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Characterization of wall dispersive and attenuative effects on UWB radar signals

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Abstract

This paper addresses the potentials of ultra-wideband (UWB) through-wall imaging radars compared with conventional narrowband systems. The challenges that limit the utilization of high precision UWB systems are examined with the aim of mitigating them. These challenges include multi-path, pulse dispersion, and antenna effects on the pulse shape due to angles of transmission and arrival. The propagation of UWB signals through walls is a crucial factor in determining the success of UWB radar technology. UWB signals, when propagating through walls, not only suffer attenuation but also distortion due to dispersive properties of the walls. This paper examines time- and frequency-domain techniques for measuring the electromagnetic properties of construction materials in the UWB frequency range. The measured parameters provide valuable insights in appreciating the capabilities and limitations of the UWB technology. Special attention is paid to time gating as a mean to extract the direct-path signal from the multi-path components. Both single-pass and multi-pass models are discussed. Multi-pass models account for the multiple reflections within the wall while the single-pass model assumes the possibility of gating out a single transmission. The partition-dependent narrowband propagation model is modified to account for the ultra-wide bandwidth of the signal. The paper illustrates the application of the modified model in indoor environments. The modified model is helpful in estimating the link power budget. It is also useful in studying the performance of UWB systems for indoor communication and positioning applications.

Keywords: Ultra-Wideband (UWB); Trough-wall; Dispersion; Propagation; Rader; Impulse radio; Insertion loss

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1. Introduction

Ultra-wideband (UWB) communication systems are generally defined as systems, which exhibit a transient impulse response. A UWB transmitter is defined as an intentional radiator that, at any point in time, has a fractional bandwidth of greater than or equal to 0.2 or occupy a bandwidth greater than 500 MHz regardless of the fractional bandwidth [1]. UWB radars are attracting increasingly more interest after the proposal by Scholtz [2] to use impulse UWB radio for personal wireless communication applications. UWB technology supports the integration of communication and radar applications such as imaging and positioning [3–5].

Time-modulated UWB signals are superior to narrowband signals by providing orders of magnitude improvement in spatial resolution. This could result in sub-centimeter range resolution. There are many situations where UWB high resolution signals can be utilized. For example, UWB technology can be used to augment the global positioning satellite system (GPS). UWB signals are immune to multi-path distortions, which are a major problem for indoor narrowband receivers. If reference stations are equipped with UWB technology, precise locations can be determined especially within buildings and areas where GPS fails to operate. This technology also allows aircraft to determine and monitor their position relative to other aircrafts and relative to the ground. Another promising application of the UWB technology is in automobile collision avoidance, and newer and more sophisticated applications are expected to emerge due to recent developments in this rapidly evolving technology.

UWB systems are anticipated to offer better wall-penetration capabilities. UWB through-wall imaging systems are allocated a bandwidth below 960 MHz or between 3.1 and 10.6 GHz. These systems detect the location or movement of persons or objects located on the other side of the wall. The technology is being tested to look inside closed rooms. Narrowband technology relies on high frequency (short wavelength) radio waves to achieve high resolution. However, shortwave signals cannot penetrate effectively through materials, while UWB radars promise good penetration through materials and has time resolution to within a fraction of nanosecond.

Recent years have witnessed increasing research activities devoted to the UWB through-wall technology. Attiya et al. [6] experimentally studied the potentials and limitations of through-wall human body detection by means of UWB signals. They concluded that the loss and dispersive properties of the wall cause a low-pass filtering effect, which limits the high resolution capability of the original UWB pulses. Mahfouz et al. [7] developed a compact UWB radar for see-through-walls applications. The image is formed by scanning a beam across the radar scene and utilizing a receiving array and beam-forming process. Chia et al. [8] developed a UWB radar for medical imaging that can measure the heartbeats and breathing rate of human in a 1-m range. The system was also successfully tested with a targeted human object obstructed with a typical wall partition. Regarding the impact of wall and obstructions on UWB indoor ranging, it is reported in [9] that the average ranging error for line-of-sight (LOS) scenarios is 6 cm. This error increased to 24, 38, and 84 cm for sheet rock, plaster, and cinder block wall materials, respectively, in none-LOS (NLOS) conditions. Hantscher et al. [10] has described a complete low-cost UWB radar system for wall scanning applications. The proposed system can reconstruct the shape of simple targets like water pipes.