A Dip Meter Fixture for Determining
Resonant Frequency

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Introduction

A traditional Grid Dip Meter loosely couples to a resonant circuit and provides a dip in its reading at the resonant frequency, due to the resistance that gets imposed on the meters coupling coil. We can do a similar thing using a VNA in Reflection or Transmission mode. Here we present a fixture for this purpose, and demonstrate its use with Scotty's MSA.

The Fixture

Figure 1 shows an example of the fixture, which can be built in many different ways.

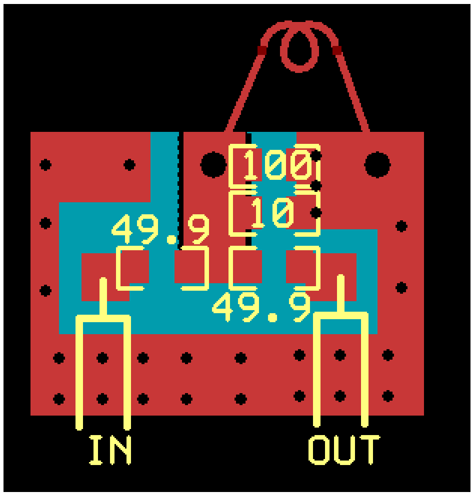

Figure 1—Dip Meter Fixture

The concept of this fixture is discussed in more detail elsewhere. It contains two coax cables, leading to the Tx and Rx ports of a VNA. Their shields are directly soldered to the top ground plane. Flexible coax such as RG-174 would make it easy to position the fixture as needed. 49.9 ohm resistors lead from the input and output to a common point, where a 10 ohm resistor is shunted to ground. This constitutes a shunt fixture with reference impedance of 16.7 ohms. A small coil is shown attached where the DUT normally attaches to a shunt fixture.

There is also a 100 ohm resistor, which is for Reference calibration. Such calibration for a shunt fixture is typically done with an Open—i.e. nothing attached. That approach can be used here, but better frequency range is obtained by using the 100 ohm resistor as the "Open". This is fine with the MSA as long as you tell it that the Open has resistance of 100 ohms.

Normally, you would attach the 100 ohm resistor only for calibration (in place of the coil) and then remove it. However, it is simpler to leave it in place. For purposes of use as a dip meter, the measurement distortion caused by leaving it in place is minor up to perhaps 30 MHz.

The reactance of the fixture coil has some tendency to mask the resonant response, so as few turns as possible should be used, and the leads to the coil should be as short as possible. A couple of turns with inductance of 35 nH is no problem at 20 MHz. Obviously, keeping the number of turns down is more important at high frequencies. Construct the coil of wire rigid enough for it to hold its shape—perhaps 22-26 ga. It is better to use fewer turns and locate the coils close together rather than use more turns and locate them further apart.

This fixture should be very functional to at least 80 MHz, perhaps using only a single-turn coil at that frequency. For low frequencies, a larger diameter coil might be more suitable.

A clarification regarding "references": The fixture has a reference impedance (Z_0) of 16.7 ohms. That simply means the DUT effectively sees 16.7 ohms looking toward the input or output, so the net impedance it sees is 16.7/2 ohms. In Reference calibration, we establish a reference signal level using the impedance used in calibration, here 100 ohms. That calibration reference is not the same as the reference Z_0 of the fixture. Finally, when we graph S-parameters, we normally use a reference Z_0 of 50 ohms. So there are three entirely separate "reference" impedances involved. (Maybe it would have been less confusing to call the fixture Z_0 its "characteristic" impedance.)

Use of the Fixture in Reflection Mode

The process of using this fixture in Reflection mode is as follows:

1. Disconnect the "hot" end of the fixture coil, attach the 100 ohm resistor (unless it is permanently attached) and perform Reference calibration over the desired frequency range. You need to tell the MSA that the fixture impedance is 16.7 ohms and the Reference standard is 100 ohms. (You could perform full OSL calibration, in which case you calibrate with an Open, Short and Load. The Load value does not matter as long as you tell the MSA what it is. But ideally you want a value that has no net inductance, and a 100 ohm resistor is optimal for this.)

2. Reconnect the coil. Set the MSA to graph series resistance (Rs) or S_{11} magnitude ($|S_{11}|$). For resistance, use a scale from 0 to 2 ohms. For S11 use -5 dB to 0 dB.

3. If the resonant circuit contains a cylindrical coil, place the fixture coil near the end of the resonance coil, or in any position that will create some inductive coupling.

4. If the resonant circuit contains a toroidal coil, place the fixture coil between the toroid leads, oriented so as to create inductive coupling. It may help to create a small loop in one lead of the toroidal coil, and place that "face to face" with the test fixture coil loops.

5. For other resonant circuits, such as an antenna, you can create a loop that is attached to the antenna feed line, and couple to that loop, exactly as you would with a grid dip meter.

6. Start scanning. Adjust the distance between the fixture coil and the resonant circuit to get a small, sharp response at resonance. If you are graphing $|S_{11}|$, the response will be a dip. If you are graphing resistance it will be a peak. The aim is to get the smallest response that gives a clear measurement of frequency.

7. The resonant frequency is the point of minimum $|S_{11}|$ or maximum resistance.

The basic principle is that at the resonant frequency maximum energy will be dissipated in the resonant circuit (as long as the coupling is loose), which will create a maximum resistance in the coil attached to our fixture. Figure 2 shows a sample response.

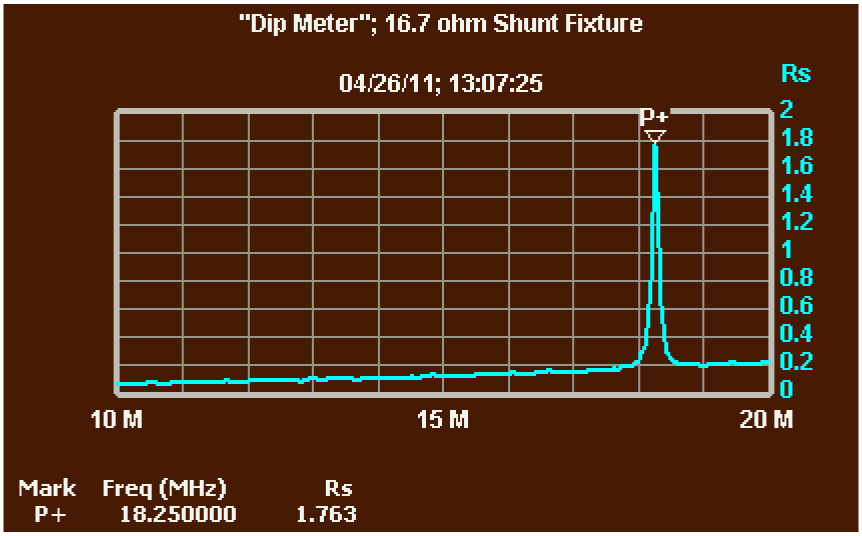

Figure 2—Dip Meter Response

Here, we get a resistance peak at 18.25 MHz, which is thus the resonant frequency of the parallel inductor/capacitor combination being tested. In this case, the inductor was wound on a toroid, so in order to get some coupling a loop was made in one of its leads, which was then placed near the fixture coil. Adding that loop of course increased the inductor impedance, but by a negligible amount.

The key to accuracy is to maintain loose coupling between the coils, so we do not significantly load or change the resonant frequency of the resonant circuit. The looser the coupling, the less resistance will be created in the fixture coil, so it is useful to be able to measure very small resistances. We could have separated the coils even further, since we could easily have detected a resistance peak below 1 ohm.

Figure 2 was produced without removing the 100 ohm calibration resistor. The effect of that resistor is (1) to create some bogus base resistance due to interaction with the reactance of the fixture coil, and (2) to reduce the resistance value at the peak. We don't care about the actual resistance value at the peak, and the base resistance is less than 0.2 ohm to 20 MHz, so neither factor is a problem.

This approach will even work at higher frequencies where the base resistance is rising significantly due to measurement errors. As long as the resonance creates a significant sharp movement, the fact that the base resistance is moving upwards will not significantly alter the measured peak frequency. It is probably a good idea to be sure the resistance peak is 5-10 times the level of the base resistance around the peak.

Graphing S_{11} Instead of Resistance for the Dip Meter

Rather than graphing resistance, we could have graphed S_{11} in dB and looked for a dip in the graph, which would correspond to the peak in resistance. The correspondence is not perfect, but the minimum S_{11} will occur at very nearly the same frequency as maximum resistance, as long as the resistance is small compared to the Z_0 used for the graph. If the resistance is large, the coupling should be reduced. For highest accuracy, the graph can be recalculated at a higher S-parameter reference impedance (by changing Graph Z_0 in the Sweep Parameters window).

The Appendix provides more technical details of the difference between viewing S_{11} and resistance.

Use of the Fixture in Transmission Mode

The process of using this fixture in Transmission mode is similar to Reflection mode, with the following differences:

1. Reference calibration is done the same way, but constitutes Through calibration in Transmission mode. In Transmission mode, the MSA does not care what the fixture impedance is.

2. The graph produced by Transmission mode will be S_{21}, which will show a gradual increase due to the increasing reactance of the coil as the frequency increases, with a sharp peak at resonance. The coupling should be adjusted to make the peak as small as it can be and still clearly indicate the resonant frequency.

Low Frequency Fixture

For frequencies below a few MHz, a larger fixture loop may be required. Figure 3 shows a loop designed to measure the resonant frequency of low frequency RFID tags.

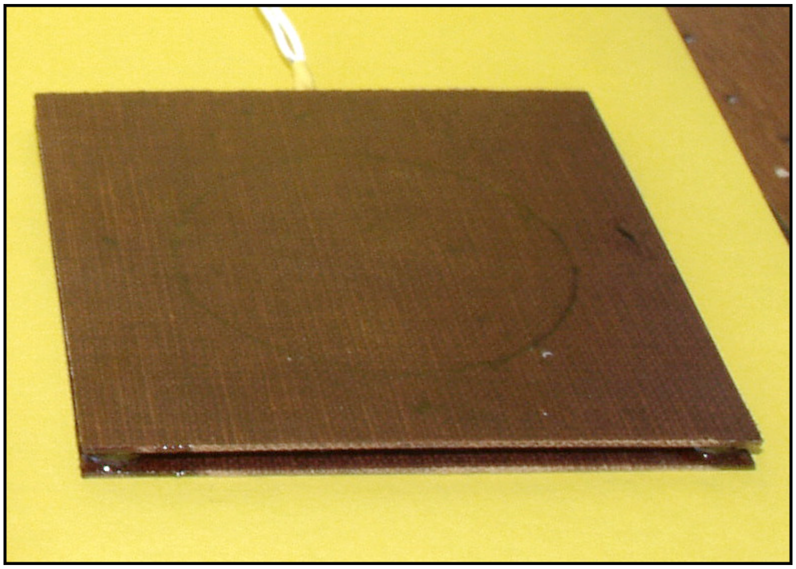

Figure 3—Low Frequency Coupling Loop

This loop is sandwiched inside two pieces of plastic, epoxied around the edges. You can just barely see a circular marking indicating the loop location. The loop is a single loop, 1.5" in diameter, connected to the white leads at the top. The item being tested is placed on the surface, centered in the circle. This worked well at 125 kHz. At frequencies of several MHz, it was necessary to raise the item as much as 1" above the surface with a piece of plastic as a spacer, in order to keep the coupling low.

The white leads connect to the test fixture. It would be possible to build the fixture resistors into the loop device, as long as provision is made to allow for disconnection of the ungrounded side of the loop for calibration. At frequencies below 10 MHz, Reference calibration could be done with an Open without loss of accuracy, so there is no need to attach a resistor for calibration.

APPENDIX—MINIMUM $|S_{11}|$ vs MAXIMUM RESISTANCE

The difference between looking for the point of minimum $|S_{11}|$ and maximum resistance, when using the "dip meter" fixture, is best illustrated by looking at the Smith chart.

First, a little orientation as to how resonances appear on the Smith chart. Assume a parallel inductor and capacitor, with some amount of resistance in the inductor. The graph of the resonance might appear as shown in Figure A1.

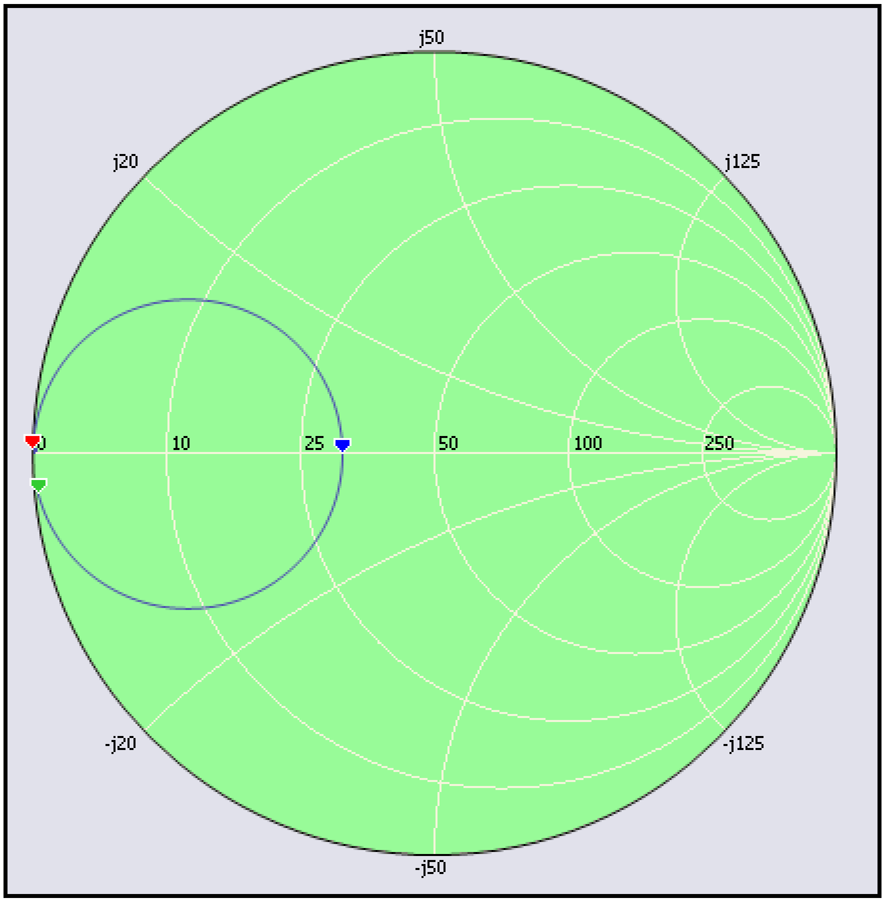

Figure A1—Typical resonance graph of parallel LC circuit

The labels on the horizontal axis are resistance, with 50 ohms in the center. Every point on the white circle passing by each label has the same resistance, and the circles are referred to as constant-resistance circles. Points are graphed using S11 magnitude (which becomes the distance from center, assuming the chart radius is one) and phase (which determines the direction we move from center; 0 degrees runs straight to the right). Thus, every point on any circle centered at the chart center has the same $|S_{11}|$ as every other such point, and the points differ only in phase. Because $|S_{11}|$ is often called rho, such circles are called constant-rho circles.

The blue circular line is the graph. At the lowest frequency, shown by the red marker, the impedance is very small because the current flows through the low impedance inductor. As the frequency increases the response follows the path toward resonance (blue marker). Inductive reactance first increases, and then gets cancelled by the capacitive reactance, so at the blue marker there is no net reactance, just a pure resistance, here about 30 ohms. As the frequency increases beyond resonance, the net capacitive reactance increases until the frequency is high enough that the inductor has such high reactance that it becomes largely irrelevant, and we are just left with the capacitive reactance, which tends toward zero, so we return to the starting point.

For such a resonant circuit, it is clear that the maximum resistance occurs at resonance. It is also clear that $|S_{11}|$ (the reflection coefficient, which is the distance from the center of the chart to the graph point, relative to the radius of the chart) reaches a minimum at resonance, because the blue marker is at the graph point closest to the center.

It is quite possible for the resonance graph to encircle the chart center, making things a bit more complicated. But with our dip meter fixture, we always adjust the coupling to make the resonance response relatively small, so we will assume that the resonance graph does not circle the chart center. (To include the circle in the center, the maximum resistance for the graph would have to exceed 50 ohms. We typically would adjust the coupling to end up with no more than a few ohms.)

Often, a resonance does not appear all by itself, which is the case with our dip meter fixture. Figure A2 shows a Smith chart graph of a resonance of the type that might be encountered with our fixture. The blue circular line is the graph, which starts at 30 MHz near the j20 label and ends at 70 MHz near the j50 label.

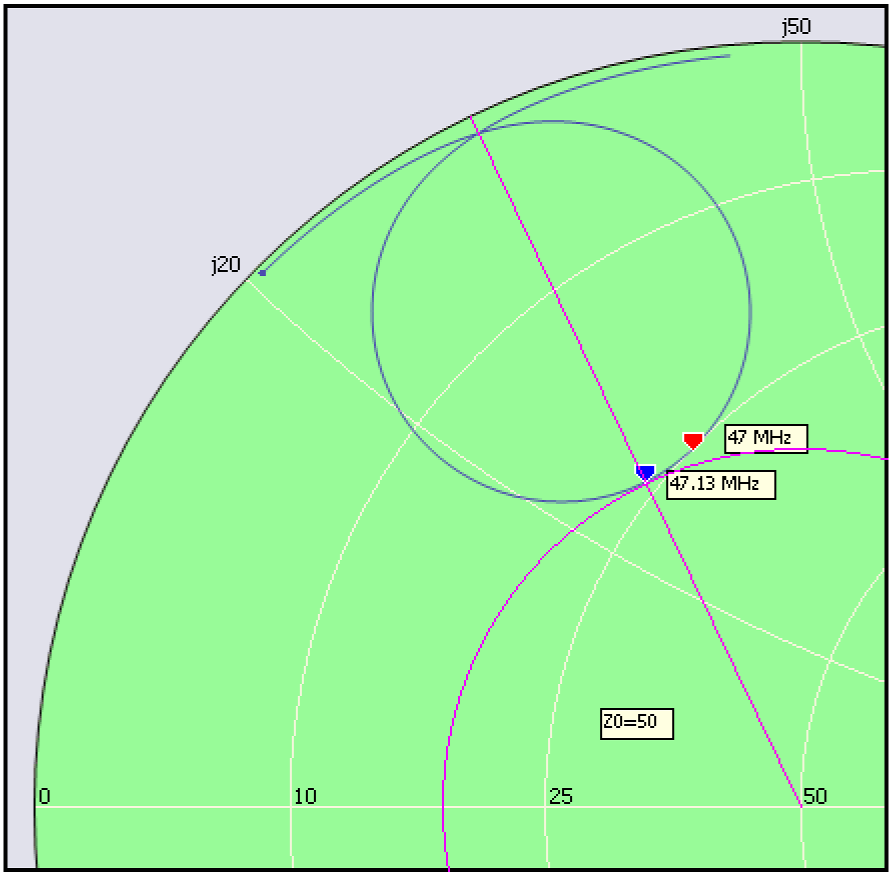

Figure A2—Resonance graphed re 50 ohms

The overall trend is clockwise movement near the chart boundary, due to the increasing reactance of the fixture coil. Near the middle, though, there is a rapid circular movement, which is the result of resonance superimposed on the coil response. The minimum value of $|S_{11}|$ occurs at the blue marker (47.13 MHz), where the graph is tangent to the purple arc, which is part of a constant-rho circle centered at the center of the chart. The maximum resistance occurs at the red marker (47 MHz), where the graph is tangent to the 25-ohm constant-resistance circle.

Clearly, the minimum $|S_{11}|$ and the maximum resistance do not occur at the same frequency. This is the result of the fact that the relevant constant-rho and constant-resistance circles follow very different paths in the area of resonance. That in turn is due to the fact that constant-rho circles are centered at the chart center, whereas constant-resistance circles are centered at various points on the horizontal axis to the right of center (except zero resistance, which is centered at the chart center). The varying centers of the constant resistance circles can be seen in Figure A1, in which each resistance circle is labeled where it crosses the horizontal axis.

Now, let's re-graph the same data, but using a graph reference impedance of 200 ohms. Note that this does not involve any change to the physical circuit and therefore has no effect on the resonant frequency. The result is shown in Figure A3.

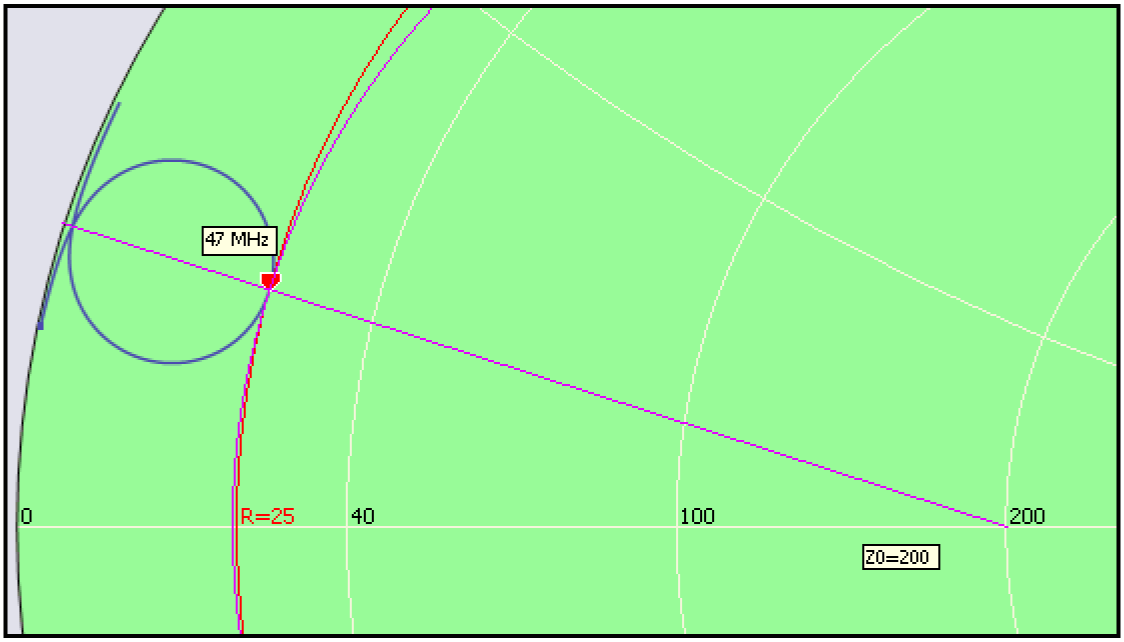

Figure A3—Same data, graphed with Z_0=200 ohms.

Figure A3 shows a graph similar in shape to that in Figure A2, but it has become smaller and rotated toward the 0 label. The actual impedances at each graph point have not changed, but the points move because S11 has changed due to the change in Z_0 from 50 to 200 ohms. Minimum $|S_{11}|$ is again the point where the graph is tangent to the purple arc, which is part of a constant-rho circle centered at the chart center (now 200 ohms). The minimum resistance is again the point where the graph is tangent to a constant resistant circle, here shown in red at 25 ohms. Clearly, the constant-rho circle and the constant-resistance circle are almost the same, which causes both minimum $|S_{11}|$ and maximum resistance to occur at almost the same frequency, 47 MHz.

One might wonder whether minimum $|S_{11}|$ or maximum resistance is the true indicator of resonance. The answer is clear from the above graphs. We made no physical changes to the circuit, so the resonant frequency is the same in both graphs. The frequency for minimum $|S_{11}|$ changed between the two graphs, so that frequency is clearly not a reliable indicator of the resonant frequency. The frequency of maximum resistance, however, did not change, so that is the frequency of resonance.

As we have just shown, the difference between the frequencies of minimum $|S_{11}|$ and maximum resistance becomes negligible when the Smith chart graph is confined to an area near the left side of the Smith chart, where resistances and reactances are small compared to the Z_0 of the graph. If they are not inherently "small", we can make them small by graphing with a large Z_0 value.

In the case of a dip meter, the simplest solution is to reduce the coupling to make the resonance effect small. If the coupling had been reduced in creating Figure A2, the basic graph would still lie between the j20 and j50 labels, but the resonance loop would be smaller. For very small loops, the relevant constant-rho and constant-resistance circles become very similar, so minimum $|S_{11}|$ and maximum resistance occur close together, even if the graph is high up on the left side of the Smith chart, so there is no need to graph with a high Z_0 in order to rotate the graph down toward the zero impedance area. However, if the fixture coil has enough reactance to swing the resonance graph over to the right side of the Smith chart, even small small resonance loops start to create separation between minimum $|S_{11}|$ and maximum resistance, so if $|S_{11}|$ is used to identify resonance, it is good to increase the graph Z_0 to rotate the graph back to the left.