4-40 GHz Transmission Measurement of Indoor Building Materials at Normal Incidence

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***Abstract*—Transmission of common building materials, such as drywall, cinder block, gypsum board, and glass are characterized over the 4-40 GHz range for normal incidence in a compact anechoic chamber. Results indicate that many interior materials only exhibit modest increase in loss compared to UHF (1 to 4 dB), whereas cinder block can increase loss by as much as 20 to 30 dB.**

I. Introduction

There is recent interest in exploiting millimeter-wave (mm-wave) bands in the 30-300 GHz range to provide the needed communications bandwidth for 5G and beyond [1]. However, employing these bands as a replacement for UHF services is challenging, due to the line-of-sight (LOS) nature of the channel, likely necessitating advanced beamforming at the base station and user terminals. The focus of this paper is to consider high microwave bands (Ku-Ka) in the 10-40 GHz range as a more feasible near term replacement for existing UHF-based services. Our recent measurement campaign suggests that non-LOS communications may be supported in the K band (24 GHz) within a single room or hallway and possibly through a single wall, which would be sufficient for many existing WiFi deployments [2].

Planning and optimization of wireless networks is accelerated by detailed ray-tracing simulations based on accurate physicals models of propagation environments of interest. Unfortunately, reliable estimates of building material parameters, especially in the Ku-Ka bands, are very scarce in the open literature. The purpose of this paper is to document the initial phases of a measurement campaign, whose aim is to rectify this situation. In this initial study, normally incident transmission measurements for a few common materials are presented.

II. Measurement Setup

A block diagram and photo of the measurement setup are shown in Figs. 1 and 2, respectively. Transmission measurements were performed in an a compact, cube-shaped anechoic chamber with an edge length of 2.5 m on each side. Microwave absorber covered the walls, ceiling, and floor where possible. Each material sample was placed at the center of the chamber and probed using double-ridged, vertically polarized broadband horn antennas operating from 4-40 GHz, which were placed on tripods. The spacing between the openings of the horns was 50 cm. An Agilent vector network analyzer (VNA) covering 0-67 GHz was used in the measurements, where a through calibration was performed to minimize the effects of cable loss. For each sample, $S_{21}(f)$ was measured without ($S_{21,\mathrm{cal}}$) and with ($S_{21,\mathrm{sample}}$) the sample present, where f is frequency. The power transmission coefficient T is then computed in dB as

$$T_{\mathrm{dB}}(f) = 20\log_{10}\frac{|S_{21,\mathrm{sample}}(f)|}{|S_{21,\mathrm{cal}}(f)|}. \quad (1)$$

Most of the materials were sufficiently light to be clamped to a thin wood riser on the floor of the chamber.

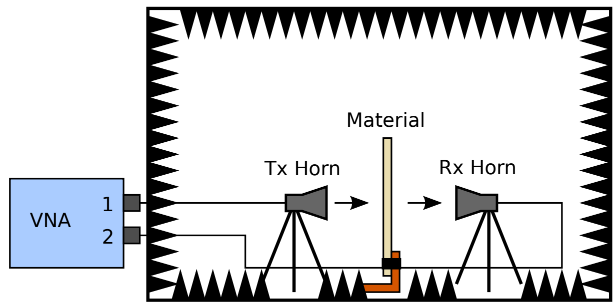

Fig. 1. Measurement setup for transmission measurements.

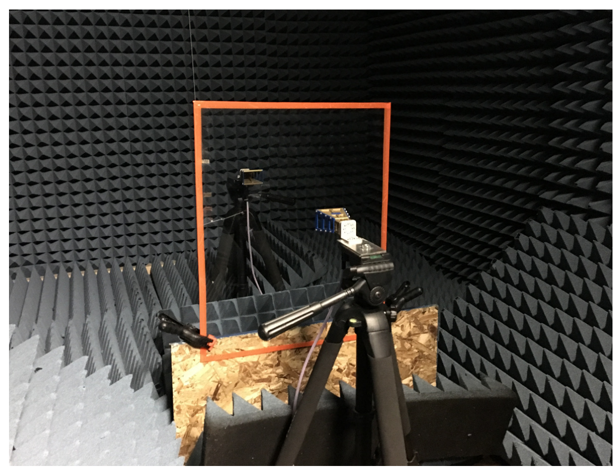

Fig. 2. Photo showing measurement setup (glass sample).

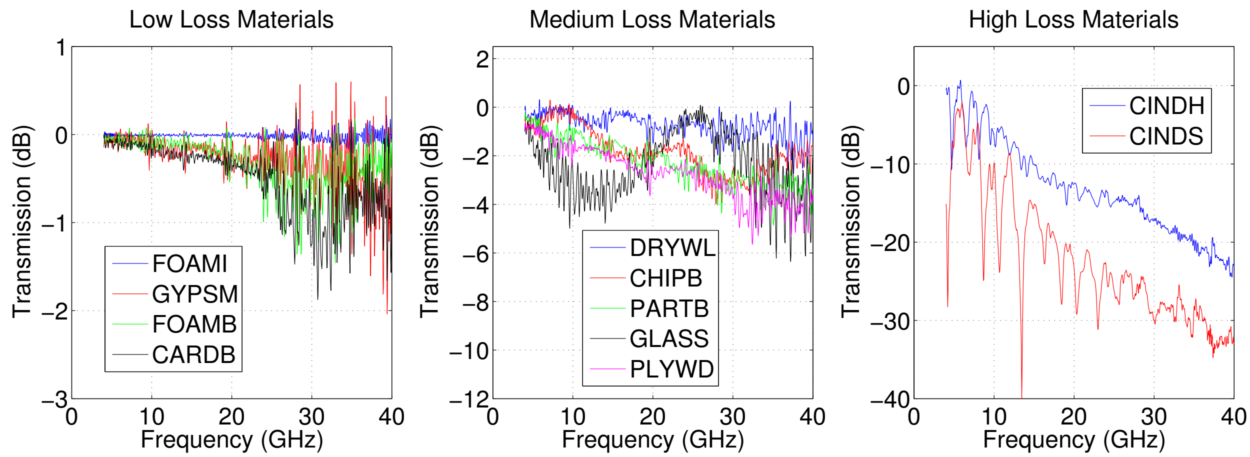

Fig. 3. Raw transmission measurements for the different building materials, computed according to (1). Materials have been grouped into three plots according to the loss severity.

TABLE I
MATERIALS

Label	Thick -ness	Description	a (dB)	b (dB /GHz)
CARDB	1.1 cm	Corrugated cardboard	0.12	-0.028
CHIPB	1.0 cm	Chipboard	-0.33	-0.068
CINDH	19.5 cm	Cinder block (aligned (w/ hollow part)	-0.86	-0.560
CINDS	19.5 cm	Cinder block (aligned w/ solid part)	-7.47	-0.674
DRYWL	1.2 cm	Drywall	-0.03	-0.032
FOAMB	0.5 cm	Thin foam sheet (poster backing)	0.02	-0.015
FOAMI	1.4 cm	ESR-2142 foam	0.00	-0.001
GLASS	0.25 cm	Solid glass plate	-2.29	-0.003
GYPSM	1.5 cm	Gypsum ceiling tile	0.07	-0.016
PARTB	1.9 cm	Particle board	-0.44	-0.085
PLYWD	2.0 cm	Plywood	-0.61	-0.096

The cinder blocks were too heavy for this, and were simply stacked high enough to fill the half-power beam illuminated by the horn antennas.

The half-power beamwidth of the horn antennas above 18 GHz was nominally 16° and 20° in the vertical and horizontal planes, respectively. Below 18 GHz, the beamwidth increased steadily, which at 4 GHz reached approximately 30° and 40° in the vertical and horizontal planes, respectively. The broad side of each sample was at least $40\text{ cm} \times 40\text{ cm}$, which at a spacing of 25 cm ensures the half-power beamwidth was smaller than the angle subtended by the sample at all frequencies.

III. Building Material Results

Table I lists the materials that were measured and their nominal thickness. Coefficients a and b represent a fit to a simple linear model explained below. Note that two different measurements were performed on the cinder block, where horns were centered on the hollow part (CINDH) and solid part (CINDS) of the internal structure. Figure 3 plots the transmission coefficient (1) versus frequency for the various building materials. Styrofoam, cardboard, and gypsum had relatively low loss (less than 2 dB) over the complete frequency range. Drywall, glass, and wood samples had moderate loss (less than 6 dB) and exhibited more periodic behavior (especially glass). The relatively thick cinder block had the most pronounced loss, which depended significantly on the alignment of the horns with the inner wall of the blocks. We note that at some frequencies, slightly positive transmission (negative loss) values were seen, likely due to imperfect calibration. Overall, the results show that the ability to employ the Ku-Ka bands for non-LOS transmission will depend critically on the interior construction of the walls. Walls composed of wood, drywall, and glass may exhibit only modest increase in loss, whereas cinder block walls can reduce transmission by as much as 30 dB.

For numerical comparison, the results were fit to the simple linear model $T_{\text{dB}}(f_{\text{GHz}}) = a + bf_{\text{GHz}}$ where coefficients a (dB) and b (dB/GHz) were found using a least mean squares fit of each plot and are given in Table I.

IV. Acknowledgment

This work was supported in part by an NSF MRI grant (Award Number 1725970). The authors would like to thank Dr. Karl Warnick for use of his compact chamber at BYU.

References

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