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To: EDGES Group

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Subject: Estimation of VNA accuracy for measurements of antenna S11

The VNA accuracy can be checked using the "reversed 2-port test." In this test an unknown passive 2-port for which

S12=S21 and $\left|\text{Im}\, S12\right| > 0$

Is measured by

1] Calibrating VNA with 3 known loads

2] Measuring 2-port with the same 3 loads

3] Reversing the 2-port and re-measuring

In this case we define a "sum" and if

$$\text{sum} = \left|S11 - SR22\right| + \left|S22 - SR11\right| + \left|S12S21 - SR12SR21\right| > 0$$

There is an error in the VNA which cannot be corrected with a reciprocal 2-port or there is an error in the S11 values of the loads.

The 3 loads must have different values of S11 and one needs to have a non zero value of real impedance. Further if one, the nominal 50 ohm load, has a known S11 the S11 values of the other 2 loads can be found from 9 measurements since there are only 3 unknowns for the 2-port, 3 unknowns for the VNA and 3 unknowns for the loads.

The requirement for a known value of real impedance defines the scale of resistance in "standard" ohms.

1] Sensitivity study

There are sensitivity studies that can be carried out using simulation with computer code. In the first we can determine the effect of the choice of unknown 2-port on the detection of sources of error. For this we examined the magnitude of sum averaged over 10 to 310 MHz for errors in calkit short open and load and the results are given in Table 1. The choice of 2-port unknowns were

A. a short between port 1 and 2
B. a 10 dB attenuator
C. 50 ohms between port 1 and 2 with 30 pf from port 2 to ground
D. 10 ns one-way 50Ω cable
E. 10 ns one-way 50Ω cable with 50 ohms in series.

No errors can be detected in the case of A which should produce a zero sum within the noise so that the only errors would be due to drift. Case A is equivalent to a "cross-check" in which the open, short and load are re-measured following calibration. It may be advantageous to include a cable as part of a 2-port as the effects of errors are more easily identified as a "ripple" is produced as shown in Figure 1 for case E with 1 ps error in the open.

2-port	0.001 error in load magnitude	0.001 error in short magnitude	1 ps error in short	0.001 error in open magnitude	1 ps error in open
A	0	0	0	0	0
B	0	0.0009	0.0009	0.0009	0.0009
C	0	0.0014	0.0019	0.0012	0.0010
D	0	0.0013	0.0012	0.0013	0.0012
E	0	0.0011	0.0010	0.0016	0.0016

Table 1 Effect of errors in open, short and load as indicated by the value of the sum defined in the text.

The second sensitivity study is to check the magnitude of the error in antenna S11 expected for an observed value of the sum. While an error in the assumed S11 of the load is not detectable using the reversed 2-port test an error of 0.001 in the load S11 will produce an error of close to the same value in the measured S11 of the antenna. Errors of about 0.001 in the sum results from errors the antenna S11 about an order of magnitude smaller.

While 2-port cases B and D can detect an error in the open and the short the values for the open and short cannot be uniquely determined since these 2-port devices are symmetrical with S11=S22. In this case an error in the open can be masked by an error in the short. S11 needs to be significantly different from S22 as in cases C and E in order to be able to solve for errors in the open and the short. However simulations show that an error in the loss which is in the same direction for both the open and short can be detected with an unknown symmetrical 2-port. Some examples of the effect of calibration data errors on the measurement of the antenna S11 are given in Table 2.

Errors in antenna S11	Error in calkit
0.001	0.001 error in load magnitude
0.001	1 radian error in load S11 phase at -60dB
0.0001	0.001 error in open or short magnitude
0.0001	1 ps error in open or short

Table 2. Effect of errors on antenna S11

These results are for an antenna S11 around -15dB for which an error of 0.001 corresponds to about 0.05 dB in amplitude and 0.3 degrees of phase. From these simulations it might be reasonable to assume that reversed 2-port errors below 0.05 dB and 0.3 degrees of phase indicate we should get an accuracy of better than 0.005 dB and 0.03 degrees of phase in S11 measurements of the antenna.

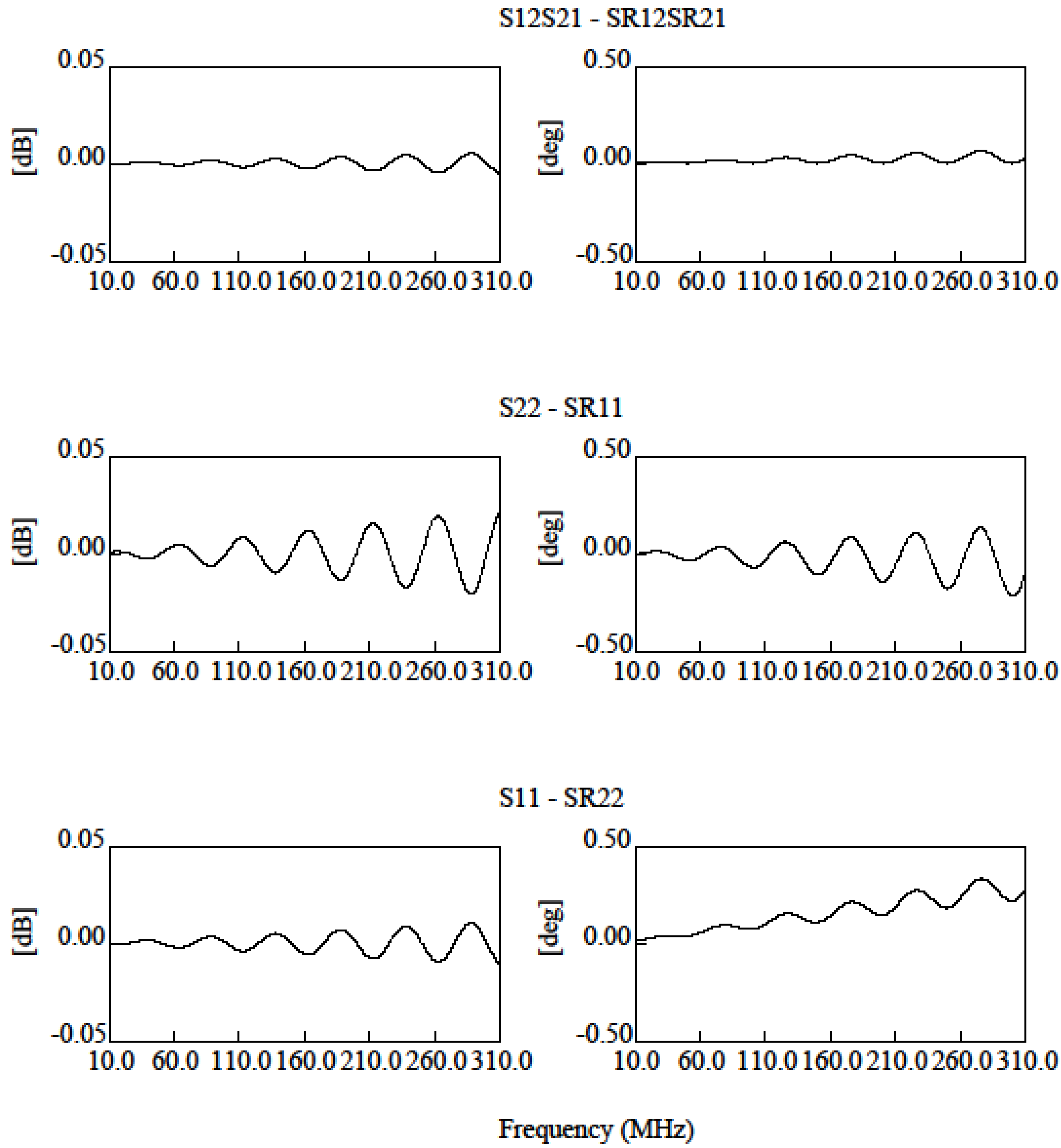

Figure 1. Effect of 1 ps error in open electrical length.