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MATERIALS' INSERTION LOSS AT 2.4, 3.3 AND 5.5 GHz BANDS

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Abstract—The insertion loss of different materials is measured at 2.4, 3.3 and 5.5 GHz bands. Directive antennas with a nominal gain of 19 dB are used in the measurement campaign. The height of the antennas has been selected to have the minimum possible reflection from around surfaces. Metallic door with porthole window, metallic grid, glass window, human beings and tree's insertion loss are measured. The metallic grid presents a band pass filter function with a resonance frequency between 3.2 to 3.3 GHz. Other materials have an insertion loss that increases with the increment of the operating frequency.

1. INTRODUCTION

In indoor communications and localization, propagation loss measurements due to miscellaneous phenomenon are of vital importance [1, 2]. Possible mechanisms of propagation are free space with and without multipath, transmission through materials, walls, floors, and diffraction.

In [3–5], the propagation loss is given for different scenarios and mechanisms. In [6–8], the human body shadowing variability in short-range indoor radio links at has been presented. A shadowing of 30 dB at 5.5 GHz can be experienced when a person cuts the LOS between the transmitting antenna and the receiving. In [6], the human body shadowing variability in short-range indoor radio links at 3–11 GHz band has been presented. A shadowing of 30 dB at 5.5 GHz can be experienced when a person cuts the LOS between the transmitting antenna and the receiving one. In [9], the effect of metal door on the indoor radio channel received signal has been studied. Three frequency

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bands namely, (850–950) MHz, (2.4–2.5) GHz and (5.1–5.3) GHz have been used in the measurement campaign. It has been noticed that the door attenuation is higher than 40 dB at the 5.2 GHz band. In [10], the outdoor-to-indoor propagation loss measurements for broadband wireless access in rural areas are given. In [11], a combination of the ray optical and FDTD methods has been used to calculate the indoor propagation loss.

The main objective of this study is to present the propagation loss due to different materials at the 2.4, 3.3 and 5.5 GHz bands. These frequencies have been chosen since that they present the frequencies at which WiFi and WiMAX work. The measured data would be very helpful to understand propagation losses at these Bands.

2. MEASUREMENT SYSTEM

A Network Analyzer (6 GHz ZVL of Rohde & Schwarz) has been used to measure the propagation loss at the (2.4, 3.3 and 5.5) GHz bands. Calibration has been carried out with cables up to 20 m long depending on the studied scenario. Directional antennas with a nominal gain of 19 dB have been used in the measurements. The transmitted power in all of the measurements was 20 dBm with a measurement dynamic range of almost 100 dB. The height of the antennas has been selected to have the minimum possible reflection from around surfaces.

3. PROPAGATION THROUGH A METALLIC DOOR WITH PORTHOLE WINDOW

Figures 1 and 2 show the metallic door with the porthole window. Measurements are given at 9 different points around and at the center of the porthole window with 25 cm diameter. The transmitting antenna was located 2 m from the metallic dooor. On the oposite side of the door, the recieving antenna was located also at 2 m from it. With the door totally open, calibration has been done (setting 0 dB reference level for free space propagation).

Figure 3 shows the propagation loss at the nine points of measurements for the horizontal and vertical polarizations. For the horizontal polarization, it can be noticed that the minimum propagation loss is due to the point B with 2 to 4 dB final propagation loss due to the propagation through the glass of the porthole window and the diffraction from the edge of the porthole window. The worst point is F with a propagation loss of 45 dB. For the vertical polarization the minimum propagation loss is due to the point B with 3 to 6 dB final propagation loss due to the propagation through the glass of the

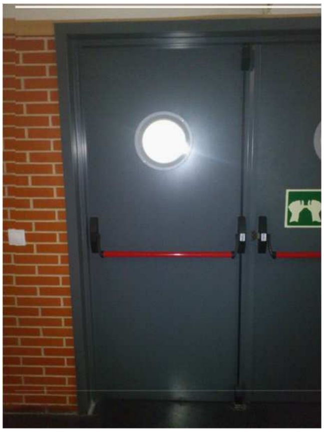

Figure 1. Metallic door with porthole window.

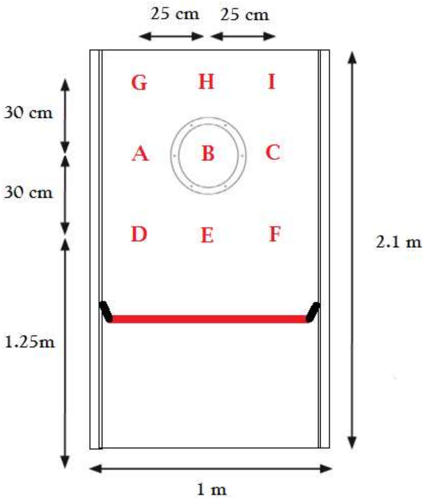

Figure 2. Measurements point of the metallic door with porthole window.

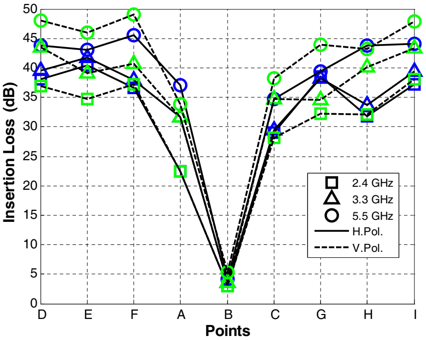

Figure 3. Insertion loss of the metallic door with porthole window for both horizontal and vertical polarization.

Figure 4. Metallic grid picture.

porthole window and the diffraction from the edge of the porthole window. The worst points are F with a propagation loss of 49 dB. Comparing these results with that of [9], it can be noticed that the insertion loss at the farthest points of our metallic door is almost the same of work [9].

4. PROPAGATION THROUGH METALLIC GRID

Figure 4 shows the metallic grid used in the measurements. It consists of many holes of $4 * 4$ cm and a metallic part of 4 cm of width. Measurements have been carried out at 36 different points.

Figure 5 shows the propagation loss for the horizontal polarization. Watching the average value of the insertion loss, a resonance effect can be noticed at 3.3 GHz with low insertion loss. In this case, the grid works as a band pass filter with a center frequency of 3.3 GHz. The resonance frequency can be expressed by:

$$f_{\text{GHz}} = 13.2/W_g$$

where W_g is the grid's hole width in cm. Here, the insertion loss has a low value of standard deviation.

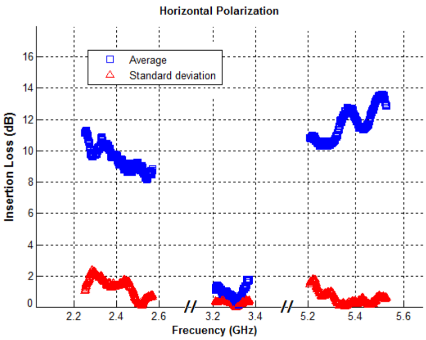

Figure 5. Metallic grid insertion loss at horizontal polarization.

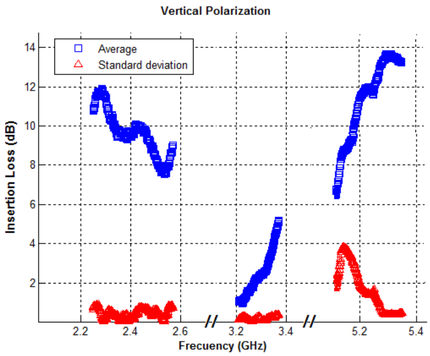

Figure 6. Metallic grid insertion loss at vertical polarization.

Figure 6 shows the propagation loss for the vertical polarization. Observing the average value of the insertion loss, a resonance effect can be noticed at 3.2 GHz with low insertion loss. In this case, the grid works as a band pass filter with a center frequency of 3.2 GHz. The resonance frequency can be expressed by:

$$f_{\text{GHz}} = 12.8/W_g$$

Here, the insertion loss has a low value of standard deviation at 2.4 and 3.3 GHz bands. Moderate value can be noticed at 5.5 GHz.

Theoretically, the resonance frequency is given by:

$$f_{\mathrm{GHz}} = 30/(W_g + W_m)$$

where W_m is the grid's metal width given in cm.

In our case $W_g = W_m$, thus:

$$f_{\mathrm{GHz}} = 15/W_g$$

The difference between the practical and the theoretical resonance frequency is maybe due to the finite gain of antennas, finite thickness of the grid and finite distance of measurements.

No other work has treated this case in our studied frequency bands.

5. PROPAGATION THROUGH GLASS WINDOW

Figure 7 shows one of the places used in the measurements with a double glass window of $2 * 2$ m and a thickness of $(2 + 8 + 3)$ mm where the glass thicknesses are 2 mm and 3 mm, respectively, and the air gap thickness is 8 mm. In each zone of work, the insertion loss is measured at the center of the window and at four points around it.

Figure 8 shows the propagation loss for the horizontal and vertical polarizations. Let us now present the result for the horizontal

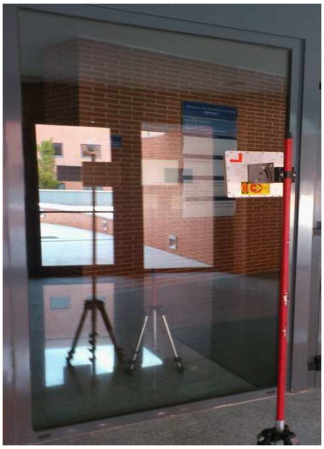

Figure 7. Glass window picture.

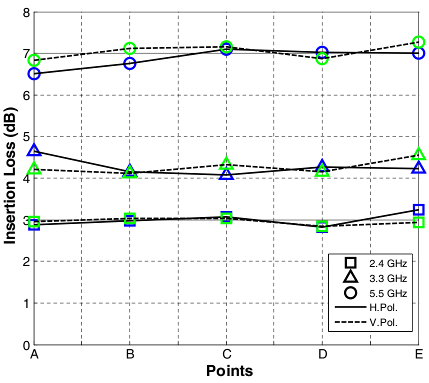

Figure 8. Insertion loss of the glass window for both horizontal and vertical polarization.

polarization. At 2.4 GHz, an insertion loss of 3 dB can be noticed. At 5.5 it increases to 7 dB. Insertion loss can be approximated by:

$$L_{glass}(\text{dB}) \approx 3 + 1.2(f_{\text{GHz}} - 2.4)$$

Let us now present the results for the vertical polarization. At 2.4 GHz, an insertion loss of 3 dB can be noticed. At 5.5 it increases to 7 dB. Here also, the insertion loss can be approximated by the same equation given before for the horizontal polarazation.

Measurements at others points in different places shows that average value of the insertion loss is almost the same as shown in Fig. 8 with a very low standard deviation of 0.25 dB at 5.5 GHz.

6. HUMAN BEINGS EFFECT

Thirty six persons have been used to get the results. Here we will present the results of three different cases.

Firstly we will study the effect of the presence of one person between the transmitting and receiving antennas. Here 30 different persons have been used in the measurements. Fig. 9 shows the insertion loss for the three bands. An insertion loss of 10 dB has been recorded in the 2.4 GHz band increasing to 18 dB at the 5.5 GHz band. The standard deviation of the loss is a function of frequency. It increases with the increment of the operating frequency.

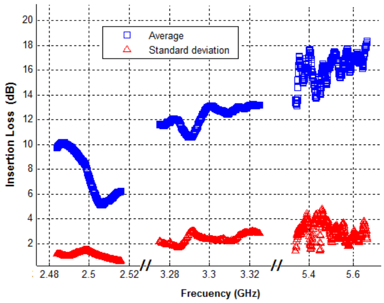

Figure 9. One person insertion loss.

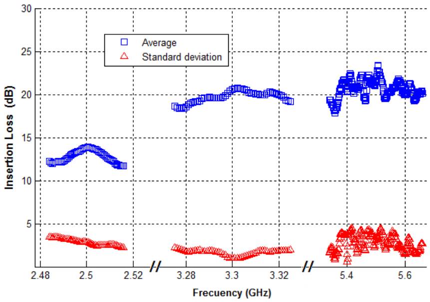

Figure 10. Three person side to side insertion loss.

Secondly we will study the effect of the presence of three persons side to side between the transmitting and receiving antennas. Fig. 10 shows the insertion loss for the three bands. An insertion loss of 14 dB has been recorded in the 2.4 GHz band increasing to 23 dB at the 5.5 GHz band. This indicates that the diffraction from the side parts of the persons in the previous case is now lower. The standard deviation of the loss has its maximum value at the 5.5 GHz band.

Finally we will study the effect of the presence of two persons between the transmitting and receiving antennas. Fig. 11 shows the insertion loss for the three bands. An insertion loss of 12 dB has been recorded in the 2.4 GHz band increasing to 18.2 dB at the 5.5 GHz band. Here also, the standard deviation of the loss has its maximum value at the 5.5 GHz band.

Other works, such as [6, 7], report an insertion loss up to 30 dB per person but in different environment.

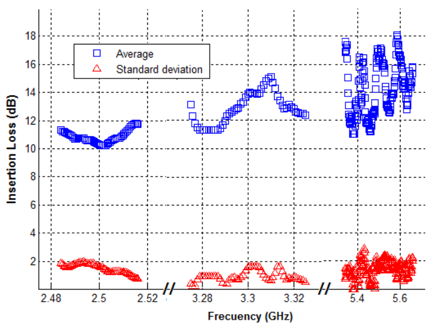

Figure 11. Two person insertion loss.

Figure 12. Picture of studied tree.

7. PROPAGATION THROUGH TREE'S FOLIAGE

Figure 12 represents the picture of an individual tree of the type (Melia Azedarach). Figs. 13 and 14 represent the measurements points and the direction where the antennas appoint Five directions namely 0° +10°, +20°, −10° and −20° have been used to get the results. Let us present the foliage loss at points C and D.

Figure 15 represents the foliage insertion loss at 2.4 GHz. At point D and 0 degree, an insertion loss of 10.2 dB can be noticed at 0° Higher loss can be noticed at other measurement angles. Lower insertion loss can be noticed at point C.

Figure 16 represents the foliage insertion loss at 3.3 GHz. At point D and 0 degree, an insertion loss of 11.7 dB can be noticed at 0°. Higher

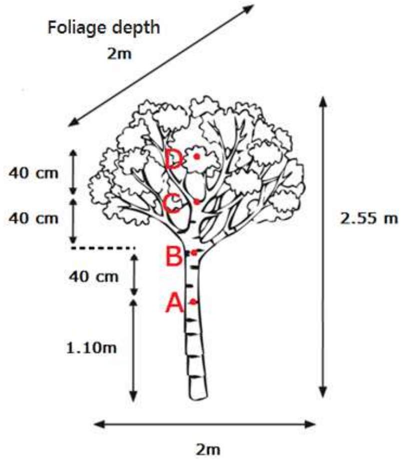

Figure 13. The studied tree measurements points.

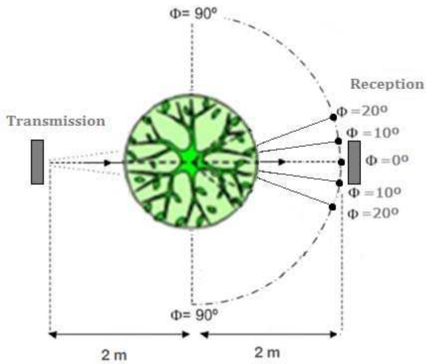

Figure 14. The studied tree measurements directions.

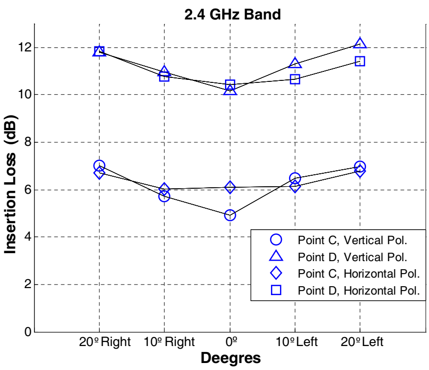

Figure 15. Tree's insertion loss at 2.4 GHz band.

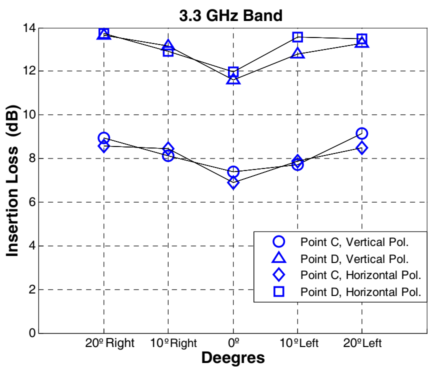

Figure 16. Tree's insertion loss at 3.3 GHz band.

loss can be noticed at other measurement angles. Lower insertion loss can be noticed at point C.

Figure 17 represents the foliage insertion loss at 5.5 GHz. At point D and 0 degree, an insertion loss of 13.2 dB can be noticed at 0°. Higher loss can be noticed at other measurement angles. Lower insertion loss can be noticed at point C.

A logical increment of the insertion loss with the increment of the operating frequency can be noticed comparing the results given by Figures 15, 16 and 17.

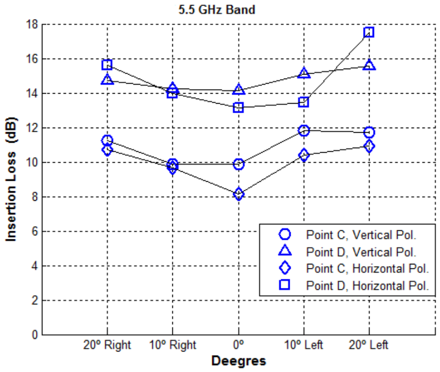

Figure 17. Tree's insertion loss at 5.5 GHz band.

Insertion loss can be approximated by:

$$L_{\mathrm{dB}} \approx -0.318 f_{\mathrm{GHz}}^2 + 3.477 f_{\mathrm{GHz}} + 3.683$$

where f_{GHz} is the operating frequency in GHz.

8. CONCLUSIONS

The insertion loss of different materials has been measured at 2.4, 3.3 and 5.5 GHz bands. Metallic door with porthole window, metallic grid, glass window, human beings and tree's insertion loss have been measured. The metallic grid has presented a band pass filter function with a resonance frequency between 3.2 to 3.3 GHz. Other materials have an insertion loss that increases with the increment of the operating frequency.

REFERENCES

1. Roozbahani, M. G., E. Jedari, and A. A. Shishegar, "A new link-level simulation procedure of wideband MIMO radio channel for performance evaluation of indoor WLANS," *Progress In Electromagnetics Research*, Vol. 83, 13–24, 2008.
2. Tayebi, J. G., F. Saez de Adana, and O. Gutierrez, "The application of ray-tracing to mobile localization using the direction of arrival and received signal strength in multipath indoor environments," *Progress In Electromagnetics Research*, Vol. 91, 1–15, 2009.
3. Bertoni, H. L., *Radio Propagation for Modern Wireless Systems*, Prentice Hall PTR, New Jersey, 2000.

4. Rappaport, T. S., *Wireless Communications*, Prentice Hall PTR, New York, 1996.
5. Saunders, S. R., *Antennas and Propagation for Wireless Communication Systems*, J. Wiley & Sons, New York, 1999.
6. Kara, A., "Human body shadowing variability in short-range indoor radio links at 3–11 GHz band," *International Journal of Electronics*, Vol. 96, No. 2, 205–211, February 2009.
7. Kara, A. and H. L. Bertoni, "Effect of people moving near short-range indoor propagation links at 2.45 GHz," *Journal of Communications and Networks*, Vol. 8, No. 3, 286–289, September 2006.
8. Taha Ahmed, B., D. F. Campillo, and J. L. Masa Campos, "Short range propagation model for a very wideband directive channel at 5.5 GHz band," *Progress In Electromagnetics Research*, Vol. 130, 319–346, 2012.
9. Choi, J., N.-G. Kang, J.-M. Ra, J.-S. Kang, and S.-C. Kim, "Effect of metal door on indoor radio channel," *The 18th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'07)*, 1–5, 2007.
10. Chee, K. L., A. Anggraini, T. Kaiser, and T. Kürner, "Outdoor-to-indoor propagation loss measurements for broadband wireless access in rural areas," *Proceedings of the 5th European Conference on Antennas and Propagation (EUCAP)*, 1376–1380, 2011.
11. Nagy, L., "FDTD and ray optical methods for indoor wave propagation modeling," *Microwave Review*, 47–53, July 2010.