Table of Contents Search Author Index

# UWB PARTITION-DEPENDENT PROPAGATION MODEL

*Ali Muqaibel, Ahmed Safaai-Jazi, Sedki Riad*

*Electrical Engineering Department
King Fahd University of Petroleum & Minerals
P.O. Box 1734, Dhahran 31261, Saudi Arabia

**The Bradley Department of Electrical and Computer Engineering
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061-0111, USA

## ABSTRACT

The partition-dependent narrow-band propagation model is modified to account for the occupied spectrum. The paper illustrates the application of the modified model in indoor environments. The modified model helps in estimating the link-budget. It is also useful in studying the performance of UWB systems for indoor communication and positioning applications.

## 1. INTRODUCTION

Ultra wideband (UWB) systems use precisely timed, extremely short coded pulses transmitted over a wide range of frequencies [1,2]. Recently, UWB wireless communication has been the subject of extensive research due to its potential applications and unique capabilities.

In addition to the use of UWB technology for communication, UWB technology supports integration of services. One of the services and applications that can be integrated with UWB communications is indoor-positioning [3]. Narrowband technology relies on high-frequency radio waves to achieve high resolution. Unfortunately, high-frequency radio wave has short wavelength and cannot penetrate effectively through materials. On the other hand, UWB receiver can time the transmitted pulses to within a few thousand billions of seconds, and still promise good penetration through materials.

Many important aspects of UWB-based signal propagation have not yet been thoroughly examined. The propagation of UWB signals in indoor environments is one of the important issues with significant impacts on the future of UWB technology. Researchers are nowadays devoting considerable efforts and resources to develop robust channel models that allow for reliable ultra-wideband performance simulation.

One method for modeling large-scale path losses is to assume logarithmic attenuation with various types of structures between the transmitter and receiver antennas [4]. It has also been stated that adding the individual attenuations results in the total dB loss [4]. Furthermore, it is important to note that when assuming no dispersion takes place, a narrow band approximation is implied. This assumption is not as good for UWB because the dielectric constant decreases slowly with frequency.

Many results for the propagation through walls have been published. A good summary is given in [4]. However, these results were often obtained at specific frequencies. Many of the narrowband channel characterization efforts are performed at specific frequencies. For UWB characterization, one has to define the pulse shape or its spectrum occupancy. Results generated for a specific pulse might not be generalized to other UWB signals.

The remaining part of this paper introduces the partition-dependent model as function of frequency. A detailed example is presented that illustrates the use of the model. The paper ends with some concluding remarks.

## 2. FREQUENCY DEPENDANANT INSERTION LOSS

In this section, the results for the loss of tested materials presented in [5] are used to develop UWB partition-dependent propagation models. The partition based penetration loss is defined as the path-loss difference between two locations on the opposite sides of a wall [6]. The penetration loss is equal to the insertion loss. The free space path-loss exponent is assumed to be $n$=2. The total loss along a path is sum of the free-space path loss and the loss associated with partitions present along the propagation path.

A straight line is used to model the insertion loss versus frequency [7]. The fitted insertion transfer functions for different materials are reproduced from [5] in Figure 1. The corresponding parameters for the linear fit are also given in [5]. The insertion transfer function for the door is re-plotted in part (b) of Figure 1 for ease of comparison. Cloth partition shows higher loss due to support elements inside the partitions. The results for the brick wall and the concrete block wall are over smaller bandwidths because of higher losses of these materials that reduce their useful bandwidths.

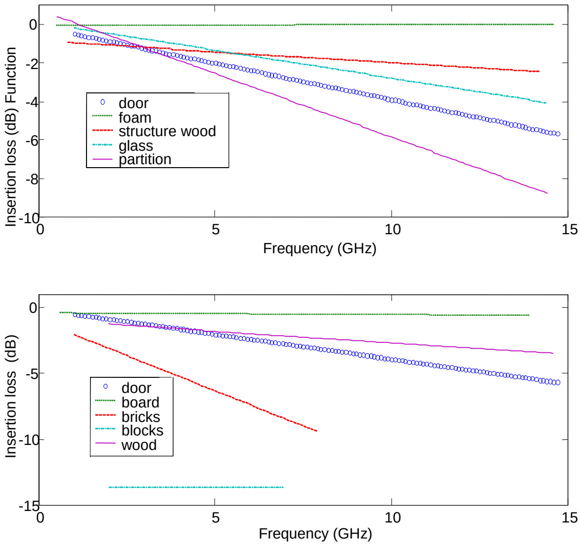


**Figure 1.** Insertion transfer function plotted versus frequency for different materials

## 3. FREQUENCY DEPENDENT MODEL

In the narrowband context, the path loss with respect to1 m free space at a point located a distance *d* from the reference point is described by the following equation

$$PL(d) = 20\log_{10}(d) + a \times X_a + b \times X_b........, \qquad (1)$$

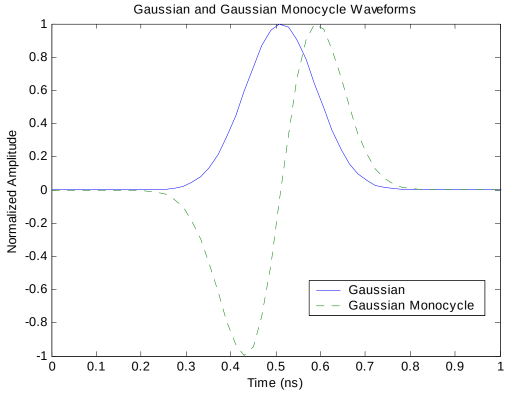
where *a*, *b*, etc., are the numbers of each partition type and $X_a$, $X_b$, etc., are their respective attenuation values measured in dB [8]. To extend this concept to UWB communication channels, we introduce the frequency dependent version of equation (1),

$$PL(d,f) = 20\log_{10}(d) + a \times X_a(f) + b \times X_b(f)........, \qquad (2)$$

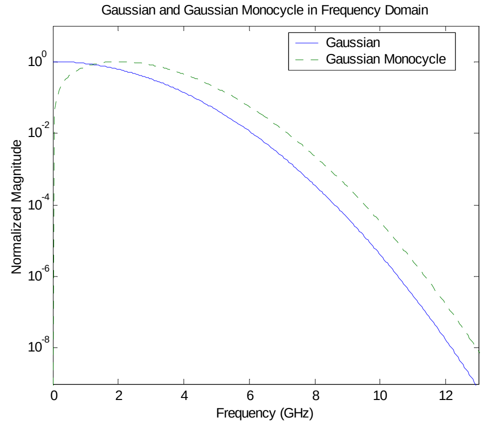
where $X_a(f)$, $X_b(f)$ are the frequency dependent insertion losses of partitions. Equation (2) gives the path loss as function of frequency. In order to find the pulse shape and the total power loss we need to find the time domain equivalent of (2) by means of inverse Fourier transform over the frequency range of the radiated signal. In doing so, we start with the radiated pulse, $p_{rad}(t)$. In most wideband antennas such as TEM horns, this signal is proportional to the derivative of the input signal to the antenna. Then, we determine the spectrum of the received signal at the location of the receive antenna using the following relation ship,

$$P_{rec}(f) = \frac{P_r(f)}{\left[10^{(a \times X_a(f) + b \times X_b(f).......)/20}\right] \cdot d} \qquad (3)$$

It is important to note that the attenuation is applied to the radiated signal rather than the input to the antenna. The transmit antenna alters the spectrum of the input signal as illustrated in Figure 2. Starting with a Gaussian pulse, the time-domain received signal, $p_{rec}(t)$, is obtained by inverse Fourier transforming $P_{rec}(f)$. With the received pulse determined, one is able to assess pulse distortion and the total power loss. It has been assumed that the dielectric constant of the partitions remain constant over the spectrum of the radiated signal.



*(a) Gaussian and Gaussian monocycle waveforms*



*(b) Corresponding normalized spectrum for Gaussian and Gaussian monocycle waveforms*

**Figure 2.** Gaussian and Gaussian monocycle waveforms and their corresponding normalized frequency

## 4. ILLUSTRATIVE EXAMPLE

In this example we illustrate how to utilize the material characterization results and apply them to a partition problem. The objective is to find the power loss through a propagation path and to estimate the pulse shape and the frequency distribution of the received signal. Consider a line-of-site path with two partitions between two TEM horn antennas as shown in Figure 3a . The first partition is a sheet of glass and the second is a wooden door with the same thickness as those that have been characterized. The input signal to the antenna and that radiated from it are displayed in this figure. These signals are obtained through measurements.

To estimate the signal passed through the glass partition, Fourier transform is used to determine the spectrum of the radiated signal and the frequency dependent loss is applied to this spectrum. Inverse Fourier transform is then used to obtain the time-domain signal passed through the glass sheet. The same procedure is repeated to estimate the signal passed through the wooden door partition. Examining the loss in the signal power is evident in Figure 3b. It is also noted that higher frequencies are smoothed out. The change in frequency distributions is more evident in Figure 3c. At lower frequencies, the spectra of the radiated signal, signal after the glass and signal after the wooden door are very close, whereas at higher frequencies the differences are more pronounced. This analysis is helpful in link-budget analysis and understanding of potential interference effects from indoor to outdoor environments.

## 5. CONCLUSIONS

In this paper the frequency dependence was introduced to the partition-dependent propagation model. The modified model was applied to a representative example to illustrate it applicability. The model was shown to be valuable in evaluating the potential for indoor communication applications as well as positioning applications. It is shown that the equipped spectrum and type of environment will determine the extent of the application. Receiver design should consider the effect of frequency dependence for optimal reception.

## Acknowledgment

The authors acknowledge King Fahd University of Petroleum and Minerals, KFUPM, for supporting this research.

## 6. REFERENCES

[1] A. Muqaibel, Characterization of UWB Communication Channels, Ph.D. dissertation, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA 2003.

[2] R. A. Scholtz, “Multiple Access with time-hopping impulse modulation,” MILCOM ’93, vol. 2, 1993, pp. 447-450.

[3] R. J. Fontana and Steven J. Gunderson, "Ultra-Wideband Precision Asset Location System," in Proc. Of .IEEE Conference on Ultra Wideband Systems and Technologies, 21-23 May 2002, pp. 147-150.

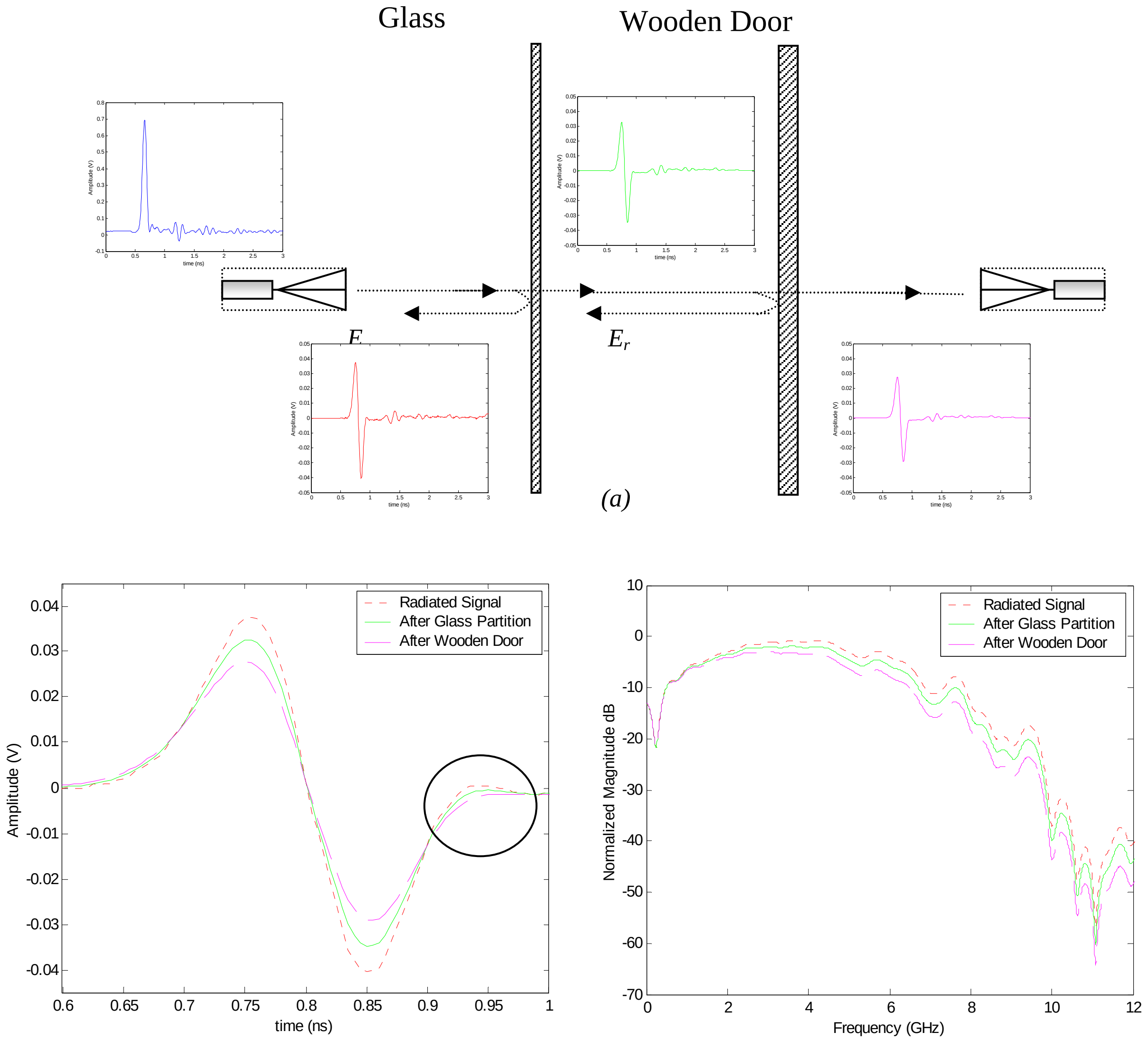
[4] H. Hashemi “The Indoor Radio Propagation Channel” *Proceeding of the IEEE*, vol. 81, no. 7, pp 943-968, July 1993.

[5] A. Muqaibel, A. Jazi, A. Bayram and S. Riad, “Ultra Wideband Material Characterization for Indoor Propagation” *IEEE*-APS, June 22-27,Columbus, Ohio, 2003.

[6] C. R. Anderson, T. S. Rappaport, K. Bae, A. Verstak, N. Ramakrishnan, W. Tranter, C. Shaffer, and L. Watson, “In-Building Wideband Multipath Characteristics at 2.5 & 60 GHz,” Proceedings of IEEE 56th Vehicular Technology Conference, vol.1, 2002. pp. 97-101.

[7] T. Gibson and D. Jenn, “Prediction and Measurements of Wall Insertion Loss” *IEEE Transactions on Antennas and Propagation*, vol. 47, no. 1, pp. 55-57, Jan. 1999.

[8] G. Durgin, T.S. Rappaport, and H. Xu, “Measurements and Models for Radio Path Loss and Penetration Loss in and Around Homes and Trees at 5.85 GHz**”**, *IEEE Transactions on Communications*, vol. 46, no. 11, pp. 1484-1496, Nov. 1998.



(a)

(b)

(c)

*(a) Illustration of the partitions setup*

*(b) Frequency distribution of the signal at different points*

*(c) Radiated signal, signal after the glass partition, and the signal after the wooden door*

**Figure 3.** Illustrative example for UWB partition dependent Modeling