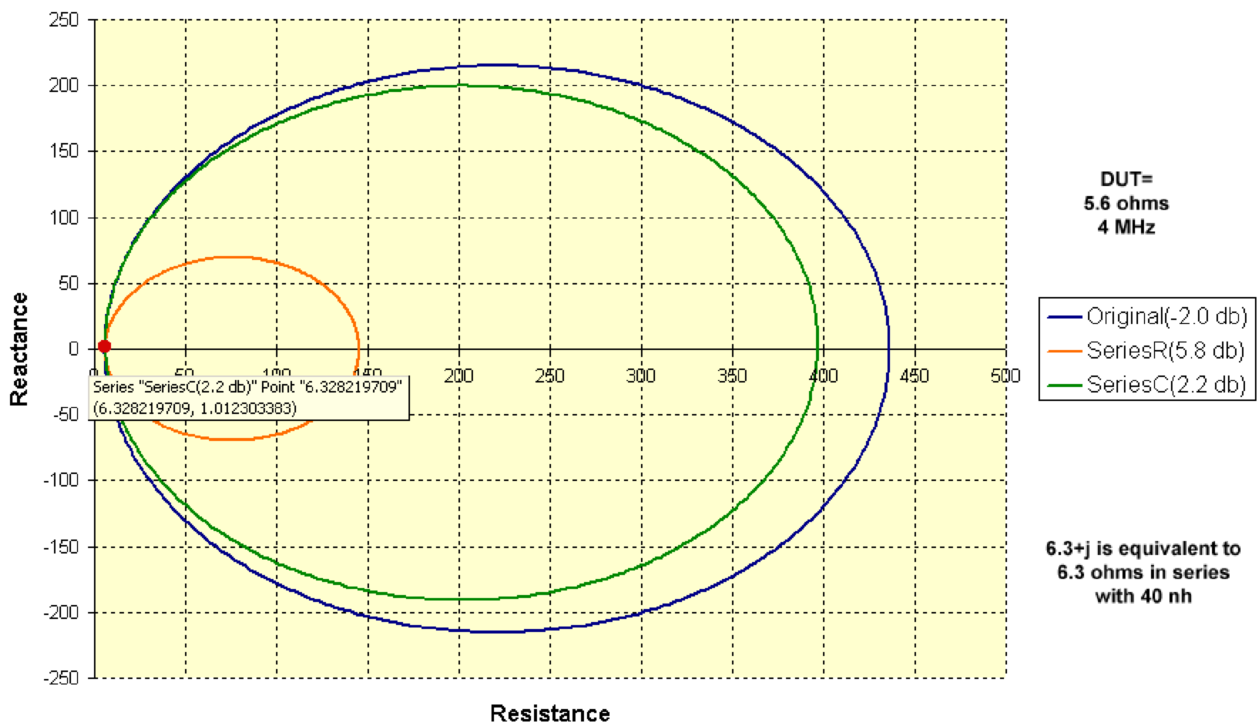


Test 1—47 ohm resistor at 1.6 MHz. Accuracy for impedances near 50 ohms is very good because we get dramatic shifts from circle to circle.

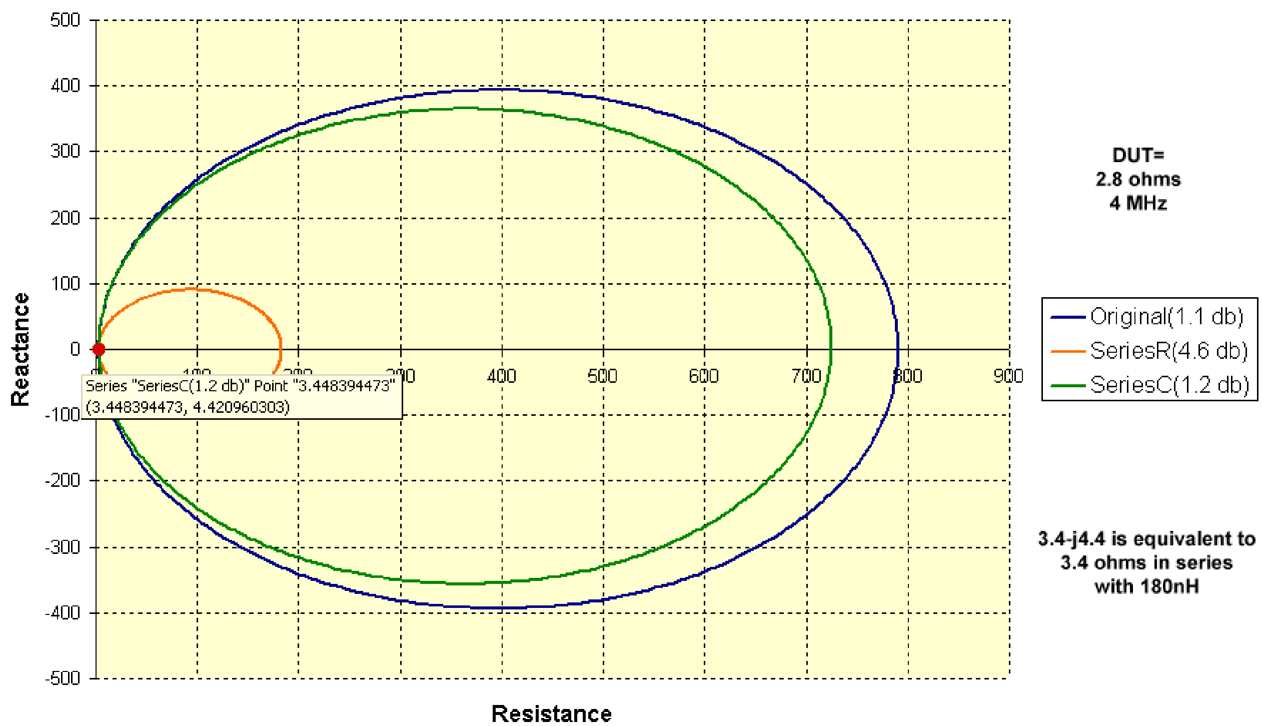


Test 2—47.5 ohm resistor parallel to 62 pf. Again the accuracy is very good.

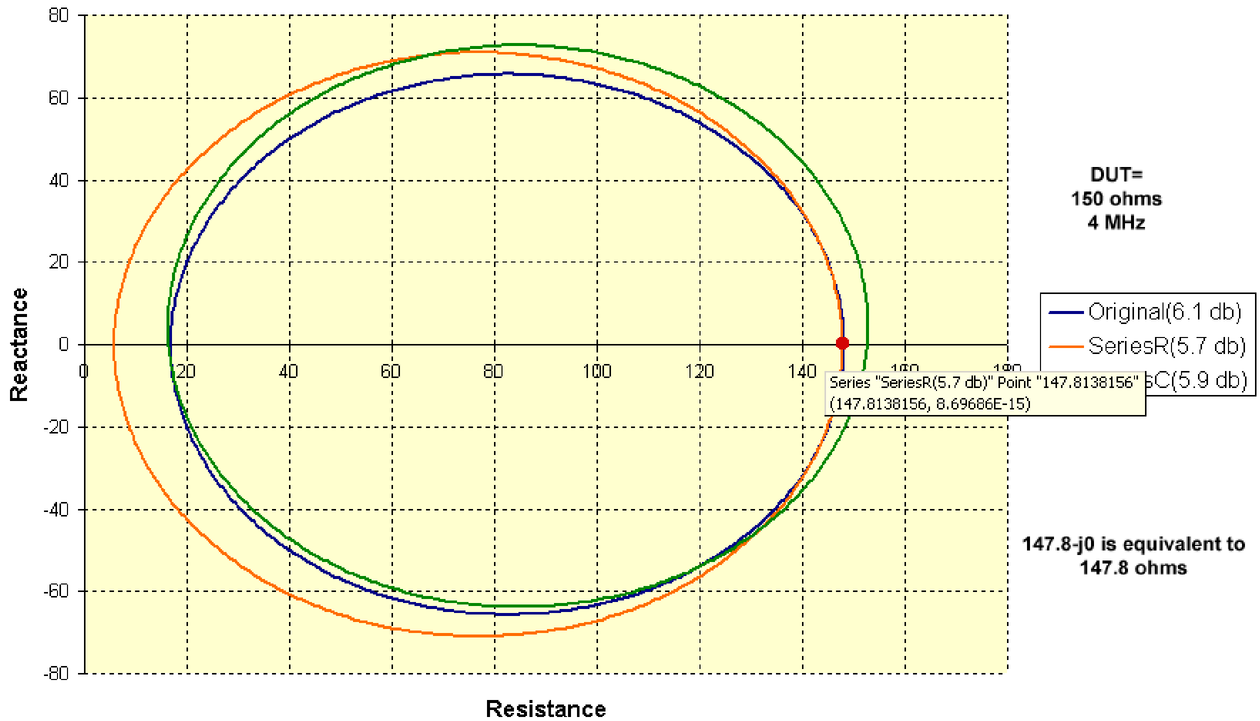
Test 3—25 ohm resistor. Due to measurement errors, the circles do not always touch in situations where they should be tangent. But making a guess at the intersection point still gives decent accuracy in this situation.



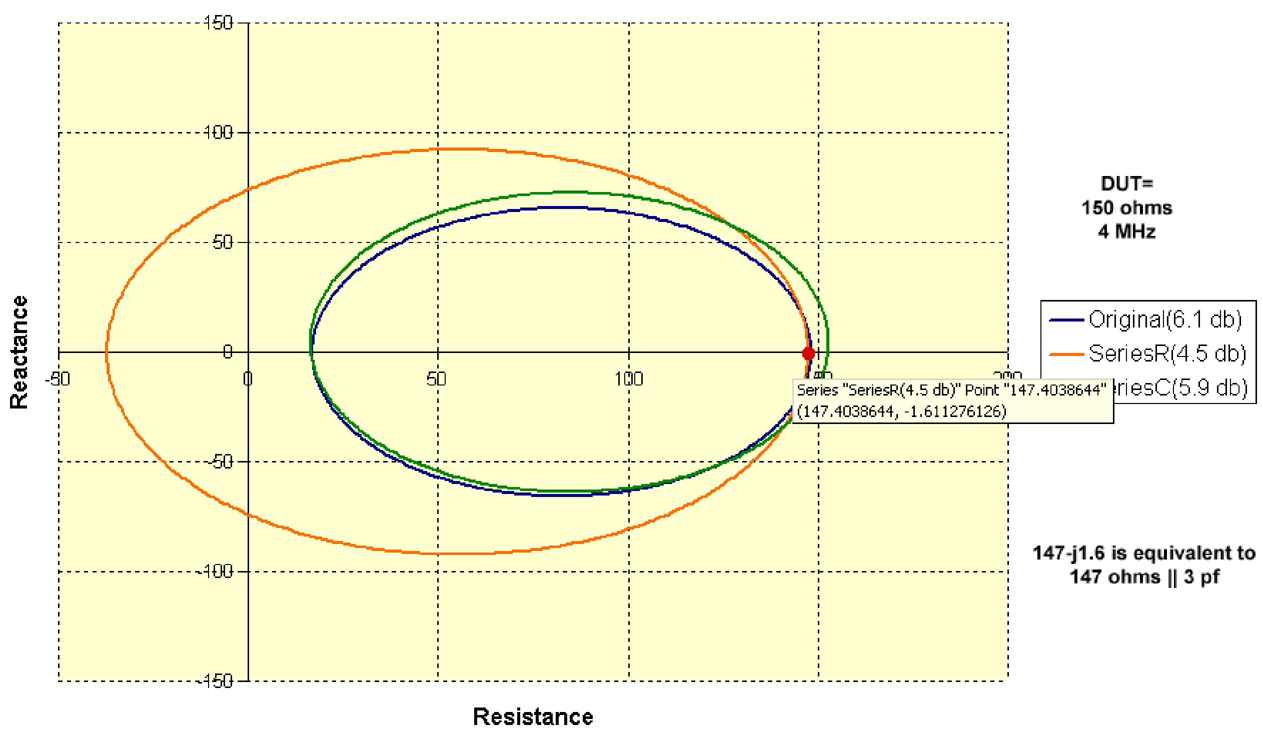
Test 4—5.6 Ohms. For a value so far from 50 ohms, this is still pretty decent accuracy. The resistance is measur



Test 5—2.8 ohms. We are now in the range where we can only get a ballpark estimate. A smaller capacitor value would cause a bigger shift in the green circle, which would help.



Test 6—150 ohms. The orange and blue intersect very close to 150 ohms, but the green and blue intersect far from there. We are not getting enough shift from circle to circle to be confident of the result.



Test 7—150 ohms repeated but using 49.9 ohms for the resistor shift. We would need a smaller capacitor value to get good shift in the green circle, but the blue and orange have a fairly unambiguous intersection, so we don't really need the green circle.