Test Results of Component Measurement with the MSA

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The Measure Components feature of the MSA (Transmission mode, menu Analysis→Measure Components) is intended for measuring values of resistors, capacitors and inductors. The MSA automatically chooses an appropriate frequency between 100 kHz and 40 MHz for the measurement. This is not as complete or precise as graphing the component value in Reflection mode, which can show the behavior of the component over frequency. But it is a quick and simple way to find the "nominal" value of the component.

The results shown here are based on crude test fixtures, using alligator clips. Better results are obtained with more compact fixtures with on-board attenuators to establish the 50-ohm source and load, and smaller connectors with less parasitic capacitance. But part of the objective of these tests is to show that nice results can be obtained with fairly crude test fixtures.

Component Measurement was first tested with a series test fixture consisting of a 5 dB attenuator, two SMA connectors soldered together, and then a 10 dB attenuator. The SMA connectors have alligator clips to attach the components, as shown in Figure 1.

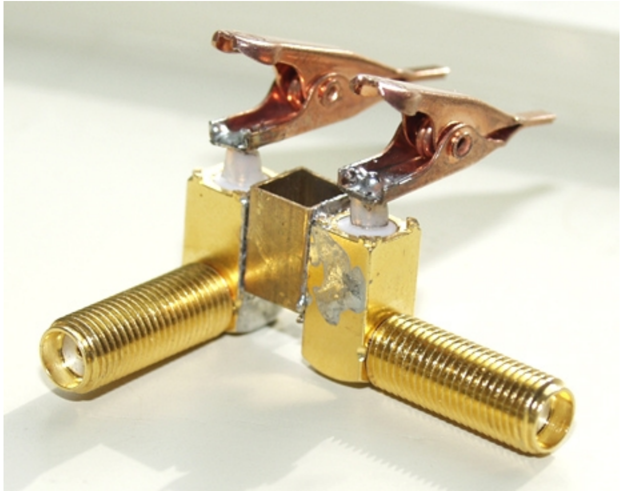


Figure 1—Series test fixture with alligator clips

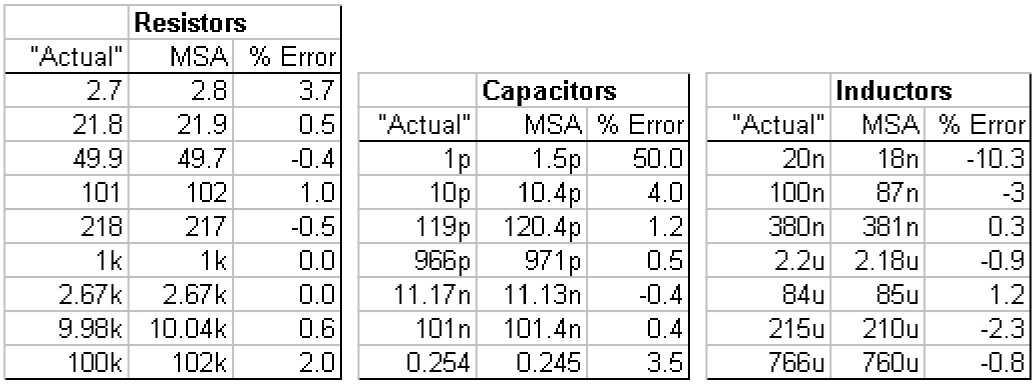
A brass strip was used as a short for calibration

The essence of the series fixture is that the test signal is run directly through the component and then on to the MSA. The transmission of the component is compared to the transmission of a short, and mathematically converted into impedance.

Note that it is the placement of attenuators near the component that allows this method of measurement to be accurate without much concern about the length of the cables connecting the fixture to the MSA. In standard RCL meters, capacitance or inductance of the leads is a big issue. Here, the effect of the connecting cables is calibrated out. The only thing that is important is that the component sees 50 ohms on each side. With good attenuators close to the component, the cabling is not critical as long as it is reasonably 50-ohmish.

From within the Measure Components window, the fixture is calibrated by attaching the short and clicking Calibrate. The type of component is then selected (R, C or L). When Measure is clicked, the MSA continuously scans and displays the component value. This fixture is not as precise as would be one with a more compact method of attaching the DUT, but it is easy to use.

Results of tests with various resistors, capacitors and inductors are shown in Figure 2.



	Resistors	
"Actual"	MSA	% Error
2.7	2.8	3.7
21.8	21.9	0.5
49.9	49.7	-0.4
101	102	1.0
218	217	-0.5
1k	1k	0.0
2.67k	2.67k	0.0
9.98k	10.04k	0.6
100k	102k	2.0

	Capacitors	
"Actual"	MSA	% Error
1p	1.5p	50.0
10p	10.4p	4.0
119p	120.4p	1.2
966p	971p	0.5
11.17n	11.13n	-0.4
101n	101.4n	0.4
0.254	0.245	3.5

	Inductors	
"Actual"	MSA	% Error
20n	18n	-10.3
100n	87n	-3
380n	381n	0.3
2.2u	2.18u	-0.9
84u	85u	1.2
215u	210u	-2.3
766u	760u	-0.8

Figure 2—Test Results

The “Actual” values in Figure 2 were determined by measurements believed to be accurate to 1% for capacitors (based on AADE meter) and resistors (based on ohmmeter); in a few cases the components were known to be more precise. Specifically, the 49.9 ohm resistor is accurate to 0.1%, and the 11.17 nF capacitor is accurate to 0.5%. The “actual” inductor values are based on the AADE meter, and must be taken with a grain of salt. Inductor values notoriously vary with the measurement frequency, especially if they have a core. Therefore, accuracy in measuring inductors is a little hard to gauge. However, there is no apparent reason why the MSA accuracy in measuring inductors would be any different than it is with capacitors.

The MSA values are the values displayed by the MSA, and the percentage error is the MSA reading minus Actual, divided by actual, and then multiplied by 100.

As can be seen, resistor measurement appears to be very accurate over a very broad range. The series fixture is known to decrease accuracy below about 10 ohms. For very low resistances, the shunt fixture is more accurate, and has measured a 0.25 ohm resistance within several percent.

Both capacitor and inductor measurement also have a broad range of accuracy. Their error increases at low values, probably because of the effects of parasitics. For example, with axial inductors, simply varying the point of attachment to the leads can alter inductance readings by several nH. There is significant capacitance between the alligator clips, which makes it more difficult for the MSA to sort out the effects of tiny capacitors or inductors. A different style of series connector, with header pins to attach the components, has provided better results.

Capacitance measurement became erratic at 1 uF. So 0.25 uF is the practical upper limit for capacitor measurements with this fixture. (A shunt fixture, which is better at measuring low impedances, successfully measured capacitors to 2 uF.)

I did not have a suitable inductor above 766 uH for testing. The winding capacitance of large inductors can be large enough that their self-resonant frequency falls near 100 kHz, the lowest frequency used in Component Measurement. One large inductor (well over 1 mH) actually measured at 100 kHz as having capacitance rather than inductance, meaning that 100 kHz is above its self-resonant frequency. As a practical matter, for RF work inductors above 1 mH have little relevance.

A Shunt Fixture

A shunt fixture was also tested. This fixture was similar to that in Figure 1, but the two connectors were directly soldered together without a spacer and one of the alligator clips spanned the two center pins of the connectors, providing a direct transmission path. The other was soldered as a ground to the body of one of the connectors. This fixture is shown in Figure 3.

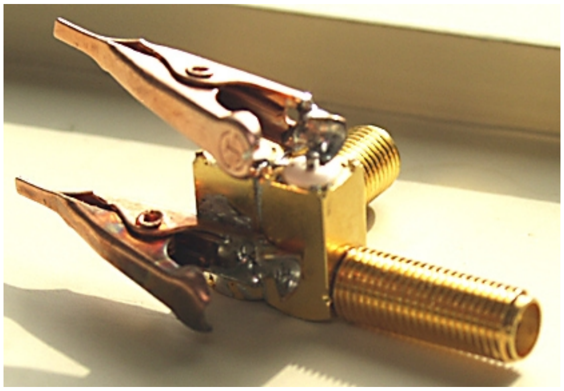
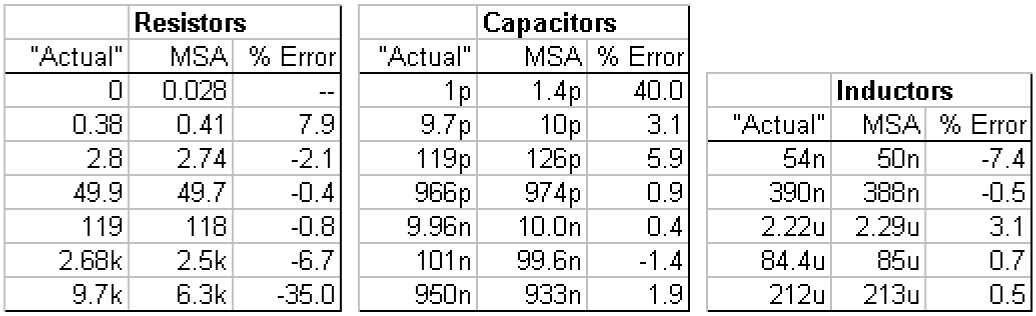


Figure 3—Shunt Fixture

The component is thus shunted to ground from the transmission path connecting the input and output. Calibration of the shunt fixture is especially easy, since it is done with an open circuit—i.e. nothing connected to the component terminals.

Figure 4 shows results of tests with this fixture.



Resistors "Actual"	Resistors MSA	Resistors % Error
0	0.028	--
0.38	0.41	7.9
2.8	2.74	-2.1
49.9	49.7	-0.4
119	118	-0.8
2.68k	2.5k	-6.7
9.7k	6.3k	-35.0

Capacitors "Actual"	Capacitors MSA	Capacitors % Error
1p	1.4p	40.0
9.7p	10p	3.1
119p	126p	5.9
966p	974p	0.9
9.96n	10.0n	0.4
101n	99.6n	-1.4
950n	933n	1.9

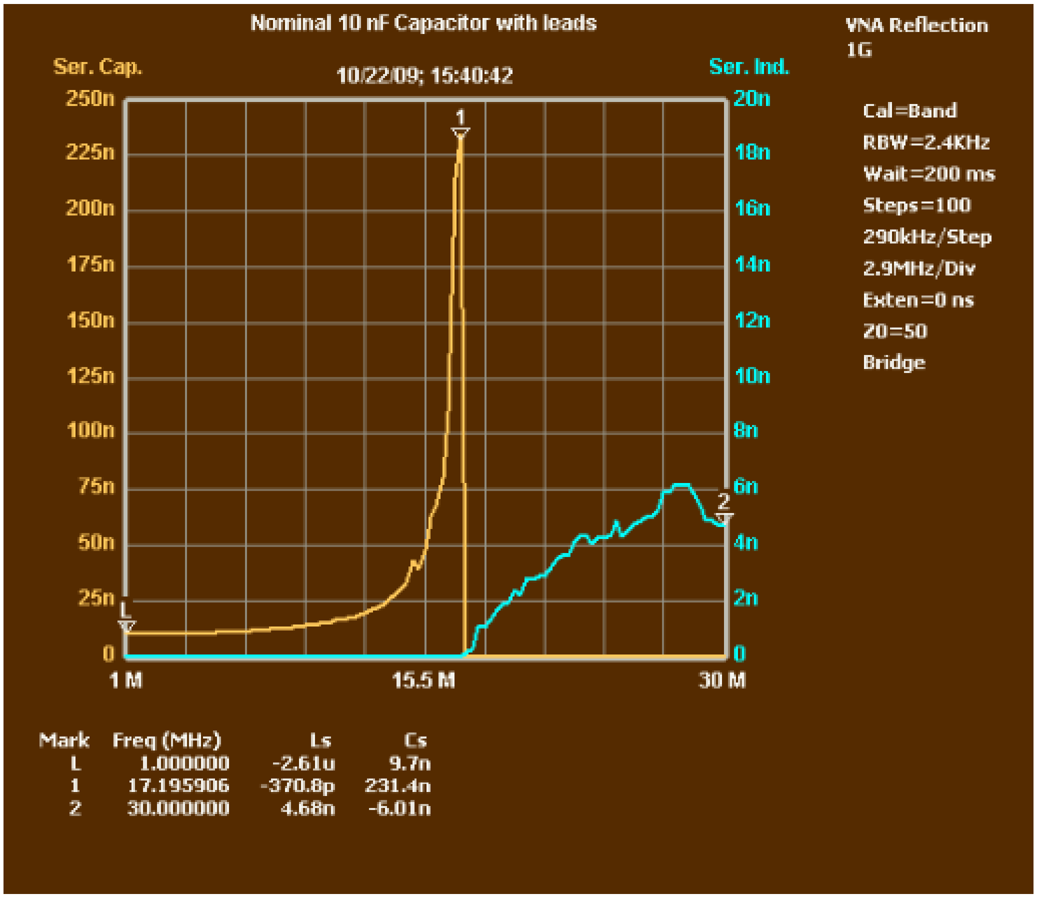
Inductors "Actual"	Inductors MSA	Inductors % Error
54n	50n	-7.4
390n	388n	-0.5
2.22u	2.29u	3.1
84.4u	85u	0.7
212u	213u	0.5

Figure 4—Tests with Shunt Fixture
The 1 pF reading was actually erratic

Figure 4 shows that the shunt fixture generally does a better job of measuring small resistors and large capacitors. In fact, it even got stable results with a 2 uF capacitor, though I don't have enough information on the exact capacitance to include it here. You would think this added accuracy would extend to small inductors as well, but apparently it is not so. On the other hand, it does less well than the series fixture with large resistors and small capacitors. It comes down to a question of what range you want to cover. The fixtures are so simple, there is no reason not to have both.

Self-Resonance

Capacitors all have some series inductance, especially capacitors with leads. That inductance will form a series resonance with the capacitance. Figure 5 shows a graph in Reflection mode of a 0.01 uf leaded capacitor.



Cal=Band
RBW=2.4KHz
Wait=200 ms
Steps=100
290kHz/Step
2.9MHz/Div
Exten=0 ns
Z0=50
Bridge

Mark	Freq (MHz)	Ls	Cs
L	1.000000	-2.61u	9.7n
1	17.195906	-370.8p	231.4n
2	30.000000	4.68n	-6.01n

Figure 5—Self-Resonance of a 0.01 uF capacitor
Net series capacitance is orange; net series inductance is blue.

Normally, we think of series resonance as a frequency where the impedance drops, theoretically to zero. But Figure 5 presents resonance in terms of the effective component value. At low frequency at marker L, the component acts as a 9.7 nF capacitor, which is the value we would measure with the Measure Components feature. As it approaches resonance at marker 1, the effective capacitor value increases, corresponding to a drop in impedance. This increase in capacitor value results from the series inductive reactance, which partially cancels the capacitive inductance. The net reactance is still capacitive (i.e. negative), and corresponds to that of an ever-increasing capacitor value. At marker 1, the capacitor looks like a 231 nF capacitor. At that point, the small capacitive reactance goes to zero, and the component starts to look like a very small inductor, gradually increasing to about 5 nH. That 5 nH of series inductance was always present in the capacitor, but at the lower frequencies it was dominated by the capacitance.

(A point on negative capacitance: After the capacitance drops to zero in Figure 5, it actually becomes negative, but the graph truncates it at zero. A negative capacitance is a legitimate value, but actually indicates an inductance. But -6 nF of capacitance does not mean +6 nH of inductance, rather, it means a inductance that has reactance that is the negative of that of a 6 nF capacitor; what value of inductance that represents depends on frequency.)

The significance of self-resonance is that the "value" of a capacitor varies significantly over frequency, and can start to increase at a frequency that is only 10% of series resonance. To get a complete picture of capacitor performance, you need a graph such as that of Figure 5. To get a meaningful single number for a capacitor value, you generally want to be well below series resonance. The same thing goes for inductors, which have parasitic parallel capacitance, and are affected by parallel resonance. The MSA chooses a measurement frequency that is generally suitable, but for components with unusually high parasitic components—such as a capacitor with long leads—the chosen frequency may be too high. The MSA allows the user to Stop the measurement and adjust the frequency with the "+" and "-" buttons, to deal with this situation. For very large inductors with many windings, as noted above, the self-resonant frequency may be below 100 KHz, the lowest measurement frequency allowed in Component Measurement.

When the MSA does component measurement, a graph of S21 appears in the background. It only contains 9 points, but that is enough to get a picture of what is going on. With the series fixture, the graph of S21 dB for a capacitor should rise with frequency, as more and more signal is allowed through. If it changes direction, that is a sign that resonance has occurred. Inductors in the series fixture should show a decline with frequency. If they change direction, resonance has occurred. Very large inductors may start out rising even at low frequency, which means their resonance has already occurred and they have already turned into a capacitor.

A Suggested Series Probe

As mentioned before, these tests used relatively crude fixtures with a lot of parasitics, just to show that good results could be obtained without fancy fixtures. Better results could be obtained if the DUT connections had smaller parasitics, and if the attenuators were located closer to the DUT connections. Figure 6 shows a suggested PCB for this purpose.

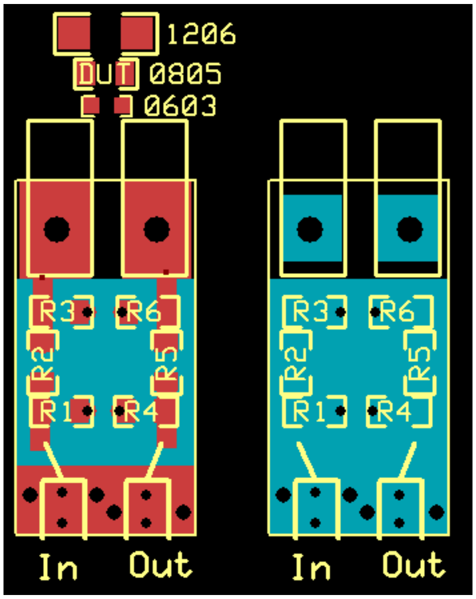


Figure 6—Series Probe
Red is top layer, blue is bottom; Top is invisible on right

The input and output in Figure 6 would be coax cables soldered directly to the PCB, perhaps secured by a wire wrapped over the top and through the larger holes on the PCB. Small, flexible cable such as RG-174 would be perfect, and could probably be 1-2 feet long without affecting the measurement. The resistors form ordinary pi attenuators; 6-10 dB would be advisable, depending on the source and load return losses. It is important that each attenuator present 50-ohm impedance to the component. Values of 120-49.9-120 ohms (0.1% resistors) make a standard 7.7 dB pi attenuator with excellent return loss.

The connection to the component is at the top of Figure 6 and could take several forms. Probes in the form of small metal bars could be soldered flat on the PCB; the large holes attached to the bottom pad (shown on the right of Figure 6) provide some mechanical durability so the top pad does not rip off easily. The spacing between such bars would allow them to be pressed directly onto SMD components of various sizes. It might even be possible to get suitable silver bars from a jewelry supply house for minimal cost, though brass is likely to be perfectly adequate. With short bars 20-30 mils thick, capacitance between the probes will not be a problem.

Alternatively, for components with leads the component connections could be made by sockets soldered directly into the large holes, or soldered flat, extending off the edge of the PCB. The large holes here are spaced 0.2” apart; different spacing could be used to accommodate spring-loaded terminal blocks. And, of course, you could always use alligator clips. Even with such clips, the performance would be better than the fixtures tested here, because of the proximity of the attenuators to the component.

Figure 7 shows a board similar to that of Figure 6, but using a less convenient short, fat form factor, and fairly rigid coax (it was originally designed to hold a crystal).

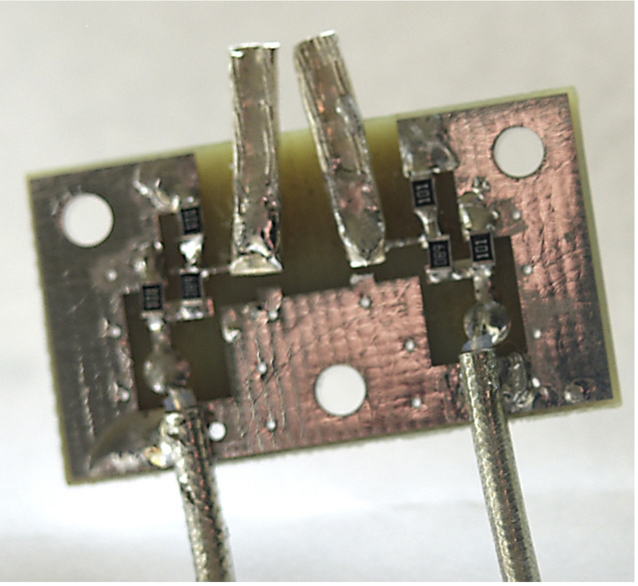


Figure 7—A more compact series fixture
The probes are flattened silver tubes.

The probes in Figure 7 are made of square silver tubes flattened with pliers. They are angled to allow the tips to come close together. Their proximity, and the fact that the planes at the probe ends are not parallel, make them very convenient for testing SMD devices of different sizes, as the connectors on the end of the components will make good contact with the probes. Silver is used because even if it tarnishes slightly, it will make good contact. Of course, it has low resistance, but that is not really a factor here, for very short probes at low frequencies.

Some tests were done with the probe of Figure 7. It generally performed slightly better than the fixture with alligator clips, but for small capacitors and inductors it was significantly better. The capacitance with no component attached measured 0.17 pF; if you subtract that from the measurement, a 1.14 pF capacitor (per AADE meter) measured 1.23 pF; a 119 pF capacitor measured 120.4 pF.

I cut a small strip out of the middle of a small brass strip, leaving it U shaped, with the two sides close enough together that the probe could contact both sides. At the bottom of the U, the inductance measured 2 nH; as I moved up the U so the signal had to travel further, the inductance steadily increased up to 9 nH. I have no way to verify the accuracy, but the values are plausible, and the measurements were very stable.

Conclusion

Even with the relatively crude series fixture used here, the MSA can measure resistances with likely accuracy of 1-2% over a broad range, with accuracy deteriorating a bit at the edges of the range. The useful range for resistances is about 2 ohms to 100 kohms; for capacitors, 10 pF to 0.25 uF; and for inductors, 20 nH to 1 mH. A similar fixture in a shunt configuration did better on large capacitors, getting stable results at 2 uF, and on small resistors, doing well to about 0.4 ohms. A higher quality series probe was shown, which does much better for small capacitors and inductors.