Applying and Measuring Ferrite Beads, Part II ~ Test Fixtures

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II-1. Introduction

In Part I we described ferrite beads and their applications and simple test and calibration fixtures for measuring ferrite bead impedance [Reeve]. Our original plan for Part II was to describe our measurements over a limited frequency range (200 MHz). However, in the interim two month period we decided to investigate additional test fixtures and to extend the frequency range of our measurements to around 1 GHz.

During the time from publication of Part I to the present, Kurt Poulsen joined us as co-author and the three of us have made thousands of measurements. Also, we ordered a large number of beads from Fair-Rite in various sizes and materials but received them much too late to measure and present the results at this time. Therefore, our revised Part II describes the test fixtures so far investigated and the problems encountered over the extended frequency range. No actual measurements are provided here. It was noted that as we increased the measurement frequency the evolution of the test fixtures followed a path needing increased vector network analyzer (VNA) calibration accuracy and reduced influence of the radio frequency environment in our measurement labs.

II-2. Test Fixture Evolution

Our work on developing an inexpensive method for ferrite bead measurements originally was based on a wood-framed ferrite bead test fixture that Reeve built in 2012 (figure 1). This fixture was built large enough to measure up to five ferrite beads in a series string; however, the fixture has a sharp resonance at 100 MHz, was of little use above about 30 MHz and did not accurately indicate the impedance of a series string of beads even at 30 MHz.

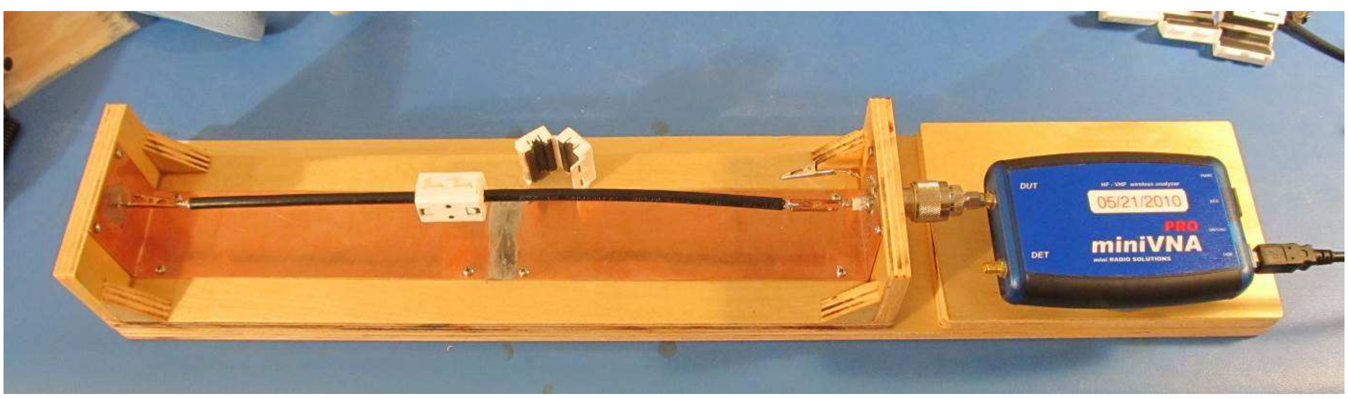


Figure 1 ~ Original ferrite bead test fixture shown with the inexpensive MiniVNA Pro vector network analyzer. It was of little use above 30 MHz and useless for measuring more than one bead. The fixture consists of a strip of copper 50 mm wide fastened to a wood frame between two end brackets separated by about 400 mm. Ferrite beads are placed on a piece of coaxial cable with shield and center conductor shorted at both ends. The coax is connected directly to the copper strip at one end and to an RF connector center contact at the other end. The impedance is measured between the connector center contact and copper strip. Prior to measurements, the VNA is calibrated in the normal way with a precision Short, Open and Load (SOL). (Image © 2013, W. Reeve)

The limitations of the original test fixture inspired Hagen to make new test fixtures from small rectangular pieces of single-sided printed circuit board (figure 2). We built two sets, one with BNC connectors and one with SMA connectors. Each set consists of a Short circuit fixture, Open circuit fixture and Load circuit fixture for VNA calibration. The Short fixture also serves to hold one ferrite bead during measurement. This type of fixture is suitable only for clamshell beads (see Part I for a description of different bead types) because of the permanent copper conductor (loop) used to hold the bead. The Load fixture uses ordinary resistors in a series-parallel arrangement to provide a 50 ohm load. The resistors in the Load fixture and the conductor used in the Short fixture have inductance and distributed capacitance leading to calibration and measurement problems at very high frequencies (VHF). Another variation of the PCB fixtures built by Hagen essentially was a scaled-down version of the original wood-frame fixture (figure 3)

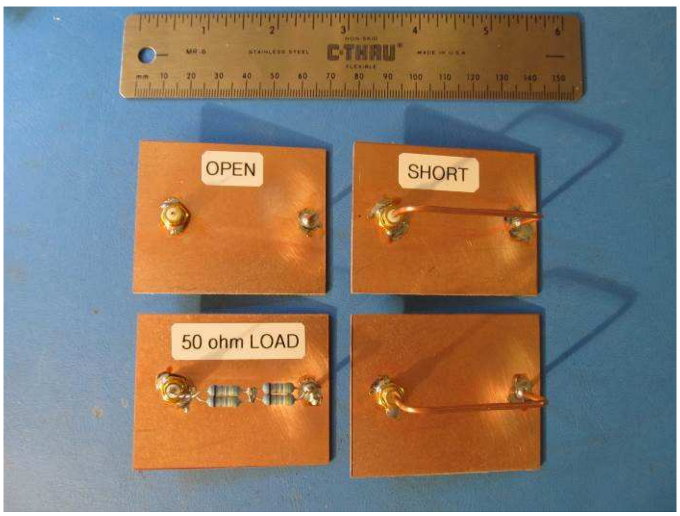


Figure 2 ~ Printed circuit board (PCB) fixtures with SMA connectors. PCB dimensions are 2.0 x 2.5 in (51 x 64 mm). A layout drawing was provided in Part I. These fixtures are used as Short, Open and Load for vector network analyzer calibration. A ferrite bead is then placed on the Short fixture for measurements. These fixtures provided usable measurements up to about 100 MHz. (image © 2013, W. Reeve)

Figure 3 ~ Printed circuit board (PCB) fixtures built by Hagen with end brackets and sides. These fixtures provided no measurement advantages over other types. (image © 2013, T. Hagen)

Our next test fixture iteration used the Short fixture (now called Loop fixture) to hold the bead during measurements, as before, but new PCBs were made with higher accuracy short and load circuits (figure 4). Each fixture has a panel-mount SMA connector (figure 5). For the Load fixture we used surface mount device (SMD) resistors soldered directly to the back of the SMA connector. For the Short fixture we soldered a brass disk directly to the back of the SMA connector or simply filled the well on the back of the connector with solder. The

Open fixture was the same as before and consists of an SMA connector with the center contact filed down at the back. We also used Open fixtures without filing down the center contact. The reference plane for the three calibration fixtures is the same, so we could calibrate the VNA without delay offsets. However, the Open fixture still had end-point radiation to worry about (slightly more than 2 ps each direction depending on the center contact arrangement).

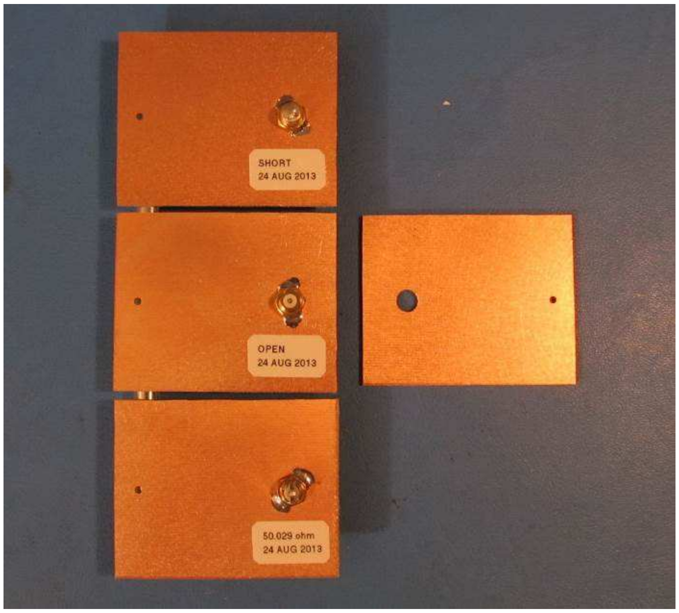


Figure 4 ~ modified printed circuit board fixtures with SMA connectors. The PCB on the right is a blank board prior to installation of a connector. These fixtures eliminated the distributed capacitance and inductance of the previous calibration fixtures. However, the bead measurements still include the inductance and capacitance of the Test Loop but provide good measurements (±20%) up to about 200 MHz. (image © 2013, W. Reeve)

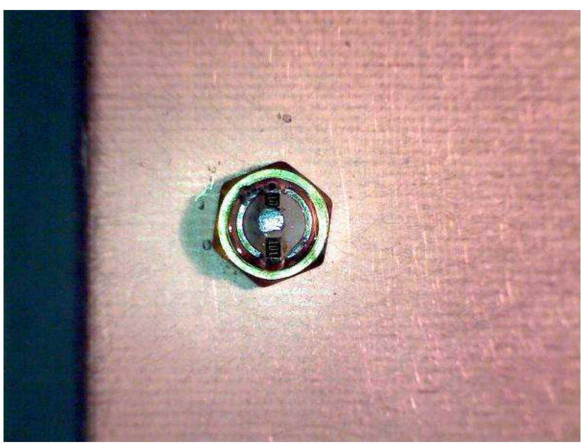


Figure 5 ~ PCB calibrators. (images © 2013, W. Reeve)

<u>Upper-left</u>: The Load fixture uses two SMD 0805, 100 ohm, 0.1% resistors in parallel soldered directly to the back of a panel-mount SMA connector between the center contact and the connector body.
<u>Upper-right</u>: The Open fixture is an SMA connector with the center contact on the back filed down flush with the connector body.
<u>Lower-left</u>: The Short fixture is an SMA connector with a small brass plate with a hole in the middle soldered to the back center contact and connector body.

These fixtures improved measurement accuracy at frequencies above 100 MHz. We found we could improve the measurements above 100 MHz by using a frequency dependent variable in the VNA software to compensate for stray inductance and capacitance. It also was noted that the measurements varied with the position of the bead on the fixture pin, wire or loop, including whether it was concentric or not. For repeatable measurements, we found it necessary to make the outside diameter of the fixture wire the same (or close to) the inside diameter of the bead and to center the bead in the fixture.

We further refined the PCB fixtures by using commercial precision SOL calibrators (figure 6) to calibrate the VNA and then use the Loop fixture for bead measurements. Because the reference plane for each calibrator is different, we took into account the delay offsets during calibration. This method yielded slightly better measurement accuracy at frequencies above about 100 MHz.

Figure 6 ~ Precision Short, Open and Load calibrators used for VNA calibration prior to bead measurements. These calibrators are based on SMA connectors and when not in use are stored in a small tin box. Note the dimensional information for the Short and Open/Thru units that is used to determine their electrical delays. (image © 2013, W. Reeve)

Poulsen built another variation of the PCB fixtures, which consisted of a single PCB with a loop and three separate connectors for Short, Open and Load calibration. Two versions were built, one with hard-soldered U-shaped loop and another with a removable loop (figure 7). Poulsen also investigated an “open air” test fixture based on connectorized adjustable rail-mounted brackets (figure 8). This fixture suffered environmental effects due to stray reactance.

While developing better VNA calibration fixtures and methods, Poulsen noticed considerable effects on the measurements above 500 MHz due to his lab’s RF environment and external resonance effects. This led to the development of enclosed test chambers that shield the beads from the environment (figure 9 and 10). Poulsen found that his measurements were more repeatable and stable when using a test chamber. Reeve’s lab RF environment apparently is not as active because he noted very little difference between measurements made with a PCB fixture and those with a test chamber. Nevertheless, additional investigations of test chambers are ongoing.

The chambers as of this writing are equipped with SMA connectors on each side that are connected by a copper wire, thus allowing s11 measurements using both the reflection or transmission method. For the reflection method, one of the SMA connectors is terminated with a Short circuit calibrator and the VNA transmit port is connected to the other SMA connector. For the transmission method, one SMA connector is connected to the VNA transmit port and the other connector is connected to the VNA receive port. The advantage of the transmission method is that the VNA software is able to make 12-term corrections on the s11 measurements because it has more complete knowledge of the device's characteristics.

Figure 7 (left) ~ Poulsen's version of the PCB fixtures with built-in SMA SOL calibrators seen on lower-left corner. The U-shaped loop is made from a piece of semi-rigid coaxial cable with the shield and center conductor soldered together on the right end in the image. The arrangement shown allows the loop to be removed and reused in a test chamber shown later. It also allows larger solid beads and toroid cores to be slipped over the loop. (image © 2013, K. Poulsen)

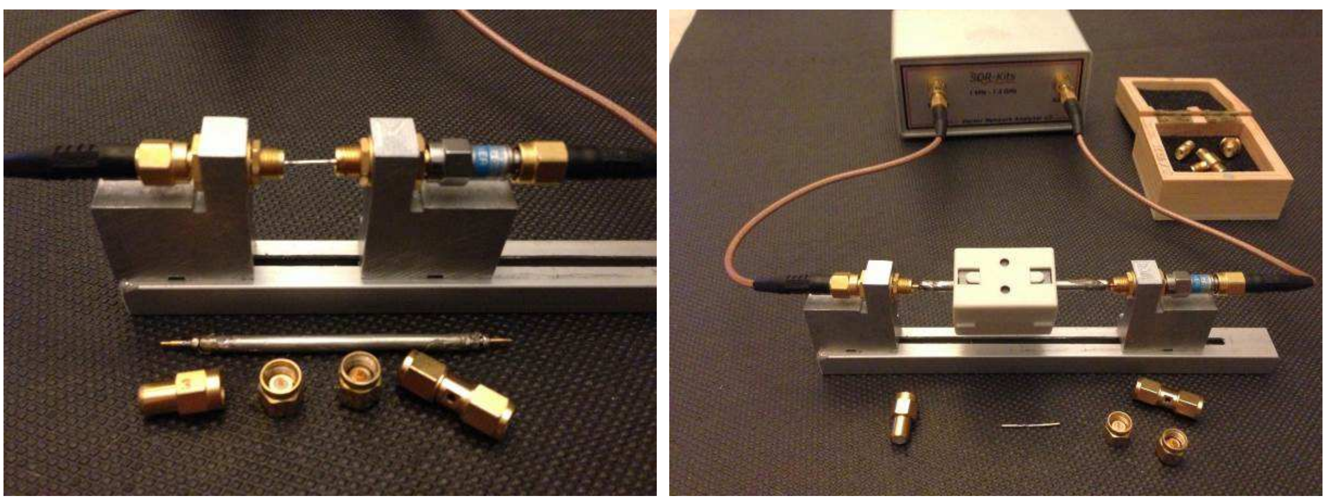


Figure 8 ~ Rail-mounted test fixture. The two end brackets each hold an SMA connector, which are connected with different length pins to hold a ferrite bead or toroid. The left image shows a close-up and the right image shows the fixture used with the VNWA-3E vector network analyzer setup in transmission mode. (images © 2013, K. Poulsen)

While pondering the use of and experimenting with test chambers, we found an instruction manual for the Agilent Technologies 16454A Magnetic Material Test Fixture [Agilent], which is used to measure toroid components. This provided the mathematical basis for measuring complex permeability as well as some ideas for how their test chambers are built. Hagen discovered some typographical errors in the mathematical formulas provided in the manual and worked out the remaining math (we found additional papers on the subject of measuring complex permeability and they also repeated the same errors). Eventually, we hope to be able to measure complex permeability using the methods we are developing.

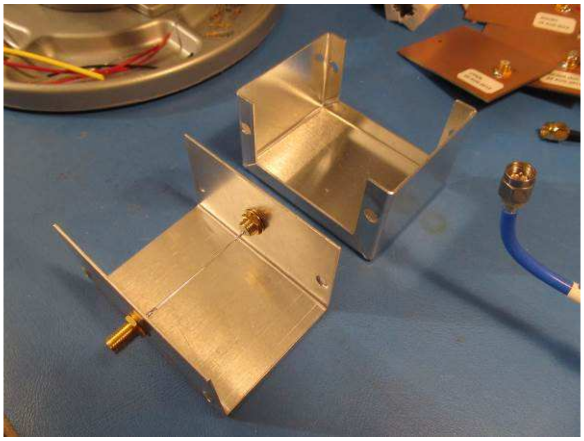
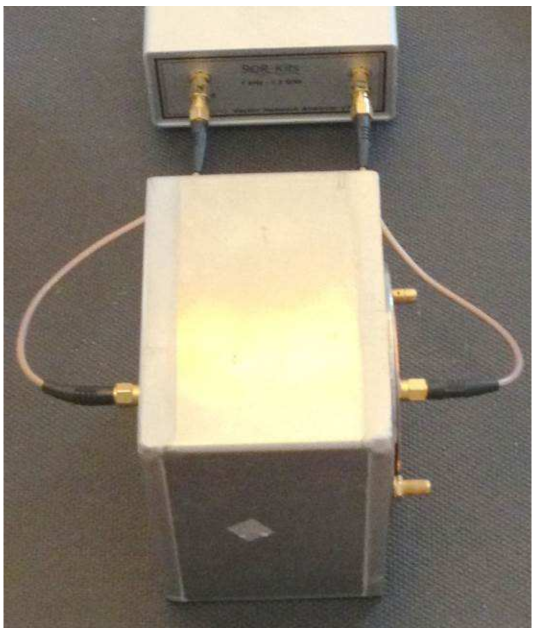


Figure 9 (left) ~ Test chamber built by Reeve to shield ferrite beads from the lab RF environment. It is based on an aluminum utility box with dimensions 2.75 x 2.125 x 1.625 in (70 x 54 x 41 mm) and two SMA panel-mount connectors connected by a 22 AWG tinned copper wire. A clamshell bead is installed over the wire and the box cover snapped in place prior to measurement. (image © 2013, W. Reeve)



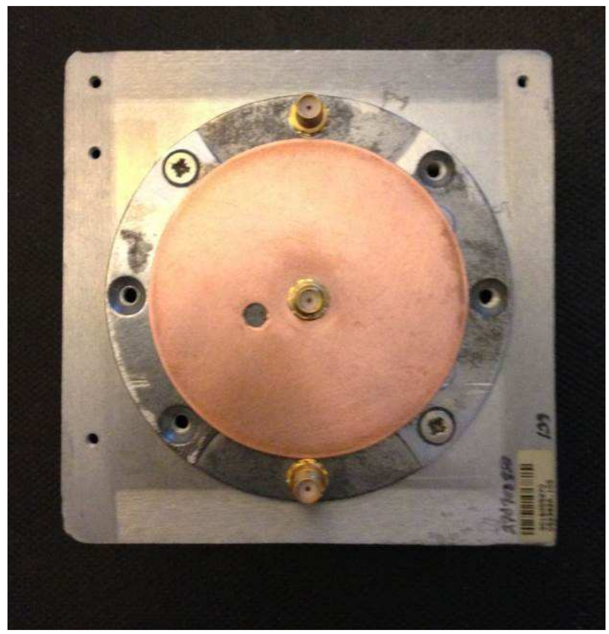


Figure 10 (above and left) ~ Test chambers built by Poulsen. (images © 2013, K. Poulsen)

<u>Upper-left and -right</u>: This chamber is based on a rectangular aluminum enclosure with removable circular end-caps. Dimensions are 110 x 110 x 80 mm. The caps each have an SMA connector in the center and two connectors on the edge. The enclosure can be setup for transmission mode by installing a bead on a straight pin that connects the two center connectors. For reflection mode, a U-shaped loop is used to connect the center connector to one of the edge connectors, or a straight pin can be used with a Short circuit on one end.

<u>Lower-left</u>: The cylindrical chamber is based on a small tin can used for the storage of Chinese tea. Dimensions are 59 x 64 mm. SMA connectors are installed on each end and are connected by removable pins seen in center of image. One set of pins has a foam polyethylene (PE) cylinder from the dielectric of a coaxial cable whose diameter matches the ferrite bead inside diameter.

II-3. Conclusions

Our test fixtures continue to evolve. We found that for measurements of ferrite bead impedances at VHF and higher we needed to better control the RF environment as well as the calibration of the vector network analyzer than at frequencies below VHF. This led to our development of various PCB test fixtures and test chambers and considerable experimentation. We obtained a number of ferrite beads with known electrical characteristics and in Part III of this paper we hope to describe measurements up to 250 MHz for Fair-Rite beads using type 31, 43 and 46 bead materials and up to 1 GHz for 61 materials.

II-4. References

References:

[Agilent] Operation and Service Manual, Agilent 16454A Magnetic Material Test Fixture, 2008

[Reeve] Reeve, W. and Hagen, T., Part I ~ Ferrite Bead Properties and Test Fixture, Applying and Measuring Ferrite Beads, Radio Astronomy, July-August, 2013