Preliminary Studies of Electromagnetic Properties of Microwave Absorbing Materials used in Calibration Targets [*]

Amanda E. Cox and Michael D. Janezic
Electromagnetics Division
National Institute of Standards and Technology
Boulder, CO 80305, U.S.A.

Abstract—**As part of the ongoing effort at NIST to develop a microwave brightness temperature standard, we are exploring the electromagnetic and thermal characteristics of microwave calibration targets. Part of this effort is focused on measuring the electromagnetic properties of absorber materials used in the construction of microwave calibration targets. Improved materials characterization would also support applications of absorber materials beyond their use for calibration targets; for example, anechoic chamber design would benefit from this improved understanding.**

Keywords-microwave absorber; microwave radiometry; radiometer calibration; remote sensing; standards

I. INTRODUCTION

There are numerous microwave absorbing materials on the market designed for a wide variety of applications. These materials cover a broad range of performance characteristics that are not always well understood or well publicized. The electromagnetic properties of microwave absorbers are often frequency dependent, and in many cases are used at frequencies for which they were not initially designed or for which the properties have yet to be measured. The measurement techniques used by different manufacturers are not necessarily standardized or publicly documented. Information on the electromagnetic properties of these materials is sometimes provided by the manufacturer, but in many cases the information is unavailable or incomplete, or the uncertainties associated with the data provided are not well-established. A user of one of these materials may have to make certain assumptions about the material performance and, in the case of modeling performance across a range of frequencies, may have to interpolate or extrapolate from the information provided.

Microwave calibration targets are used in radiometer systems to provide a calibration source of known microwave brightness temperature. The targets are typically constructed of a thermally-conductive substrate coated with microwave absorbing material to provide a near black-body radiator at the frequencies of interest. These targets are designed to achieve a radiating surface with an emissivity near 1.0. The targets are heated or cooled to provide a specific brightness temperature as viewed by the radiometer. In order to know the effective microwave brightness temperature of the calibration target, one must know the physical temperature and emissivity of the target, plus the contributions of any reflected background. The physical temperature is measured through temperature sensors embedded in the target, but the emissivity must be characterized through other means. The overall emissivity of a target is dependent upon the electromagnetic properties of the surface material, the thickness of the material relative to the frequency at which it is observed, and the geometry of the target surface. Estimates of the emissivity are often made from reflectivity measurements. Emissivity values can also be modeled from knowledge of the electromagnetic properties of the materials used, but there is currently no widely accepted standard method for determining the emissivity of a microwave calibration target.

The U.S. National Institute of Standards and Technology (NIST) is developing a national standard for microwave brightness temperature. This standard would support passive microwave radiometer measurements performed in free-space by providing a stable reference for comparison of different instruments over large spans of time. One proposed realization of this standard calls for a combination of a standard radiometer and a standard calibration target with associated uncertainty analyses [1]. A standard calibration target can also be used as a transfer standard to transfer the brightness temperature scale to other targets and radiometers. Although a national standard calibration source does not yet exist, many microwave calibration targets are in use that provide a brightness temperature scale for microwave radiometers. In all of these cases, it is important to characterize the performance of the target properties including emissivity. This work is important for establishing industry standards for measuring and reporting not only target performance, but the performance of microwave absorbing materials in general.

To carefully characterize the electromagnetic properties of absorber materials incorporated in calibration targets, we have collected a number of different samples that could be measured in waveguide, from various manufacturers. Using the transmission/reflection (T/R) method [2] for measuring the relative permittivity and permeability, we have measured various absorber material samples in a series of rectangular

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waveguide fixtures at frequencies ranging from 8 to 18 GHz. In this method, the relative permittivity and permeability of the sample are calculated from the measured S-parameters of a sample-loaded waveguide and the dimensions of both the sample and waveguide fixture. In this paper, we present the results for two waveguide bands, from two materials: a ferrous-doped epoxy and carbon-loaded closed-cell foam. These bands were chosen because they contain common frequencies at which microwave remote sensing radiometers operate and represented a natural extension of existing NIST capability. We chose to use waveguides rather than coaxial transmission lines for ease of sample preparation and to allow future extension of the measurements to 26.5 GHz or higher.

In Section II we describe the materials measured, in Section III we present the measurement techniques and results, and in Section IV we summarize the results and discuss plans for future work.

II. MATERIALS

One common absorber material used in microwave radiometry consists of a foam base impregnated with carbon. The foam base can be open- or closed-cell and is typically made from substances such as silicone or polyurethane. This lightweight absorber comes in many different geometric configurations and is used for many applications besides calibration targets. Because of its ease of use, it is routinely used as a calibration target in ground-based field applications. It is not commonly used for space applications due to the out-gassing of contaminants in a vacuum. This class of materials is also frequently used to line anechoic chambers. The particular sample used and presented here is a flat slab of carbon-impregnated polyethylene foam and was cut to size for each waveguide band.

Another common material used in calibration target construction is ferrous-doped epoxy absorber. This material is composed of an epoxy base material doped with a ferrous substance (e.g., carbonyl iron powder). The absorber can be obtained either as a rigid machinable stock or in a castable version for which the absorber ingredients are combined at the time of target manufacture. The electromagnetic properties are controlled by the concentration of the ferrous particles, and several different concentrations are available to cover a variety of applications and frequency ranges. The absorber material is heavy, brittle, and difficult to machine; but despite this, it is frequently used for space applications due to its low out-gassing properties. The results presented here are for one specific concentration of lossy material in a machinable epoxy base. Since the cross sectional size of the material relative to the waveguide dimensions is critical, the material samples were hand lapped on a diamond cutting surface to obtain the best surface flatness and guide-wall contact possible.

III. MEASUREMENTS

In order to measure the complex permittivity and permeability of the two absorber materials, we employed the transmission/reflection (T/R) method [2]. In this method, a waveguide section is partially filled with the material under test. Although it is not necessary that the material extend the entire length of the waveguide, the material must completely fill the waveguide's cross-section. Using a vector network analyzer, the calibrated scattering parameters of the loaded-waveguide section are measured as a function of frequency. We employ a thru-reflect-line (TRL) method to calibrate the vector network analyzer [3]. From the measured scattering-parameters and the dimensions of the material and waveguide, we use the T/R algorithm to calculate the material's complex permittivity. If the material is also magnetic, the T/R method is used to calculate the relative permeability.

The T/R method can only be employed if there is a single TE_{10} mode propagating in the loaded-waveguide section. Therefore, two waveguide bands are required to cover the frequency range from 8 to 18 GHz: WR-90 (8 – 12.4 GHz) and WR-62 (12.4 – 18 GHz). Separate network analyzer calibrations and S-parameter measurements are performed in each waveguide band for the sample-loaded waveguide fixtures. Successful TRL calibration depends upon calibration samples of appropriate phase length, so special through sections of waveguide were made for each waveguide band calibration.

Air gaps between the waveguide walls and the measurement sample affect the relative permittivity and permeability results and must be taken into account [2]. If the air gaps are not accounted for properly, as documented in a NIST-sponsored intercomparison [4], large systematic errors are introduced into both the computed permittivity and permeability. This effect is even more critical as measurements are performed at higher frequencies and the waveguide dimensions decrease. Even after we carefully machined the absorber materials to fit into the high-quality waveguide sections, a small gap remained. To account for this small gap, we used the method described in Appendix C of [2].

In Fig. 1 we show results for the measured complex permittivity of the foam absorber material as a function of frequency. There is a slight discrepancy between the measurements made in the two bands. Since the samples were prepared from the same material lot, we suspect that slight differences in the foam's density, due to compression of the sample, is the cause of this discrepancy. However, the results agree within the measurement uncertainties for both the real and imaginary parts of the relative permittivity. This material is non-magnetic, so only the permittivity results are shown.

In Figures 2 and 3 we show results for the complex permittivity and permeability of the ferrite-loaded, epoxy absorber material. For the complex permeability, we see good agreement between the two waveguide bands. However, we see some discrepancy in the complex permittivity results. The samples for each band were machined from different lots, and there is a possibility that there is a slight batch-to-batch variation of the material properties. The air gap between the sample and waveguide differs for each band and the correction becomes more critical as frequency increases; we plan to investigate this discrepancy further. The results for the lower frequency band are consistent, within defined uncertainties, with those measured during previous tests [2] for the same sample.

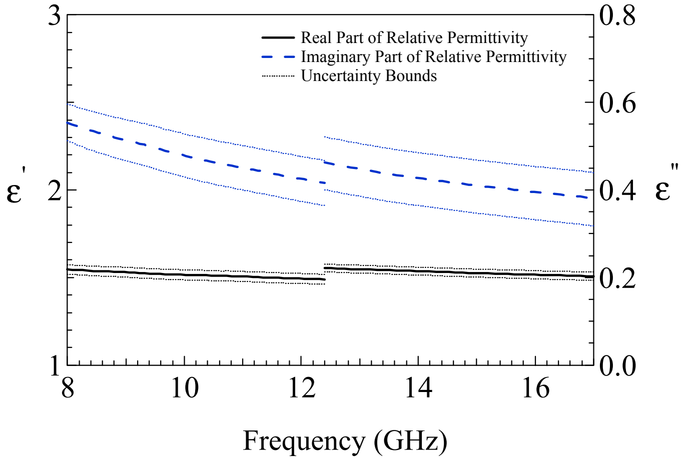

Figure 1. Complex permittivity of closed-cell foam.

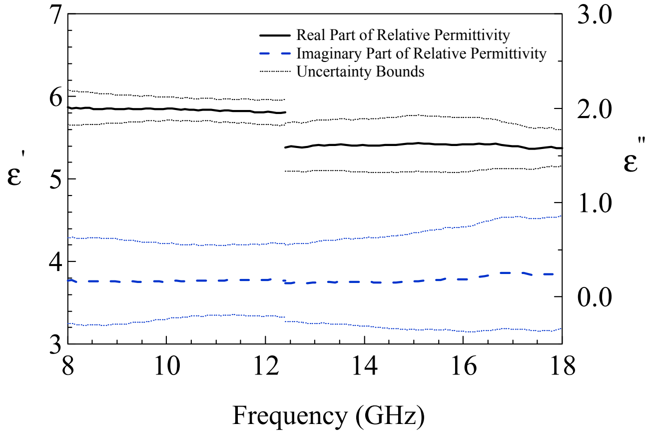

Figure 2. Complex permittivity for ferrous-doped epoxy.

IV. SUMMARY

We have begun to establish accurate methods for measuring and reporting the electromagnetic properties of microwave absorber material. The results from these measurements can be used to better characterize passive microwave radiometer calibration targets as well as absorber for other applications. We have presented preliminary results for the complex permittivity and permeability of two different absorber materials measured in two different waveguide bands that cover the frequencies between 8 and 18 GHz. While we noted changes in the measurements from one waveguide band to the other that are within the measurement uncertainty, a smoother transition from band to band can probably be achieved. For the softer, more compressible materials, future plans include developing a tool to cut the foam to a tighter tolerance. This will achieve a more consistent fit of the sample in the waveguide from one band to the other and will ensure that the incident surface of the sample is flat and perpendicular to the waveguide walls. For the more rigid materials, accurate dimensional metrology and imaging techniques will provide more detailed information on the air gaps between the sample and waveguide walls and will allow us to refine the correction for these gaps in the calculations. In addition, more samples from each ferrous-doped epoxy batch will be machined so the batch-to-batch variation can be studied.

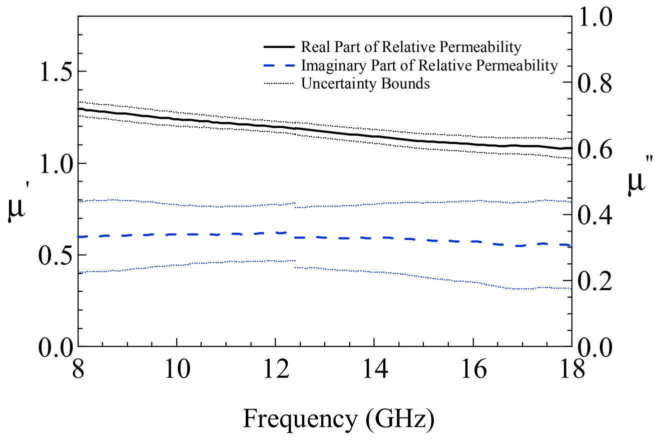

Figure 3. Complex permeability for ferrous-doped epoxy.

Measurements of more samples of varying absorber characteristics are planned. Several more samples have been obtained for measurement including ferrous-doped epoxy samples of multiple absorber concentrations, and other types of foam materials. Also being considered is a comparison between the machined epoxy base material and the castable epoxy material. We now have waveguide test fixtures to make measurements up to 26.5 GHz; this is useful since our standard radiometer measurements have been made in this frequency range. This effort is an important part of the overall process of fully characterizing microwave radiometer calibration targets.

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