PBAR NOTE 566
ELECTROMAGNETIC PROPERTIES OF ECCOSORB MF-190

Dave McGinnis

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Introduction

ECCOSORB MF is magnetically loaded epoxide material available from Emerson & Cuming Microwave Products. Sheet stock of MF-190 was used to build the microwave absorbers used in the 6 Ghz slow wave pickup that was described in Pbar Note No. 565. This note describes the setup and results of a test to measure the electromagnetic permittivity and permeabilty of MF-190.

Test Setup and Theory

A waveguide shorted transmission was built using WR159 waveguide as shown in Figure 1. Waveguide WR-159 has dimensions of 1.6” x 0.8” which gives it a cutoff frequency at 3.7 Ghz and a useable single mode passband from 5-7 Ghz. The effects of the microwave launch were removed by using the Thru-Reflect-Line calibration technique available on the HP8510. Two pieces of 0.25” thick MF-190 was machined to fit snugly into the WR159 waveguide. The reflection coefficient with a short placed behind the MF-190 material was measured for two different thickness, 0.25”(one piece) and 0.50” (two pieces). The reflection coefficient measured at the calibration reference plane can be determined using straight forward transmission line theory.

The fundamental mode for a rectangular waveguide is the TE10 mode. For the TE10 mode, the ratio between the transverse electric field to the transverse magnetic field is independent of position and is given as:

$$H_x^{\pm} = \pm \frac{1}{Z_w} E_y^{\pm} \tag{1}$$

where:

$$Z_w = \eta \frac{\kappa}{\beta} \tag{2}$$

$$\eta = \sqrt{\frac{\mu}{\varepsilon}} = \sqrt{\frac{\mu_r \mu_o}{\varepsilon_r \varepsilon_o}} = \sqrt{\frac{\mu_r}{\varepsilon_r}}\eta_o \tag{3}$$

$$\kappa = \sqrt{\mu_r \varepsilon_r}\,\frac{\omega}{c} \tag{4}$$

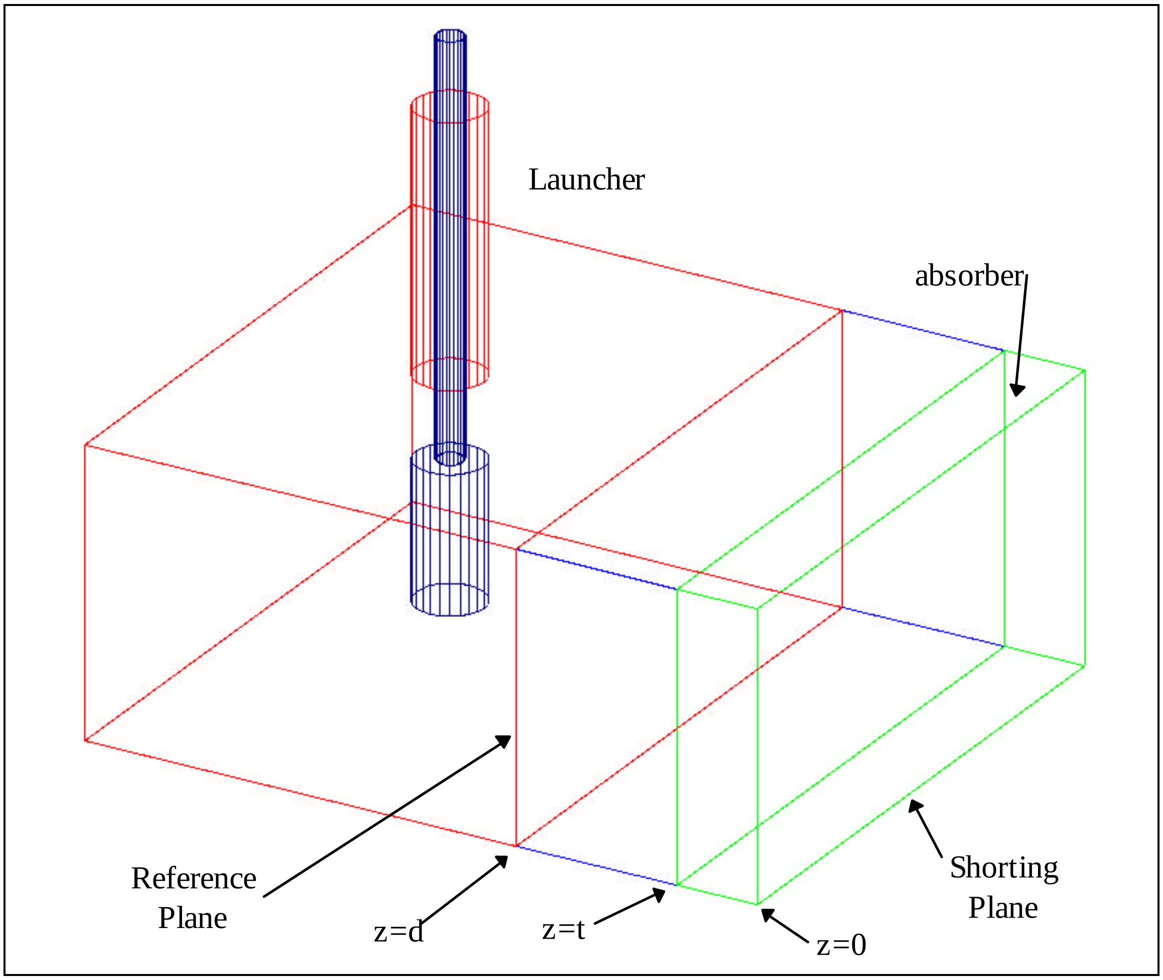

Figure 1. Schematic of test setup

$$\beta^2 = \kappa^2 - \left(\frac{\pi}{a}\right)^2 \tag{5}$$

where a is the width of the waveguide. At the short (z=0), the reflection coefficient, which is the ratio between the magnitude of the reflected transverse electric field to the incident transverse electric field is -1 because the transverse electric field must vanish at the short. The reflection coefficient at the edge of the absorber ($z = t_a$) is:

$$\Gamma = -1e^{-j2\beta_a t_a} \tag{6}$$

The wave impedance at the edge of the absorber is:

$$Z\big|_{z=t_a} = Z_{w_a} \frac{1+\Gamma}{1-\Gamma} \tag{7}$$

$$Z\big|_{z=t_a} = jZ_{w_a} \tan(\beta_a t_a) \tag{8}$$

The network analyzer returns the reflection coefficient at the reference plane of the network analyzer which has been set by the calibration procedure to be at z=d. The reflection coefficient at the reference plane is related to the reflection coefficient at the absorber interface by:

$$\Gamma\Big|_{z=t_a} = \Gamma\Big|_{z=d} e^{j2\beta_o (d-t_a)} \tag{9}$$

Using Equations 8 and 9, the wave impedance at the absorber interface is related to the reflection coefficient at the reference plane by:

$$jZ_{w_a} \tan(\beta_a t_a) = Z_{w_o} \frac{1+\Gamma\Big|_{z=d} e^{j2\beta_o (d-t_a)}}{1-\Gamma\Big|_{z=d} e^{j2\beta_o (d-t_a)}} \tag{10}$$

$$jZ_{w_a} \tan(\beta_a t_a) = F\left(t_a, \Gamma\Big|_{z=d}\right) \tag{11}$$

The wave impedance and wave number in Equations 10 and 11 can be solved if two measurements are made with the absorber being twice as thick in the second measurement as it was in the first measurement.

$$\begin{aligned} jZ_{w_a} \tan(\beta_a t_a) &= F\left(t_a, \Gamma\Big|_{z=d}^{t=t_a}\right) \\ jZ_{w_a} \tan(\beta_a 2t_a) &= F\left(2t_a, \Gamma\Big|_{z=d}^{t=2t_a}\right) \end{aligned} \tag{12}$$

If the first equation in Equation 12 is divided by the second equation, then the wave number in the absorber, can be determined:

$$\beta_a t_a = \cos^{-1}\left(-\sqrt{\frac{1}{2} \frac{F\left(2t_a, \Gamma\Big|_{z=d}^{t=2t_a}\right)}{F\left(2t_a, \Gamma\Big|_{z=d}^{t=2t_a}\right) - F\left(t_a, \Gamma\Big|_{z=d}^{t=t_a}\right)}} \right) \tag{13}$$

The wave impedance in the absorber can be found using Equation 11:

$$Z_{w_a} = -j \frac{F\left(t_a, \Gamma\Big|_{z=d}^{t=t_a}\right)}{\tan(\beta_a t_a)} \tag{14}$$

Using Equation 2, the relative permeability in the absorber is found from the wave impedance in Equation 14:

$$\mu_r = \frac{Z_{w_a}}{\eta_o} \frac{\beta_a t_a}{\kappa_o t_a} \tag{15}$$

Using Equation 5, the relative permittivity is determined from:

$$\varepsilon_r = \frac{1}{\mu_r}\left(\frac{1}{\kappa_o t_a}\right)^2\left((\beta_a t_a)^2 + \left(\pi\frac{t_a}{a}\right)^2\right) \tag{16}$$

Using this technique, the electromagnetic permittivity and permeabilty of MF-190 was measured and the results are shown in Figures 2-4.

There was a resonance in the calibration fixture at 6.8 Ghz which seems to have caused a glitch in the data at this frequency.

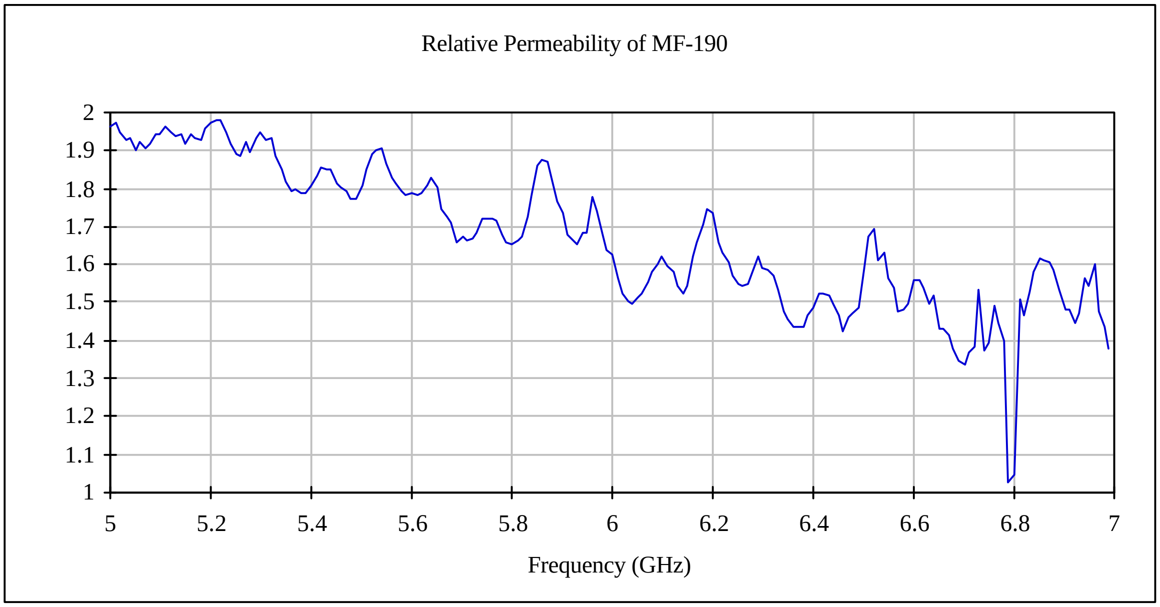

Figure 2 Magnitude of the relative permeability (m_r) of MF-190

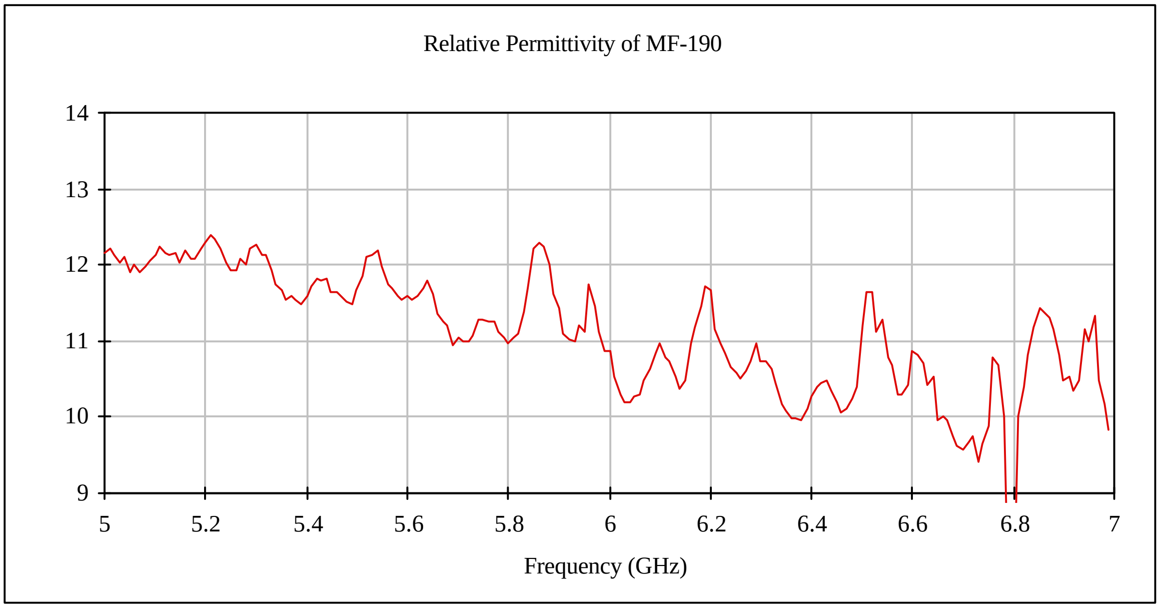

Figure 3. Magnitude of the relative permittivity (e_r) of MF-190

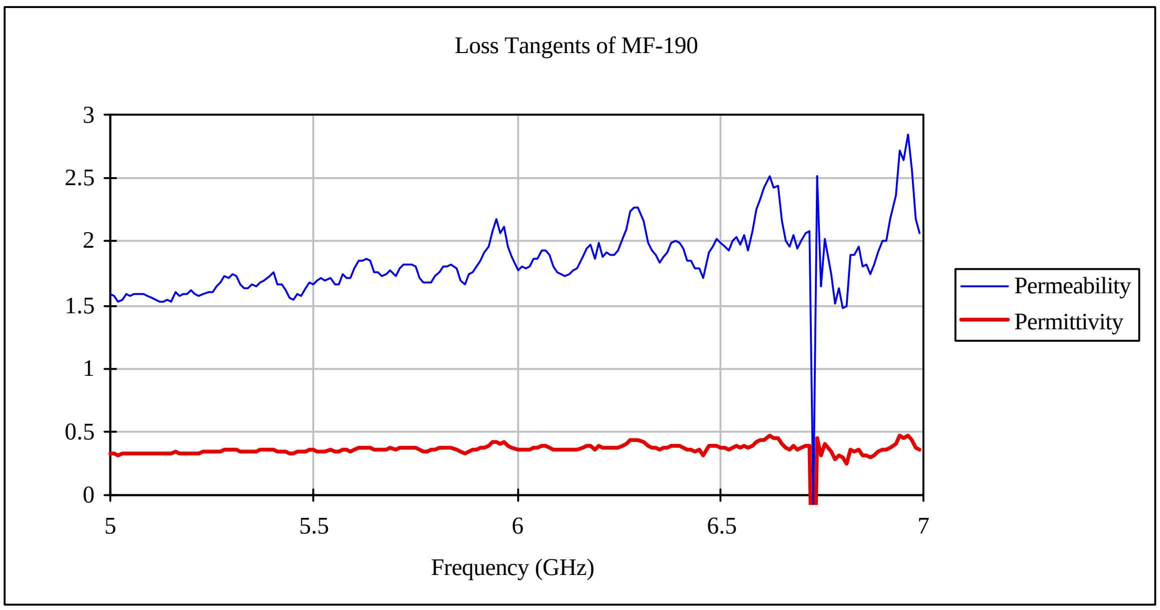

Figure 4. Loss tangents of MF-190