Report 4

Wall Transmission Frequency Characteristics

Prepared by

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1. Objective

Characterization of the Transmission Frequency Response of the residential exterior wall[1] for different angles of incidence and various standoff distances.

2. Characterization Method

We use the characterization method that is based on measuring an *insertion transfer function*, defined as the ratio of two signals measured in the presence and in the absence of the wall material under test [1]. Both the measurements must be conducted with exactly the same distances and antenna setup. The free-space measurement serves as a reference to account for all the effects that are not due to the wall. We employ time-gating to reduce significantly the effect of reflections from the floor and ceiling, and scattering from edges of the wall sample [2]. However, we will use the multiple-pass measurement technique [1], in which the portions of signal due to multiple reflections within the wall will not be gated out.

3. Tests Performed and Results

The transmission characteristics of the 12' x 8' residential exterior wall segment were measured for both HH and VV polarization using the arrangement shown in Fig. 1. Horn antennas 1 and 2 were placed on tripods, 20 ft apart, on either side of the wall. Horn 1 was used to transmit a stepped frequency signal of 7 GHz bandwidth centered at 4.5 GHz and the complex amplitudes of the gated signal received by Horn 2 were measured and recorded. The measurement was repeated using the same exact setting with one exception; the wall was not present. The ratio of the two measurements was used to determine the transmission characteristics of the wall as a function of frequency. The above measurements were repeated for different antenna positions along the wall to study the effect of looking between and through the studs and also for different downrange distances from the wall.

The above experiment was conducted for incidence angle (in the azimuth plane) of 22.5, 45 and 90 degrees for both horizontal and vertical polarization.

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[1] The wall was fabricated utilizing 2x4 wood studs placed on 16" centers. Exterior grade ¾" plywood was fastened to one side and ⅝" gypsum wallboard was applied to the other.

Since keeping the antenna setup at a fixed location is crucial to the calculation of the insertion transfer function, we kept the antennas fixed and displaced the wall along the x-axis and moved the wall to different downrange distances to emulate different antenna positions along the wall and at different distances from the wall, respectively. Also, to have radiation incident at various angles, the wall was placed at an angle with respect to the z-axis. Because of the large size of the wall sample, we were able to carry out the experiment for all of the aforementioned incident angles for larger standoff distances only. For smaller standoff distances, we only made the measurements for normal incidence.

The results are shown in Figures 2 - 7. We observe that the wall transmission frequency response is dependent on the angle of incidence and polarization. It is also a function of the stand-off distance and the position of the antennas along the wall (which determines if the antennas are stud-centered or centered between studs).

For vertical polarization, the wall transmission loss, for the 'stud-centered' case, at normal incidence for 5" and 0.5" stand-off distances is reasonably flat up to 4 GHz. For 4 and 6 GHz, the loss increases from 2.5 dB to 10 dB and from 2.5 dB to 15 dB for 5" and 0.5" stand-off distances, respectively. At frequencies beyond 6 GHz, the wall transmission loss is about 10 dB for 5" and 15 dB for 0.5" stand-off distance. The wall transmission loss for the corresponding 'between stud' cases are much lower than the stud-centered response especially for the 6 to 8 GHz frequency band.

For horizontal polarization, the wall loss, for the 'stud-centered' case, is fairly flat for normal incidence up to 5 GHz for both 5" and 0.5" stand-off distances. Beyond 5 GHz, the loss increases to 9 dB and 8 dB for 5" and 0.5" stand-off distances respectively. Again, the wall loss for the corresponding 'between stud' cases on the average are lower than the 'stud-centered' response.

For large stand-off distances, the transmission frequency response for both horizontal and vertical polarization appears to have deep nulls which shift in frequency as a function of both the incidence angle and the stand-off distance. This is true for both 'stud-centered' and 'between stud' cases.

We further note that in some of the plots, we see a gain in the transmission response instead of a loss at some frequencies. This is because of the ability of the wall to act as a dielectric lens [1].

Figure 8 shows the 'stud-centered' wall transmission response for normal incidence at 10ft stand-off distance, for both horizontal and vertical polarization, corresponding to two measurements made at different instances in time to evaluate repeatability. We note that the two vertical polarization plots are almost identical whereas the horizontal polarization plots show deviation in phase characteristics. Since the wall was being physically moved to carry out the tests at various stand-off distances and incidence angles, it is difficult to place the 12′ x 8′ wall sample at exactly the same location at two different instances in time. The wavelength at 8 GHz is 37.5mm and even an error in wall position of 1mm

would result in a fairly large phase error. This is an extremely tight tolerance requirement that cannot be met easily at all times with the current set-up.

4. Concluding Remarks

Based on our observations, we conclude that the non-uniformities in the residential exterior wall transmission response will tend to degrade image quality when the full frequency band of operation from 1 to 8 GHz is used for through-the-wall imaging.

5. References

1. A. Safaai-Jazi, S. M. Riad, A. Muqaibel, A. Bayram, "Ultra-wideband Propagation Measurements and Channel Modeling", Report on Through-the-wall propagation and material characterization, DARPA NETEX Program, 2002.
2. Agilent E5070B/5071B ENA Series RF Network Analyzers User's Guide, 2003.

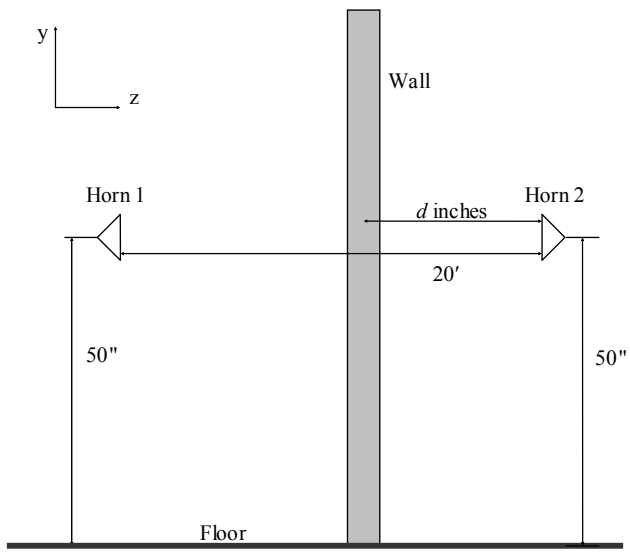


Figure 1: Experimental set-up for measurement of the transmission characteristics of the wall

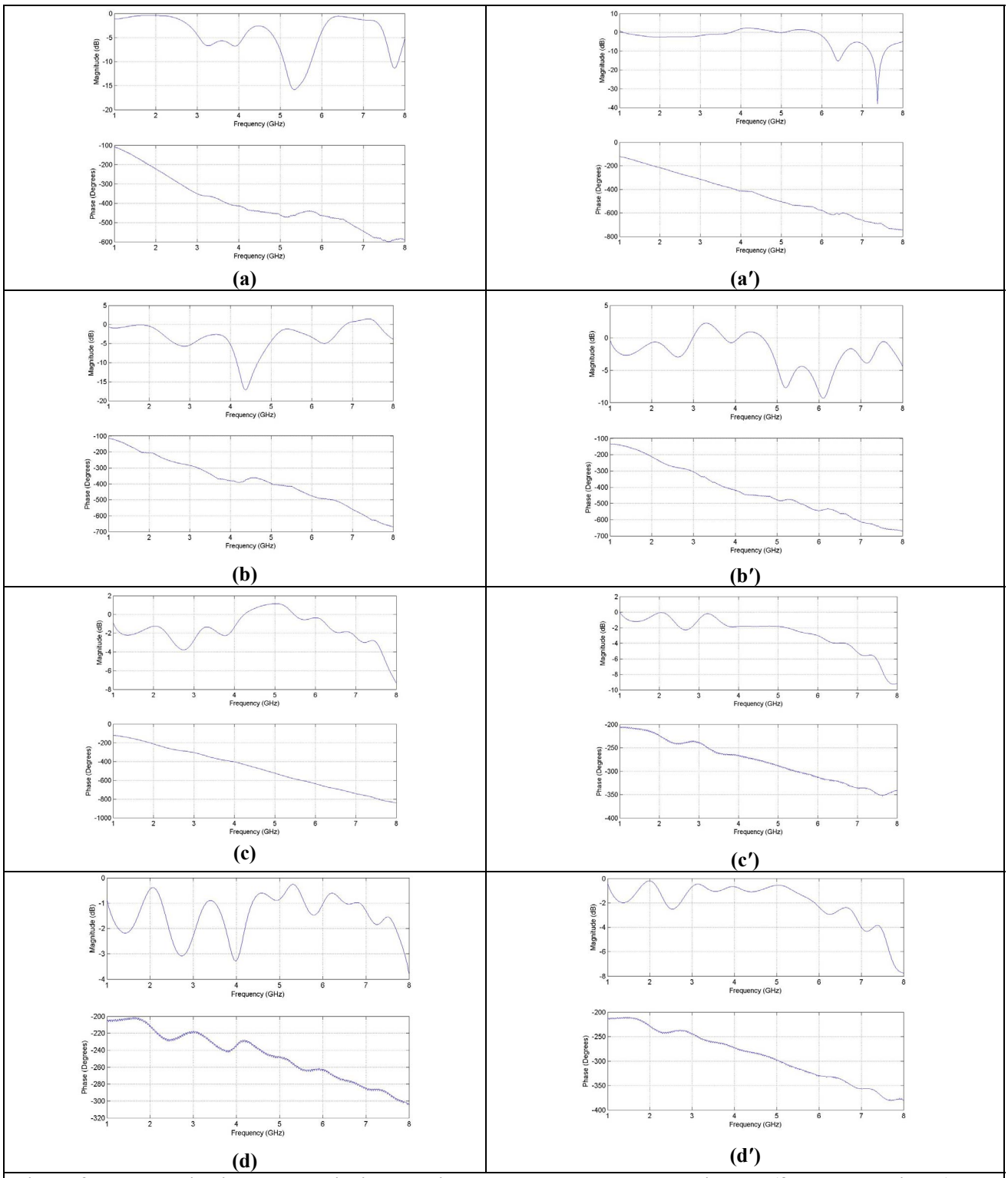


Figure 2: HH-polarization, Normal incidence with the wall at a downrange distance (from the receiver (Horn 2)) of (a) 10 ft (b) 5 ft (c) 5 inches (d) 0.5 inches. (a) - (d) are 'between stud' measurements and (a′) - (d′) are 'stud-centered' measurements.

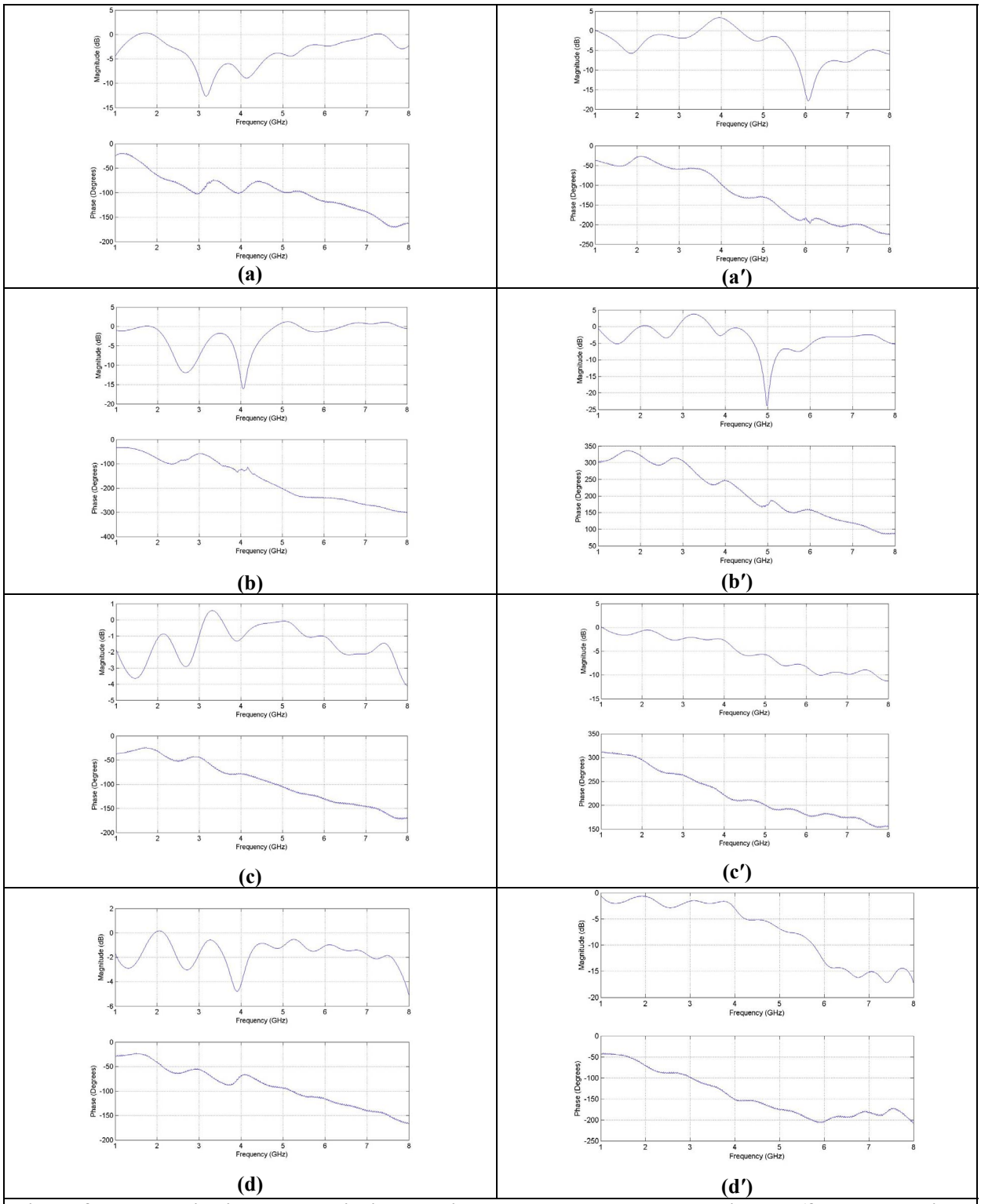


Figure 3: VV-polarization, Normal incidence with the wall at a downrange distance (from the receiver (Horn 2)) of (a)10 ft (b) 5ft (c) 5 inches (d) 0.5 inches. (a) - (d) are 'between stud' measurements and (a′) - (d′) are 'stud-centered' measurements.

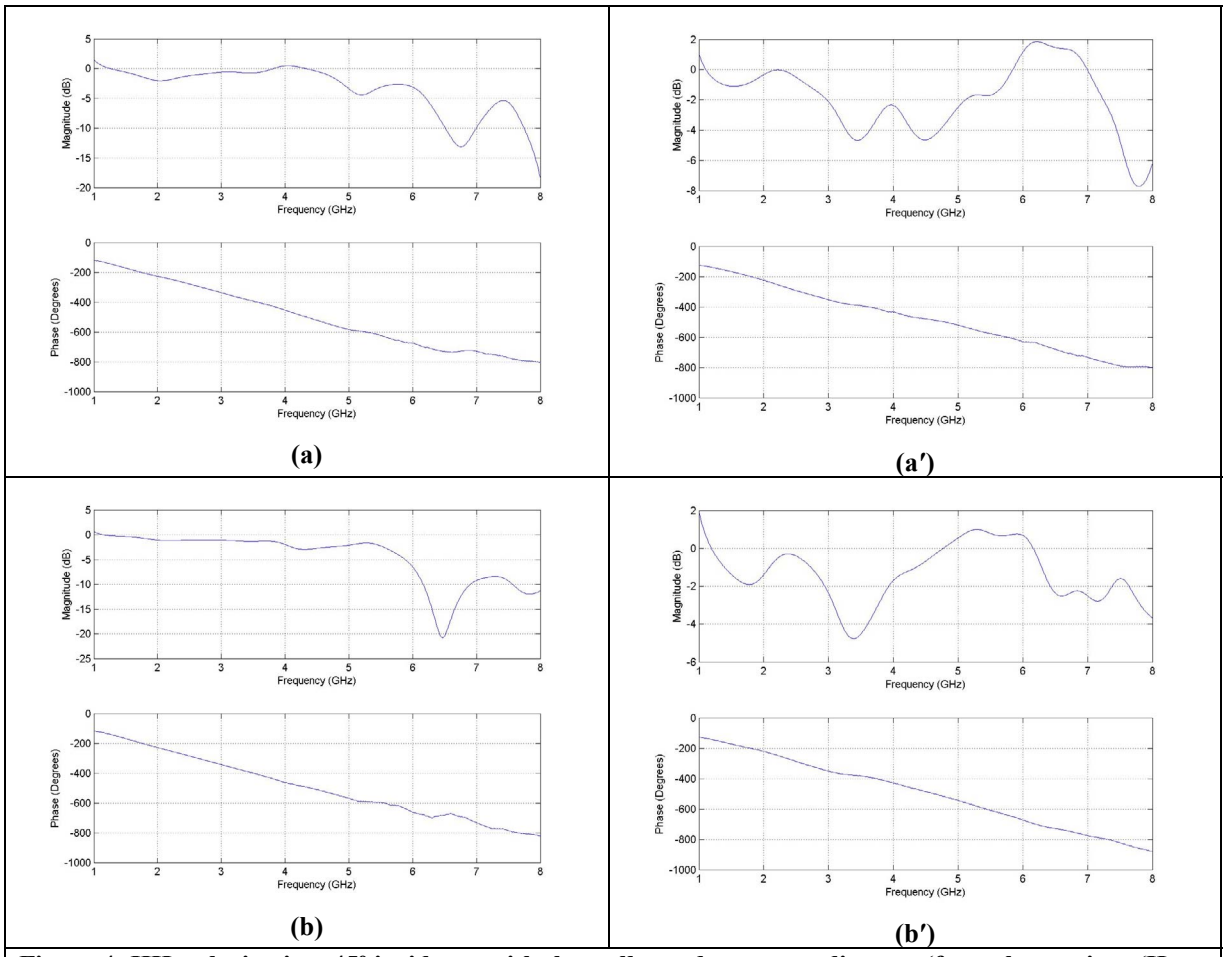


Figure 4: HH-polarization, 45º incidence with the wall at a downrange distance (from the receiver (Horn 2)) of (a) 10 ft (b) 5 ft. (a), (b) are 'between stud' measurements and (a′), (b′) are 'stud-centered' measurements.

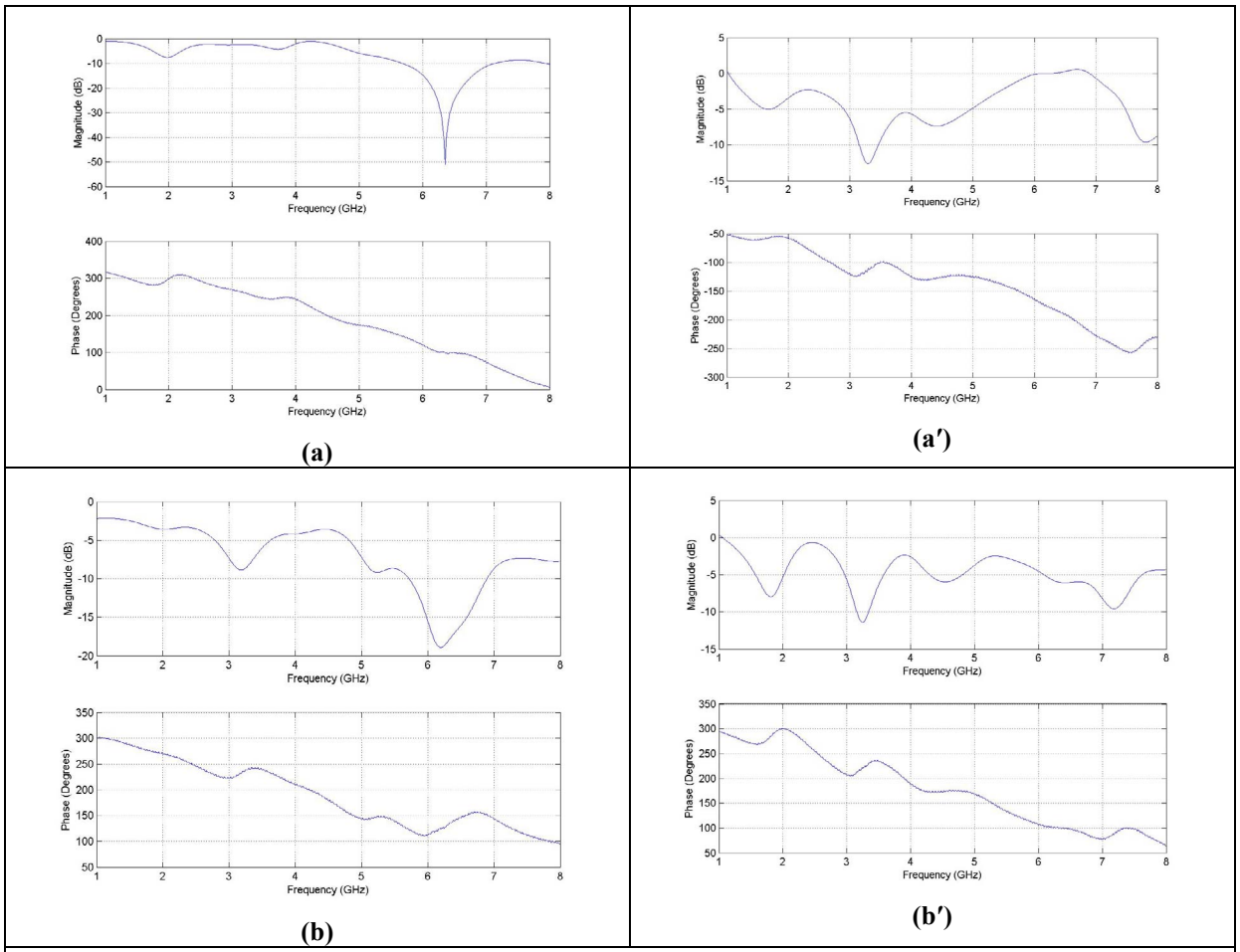


Figure 5: VV-polarization, 45º incidence with the wall at a downrange distance (from the receiver (Horn 2)) of (a) 10 ft (b) 5 ft. (a), (b) are 'between studs' and (a′) ,(b′) are 'stud centered'.

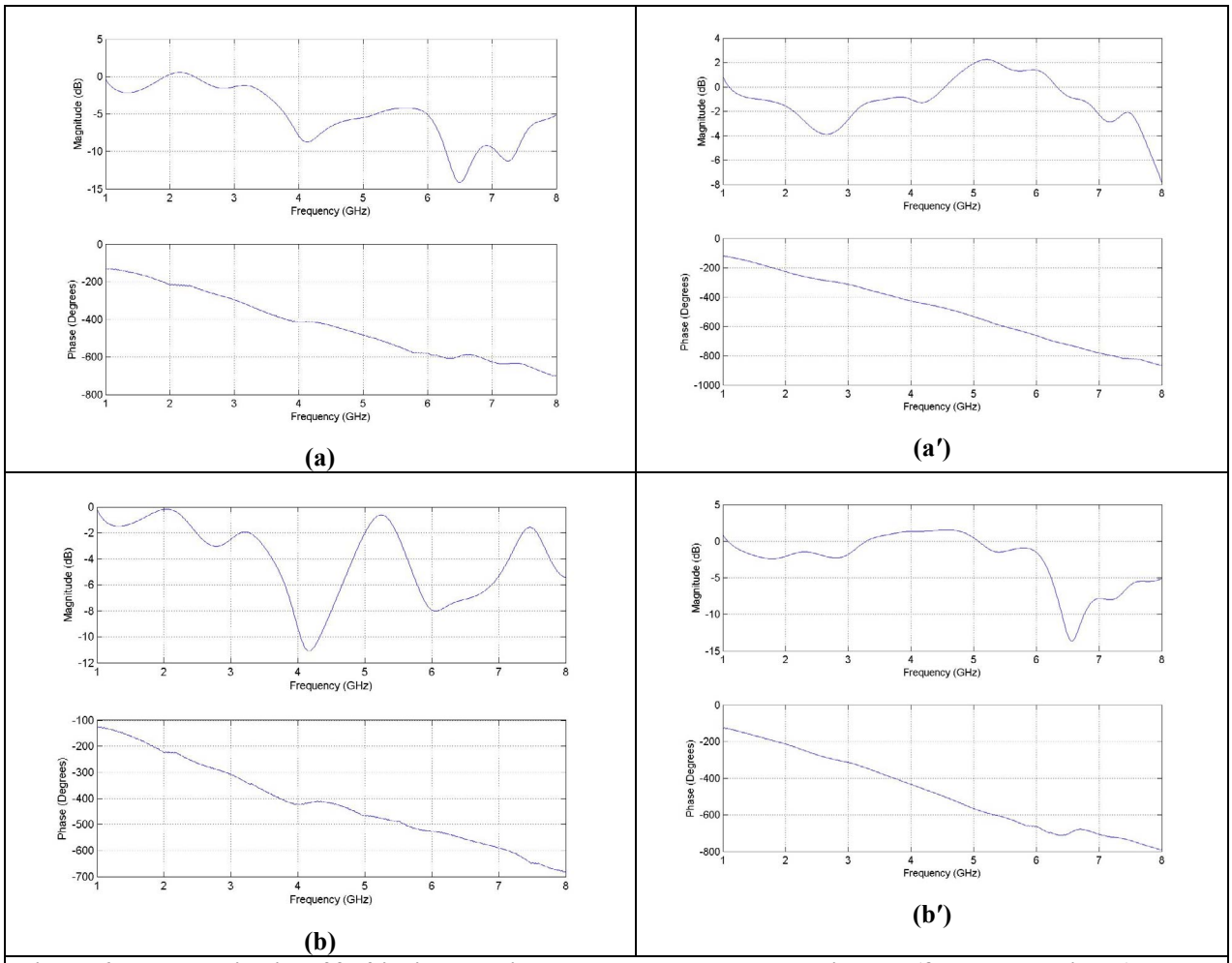


Figure 6: HH-polarization, 22.5º incidence with the wall at a downrange distance (from the receiver (Horn 2)) of (a) 10 ft (b) 5 ft. (a), (b) are 'between studs' and (a′) ,(b′) are 'stud-centered'.

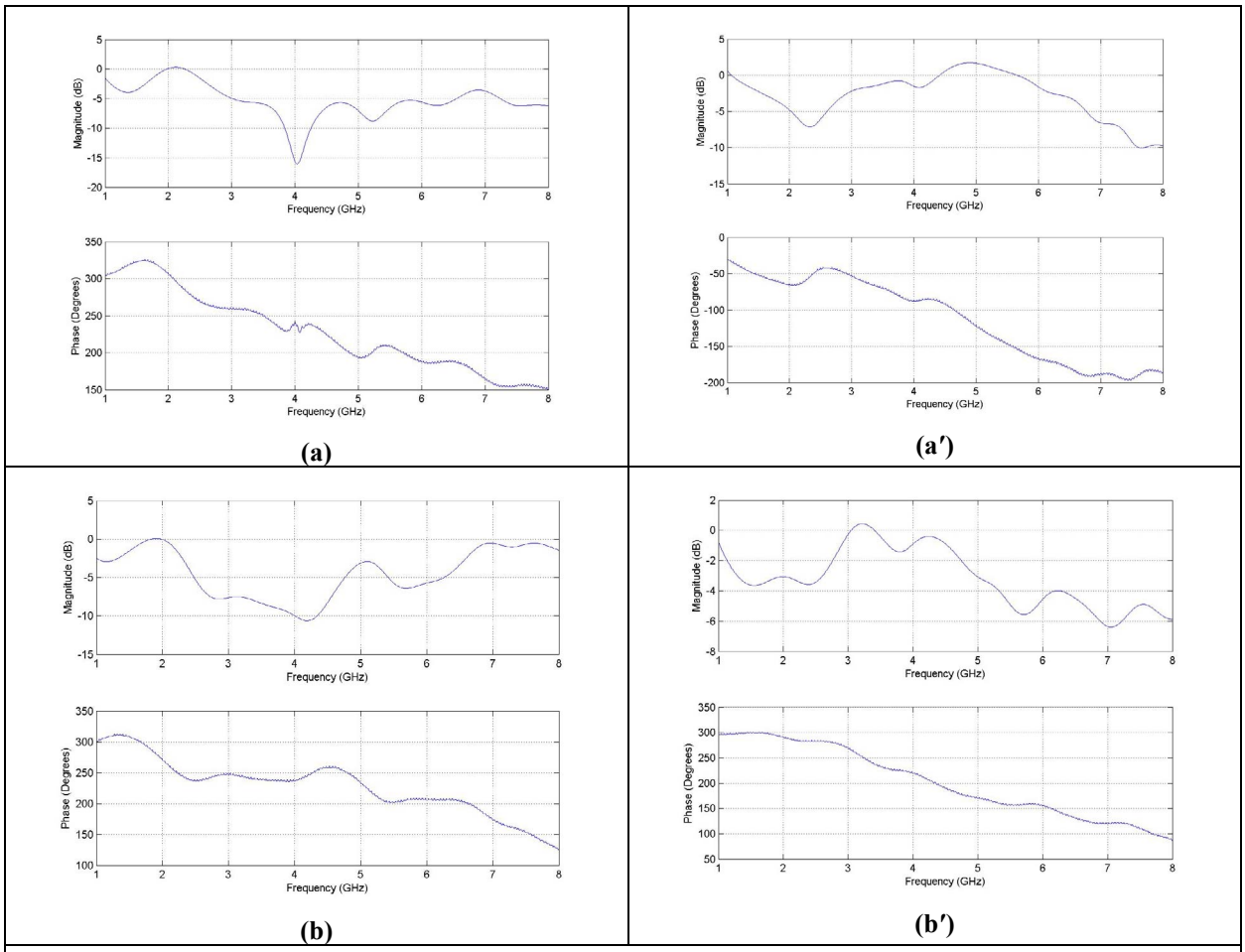
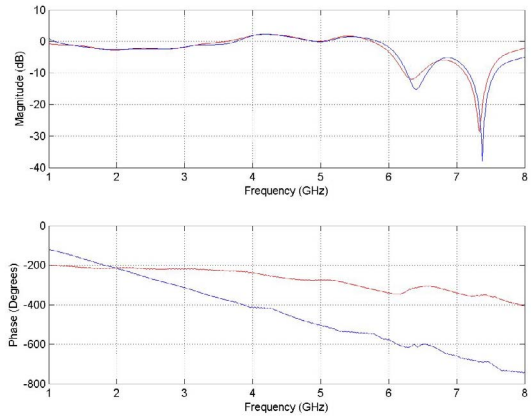
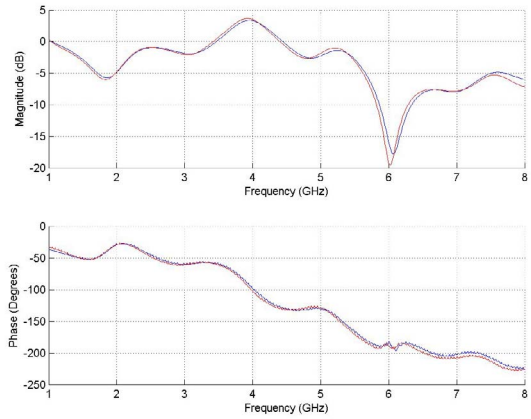


Figure 7: VV-polarization, 22.5° incidence with the wall at a downrange distance (from the receiver (Horn 2)) of (a) 10 ft (b) 5 ft. (a), (b) are 'between studs' and (a′) ,(b′) are 'stud-centered'.



(a)



(b)

Figure 8: Normal incidence measurements repeated at different times with the wall at a downrange distance of 10 ft from the receive antenna (stud-centered case), (a) HH-polarization (b) VV-polarization.