EDGES MEMO #084

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Subject: Tests of VNA accuracy

A simple tests of VNA accuracy can be made by measuring the S11 of a high quality cable with far end either open or shorted. In this case the refection coefficient measured by the VNA should be

$$\Gamma_{open/short} = \left(Z_{open/short} - 50\right) \big/ \left(Z_{open/short} + 50\right)$$

Where $Z_{open/short}$ is given by the cable model below:

Cable Model:

$$\text{C = capacitance} = 100\ pf/m$$

$$L = Z_R^2\ C\left(1 + disp\ f^{-1/2}\right)$$

$$f = \text{frequency}$$

$$R = 2\pi\ L\ disp\ f^{1/2}$$

$G = 2\pi f C \tan D$ (when $\tan D$ = loss tangent of Teflon = 2×10^{-4})

$$\gamma = \left[\left(jwL + R\right)\left(jwC + G\right)\right]^{1/2}$$

$$\Gamma = \exp\left(-\gamma c\tau\right)$$

$$Z_c = \left[\left(jwL + R\right)/\left(jwC + G\right)\right]^{1/2}$$

$$Z_{open} = Z_c\left(1 + \Gamma\right)/\left(1 - \Gamma\right)$$

$$Z_{short} = Z_c\left(1 - \Gamma\right)/\left(1 + \Gamma\right)$$

Where C,L, R, G are the cable capacitance, inductance, resistance and shunt conductance per unit length. Z_c is the complex impedance of the cable, disp is the dispension parameter c is the velocity of propagation in the cable and τ is the 2-way cable delay. The dispersion arises from the inductance from the magnetic field inside the inner and outer conductors. This inductance is the imaginary part of the skin effect impedance and is equal in magnitude to the resistance and both vary with the square root of frequency as long as the skin depth is much smaller than the thickness of the conductors (see MK5 Memo 67). The nominal cable capacitance is assumed, although it is not critical, and the values of disp, c, Z_R, the real part of the cable impedance (mini circuits CBL-10ft-SMSM+) are found which are the best least squares fit to the VNA measurements.

The results were

$$Z_R = 49 \quad \Omega$$

disp = 89

$$c = 0.69 \times 3 \times 10^8$$

Figure 1 shows the measured loss for a cable of 29 ns 2-way delay along with the expected loss based on the model above. For this cable the best fit impedance Z_c was 49 ohms which along with the impedance becoming complex at low frequencies results in some ripple in the loss similar to those in the measurements, which were made with an Agilent PNA N5222A with electronic calibration. The ~ 0.1 dB peak to peak ripple and departure from the expected result are well within the performance specifications for this network analyzer. The phase errors, which are not shown are within 0.4 degrees rms which is also within the instrument's specified performance. Better performance is expected from an impedance analyzer in this low frequency application. The next step is to test an Agilent 4191A or similar instrument. Also tests using the N5222A with manual calibration are expected to improve accuracy.

Summary of VNA error:

	Rms	Peak
S11 magnitude error	0.04 dB	0.1 dB
S11 phase error	0.4 deg	0.7 deg

The estimate of VNA accuracy assumes that the CBL cable is accurately modeled by the ideal transmission line and is free of irregularities or other defects which are not in the model. More tests with accurately manufactured semi-rigid coax and alternate methods of measurements are needed.

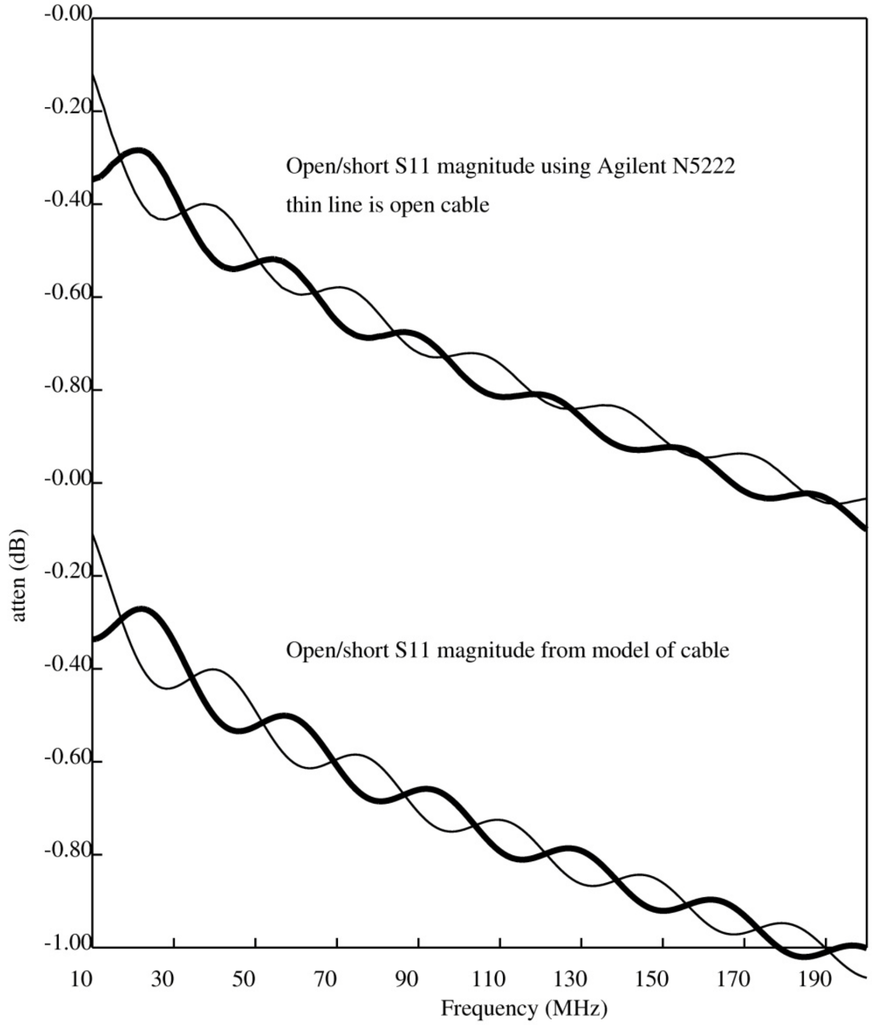

Figure 1. Comparison of VNA cable measurements with results expected from model.