4-40 GHz Permittivity Measurements of Indoor Building Materials

Jonathan R. Abel and Jon W. Wallace
Department of Electrical and Computer Engineering
Lafayette College
Easton, PA, USA
E-mail: abeljon@lafayette.edu, wall@ieee.org

***Abstract*—The transmission properties of common building materials, such as glass and red brick, are measured at normal incidence over a range of 4-40 GHz in a modular anechoic chamber using a vector network analyzer. Complex permittivity values are estimated using only transmission S-parameters of the material under test and an air reference measurement. Results suggest that the method provides reasonable estimates of complex permittivity at high microwave and lower mm-wave frequencies.**

I. Introduction

The millimeter-wave (mm-wave) bands from 30-300 GHz have been identified as a good candidate for supporting high bandwidth wireless services in 5G and beyond. High microwave bands in the Ku-Ka (10-40 GHz) range are also of interest, providing additional bandwidth over existing UHF bands, but possibly exhibiting less transmission loss than 60 GHz and above. Planning of future wireless networks can be accomplished using accurate ray-tracing simulations, but there is a lack of published data on the complex permittivity of practical building materials at these frequencies.

Previously we presented transmission loss measurements of several building materials in the 4-40 GHz range [1], and here we extend that work by exploring robust techniques for extracting the complex relative permittivity. Applying such methods is challenging due to the need for careful system calibration and the sensitivity of short wavelength signals to small movements of the measurement equipment. We present a simple method that requires only two transmission measurements per sample and no movement of probing antennas, resulting in reasonably robust estimates of the complex permittivity of materials in the 4-40 GHz frequency range. The method is very similar to the frequency-domain estimation method presented in [2]. The novelty of our work lies not so much in the measurement techniques, which are well established, but rather in the frequency range of interest and the scope of this effort.

II. Measurement Setup

Figs. 1 and 2 show a block diagram of the measurement setup and a photo of the compact anechoic chamber, respectively. The chamber is constructed from wooden frames covered with thin carpet that are assembled into a $1.8\ \mathrm{m} \times 1.2\ \mathrm{m} \times 1.2\ \mathrm{m}$ enclosure and placed on two tables. A slot between the tables allows cables and antenna supports to conveniently extend from the floor up into the chamber. Velcro-backed microwave absorber is placed on the chamber walls as well as on the bottom of the chamber where possible.

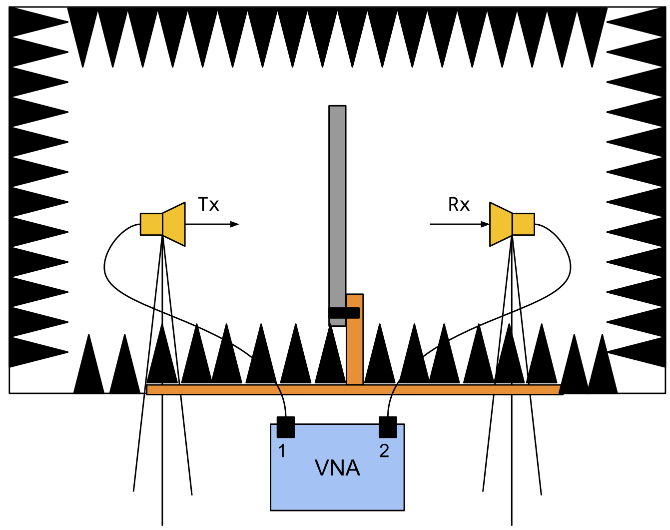

Fig. 1. Measurement setup for transmission-based permittivity measurements.

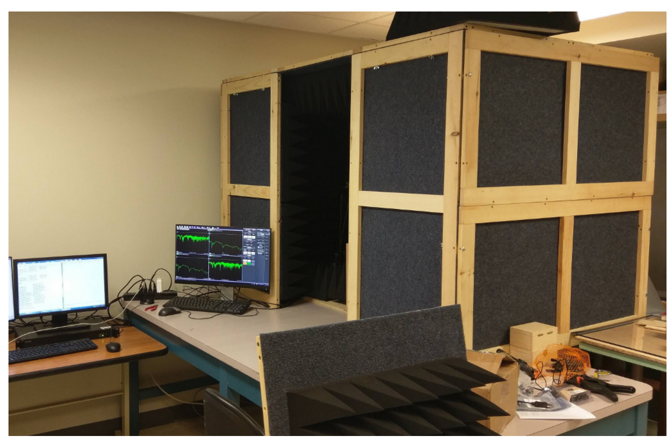

Fig. 2. Compact anechoic chamber used for measurements. The side panel is removed for easy positioning of the material and replaced for the measurement.

The side panel can be temporarily removed for positioning the antennas and the sample. The transmit and receive antennas are RFSpin QRH40 4-40 GHz quad-ridged horns, which are placed on tripods that rest on the floor and extend up through the bottom slot of the chamber. Transmission measurements are performed with a Rohde&Schwarz ZNB40 vector network analyzer (VNA), which has been calibrated to the antenna ports. Note that the VNA is placed underneath the table and controlled remotely from a PC, allowing the horns to be reached with short 1.2 m test cables. A wooden sample holder is placed on the chamber bottom midway between the two horns. Light materials such as wood, drywall, or glass can be clamped with plastic clamps to the sample holder, whereas heavier materials like brick are stacked on top of the holder.

III. Data Collection and Processing

For each sample, two measurements of $T(f) = S_{21}$ over the $f = 4 - 40$ GHz range are performed: 1) a reference measurement $T_{\text{air}}(f)$ with only air between the antennas, and 2) a sample measurement $T(f)$ with the material present. The thickness d of each sample is measured using a digital caliper. The basic steps for extracting permittivity are as follows:

1) $T(f)$ and $T_{\text{air}}(f)$ are transformed to the time domain using an inverse FFT.
2) The main response is identified and time-gated using a modified Hann window.
3) The time-domain signals are transformed back to the frequency domain signal $T'(f)$ and $T'_{\text{air}}(f)$ using an FFT.
4) The measurement reference plane is transformed to the surface of the material using

$$T''(f) = \frac{T'(f)}{T'_{\text{air}}(f)\exp(j2\pi df/c)}, \tag{1}$$

where $c = 3.0 \times 10^8$ m/s.

Ideally, $T''(f)$ captures transmission through the slab of material with the effects of antennas and free-space propagation removed. This quantity can then be compared with the transmission properties of an ideal homogeneous slab $T_{\text{slab}}(f)$ having the same thickness d and an assumed complex permittivity. A numerical search is performed to find the complex relative permittivity $\epsilon_r = \epsilon/\epsilon_0 = \epsilon' + j\epsilon''$ that fits $T_{\text{slab}}(f)$ to the measured value $T''(f)$. Since variation of material parameters with frequency is expected, the fit is performed over 20 equal-length sub-bands to see the frequency dependence.

IV. Results

A representative measurement result is shown in Fig. 3 for glass and solid red clay brick. Fig. 3(a) shows S-parameters of the measurements after an IFFT, time-gating, and FFT for the air and material measurements. Fig. 3(b) shows the extracted complex permittivity values using a best fit to a dielectric slab model. Fig. 3(c) indicates the goodness of fit by comparing the ideal slab transmission behavior to that extracted from

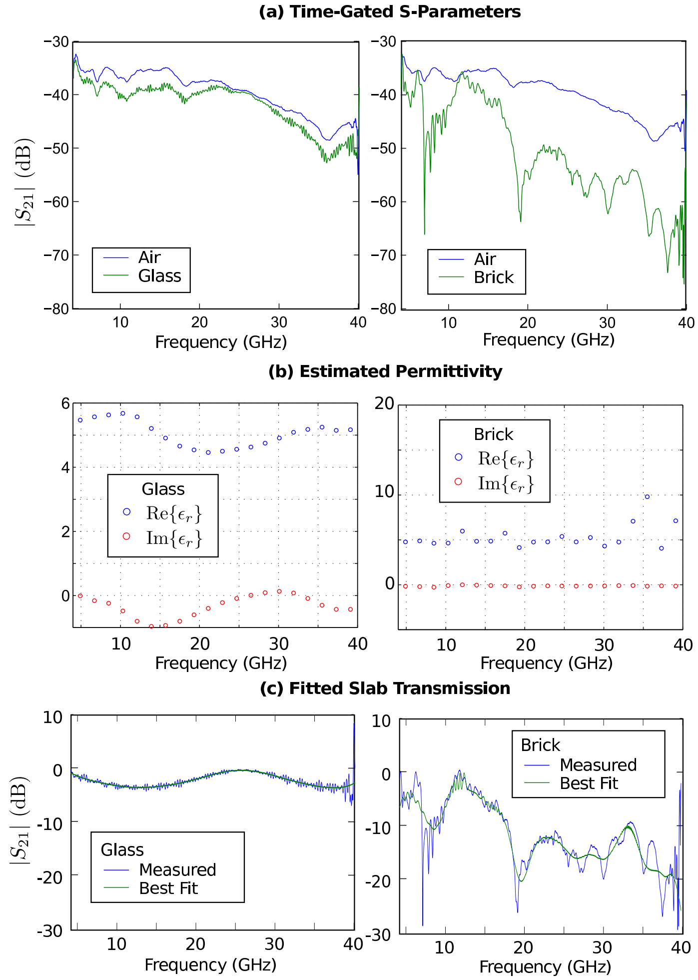

Fig. 3. Illustration of resulting complex permittivity estimate: (a) Measured S_{21} after IFFT, time gating, and FFT, (b) fitted relative complex permittivity, (c) resulting fit in S_{21} of the slab using the estimated permittivity.

the measurement showing very good agreement. Values also compare favorably with the 1-15 GHz measurements in [2], giving $\epsilon_{r,\text{glass}} \in [6.35, 6.71]$ and $\epsilon_{r,\text{brick}} \in [3.70, 4.48]$.

V. Conclusion

This paper has presented a simple method for extracting permittivity of indoor building materials in the 4-40 GHz range using a compact anechoic chamber. In future work, we will provide a more comprehensive measurement campaign of materials using this technique.

VI. Acknowledgment

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References

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