EDGES MEMO #273

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February 6, 2018

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To: EDGES Group

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Subject: Modeling of midland balun loss

The midband balun uses a larger coaxial transmission line than the lowband balun to reduce the loss and widen the antenna bandwidth. Owing to the schedule of deploying the midband antenna only limited tests of the antenna and balun were made as described in memos 267 and 270. In order to measure the midband balun a "spare" midband balun was constructed. Prior to complete assembly in which the center conductor was epoxied in place the tests described in memo 270 a potential problem of poor contact in the SMA connector outer conductor was discovered and while further tests show that this a potential problem it fails to explain the much larger loss than expected. To explore the loss further a model is constructed starting at the antenna end using transmission line sections. Each section is modeled account for the inductance within the conductors as in Ramo and Whinnery.

Section	Length (inch)	Outer diameter (in)	Inner diameter (in)	ε
1	1.0	1.25	0.5	2.7
2	16.0	1.25	0.5	1.0
3	1.0	1.25	0.5	2.7
4	16.0	1.25	0.5	1.0
5	1.0	1.25	0.5	2.7
6	0.6	1.25	0.1	1.0
7	0.6	0.161	0.05	2.05

Table 1. Coaxial transmission line sections

Material	Sections	Conductivity %	Loss tangent	
Brass	1, 2, 3, 4, 5	24		
Cu plated brass	1, 2, 3, 4, 5	40		
Polyethylene	1, 3, 5		2×10^{-4}	
Cu	6	100		
Gold plated brass	7	1.5		Center conductor
Connector brass	7	3.0		Outer conductor
Teflon	7		2×10^{-4}	

Table 2. Conductivity of sections as a percentage of copper

Figure 1 shows the measured S11 for the balun tube with the antenna end open and covered with an extention of the tube with inner diameter of 1.25". In order to obtain a model which comes close to the fitting the measured S11 the parameters listed in tables 1 and 2 were required. While the conductivity of the copper plated center conductor is lower than the approximately 100% of copper expected the large discrepancy is the very low conductivity of the connector center conductor needed to fit the measured S11. In order to test this further a measurement was made of the Ampenol 13244 panel plug with the center pin soldered. The results of this measurement are shown in Figure 2. Figures 3a and 3b show the connector in the balun tube and another connector of the same type with the center conductor shorted to the flange.

The explanation for the high loss in the connector, which has to be confirmed by discussion with the manufacturer is that below the gold plate is a layer of Nickel which has a relative permeability of about 20 at 100 MHz declining to unity at about 10 GHz (see Lucyszyn Microwave Characterization of Nickel PIERS online 4, 6 (2008)). The effect of the Nickel is to increase the loss through the skin effect since the skin depth δ is given by

$$\delta = \left[2 / \left(\sigma 2\pi f \mu_o \mu_r \right) \right]^{1/2}$$

is decreased

where σ = conductivity

f = frequency (Hz)

μ_o = permeability of free space

μ_r = relative permeability

and the resistance which is proportional to $\mu_r^{1/2}$ is increased. For a 50 microinch (1.27 μm) gold layer over a 100 microinch (2.54 μm) layer of nickel over beryllium copper the skin depths are 7.8 μm, 3 μm and 13 μm respectively so most of the conduction is in the gold and nickel with little in the beryllium copper which is effectively shielded by the nickel. In this case, the equivalent conductivity would be approximately that of the nickel reduced by $20^{1/2}$ or only a few percent of copper. Figure 4 shows the S11 of the open balun tube with the Amphenol connector replaced with an omni spectra 2051-1201-00 connector which probably has no nickel layer as it was found to have a S11 less than 0.005 dB when shorted in the same manner as shown in Figure 3b. The model parameters used for the connector used 24% conductivity in place of the 1.5 and 3.0% in table 2. Further study of the composition of connectors is underway as the composition of the omni spectra part is unknown and the part is obsolete and no longer available. It is noted that multiconductor coaxial lines are being modeled by Sherko Zinal (Modeling of Multiple Coaxial air-lines considering finite conductivity and surface roughness – Proc of 45th European Microwave Conference, 2015). But assume that nickel is non-magnetic. Figure 5 shows the S11 of the balun tube with the end shorted compared with the model.

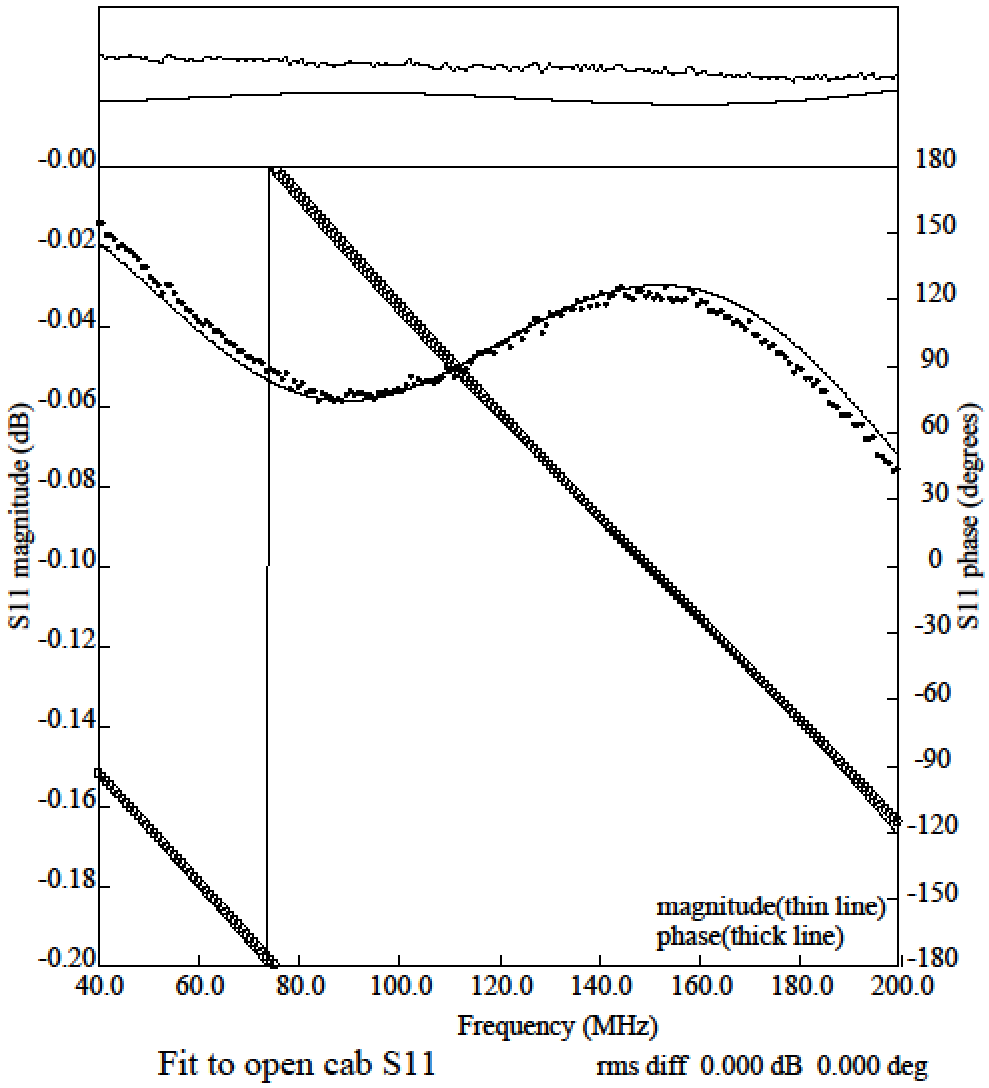

Figure 1. Measured S11 of balun with open end compared with model.

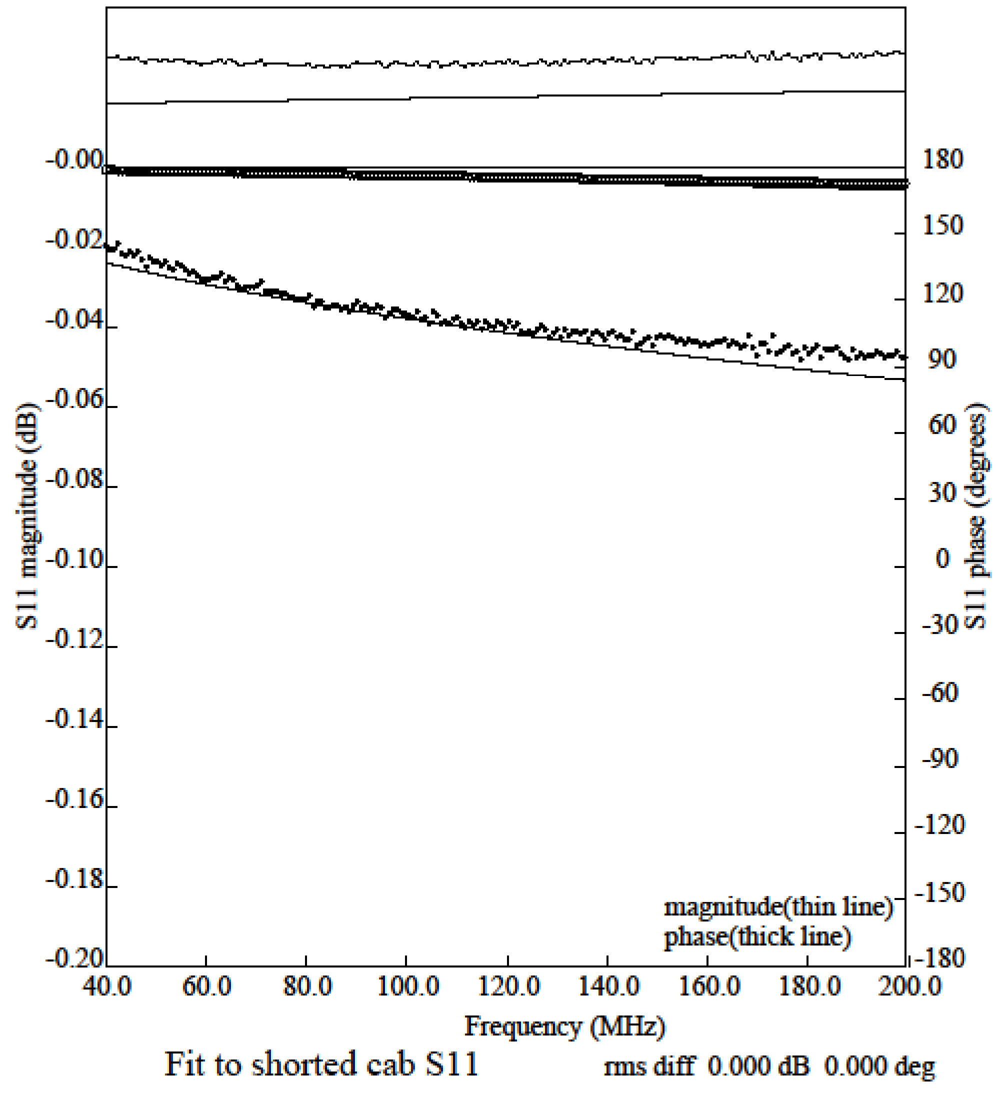

Figure 2. S11 of shorted connector (see Figure 3b) compared with model.

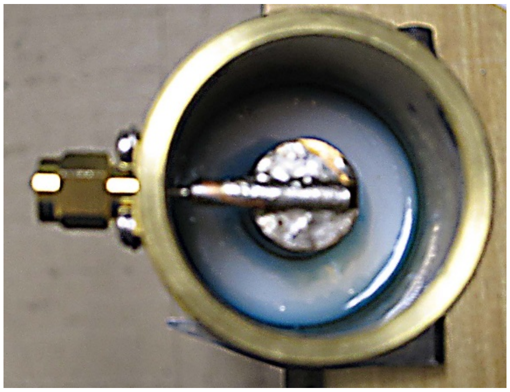

Figure 3a.

Figure 3b.

Amphenol connector in balun (a) and shorted for test (b).

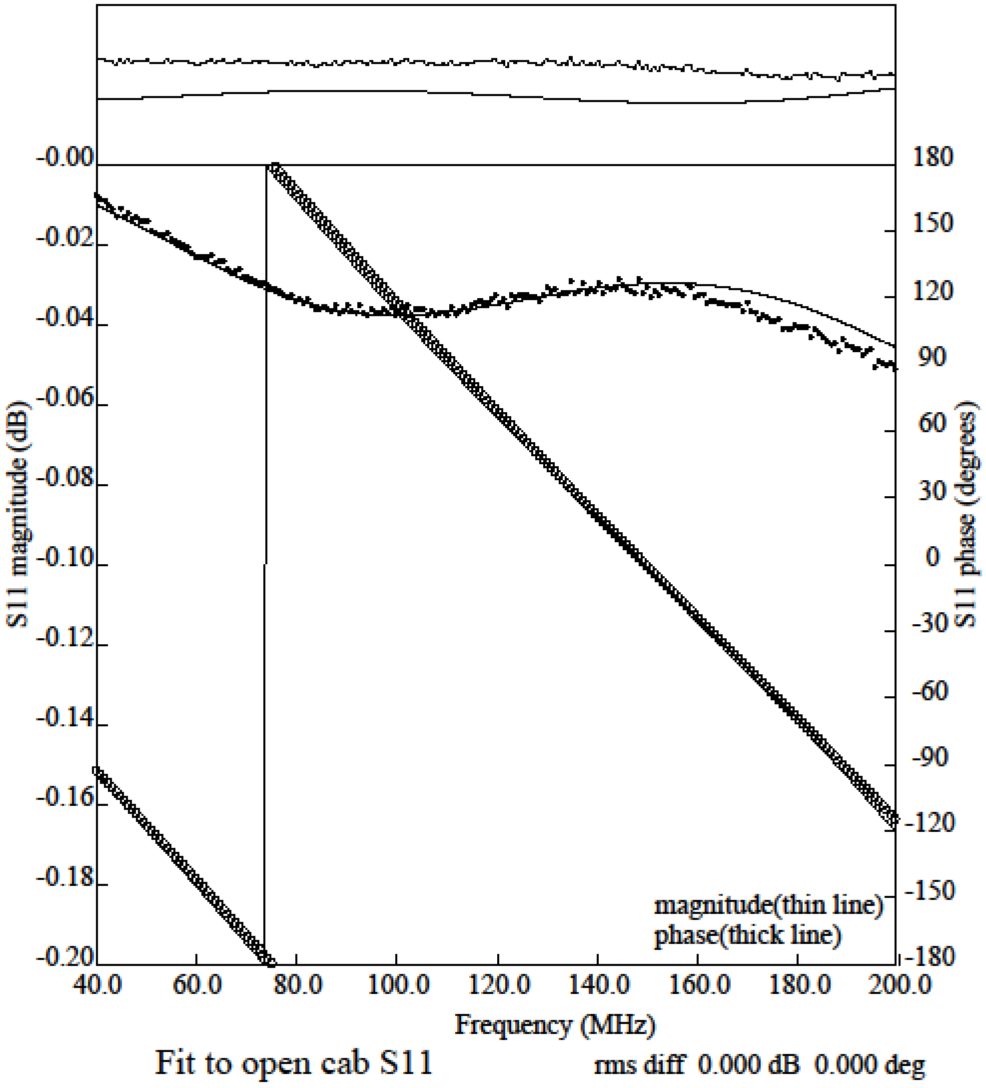

Figure 4. Measured S11 and model after replacing the Amphenol connector with Omni spectra connector. The result is a significant decrease in the loss consistent with very little loss in the connector.

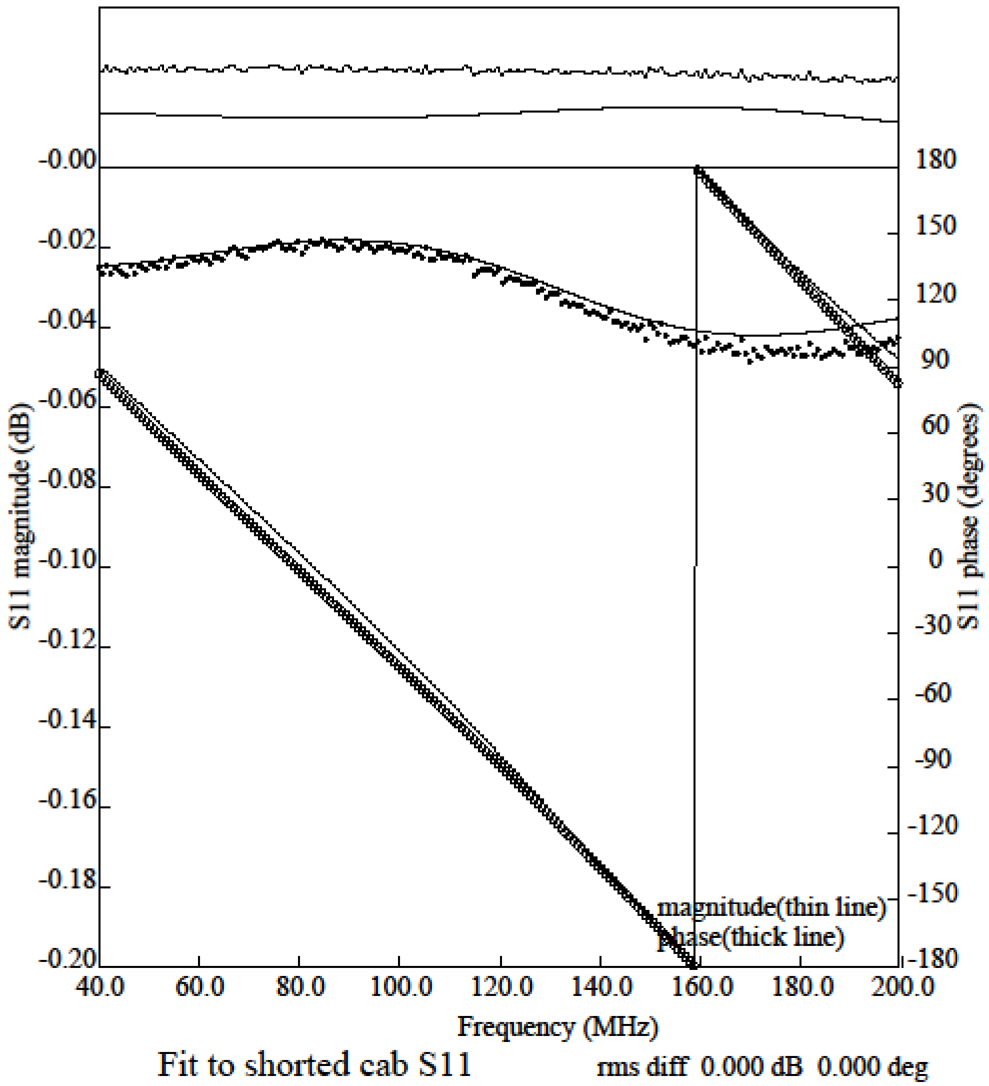

Figure 5. Measured S11 Omni spectra connector and balun end shorted compared with model.