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Effects Barrier Materials and Data Rates on Object Detection Using Ultra-Wideband Technology

Scott Heggen, James Z. Zhang, Aaron K. Ball
Kimmel School of Construction Management, Engineering, and Technology
Western Carolina University, Cullowhee, NC 28723

Abstract

Penetration capability of Ultra-Wideband (UWB) has made it possible for object detection using UWB. However, the technology is still in the developmental stage. Behavioral characteristics, including attenuation characteristics caused by obstructions, signal behaviors through various barrier materials, and transmission data rates during penetration, have yet to be determined. Defining these characteristics could lead to a better understanding of various object detection applications using UWB.

This research focuses on the empirical study of UWB performance through a designed experiment. Empirical performance data will be collected through hardware testing, taking into account the above parameters. The experiment addresses the performance issues by offering a statistical analysis of the gathered data, given a set of variables and various levels of treatment for each variable that may affect UWB transmission. The results will help to improve UWB object detection performance by optimizing setup parameters.

The expected outcome of this research is an increased understanding of behavioral characteristics of UWB for object detection. Furthermore, based on data analysis and statistical inference, a model can be created to aid in deciding where UWB is best suited.

Introduction

In the 1960s, the concept of ultra wideband was introduced through research performed primarily by Gerald F. Ross. Ultra wideband was then referred to as “carrierless”, or impulse technology [1]. During the late 1980s, the term ultra wideband was coined to refer to “the development, transmission, and reception of ultra-short pulses of radio frequency (RF) energy” [1]. Ultra wideband is now defined by the FCC as a “type of spread spectrum wireless transmission system that has instantaneous fractional bandwidth of at least 25%, or alternatively 500 MHz or more” [2].

Over the last 40 years, UWB has been stuck in the developmental stage, largely due to regulations placed on use by the Federal Communications Commission [3]. According to FCC [3], regulations were lifted in 2003, and spectrum band was allotted below 960 MHz and in the 3.1-10.6 GHz band for UWB in nonmilitary applications. Figure 1 shows the allotted spectrum for UWB technology [1].

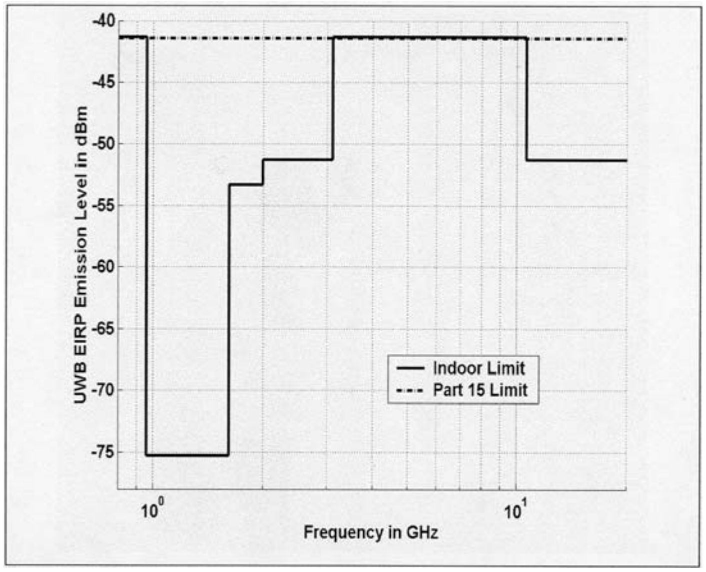

Fig. 1 FCC Bandwidth Allocation for UWB Transmission

Ultra wideband is an admirable technology due to its low power consumption, lack of interference with existing wireless technologies, covertness, high data rates, and the ability to penetrate through obstacles. Since UWB relies on pulses as its transmission medium, power consumption is kept at a minimum, and the bandwidth occupied by the signal is spread widely across the frequency spectrum. The power level of UWB is slightly above the white noise level in the frequency domain, resulting in most existing wireless technologies interpreting the UWB signal as noise. Hence, interference issues caused by UWB transmission on existing wireless technologies are primarily negligible. As an admirable side effect of its low power level, UWB is difficult to detect by a third party. Applications where detection of transmitted information could have adverse effects or security risks, such as military situations, have a great demand for UWB technology.

The information transmitted using UWB is typically controlled by the duration between each pulse and where these pulses are placed with respect to time. Since these pulses have a pulse width in the range of hundreds of picoseconds, many pulses can exist in a short period of time. The data rate of an UWB-based system is dependant on the number of pulses transmitted in these short periods of time, meaning UWB's data rate is substantially increased by increasing the number of pulses transmitted. The pulse width is so narrow, in fact, that UWB is able to penetrate through many obstacles. This quality makes UWB a good candidate for use in environments where barriers are present and object detection is necessary. Research such as [4], [5], and [6] explored the practicality of UWB being used as a motion sensor, but fail to explore the effects experienced by barriers commonly found in building foundations.

Given these admirable characteristics typical of UWB, the need for its integration into existing detection technologies can be seen. With the research previously conducted, as well as the research from this and future projects, models for UWB detection can be developed. The creation of these models will speed the process of UWB replacing less capable technologies.

Test Setup

For this project, two transceivers have been obtained from TimeDomain Corporation that utilize UWB technology for transmission. The PulsOn 210™ radios are programmable for use in data communications as well as other areas of interest. Figure 2 shows the included components of the PulsOn 210™ radios [7].

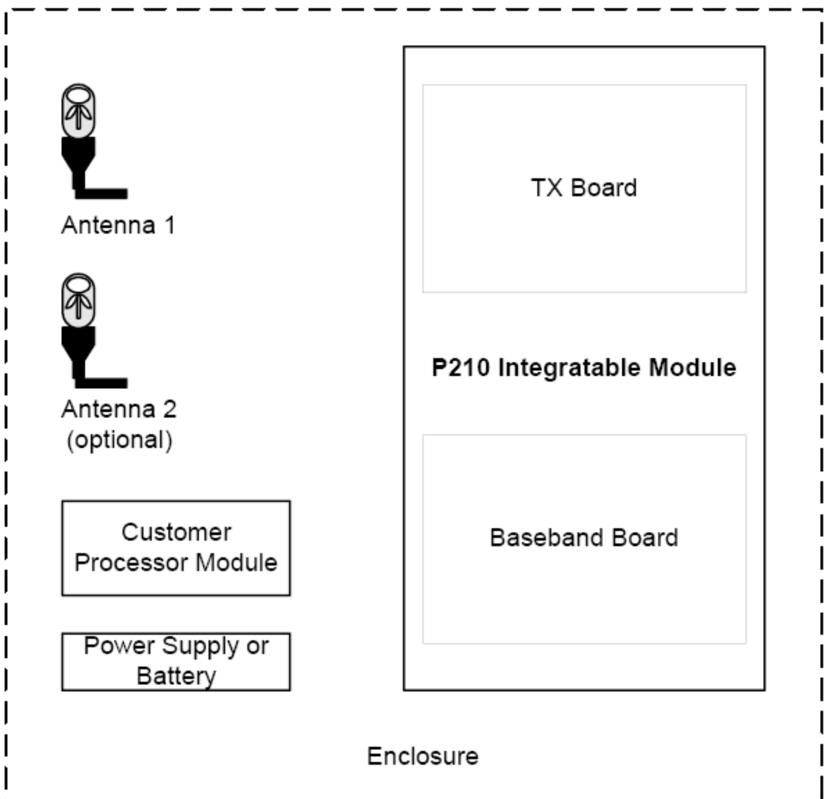

Fig. 2 Components of the PulsOn 210™ Radios

The PulsOn 210™ radios will be used to simulate an UWB transmitter and receiver. From the radio, an Ethernet cable connection will be made to a computer to record statistical information collected by the radios. Figure 3 shows the interface between the radio and computer [8].

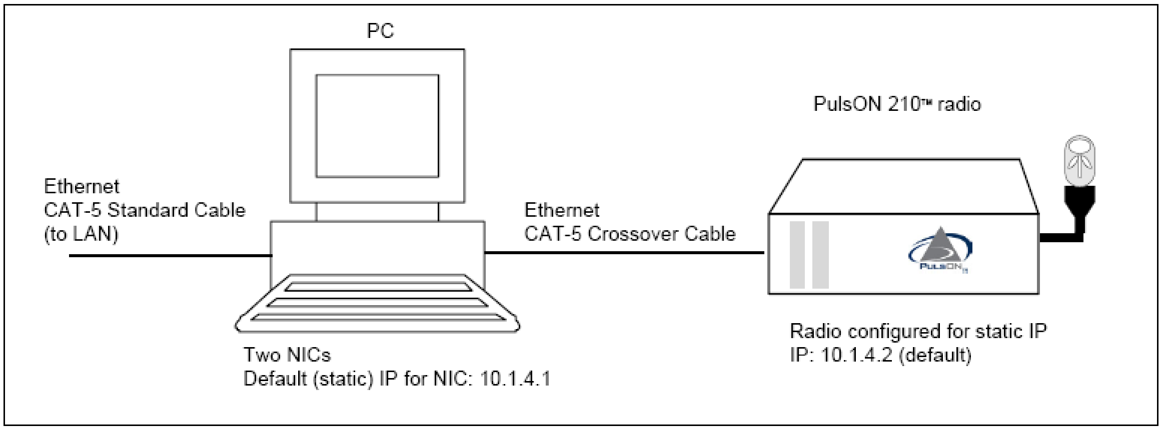

Fig. 3 Access point connection to the PC

TimeDomain has provided a few software packages with the PulsOn™ radios. The software used in this experiment is called the System Analysis Module (SAM). Figure 4 includes an image of the software package.

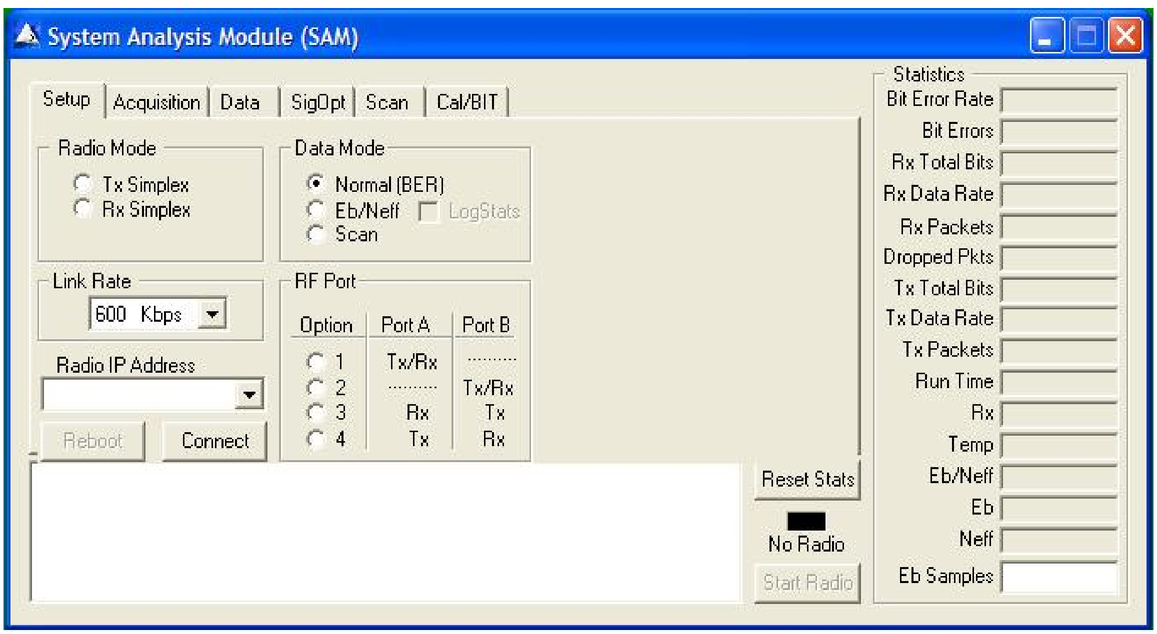

Fig. 4 SAM software used in testing

This equipment will allow for the collection of relevant statistical data describing UWB.

Statement of the problem

For given settings, the behavioral characteristics of UWB technology are unknown as the signal encounters stationary objects. Bit error rate (BER) is the behavioral characteristic most needed to be understood and quantified in order for UWB to be useful in object detection. This project will determine the effect typical stationary objects such as wood and metal have on UWB transmission quality.

Objectives

- Determine the significance of materials introduced to the UWB signal.
- Determine the significance of data rates on transmission quality.
- Determine the significance of materials at certain data rates on transmission quality.

Procedures

A matrix was determined based on what materials and data rates would be of the greatest significance. For materials, steel and wood would be used, as well as a free space treatment to compare both results to. For data rates, 600 kbps, 2.4 Mbps, 4.8 Mbps, and 9.6 Mbps were used. Four replications of every combination of material and data rate (3 materials x 4 data rates x 4 replicates = 48 total test points) were collected to produce an average value for each test combination. This ensured that nuisance factors had a minimal effect on the outcome. The run order of all 48 tests was determined by random selection. Table 1 shows the matrix used as well as the run order for the experiment.

Table 1 Matrix and run order for the experiment

Data Rate \ Materials		Control Group	Run Number	Wood	Run Number	Steel	Run Number
600 Kbps	Run 1	$Y_{1,1,1}$	35	$Y_{2,1,1}$	32	$Y_{3,1,1}$	11
	Run 2	$Y_{1,1,2}$	34	$Y_{2,1,2}$	15	$Y_{3,1,2}$	1
	Run 3	$Y_{1,1,3}$	7	$Y_{2,1,3}$	29	$Y_{3,1,3}$	39
	Run 4	$Y_{1,1,4}$	14	$Y_{2,1,4}$	3	$Y_{3,1,4}$	31
2.4 Mbps	Run 1	$Y_{1,2,1}$	10	$Y_{2,2,1}$	26	$Y_{3,2,1}$	40
	Run 2	$Y_{1,2,2}$	20	$Y_{2,2,2}$	4	$Y_{3,2,2}$	12
	Run 3	$Y_{1,2,3}$	16	$Y_{2,2,3}$	46	$Y_{3,2,3}$	21
	Run 4	$Y_{1,2,4}$	42	$Y_{2,2,4}$	28	$Y_{3,2,4}$	33
4.8 Mbps	Run 1	$Y_{1,3,1}$	41	$Y_{2,3,1}$	8	$Y_{3,3,1}$	9
	Run 2	$Y_{1,3,2}$	48	$Y_{2,3,2}$	36	$Y_{3,3,2}$	30
	Run 3	$Y_{1,3,3}$	22	$Y_{2,3,3}$	47	$Y_{3,3,3}$	25
	Run 4	$Y_{1,3,4}$	2	$Y_{2,3,4}$	27	$Y_{3,3,4}$	43
9.6 Mbps	Run 1	$Y_{1,4,1}$	37	$Y_{2,4,1}$	45	$Y_{3,4,1}$	24
	Run 2	$Y_{1,4,2}$	23	$Y_{2,4,2}$	13	$Y_{3,4,2}$	6
	Run 3	$Y_{1,4,3}$	44	$Y_{2,4,3}$	18	$Y_{3,4,3}$	17
	Run 4	$Y_{1,4,4}$	19	$Y_{2,4,4}$	5	$Y_{3,4,4}$	38

The transceivers were set up and ran according to the predetermined run order. The transmitter was covered with either steel, wood, or nothing to represent the material the UWB signal would be penetrating, and the data rates set accordingly. Each test was allowed to run for three minutes, and the BER for each test was recorded. As can be seen from Figure 4, the BER can be collected directly from the software. In addition to recording the BER, the total number of transmitted bits was also recorded. The reason for recording the transmitted bits is a discrepancy between the way the SAM program calculates the BER and the BER that is of interest to the project. Further detail on this matter is discussed later.

In the end, the entire project was run three times. During the first run, inconsistent results due to saturation of the receiver were found, and the testing was stopped short. To remedy this situation, the two radios were separated from their initial distance of 25 feet to 50 feet. The separation lowers the received power, allowing for the full signal to be reconstructed by the receiver and reducing the number of errors caused by the saturation effect. While the effect was never entirely removed, the saturation effect was reduced significantly. Future tests will conclude if this saturation is a major contributor to inconsistent results.

Also, it was determined that the position of the barrier material when placed over the transmitter could affect transmission due to small holes in them. The holes were patched and the testing was resumed.

During the second run, it was quickly determined that fixing the holes in the barrier materials also caused the transmitted signal to be completely blocked in some tests. Since the signal could not escape the materials, the size of the hole in the barrier material was controlled. The hole allowed the signal to still be transmitted and data could be collected, but still allowed us to see the effect the materials had on the signal. The final run was completed and the raw data was tabulated in Table 2.

Table 2 BER results from the final run

Data Rate	Materials	Control Group		Wood		Steel	
			BER		BER		BER
600 Kbps	Run 1	$Y_{1,1,1}$	0.00E+00	$Y_{2,1,1}$	4.00E-08	$Y_{3,1,1}$	2.60E-02
	Run 2	$Y_{1,1,2}$	0.00E+00	$Y_{2,1,2}$	6.10E-03	$Y_{3,1,2}$	1.30E-02
	Run 3	$Y_{1,1,3}$	2.30E-02	$Y_{2,1,3}$	0.00E+00	$Y_{3,1,3}$	0.00E+00
	Run 4	$Y_{1,1,4}$	1.90E-02	$Y_{2,1,4}$	9.60E-02	$Y_{3,1,4}$	0.00E+00
2.4 Mbps	Run 1	$Y_{1,2,1}$	2.30E-03	$Y_{2,2,1}$	4.60E-05	$Y_{3,2,1}$	7.30E-04
	Run 2	$Y_{1,2,2}$	2.00E-01	$Y_{2,2,2}$	1.00E-02	$Y_{3,2,2}$	1.70E-02
	Run 3	$Y_{1,2,3}$	8.20E-04	$Y_{2,2,3}$	5.60E-05	$Y_{3,2,3}$	1.20E-01
	Run 4	$Y_{1,2,4}$	4.00E-05	$Y_{2,2,4}$	4.20E-05	$Y_{3,2,4}$	9.50E-04
4.8 Mbps	Run 1	$Y_{1,3,1}$	1.20E-02	$Y_{2,3,1}$	2.90E-02	$Y_{3,3,1}$	1.70E-02
	Run 2	$Y_{1,3,2}$	1.20E-02	$Y_{2,3,2}$	1.10E-02	$Y_{3,3,2}$	1.60E-02
	Run 3	$Y_{1,3,3}$	1.30E-02	$Y_{2,3,3}$	1.10E-02	$Y_{3,3,3}$	1.60E-02
	Run 4	$Y_{1,3,4}$	1.70E-02	$Y_{2,3,4}$	1.20E-02	$Y_{3,3,4}$	1.40E-02
9.6 Mbps	Run 1	$Y_{1,4,1}$	2.50E-02	$Y_{2,4,1}$	2.50E-02	$Y_{3,4,1}$	2.70E-02
	Run 2	$Y_{1,4,2}$	3.00E-02	$Y_{2,4,2}$	4.50E-02	$Y_{3,4,2}$	4.50E-02
	Run 3	$Y_{1,4,3}$	2.50E-02	$Y_{2,4,3}$	3.30E-02	$Y_{3,4,3}$	2.80E-02
	Run 4	$Y_{1,4,4}$	6.30E-02	$Y_{2,4,4}$	6.50E-02	$Y_{3,4,4}$	2.50E-02

Results

Once all the data was collected, statistical analysis was performed. An Analysis of Variance (ANOVA) was conducted on the data set to determine the significance of the materials, data rates, and interactions among material and data rate.

Initially, the ANOVA analysis was conducted on the Bit Error Rates (BERs) provided by the SAM software. Table 3 includes the results of the test.

Table 3 ANOVA analysis of SAM software BERs

Source	SS	DF	MS	F	P value	F-crit
Average	2.760E-02	1	2.76E-02			
Material	3.362E-04	2	1.68E-04	0.122	8.8558E-01	3.25945
Data Rate	4.055E-03	3	1.35E-03	0.981	4.1273E-01	2.86627
Interaction	5.372E-03	6	8.95E-04	0.649	6.9024E-01	2.36375
Error	4.963E-02	36	1.38E-03			
Total	8.700E-02	47				

The ANOVA analysis determined that neither the material, data rate, nor any interaction of the two main effects had a significant effect on the BER at a confidence level of 95%. In other words, 1) different materials was not a significant cause of differences in the amount of errors received, 2) data rate was not a significant indicator of bit errors, and 3) no combination of material and data rate showed a significant effect on the transmission quality. The results of this test went completely against the expectations of the project. Figure 5 graphically shows the BER with respect to data rate for all three materials.

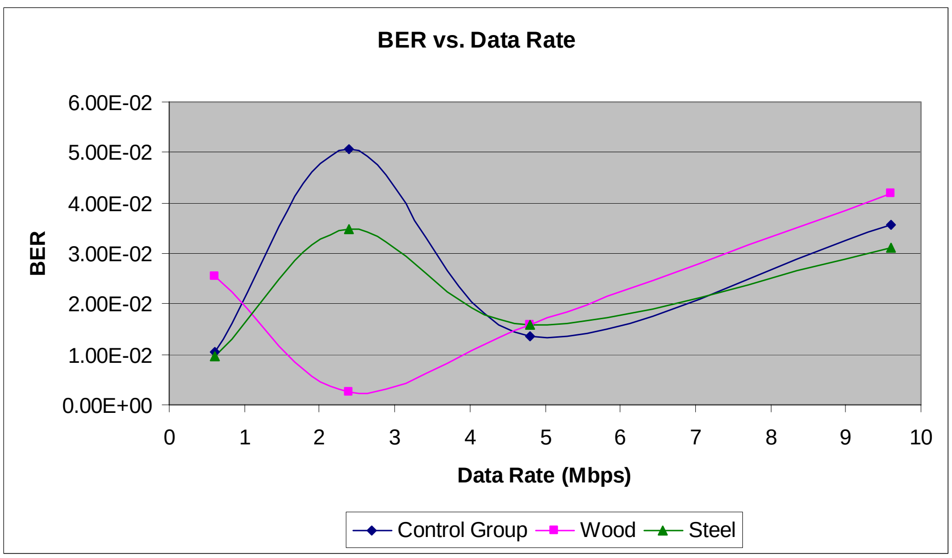

Fig. 5 BER vs. data rate for all three materials

After further investigation, it was noted that during transmission, a large number of packets were lost. These packets, while in all technicality should be considered errors since they were never received, were not included in the software's calculation of BER. Each packet consists of 32,600 bits, meaning each lost packet would have a significant effect on the BER. One might argue that the radios are aware of lost packets and remedy the situation by retransmitting the packets. While the argument is valid, the data rate is no longer valid under that assumption. If the radios take into account retransmission, then the data rate is reduced every time a packet is retransmitted. For this experiment, BER is the dependent variable, not the data rate, so the assumption is made that the data rate is constant, and all the lost packets are considered errors. The BER was recalculated taking into account these discarded bits and is included in Table 4.

Table 4 Recalculated BERs

Data Rate \ Materials		Control Group	BER	Wood	BER	Steel	BER
600 Kbps	Run 1	$Y_{1,1,1}$	2.92E-03	$Y_{2,1,1}$	4.54E-03	$Y_{3,1,1}$	6.39E-01
	Run 2	$Y_{1,1,2}$	4.51E-03	$Y_{2,1,2}$	1.77E-02	$Y_{3,1,2}$	6.72E-01
	Run 3	$Y_{1,1,3}$	3.12E-02	$Y_{2,1,3}$	6.18E-03	$Y_{3,1,3}$	8.23E-01
	Run 4	$Y_{1,1,4}$	2.62E-02	$Y_{2,1,4}$	1.13E-01	$Y_{3,1,4}$	8.97E-01
2.4 Mbps	Run 1	$Y_{1,2,1}$	8.22E-03	$Y_{2,2,1}$	2.83E-03	$Y_{3,2,1}$	8.79E-01
	Run 2	$Y_{1,2,2}$	4.09E-01	$Y_{2,2,2}$	1.64E-02	$Y_{3,2,2}$	8.08E-01
	Run 3	$Y_{1,2,3}$	6.82E-03	$Y_{2,2,3}$	3.54E-03	$Y_{3,2,3}$	7.78E-01
	Run 4	$Y_{1,2,4}$	3.52E-03	$Y_{2,2,4}$	4.57E-03	$Y_{3,2,4}$	8.99E-01
4.8 Mbps	Run 1	$Y_{1,3,1}$	1.80E-02	$Y_{2,3,1}$	3.39E-02	$Y_{3,3,1}$	7.21E-01
	Run 2	$Y_{1,3,2}$	1.34E-02	$Y_{2,3,2}$	1.46E-02	$Y_{3,3,2}$	9.22E-01
	Run 3	$Y_{1,3,3}$	2.67E-02	$Y_{2,3,3}$	1.41E-02	$Y_{3,3,3}$	9.56E-01
	Run 4	$Y_{1,3,4}$	2.34E-02	$Y_{2,3,4}$	1.41E-02	$Y_{3,3,4}$	8.12E-01
9.6 Mbps	Run 1	$Y_{1,4,1}$	2.66E-02	$Y_{2,4,1}$	2.66E-02	$Y_{3,4,1}$	9.37E-01
	Run 2	$Y_{1,4,2}$	3.76E-02	$Y_{2,4,2}$	6.97E-02	$Y_{3,4,2}$	7.06E-01
	Run 3	$Y_{1,4,3}$	2.66E-02	$Y_{2,4,3}$	4.18E-02	$Y_{3,4,3}$	8.10E-01
	Run 4	$Y_{1,4,4}$	9.88E-02	$Y_{2,4,4}$	1.97E-01	$Y_{3,4,4}$	8.82E-01

The ANOVA on the second data set, included in Table 5, was more conclusive than the first.

Table 5 ANOVA analysis of the recalculated BERs

Source	SS	DF	MS	F	P value	F-crit
Average	4.371E+00	1	4.37E+00			
Material	6.479E+00	2	3.24E+00	428.877	7.790E-26	3.25945
Data Rate	2.053E-02	3	6.84E-03	0.906	4.476E-01	2.86627
Interaction	3.647E-02	6	6.08E-03	0.805	5.729E-01	2.36375
Error	2.719E-01	36	7.55E-03			
Total	1.118E+01	47				

Again assuming a confidence level of 95%, the data rate did not show a significant effect on the transmission quality, which is expected as long as the range of the system was within specifications (the range was well within specifications for all data rates used in this experiment). Barrier material, however, shows a large significance on transmission quality. The probability of this significance being incorrect was 7.7896E-26, implying there is theoretically no chance of this significance being incorrect. Again, the interaction effect between barrier material and data rate also showed no significant, which is expected. From Figure 6 below, the steel barrier shows a significant negative effect on the transmission quality.

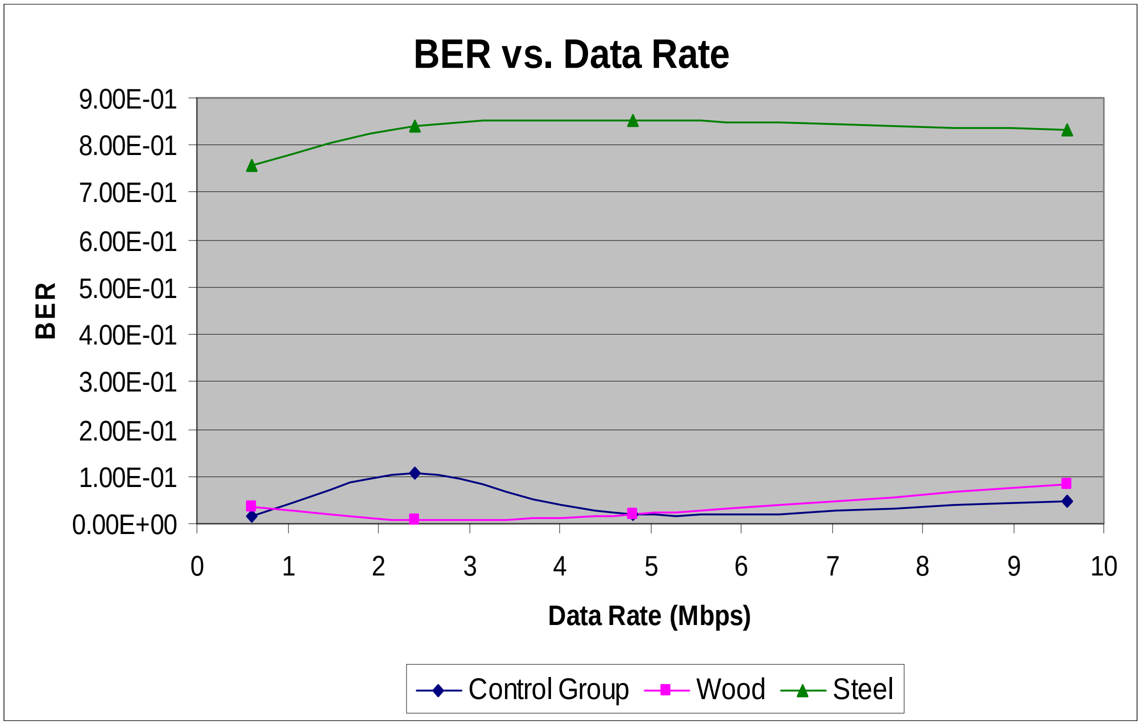

Fig. 6 Recalculated BER vs. data rate for all three materials

Conclusion

While the results are still preliminary, there is a discernable effect on transmission quality caused by the introduction of a steel barrier, while wood seems to have no effect on the quality of transmission. Some definition is still necessary in the testing process. For instance, the PulsOn™ radios claim to be able to achieve data rates up to 32 Mbps, while the best data rate achieved in this project never exceeded 7 Mbps. Also, the boxes are "configured" to run at 9.6 Mbps, yet they never achieve this data rate (usually averaging out around 6 Mbps). Other issues include thickness of materials, antennae direction, receiver and transmitter configuration problems, clarification on the meaning of the statistics presented by the radios, and more. Defining and controlling these issues is necessary in order to confidently make conclusions.

In summary, the problem initially presented was "the behavioral characteristics of UWB technology are unknown as the signal encounters stationary objects." While the problem has not been entirely resolved, the preliminary steps in determining the effects of each material are underway. The process has been designed; now it simply needs replicated to apply to a larger set of materials. Once this has been done, along with controlling the above issues, a better definition of the behavioral characteristics can be confidently outlined.

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Biography

SCOTT A. HEGGEN received his Associate of Applied Science degree in May of 2003 and his Bachelor of Science degree in May of 2005. He is currently working for the Masters of Science in Engineering Technology at Western Carolina University. Interests include Network Design, Wireless Networking, and Quality Assurance. Scott can be contacted by email at Sheggen@gmail.com.

JAMES Z. ZHANG received the B.S.E.E. (1986) from Hunan University, PRC. He received the M.A. (1993) in Telecommunications from Indiana University, M.S.E. (1993) and Ph.D. (2002) in Electrical and Computer Engineering from Purdue University. Currently he is an Assistant Professor of Electrical Engineering in the School of Technology at Western Carolina University. He is a member of ASEE and senior member of IEEE. James can be contacted by email at zhang@email.wcu.edu.

AARON K. BALL is an Associate Professor and serves as the Graduate Program Director in Engineering and Technology at Western Carolina University in Cullowhee, North Carolina. He holds a B.S. and an M.S. from Appalachian State University, and earned his doctorate from Virginia Polytechnic Institute and State University. His areas of interests include fluid power, advanced machining, prototyping systems, and applied research. Aaron can be contacted by email at ballaaron@email.wcu.edu.