Quantitative Experimental Evaluation of RFID Propagation Loss with Wooden and Metal Bookshelves

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Abstract

Radio frequency identification (RFID) is wireless multimedia applications for bookshelves experimental system to replace the barcodes media technology. The RFID propagation channel characteristics and environment effect should be known. In this study to evaluate the RFID propagation loss with wooden and metal bookshelves based on data of measurement. Experimental study evaluation of RFID multimedia system with bookshelves is using vector network analyzer (VNA) and the microstrip patch antennas of transmitter (Tx) and receiver (Rx) antennas at a frequency range from 2.4 GHz to 2.5 GHz. The results of experiment are considering the path loss, received signal strength (RSS), and comparison the path loss differences with cumulative distribution function (CDF) to evaluated, respectively. In this research work are necessary for RFID antenna design and evaluate the RFID multimedia systems.

Keywords: RFID, RFID multimedia system, RFID measurement, path loss model, microstrip antennas.

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1 Introduction

RFID (Radio Frequency Identification) is a wireless multimedia technology has gained significant prominence recently as a versatile wireless solution that has permeated various aspects of our daily lives. Originally evolving from traditional barcode systems, RFID has surpassed its predecessors in performance and functionality. While RFID has demonstrated superior capabilities, it has not entirely replaced barcode systems due to cost considerations. Nevertheless, RFID finds extensive use in diverse applications, such as shopping malls, inventory management, logistics, supply chain operations, smart cards, and libraries [1–7].

The advantages of RFID multimedia system very good ability to automatically identify and track people or objects using radio waves. This groundbreaking capability has revolutionized several industries by enabling efficient and seamless operations. RFID systems allow for quick and accurate identification, leading to enhanced reliability and productivity. For example, in libraries, RFID technology has streamlined the book recovery process, enabling quick and efficient management of books within the library premises. The durability of RFID tags ensures their longevity, contributing to long-term operational efficiency [8–13].

RFID multimedia technology operate across different frequency bands to cater to diverse requirements. These frequency bands include UHF (868–915 MHz), HF (13.56 MHz), LF (125–134.2 kHz), and radio frequency (2.45 GHz). The wide frequency range enables RFID systems to handle large volumes of data swiftly and effectively. This capability is crucial for high-speed data transfer applications, such as real-time inventory management and supply chain optimization. Furthermore, RFID multimedia systems offer the advantage of non-line-of-sight communications. RFID tags can be read and identified if they fall within the radio frequency range, allowing for seamless tracking and monitoring in various scenarios [14–19].

Understanding the propagation characteristics of RFID multimedia channels is essential for optimizing system performance. These channels exhibit intriguing phenomena, including reflections, diffraction, and scattering. Various channel models and measurement techniques have been developed to analyze and model these characteristics. These models and measurements help comprehend the impact of path loss on the overall system performance [20].

This research paper focuses on investigating and comparing path loss in two distinct types of bookshelves: wooden and metal. The study involves conducting meticulous indoor channel measurements, which provide valuable insights into the propagation loss of RFID propagation within indoor environments. The research aims to enhance our understanding of signal propagation dynamics in RFID multimedia systems by examining the effects of different bookshelves materials on path loss. Additionally, the study evaluates the resultant effects on system performance, shedding light on the complexities associated with path loss in RFID multimedia applications [21].

To achieve this, path loss measurements were conducted using a Vector Network Analyzer (VNA) operating within the frequency range of 2.3 GHz to 2.6 GHz, with a center frequency of 2.45 GHz. The collected data were analyzed using contour methods and cumulative distribution function (CDF) methods, which provide a comprehensive understanding of the relationship between channel function and path loss.

This research paper contributes significantly to the field of RFID multimedia technology by investigating path loss variations in different bookshelves materials and exploring the complexities of indoor signal propagation in RFID multimedia systems. The findings of this study serve as valuable inputs for developing efficient and optimized RFID multimedia applications, ultimately enhancing the performance and reliability of wireless identification and tracking systems in various domains. The paper is structured coherently, with Section 2 outlining the channel modeling approach, Section 3 presenting the measurement methodology and results, Section 4 delving into the indoor signal propagation analysis, and Section 5 offers conclusive insights derived from the study.

2 RFID Path Loss Model

The RFID propagation channel effects many factors on communication systems. The separate between transmitter and receiver antennas is main variable [20]. Therefore, it is necessary to understand the characteristics of propagation channels and RFID path loss. This path loss can characterize by using statistical model.

2.1 Path Loss

The path loss analysis of RFID propagation channel due to multipath which affects many factors on environment fading. The main variables are separate between the transmitter and receiver. The equation of path loss model can be written as [21]

$$PL[dB] = 10\log\left(\frac{P_t(f)}{P_r(f)}\right) = -10\log\left[\frac{\lambda^2}{(4\pi)^2 \times d^2}\right] \quad (1)$$

where $P_{\mathrm{t}}(f)$ is the power transmitter, $P_{\mathrm{r}}(f)$ is the power receiver, d the separate between the transmitter and the receiver, λ is wavelength ($\lambda = \frac{c}{f}$), c is called the phase speed (3×10^8 m/s), f is wave frequency.

2.2 RFID Path Loss Model

RFID channel measurement show that average received signal power decreases logarithmically with distance. RFID path loss model mentions to any method to modeling the association among one or more variables; therefore, the model depends linearly on the unknown parameters of data estimated. Most commonly, path loss model of RFID can be written as [22]

$$\overline{PL} = (d)[dB] = \overline{PL}(d_0)[dB] + 10n\log\left(\frac{d}{d_0}\right) \quad (2)$$

where d_0 is the reference distance set in measurement, d is the distance between transmitter antenna and receiver antenna, n is the exponent path loss which indicates the path loss rate increases with d. The n parameters and $\overline{PL}(d_0)$ are evaluated by using least square method of linear regression model between parameter $\overline{PL}$ and $\log(d)$ with $d_0 = 2$ m.

2.3 RFID Statistical Model

For RFID path loss characterized parameters X_σ in the terms of the CDF. The CDF of X_σ is respectively expressed as [23]

$$F_{X_\sigma}(x) = P\{X_\sigma \leq x\} \quad (3)$$

where X_σ is the path loss in dB, σ is standard deviation of path loss variable.

3 Experimental System Model

In this study, to conducted a comprehensive investigation of measure and estimate the path loss in RFID systems designed for operation within wooden and metal bookshelves. The objective was to gain for understanding the characteristics propagation loss and optimize the performance of RFID multimedia technology in real-world scenarios.

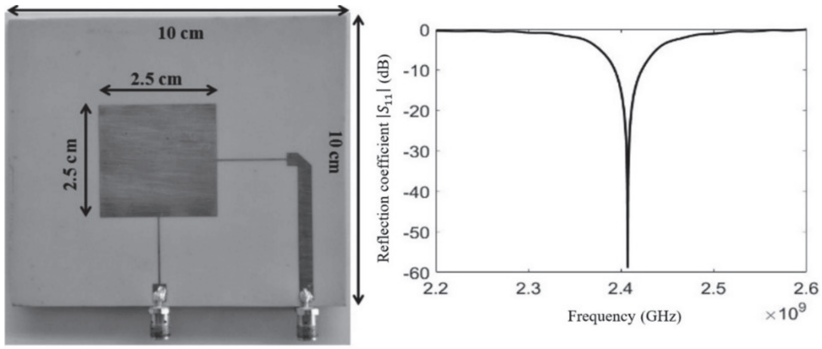


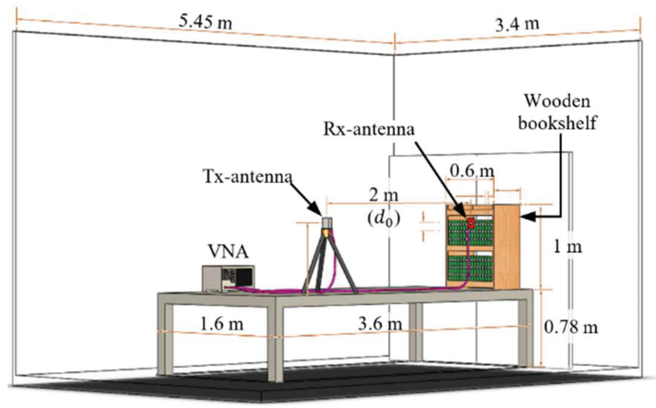
Figure 1 The structure and characteristic of microstrip patch antenna.

Table 1 Parameters of experiments

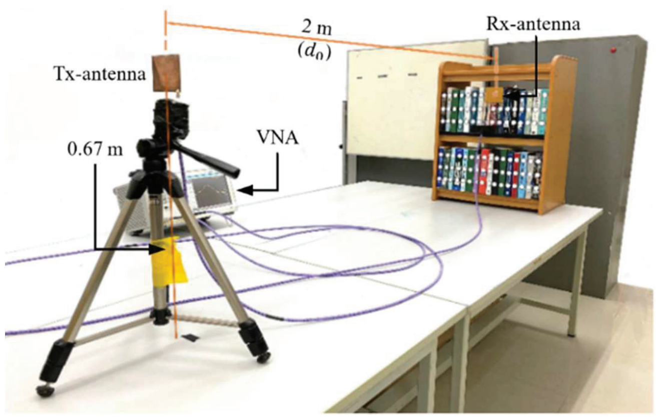
Parameters	Values
Range of Frequency	2.4 GHz to 2.5 GHz
Frequency point numbers	801
Height of Tx-antenna	0.67 m
Hight of Rx-antenna	(Rx-antenna orientation with experiment positions)
Measurement positions	96 positions for wooden bookshelves and 80 positions for metal bookshelves
Type of antennas	Microstrip patch antennas
Transmitter power	1 W

To assess the path loss accurately, using a VNA to be measured and recorder the channel response within a frequency range of 2.4 GHz to 2.5 GHz, with the frequency center is 2.45 GHz. The transmission (Tx) and reception (Rx) antennas utilized microstrip patch antenna technology, which has proven efficient and reliable in RFID applications. The specific geometry and dimensions of the antennas can be found in Figure 1, providing a visual representation of their construction.

Establish a comprehensive to understanding of the data measured, to classify the RFID system designs into five distinct tiers. Each tier presented unique advantages and disadvantages, primarily relating to power consumption and availability. Notably, we observed that redundant or duplicated designs were often implemented to address system availability and safety concerns. However, such redundancy inevitably leads to increased power consumption, which must be carefully considered in practical RFID deployments. Figure 2 illustrates the different system conditions observed based on the measured data, further emphasizing the significance of our findings.



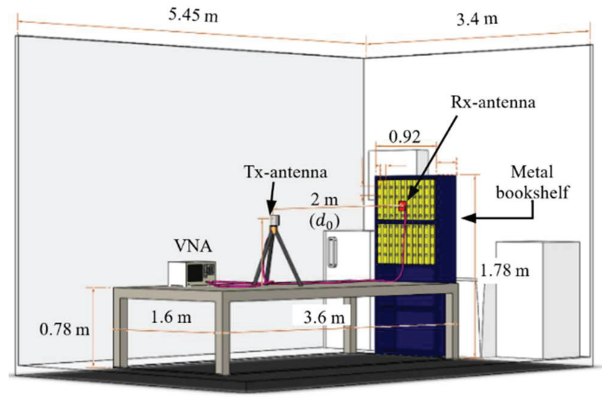
(a)



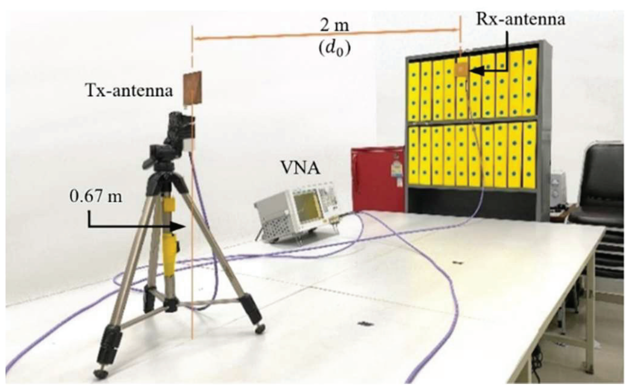
(b)

Figure 2 RFID propagation loss measurement with wooden bookshelves: (a) experimental model. (b) experimental setup.

The experimental study was conducted within the well-equipped laboratory facilities at King Mongkut's Institute of Technology Ladkrabang (KMITL), School of Engineering in Bangkok, Thailand. To meticulously designed and implemented wooden and metal bookshelves models, as depicted in Figures 2(a) and 3(a), respectively. In these models, the Tx antenna, representing the reader, was positioned 2 meters away from the bookshelves and 0.67 meters above the table surface. The Rx antenna, symbolizing the RFID tag, was strategically placed in front of the bookshelves,



(a)



(b)

Figure 3 RFID propagation loss measurement with metal bookshelves: (a) experimental model. (b) experimental setup.

aligning with the experimental setup. It is worth noting that the orientation of the Rx antenna was crucial in ensuring accurate measurements of the electromagnetic field's intensity.

To ensure robust and comprehensive data collection, we meticulously measured the electromagnetic density at multiple positions within the bookshelves. In the case of the wooden bookshelve, a total of 96 positions were sampled, whereas 80 positions were recorded for the metal bookshelves. This extensive measurement setup allowed us to capture the intricate variations in signal propagation within different bookshelves materials.

Figures 2(b) and 3(b) provide visual illustrations of the RFID propagation loss measurements conducted within the wooden and metal bookshelves for a clearer representation of the experimental setup. These setups showcase the precise positioning of the antennas, the bookshelve models, and the overall experimental environment.

4 Experiment Results

This session, the characterized of RFID propagation loss from experimental data. First, electromagnetic density contour between wooden bookshelve and metal bookshelve can show as follow in Figures 4 and 5, respectively. Show in the wooden bookshelve has better received signal than metal bookshelves. Next, the path loss of RFID propagation between wooden bookshelve and metal bookshelves are show in Figures 6 and 7. The wooden bookshelve has less than metal bookshelves. The RFID average path loss in wooden bookshelve is 49.97 dB and the RFID average path loss in metal bookshelve is 50.05 dB. Next, CDF comparison of RFID propagation loss between wooden bookshelve and metal bookshelve can show as follow in Figure 8 form this experimental results with CDF of wooden bookshelve less than metal bookshelve is 27.26%.

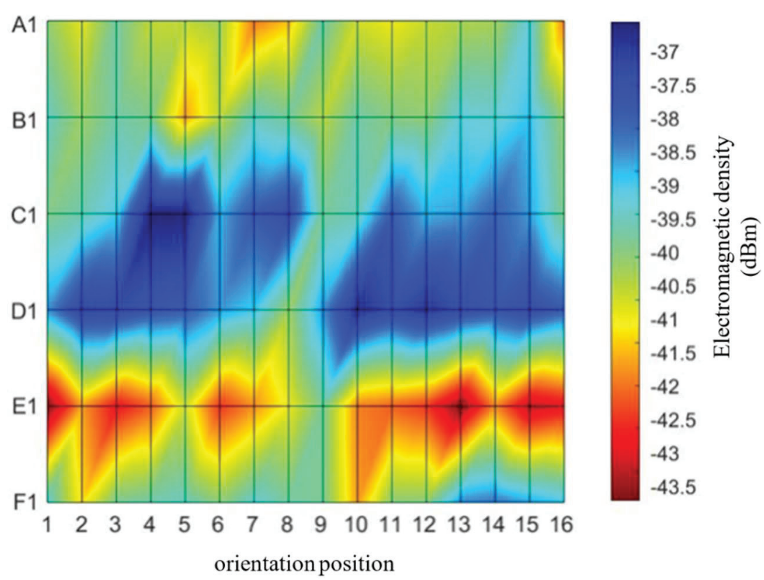


Figure 4 RFID electromagnetic density contour of wooden bookshelves case.

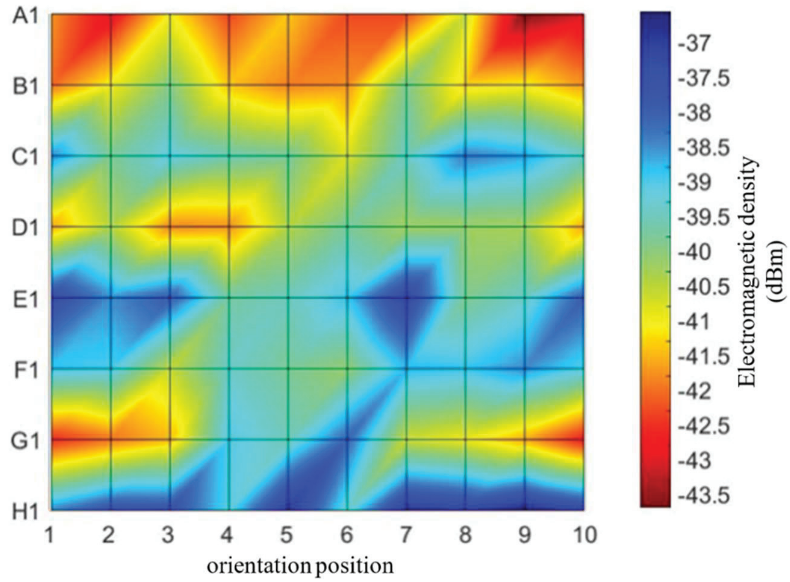


Figure 5 RFID electromagnetic density contour of metal bookshelves case.

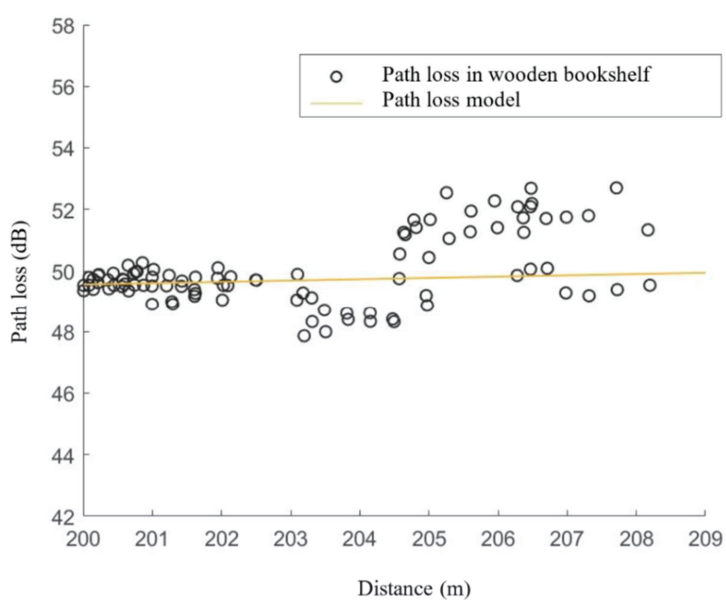


Figure 6 Path loss of RFID propagation of wooden bookshelves case.

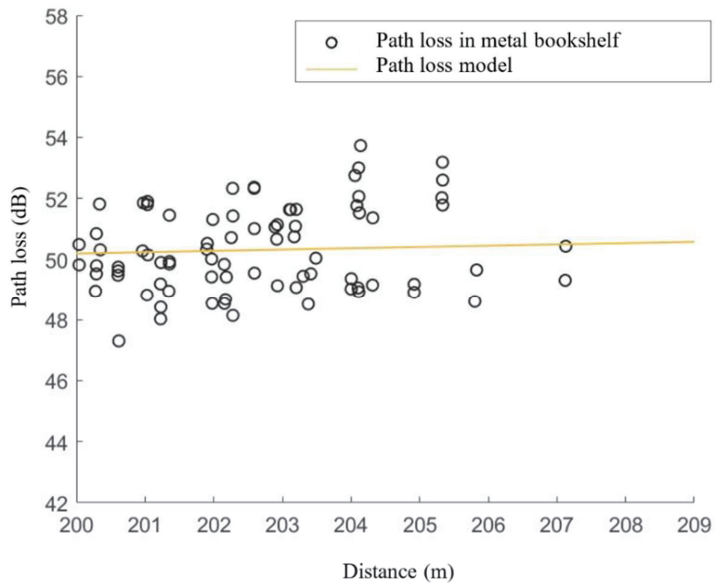


Figure 7 Path loss of RFID propagation of metal bookshelves case.

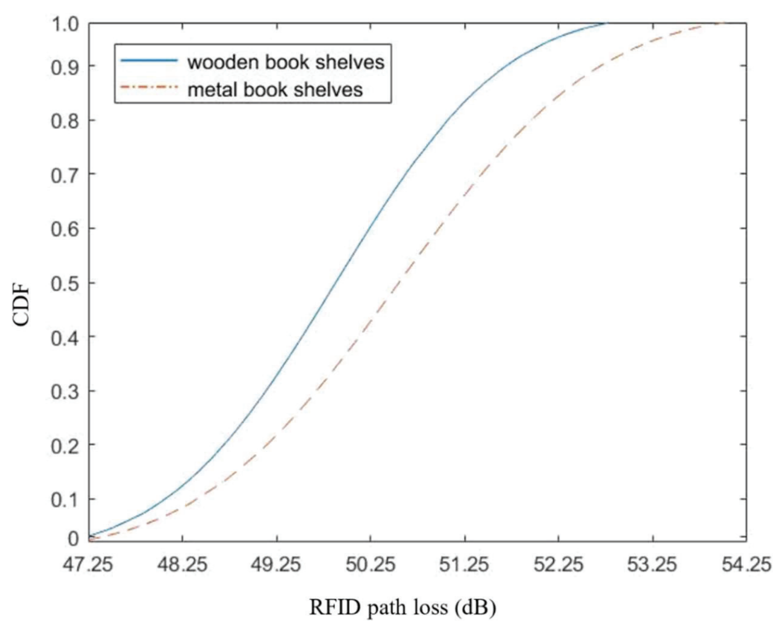


Figure 8 CDF comparison of RFID propagation loss between wooden and metal bookshelves.

5 Conclusions

In this research to evaluate the propagation loss of RFID multimedia system in an indoor environment with wooden and metal bookshelves multimedia. The path loss density, path loss distribution and channel characteristics can be seen from path loss model by using contour method and regression analysis. According to the results of the experiment, RFID path loss in wooden bookshelves is less than metal bookshelves as 0.79 dB. Consider the contour model in bookshelves showed that there was high path loss near the edge of the bookshelves. Because of the effects of the environment. In the path loss around row E1 (wooden bookshelves) and row G1 (metal bookshelves) are higher than row F1 (wooden bookshelves) and row H1(metal bookshelves). Path loss does not increase with distance. Because of the effect of the environment to the surface of the table that cause destructive interference occurs around row E1 and G1 and constructive superposition occurred around row F1 and H1. Therefore, factors of distance, environment and materials used are effect on path loss.

Therefore, can be conclude that co-polarization can work better in wood bookshelves by observation of the less path loss as compared to the metal bookshelves. Because of the effect of the material, pattern of antennas and environment. In this research very useful for RFID antennas design, RFID system design and evaluation of RFID multimedia systems with a new technology.

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Biographies

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