EDGES MEMO #133

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To: EDGES Group

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Subject: Checks of SOL calibration standards

The technique of 1-port measurements of an unknown asymmetric reciprocal 2-port device terminated with the short, open, load (SOL) used to calibrate the VNA followed by a second set of measurements with device reversed allows the determination of the S11 of the calibration short and open. While the imaginary component of the load can also be determined the real part defines the reference impedance. While the calibration kit data specify the load as exactly 50 ohms this value should be checked with a high accuracy ohmmeter. If not exactly 50 ohms the measured DC value is used in the standard load model.

The method described in memo 131, involves searching for corrections to the calibration data which minimize

$$\left|S12S21 - SR12SR21\right| + \left|S11 - SR22\right| + \left|S22 - SR11\right|$$

This method of checking calibration standard has some difficulties as follows:

1] The method relies on the symmetry of the reference plane in the connectors which is only near perfect in sexless connectors.

2] With the use of male and female connectors male and female versions of the SOL kit need to be used or a correction needs to be made for the addition of an adapter.

3] The method requires a large number of connect and disconnect operations. The continuity of the connections is critical and a torque wrench is recommended for consistency.

4] The VNA can drift between measurements so a constant temperature environment is highly desirable.

a) Maury model: The load is assumed to be a perfect 50 ohms.

The short is assumed to be a perfect short on a transmission line with one way offset of 16.684ps and the open as a capacitance given by a polynomial at an offset of 14.49 ps. The transmission line includes an approximation to the Bessel functions which account for the internal inductance within the skin depth. The normalized resistive loss is given as 1.3 Gohms/s by Maury and about twice this value in similar standards from Agilent.

b) Theoretical model

A more complete model is based on the full theoretical model of Ramo and Whinnery (see memo 126) based on the limited published mechanical data available. The difficulty of this model is lack of detailed information on the plating of the beryllium copper whose thickness is probably less than the skin depth and the 50 to 200 MHz frequency range of the EDGES project. Also in this model the capacitance of the open has to be assumed to be the same polynomial for lack of any detail. In the 50 to 200 MHz range this capacitance is about 0.063 pf.

The only aspect which results in a significant difference between the Maury model and the more complete model is the loss. In the Maury model the loss is given as a single parameter of 1.3 Gohm/s which assumes a skin depth of uniform conductivity whose thickness is inversely proportional to square root of frequency. The 2 models are virtually identical if a conductivity of 33% of the conductivity of pure copper is used in the theoretical model. This loss corresponds to 0.002 dB loss for the 16.684 ps Maury short at 100 MHz and less than 10^{-6} dB for the open..

Search for corrections to kit model

A set of 8 reverse asymmetric 2-port tests were run and the following results were obtained for the best fit correction to the offset delay and loss. The reciprocal unknown 2-port used in each case was 50 ohms between ports 1 and 2 with 30 pf from port 2 to ground (see memo 131).

The results are given in Table 1.

Test #	Offset correction ps	Conductivity % Cu	Sum (see memo 131)	Location
1	0	6	0.0014	A
2	-0.5	5	0.0008	B
3	-2.5	5	0.0026	B
4	-1.0	1	0.0030	B
5	+0.5	42	0.0020	B
6	+0.5	99	0.0021	B
7	+2.0	99	0.0027	B
8	+0.5	30	0.0017	A

Table 1 Best fit offset correction and loss

Location A and B were at the VNA port and at the end of a 3' cable respectively. The scatter in the conductivity expressed as a percentage of that of copper is too large to distinguish between the 33% from Maury and 16% from Agilent. All the tests except #2 were taken with the HP85047A/8753C. The 2nd test used the Agilent N5222A PNA. Longer integrations would help reduce the noise shown in a sample best plot of Figure 1.

However there are too many manual operations in this method. An automated set-up with mechanical switches might be viable if a transfer switch can be shown to have sufficient symmetry to "reverse" the unknown or perhaps a separate measurement of the path asymmetry could be made using a symmetrical 2-port. A simulation shows that the contribution to the normalized sum for difference between 33% and 16% is only 0.0004. A simulation shows that the effect of an error in calibration model corresponding to this difference on the measurements of antenna reflection coefficient is 0.0001 in linear reflection units which corresponds to about 0.005 dB at -15 dB.

Conclusion

It is doubtful that the connection consistency and stability of a VNA is good enough for a definitive test of the loss of the Maury calibration kit in the 50 to 200 MHz range. However, this test might meet the higher accuracy required in an implementation using an automated setup employing mechanical switches.

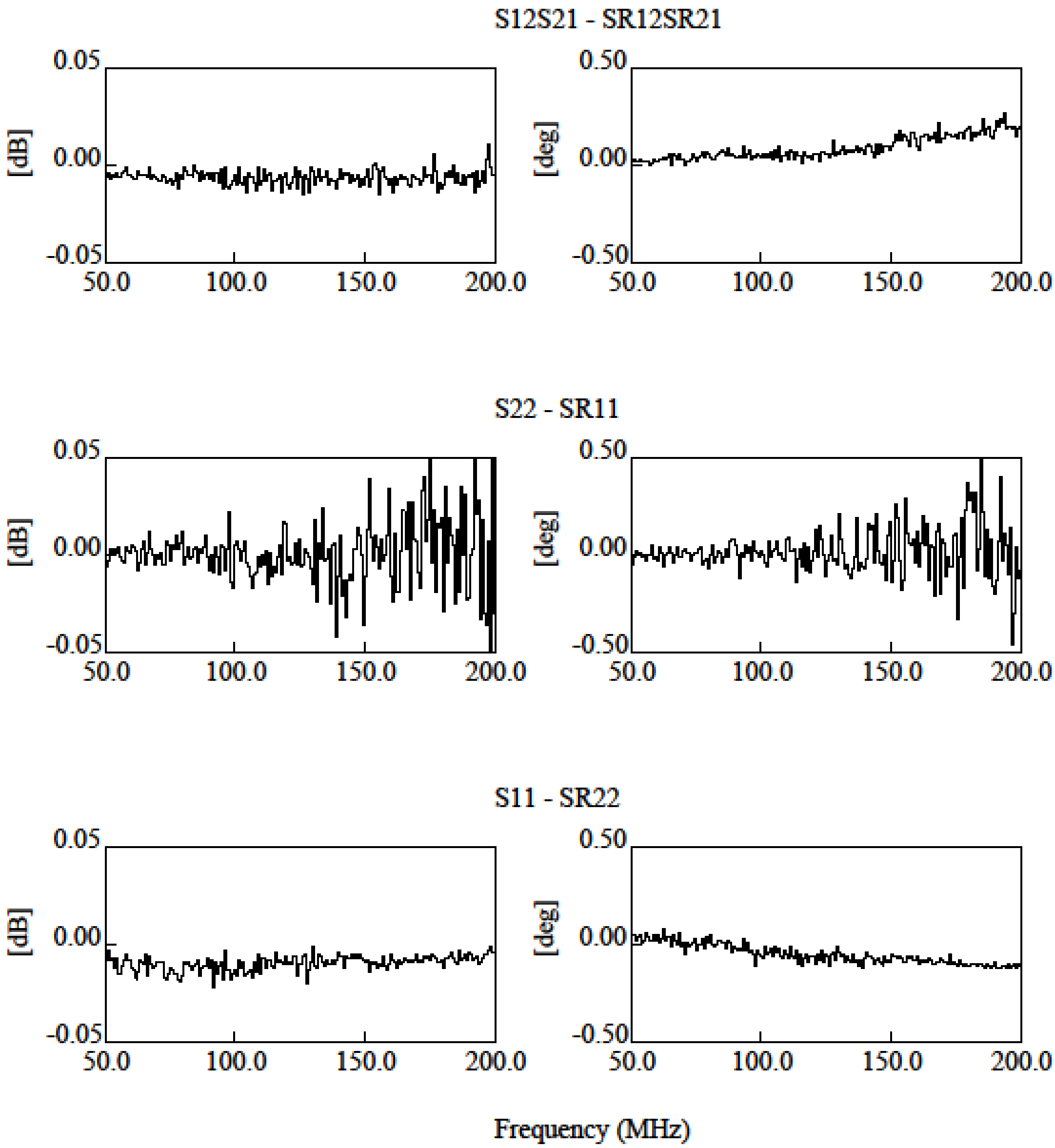

Figure 1. Results from test 8.