Indoor Path Loss

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Application Note

XST-AN005a-Indoor

June 2012

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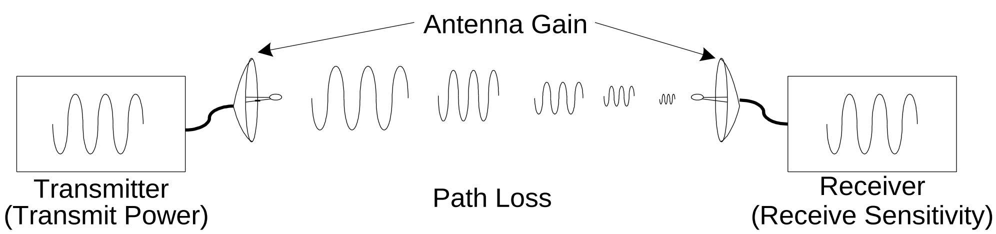
Link Margin

When designing any system, engineers and system architects usually want to know how well the various components of the system will perform. In a microprocessor, logic or other digital system these questions are usually answered in terms of clock speeds, instructions per second or data throughput. With wireless communication the most common performance questions involve range.

Unlike digital systems, trying to quantify the range performance of radio frequency (RF) communication systems can be difficult due to the large role the environment has on radio frequency signals. Buildings, trees, obstructions and lack of antenna height can all contribute to a decrease in signal strength at the receiving end. In order to estimate the communication distance (transmission range) for a system, four factors must be considered:

1. Transmit Power- The power that is broadcast by the transmitter. This is usually measured in Watts or milliwatts.
2. Receive Sensitivity- A measure of the of the minimum signal strength that a receiver can discern.
3. Antenna gain- The amount of signal gain provided by the antennas.
4. Path Loss- The signal decrease that occurs as the radio waves travel through the air or through obstacles.



Path Loss or attenuation of RF signals occurs naturally with distance. Obstacles between the transmitter and receiver also attenuate signals. The amount of attenuation varies with the frequency of the RF signal and the obstructing materials type and density. Generally speaking, the lower the frequency of transmission the better the signal will travel through the air and through objects. If two radio systems had identical transmit power and receive sensitivity, but one system was at 900 MHz and the other at 2.4 GHz, then the 900 MHz radio would perform better because it has less path loss than a 2.4 GHz system. These parameters can be used to estimate the distance a system can communicate.

Knowing how strong the communication link is or just how close a system is to failure can be important in some situations. Link Margin is a parameter that is used to measure how close the link is to failing. Link Margin is the difference between the system gains and the system losses. Successful communication takes place when the Link Margin is greater than zero.

Link Margin = Transmit Power – Receiver Sensitivity + Antenna Gain – Path Loss

Comparing an RF communications system to a human voice communication can help illustrate these principles. Transmit power represents the volume of the person speaking. Receive sensitivity represents the minimum volume required by the listener to discern the message. Antenna gain is equivalent to the use of a megaphone, and Path Loss is the attenuation that occurs as the voice travels over a distance or through obstacles. If the speaking is loud enough that the attenuation to the sound that occurs still allows the listener to hear and understand it, the communication is successful.

The transmit power on the Digi XStream 900 MHz 9600 baud radios is 100mW (20 dBm). The receive sensitivity on the same unit is -110 dBm. If you were to use these radios in a system with unity gain antennas, there could be 130 dB of signal attenuation between the transmitter and receiver and still have communication occur.

20 dBm – (-110 dBm) = 130 dB

A radio having greater transmit power of 500mW (27 dBm) and a receiver sensitivity of –93 dBm (average for industry) will have a lesser link margin of 120 dB.

27 dBm – (-93 dBm) = 120 dB

An XStream radio draws less current yet achieves greater range than radios combining 500mW transmit power with -93 dBm receive sensitivity. In line-of-site conditions, every 6dB of link margin will double the transmission range. Since the radio with a link margin of 120 dB has 10 dB less link margin than the XStream radio, it can only achieve a quarter of the range.

In line-of-site conditions the path loss can be determined by using a mathematical formula (Friis transmission equation).The path loss for 900 MHz and 2.4 GHz in free space is given for several distances in the table below.

Distance	900 MHz free-space loss	2.4 GHz free-space loss
10 meters	72.5 dB	81 dB
100 meters	92.5 dB	101 dB
1000 meters	112.5 dB	121 dB

Table 1

Figuring out the range for non line-of-site and indoor communication systems is a lot more difficult and can involve a lot of obstructions and variables. The different obstacles and materials that are found in typical indoor environments make it difficult to determine the actual path loss in a given situation. In order to know how systems will perform in a given indoor environment, on sight testing must be performed. If there are known obstructions of a particular material then estimation of signal losses through the obstruction may aid in determining link margin and antenna placement.

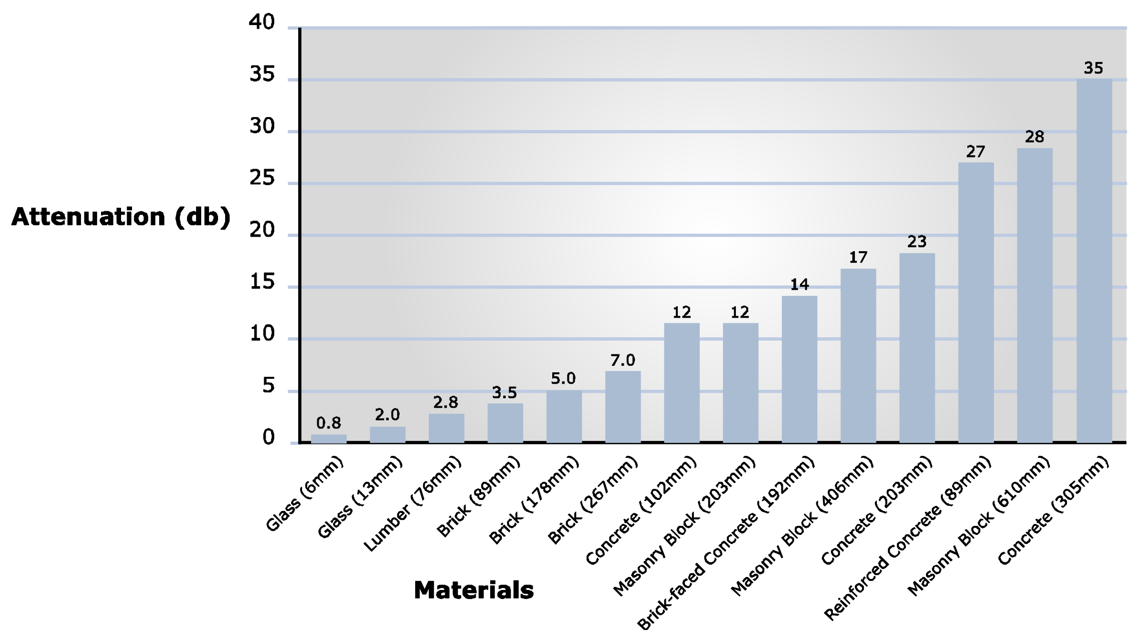
Indoor Communications

For indoor communication, the construction materials that make up the obstructions are the largest attenuators. The following is a list of common construction materials and their approximate attenuation at 900 MHz (Thicknesses of materials are given in parenthesis).

Material	**Attenuation @ 900 MHz**
Glass 0.25” (6mm)	0.8 dB
Glass 0.5” (13mm)	2 dB
Lumber 3” (76mm)	2.8 dB
Brick 3.5” (89mm)	3.5 dB
Brick 7” (178mm)	5 dB
Brick 10.5” (267mm)	7 dB
Concrete 4” (102mm)	12 dB
Masonry Block 8” (203mm)	12 dB
Brick faced concrete 7.5 “ (192mm)	14dB
Masonry Block 16” (406mm)	17dB
Concrete 8” (203mm)	23dB
Reinforced Concrete 3.5” (203mm)	27dB
Masonry Block 24” (610mm)	28dB
Concrete 12” (305mm)	35dB

Table 2

Attenuation Measures



Solid metal structures are not listed in the tables and graphs above because radio waves do not propagate through metal. In practice, metallic masses such as towers, panels, fences or vehicles that are present in the vicinity of radio transmitting equipment and the radio receiver act as reflectors and scatterers of electro magnetic radiation. The interference of the direct wave and the reflected waves can produce local maxima (constructive interference) or local minima (destructive interference) at the radio receiver.

Example:

Suppose there exists a situation where it is desired to communicate 100 meters through 4 standard sheetrock walls and one concrete wall. Table 1 indicates that the free-space loss for 100 meters at 900 MHz is approximately 93 dB. In this particular indoor situation, it is necessary to also take into account the effect the walls will have on communication. The office walls consist of two pieces of drywall (-0.8 dB each) and lumber (-2.8 dB) for a total attenuation of about 4.4dB per wall. The concrete wall is 102mm thick and attenuates the signal by 12dB. Using the equation:

Power (TX) - Sensitivity (RX) >= Signal Attenuation

130 dB >= 93 dB + (4 walls * 4.4 dB) + (12 dB)

130 dB >= 122.6 dB

The link margin of 130 dB is greater than the path loss of 122.6 dB, allowing communication to occur. It should be kept in mind that this is only a theoretical estimation. An on sight test should be performed in order to verify conditions and assumptions.

Situational Analysis

Because indoor environments vary and reflections and multi-path can make it difficult to predict the actual path of the RF signal, Digi has performed a number of different tests in real-world indoor environments. Among others, Digi has performed tests (or has applications running) in a four-story university building, an industrial facility and a hotel. All the situations are using the 900 MHz 9600 baud XStream radios (Part number: X09-009).

University Building

A University wanted to communicate to a weather station that was mounted on the roof of the building. The computer that was to collect the data was located in the basement at the opposite corner of the four-story building. The transmitting radio was placed on the roof with the weather station. Without retries and acknowledgements enabled, over 90% of the packets were successfully received. The radios were more than 600' apart.

Industrial Facility

A company had expanded to a warehouse across the street from their primary facility. A time clock system was used to keep track of the employees work hours. All time clocks needed to be linked back to a central hub. Rather than try to run cables across the street, a time clock attached inside to a masonry block wall was outfitted with a Digi radio. The signal was beamed through the masonry wall, .15 miles away to a computer located in the center of a separate concrete building. The signal went through four drywall walls and one concrete wall. The installation has been operational for over a year and a half.

Hotel

A hotel had an application that involved keeping track of the temperature and location of their refrigerated food delivery carts. During initial testing, it was found that radio signals were received with 92% of packets getting through with the radios more than four stories and 200’ apart.

Conclusion

When trying to determine just how far any particular radio will transmit indoors, the main difficulty lies in figuring out just what path the radio signal will take and how many walls and obstacles the signal must transmit through. While taking into account the different building materials and their thicknesses can be helpful for estimation purposes, testing in the actual environment is the only sure way to determine whether or not communication will be successful.

The radio transmit power, receive sensitivity and frequency need to be considered in any wireless communication systems. Antenna or radio placement can help in avoiding some obstacles, but in most situations the system designer does not have control over what building materials must be transmitted through. That leaves transmit power, receive sensitivity and antenna gain as the only parameters that are left to the designer’s choosing. If communication in a particular environment is not robust, choosing a radio set with better link margin can help improve data reliability. The expectation should be that some data will be lost. Protocols can be developed that allow for graceful recovery from data corruption and reliable delivery of the information. Whatever the conditions, estimating materials and doing site testing in the actual environments can aid in setting performance expectations during the design phase of the system.