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The Performance of Measurement-Based Simple Models for the X-band Complex Permittivity of 370 Ω/sq. Kapton XC®

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1. Introduction

The X-band complex permittivity of a commercially-available, carbon loaded, polyamide film is measured. Simple though approximate models are obtained which are shown to be necessary and suitable for analytic or computational modeling of thin absorbing structures realized with the thin lossy film. The utility of each model is tested against experimental results for thin high-impedance surface (HIS) enhanced Salisbury absorbers, enhanced in the sense that the HIS augmented absorber is much thinner than a conventional Salisbury absorber [1, 2].

2. Kapton XC® Resistive Film

Kapton XC® is a commercially-available, carbon-loaded polyamide film manufactured by Dupont® [3]. Though these films are exceptionally durable and available in a range of surface resistivities, their effective permittivity is complex valued and, therefore, their sheet impedance is frequency dependent as is typical of carbon-loaded dielectrics [4, 5]. We have measured the X-band complex permittivity of Kapton XC® with a manufacture's quoted direct current (DC) sheet resistivity of approximately 370 Ω/sq. and thicknesses of 40.0 μm. The S-parameters of the sample was measured using the freespace system and techniques described in [6]. Assuming illumination by a normally incident uniform plane wave (UPW), the measured transmission coefficient S_{21} for an electrically thin high dielectric contrast film can be related to the complex permittivity of the film by a resistive boundary condition [7]:

$$\varepsilon_{r,eff} = 1 - 2j\frac{1 - S_{21}}{S_{21}k_0\delta} \quad (1)$$

where $k_0 = \omega\,[\varepsilon_0\mu_0]^{1/2}$ and δ is the thickness of the film. The measured, relative effective permittivity given by Eq. (1) is then approximated by either a simple conductor model or a single term Debye type model [8] respectively:

$$\varepsilon_{r,eff} = \varepsilon_r' - j\frac{\sigma_{lf}}{\omega\varepsilon_0} \quad (2)$$

$$\varepsilon_{r,eff} = \varepsilon_{hf} + \frac{\varepsilon_{lf} - \varepsilon_{hf}}{1 + j\omega\tau} \quad (3).$$

Figs. 1(a) and 2(a) illustrates the fit of the models to the X-band complex permittivity calculated with Eq. (1) from measured S_{21} data and provide the necessary parameters for Eqs. (2) and (3) in the captions. The approximate nature of the two simple models is

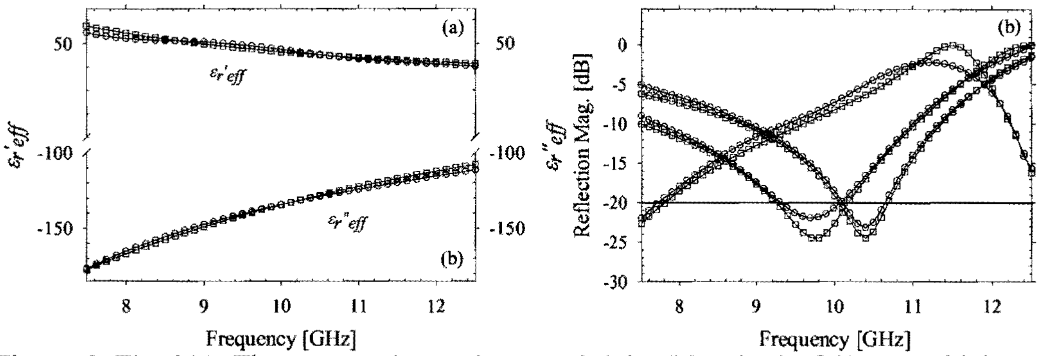

Figure 2. Fig. 2(a): The measured complex permittivity (blue dots) of 40.0 μm thick, 370 Ω/sq., Kapton XC® vs. a single term Debye model (Eq. (3), green squares) with the following parameter values: $\varepsilon_{hf} = 31.91$, $\varepsilon_{lf} = 1219.88$, and $\tau = 1.466\times10^{-10}$. Fig. 2(b): The measured (blue dots) and calculated (Eq. (7) green squares) reflection magnitude. Here the high- impedance surface is identical to that described in Fig. 3(a) and the permittivity of the Kapton XC® film is given by Eq. (3). The Kapton XC® film is placed t = 2.392 mm, 3.572 mm, and 7.142 mm above the plane of the high-impedance surface.

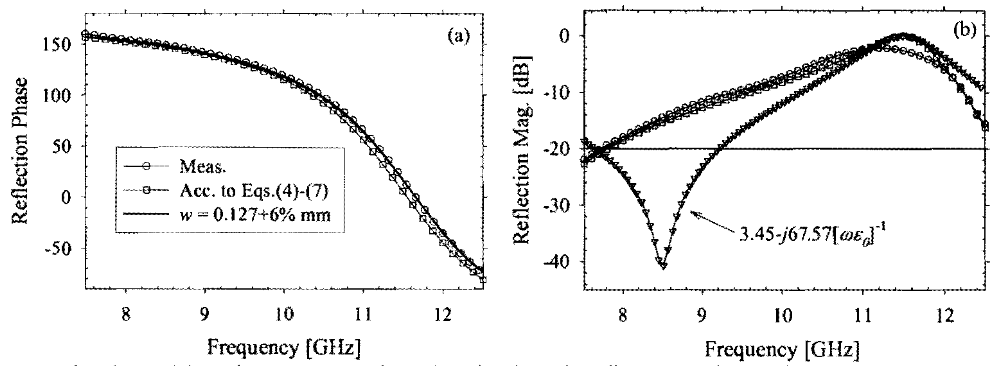

Figure 3 Fig. 3(a): The measured and calculated reflection phase for a high-impedance surface consisting of square metal patches (D = 5.0 mm, w = 0.127 mm) on GML 1000 substrate ($\varepsilon_r = 3.2$, d = 0.762 mm). Note the sensitivity of Eqs. (4)-(7) to small changes in w. Fig. 3(b): The measured (blue dots) and calculated (Eq. (7)) reflection magnitude where the Kapton XC® film is placed t = 7.142 mm above the plane of the high-impedance surface. The high-impedance surface is identical to that described above and the permittivity of the Kapton XC® film is given by Eq. (3), and the simple conductor model $3.45\text{-}j\,67.57[\omega\varepsilon_0]^{-1}$.

4. Conclusions

This study showed the need for relatively precise knowledge of the real part of a carbon particulate loaded, lossy thin film's permittivity in order to accurately engineer the reflection coefficient of high-impedance surface enhanced electromagnetic absorbers. Specifically, simple, approximate models can be obtained for the X-band complex permittivity of commercially available, carbon loaded, 370 Ω/sq., Kapton XC® thin film. These simple, approximate models can be used in the analytic modeling of high-impedance surface enhanced X-band absorbers or computational modeling of other possibly more complicated absorbing structures which are composed, in part, of 370 Ω/sq. Kapton XC® and designed to operate within the X-band. Finally, the results of this study illustrate the need for simple models for calculating the complex permittivity spectra of 370 Ω/sq. Kapton XC® over a relatively broad bandwidth (1–20 GHz) to facilitate accurate analytical and computational modeling.

obvious and provides motivation to investigate their utility in an analytic model of a thin absorber against experimental data for the same.

3. High-impedance Surface Enhanced Absorber

Previous work has shown that the reflection magnitude of a HIS absorber can be used to characterize the frequency dependent behavior of a HIS [9, 10] provided the properties of the absorbing film are well known. Conversely, if the properties of the HIS are well known the engineering utility of the frequency dependent model of the film may be tested. Here we employ the accurate analytical model (See Fig. 3(a)) for a square patch HIS [11]:

$$Z_{HIS} = Z_{SCL}[1 + Z_{SCL}/Z_G]^{-1} \tag{4}$$

$$Z_G = -j\pi[\omega\varepsilon_0(\varepsilon_r + 1)D\ln(\frac{1}{\sin(w\pi/2D)})]^{-1} \tag{5}$$

where $Z_{SCL} = \eta\mathrm{Tan}[d\omega\,[\varepsilon_r\varepsilon_0\mu_0]^{1/2}]$, and $\eta = [\mu_0(\varepsilon_r\varepsilon_0)^{-1}]^{1/2}$ other necessary parameters are given in the caption of Fig. 3(a). If a layer of Kapton XC® covered ultra low dielectric constant structural material ($\varepsilon_r \sim 1$) is placed above the HIS, an enhanced Salisbury absorber is obtained:

$$Z_{inp} = Z_f\eta_0^{\,2}\frac{Z_{HIS} + Z_{SCL}}{\eta_0^{\,2}(Z_f + Z_{HIS} + Z_{SCL}) + Z_f Z_{HIS} Z_{SCL}} \tag{6}$$

$$\Gamma = \frac{Z_{inp} - \eta_0}{Z_{inp} + \eta_0} \tag{7}$$

where, $Z_{SCL} = \eta_0\mathrm{Tan}[k_0 t]$, $Z_f = [j\omega\varepsilon_0(\varepsilon_{r,eff} - 1)\delta]^{-1}$, and Γ is the calculated reflection coefficient for a normally incident UPW. The results of Fig. 1(b) and Fig. 2(b) about 8 GHz suggest the need for accurate knowledge of the real part of the Kapton XC® film's effective permittivity for use in the analytical model of HIS enhanced Salisbury absorbers. In Fig. 3(b), we further demonstrate the necessity of obtaining models from X-band measurements of the complex permittivity. Specifically, Eq. (3) is compared to a simple conductor model where the real part is taken as the real part of the permittivity of unloaded Kapton, $\varepsilon'_r = 3.45$, and the DC conductivity, $\sigma_{lf} = 67.57$, is taken from the manufacture's quoted sheet resistivity and thickness. The effect of the real part of the Kapton XC® film's permittivity on the center frequency of the absorber is pronounced.

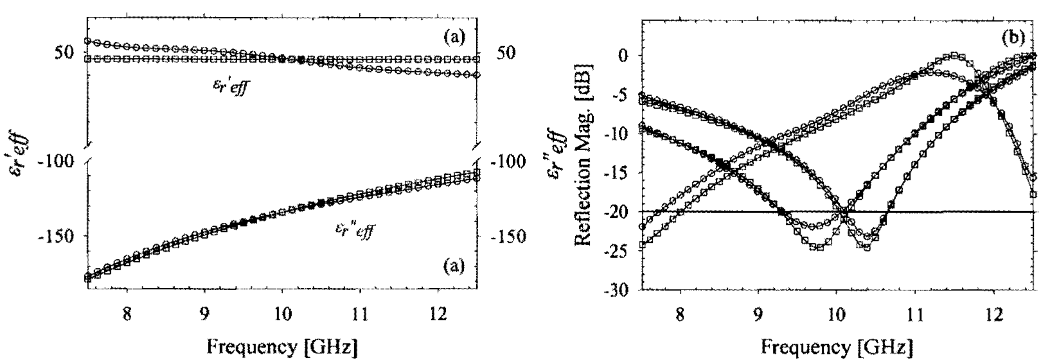

Figure 1 Fig. 1(a): the measured complex permittivity (blue dots) of 40.0 μm thick, 370 Ω/sq., Kapton XC® vs. a simple conductor model (Eq. (2), green squares) with the following parameter values: $\varepsilon'_r = 47.06$, and $\sigma_{lf} = 74.65$. Fig. 1(b): Here the high-impedance surface is identical to that described in Fig. 3(a) and the permittivity of the Kapton XC® film is given by Eq. (2). The Kapton XC® film is placed $t = 2.392$ mm, 3.572 mm, and 7.142 mm above the plane of the high-impedance surface.

Acknowledgement

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