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Research Paper

Effects of Varying Angle of Incidence on Wireless Signal Propagation

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Abstract: *For different wall thicknesses, the effect of varying angle of incidence on wireless signal propagation through concrete walls is presented in this paper. In indoor and outdoor built sites RF signal attenuations are caused by losses due to reflected wave among other causes for example multipath, and non-line of sight blockage. The effects of varying angle of incidence on signal strength at 2.457 GHz were determined by using a Hameg HM8135 signal generator and a spectrum analyzer Tektronix RSA3303B. Results showed that signal attenuation levels reduced with an increase of angles of incidences. It was found that there were no significant differences between the model and measured values with 95% confidence for all tests. Results also showed that the Friis model for wireless link need to be modification depending on what type of site conditions and equipment used.*

Keywords: Incidence, wireless propagation, transmission coefficient.

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1. Introduction:

A wireless system in an indoor concrete structure environment is affected by signal shielding or multipath effects as the signal is propagated through the concrete walls, causing a major interference to Received Signal Strength Indication (RSSI) precision [4];[11]. Multipath interference is caused by constructive, destructive, and phase shifting components of radio signals when receiver combines multipath signals from direct and reflected paths [1];[6]. The interaction between these signals causes strengths of the waves decrease as the distance between the transmitter and receiver is increased [13].

Two types of walls are commonly found in modern buildings namely concrete walls and reinforced concrete ones. Concrete is a porous, heterogeneous material which is strong in compressive strength but weak in tensile strength. Reinforced concrete is concrete embedded with steel to improve on tensile strength [7].

Both types of walls tend to affect the signal propagation due to absorption and reflection of the concrete wall [9]. Theoretical and numerical analysis have been used to study the propagation of electromagnetic waves through concrete slabs. In the studies, concrete has been considered as a dielectric material having both the real part of the complex permittivity and the effective conductivity [3]. For the two types of walls, multipath reflections and transmissions are usually modeled by Fresnel coefficients, which is a rough approximation of the propagation when ray-tracing method is used [5].

A perfectly transparent medium permits the passage of a beam of radio wave without any change in intensity other than that caused by the spread or convergence of the beam, and the total radiant energy emergent from such a medium equals that which entered it. Emergent energy from an absorbing medium is less than that which enters and in the case of highly opaque medium the wave intensity is reduced practically to zero.

Based on Lambert-Bouguer law, the effect of the thickness of the absorbing medium on the absorption is expressed by the equation;

$$I = I_o e^{-\alpha t} \qquad (1)$$

where ,

I is the intensity to which the electromagnetic wave is attenuated,
I_o is the intensity of the wave at the surface incidence,
α is the absorption coefficient for the medium, and
t is the thickness of the medium the wave traverses.

The above exponential relation can be expressed in an equivalent logarithmic form as;

$$\log_{10}\left(\frac{I_o}{I}\right) = \left(\frac{\alpha}{2.303}\right)t = kt \qquad (2)$$

where

k is called the extinction coefficient for radiation of the wavelength considered.

The quantity is often called the optical density or the absorbance of the medium [10]. The Snell's law of refraction relates the angle of incidence to the angle of refraction as shown in Fig. 2.3 and can be expressed by the equation[10];[8].

$$\frac{\sin\theta_i}{\sin\theta_r} = \frac{n_r}{n_i} \qquad (3)$$

where
θ_i is the angle of incidence of the penetrating wave,
θ_r is the angle of refraction of the wave,
n_r is the refractive index of the refractive media, and
n_i is the refractive index of the surface media.

If the original medium is denser than the refracting medium, that means n_i greater than n_r, then sin θ_r will be greater than sin θ_i and therefore there will be some acute angle less than 90° for the incident ray corresponding to an angle of refraction of 90°. This angle of incidence is known as the critical angle. For angles of incidence greater than the critical angle, refraction cannot take place and the incident ray is instead reflected back into the original medium according to the law of reflection [10].

In an indoor concrete wall environment, the refractive index causes the path of the signal to curve. This changes the geometry of the signal propagation within the medium. Although the signal does pass through objects within which refraction will occur, the signal will come out at a different position than expected as shown in figure 2.3[8];[2]. Thus, obstructions change the path of the radiation by an offset distance (d) calculated based on Snell's law of refraction and expressed by the equation;

$$d = \frac{t}{\cos\theta_r}\sin(\theta_i - \theta_r) \qquad (4)$$

Where,

t is the thickness of the obstructive medium, and
d is the offset distance.

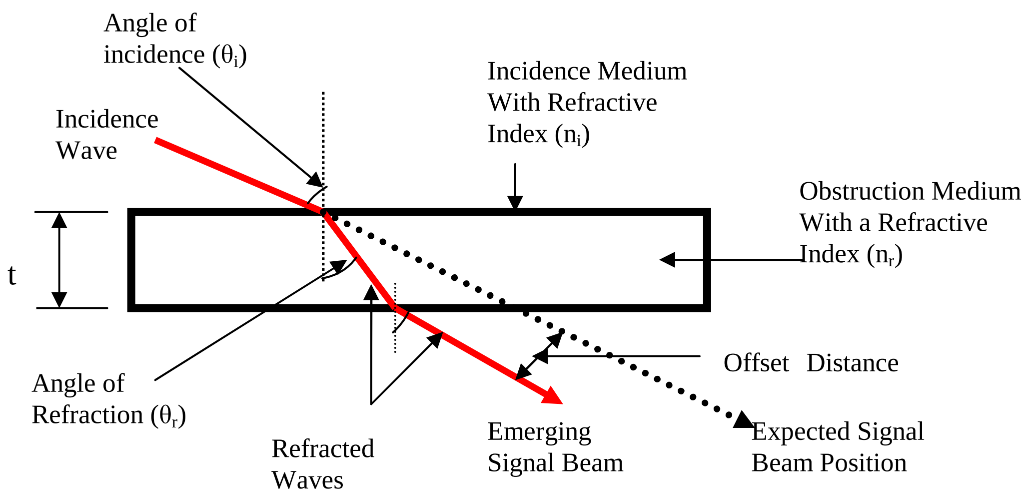


Figure 1. Signal Propagation Refraction Geometry [10]

The transmission coefficient T_{vp} (vertical polarization), T_{hp} (horizontal polarization) and attenuation factor (α), can be expressed as a function of relative permittivity (ε_γ), the conductivity of medium (σ_e) and the incident angle (θ_i) as follows:

T_{vp} Vertical (Perpendicular) polarization = $$\frac{4\cos\theta_i\sqrt{\varepsilon_r - \sin^2\theta_i}}{\left(\cos\theta_i + \sqrt{\varepsilon_r - \sin^2\theta_i}\right)^2} \qquad (5)$$

T_{hp} horizontal (Parallel) polarization = $\dfrac{4\varepsilon_r \cos\theta_i \sqrt{\varepsilon_r - \sin^2\theta_i}}{\left(\varepsilon_r \cos\theta_i + \sqrt{\varepsilon_r - \sin^2\theta_i}\right)^2}$ (6)

The equivalent medium attenuation coefficient α in Siemens per meter (Sm^{-1}) is given by

$$\alpha = \omega\sqrt{\mu_0\varepsilon_0\varepsilon_r}\sqrt{\frac{1}{2}\left[\sqrt{1+\left(\frac{\sigma_e}{\omega\varepsilon_o\varepsilon_r}\right)^2}-1\right]} \quad (7)$$

[12].

where $\mu_0 = 4\pi\times10^{-7}\ henry\ m^{-1}(Hm^{-1})$ is the permeability of free space;
$\varepsilon_0 = 8.85\times10^{-12}\ Farads\ m^{-1}(Fm^{-1})$ is the permittivity of free space;
ε_r is the relative permittivity;
σ_e is the electrical conductivity; and
$\omega = 2\pi f$ is the angular frequency of radiated and f is the frequency in Hz.

2. Materials and Methods/Definitions and Preliminaries:

The calculated angles of incidence were verified practically by carrying out measurements using the experimental setup shown in Figure 2. The walls of thicknesses 15.5cm, 18cm, 25.5cm, 27cm, 28cm and 30cm were subjected to a signal transmission from the transmitter and signal received by spectrum analyzer as shown in Figure 1.

In this test, the horn antenna on the receiver side was mounted on fixed tripod, while the horn antenna on the transmitter side was mounted on a platform which could be rotated at 10^0 intervals up to a maximum angle of 90^0. The received signal strengths, for signals transmitted at different angles of incidence at the penetration face were monitored using the spectrum analyzer and the readings recorded.

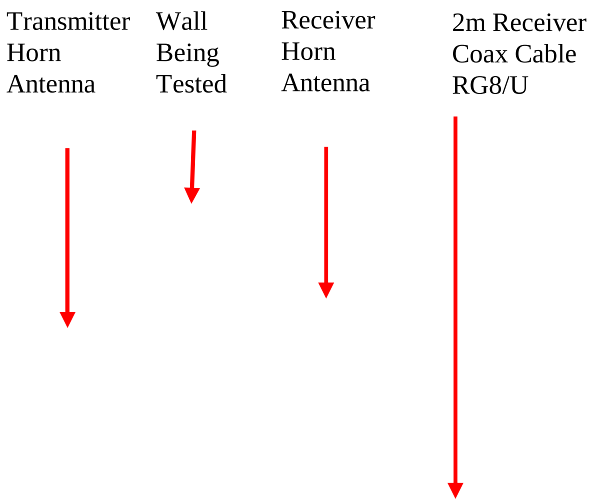


Figure 1. Signal Generator HM8135, Horn antennas and Spectrum Analyzer Tektronix RSA3303B Equipments Setup.

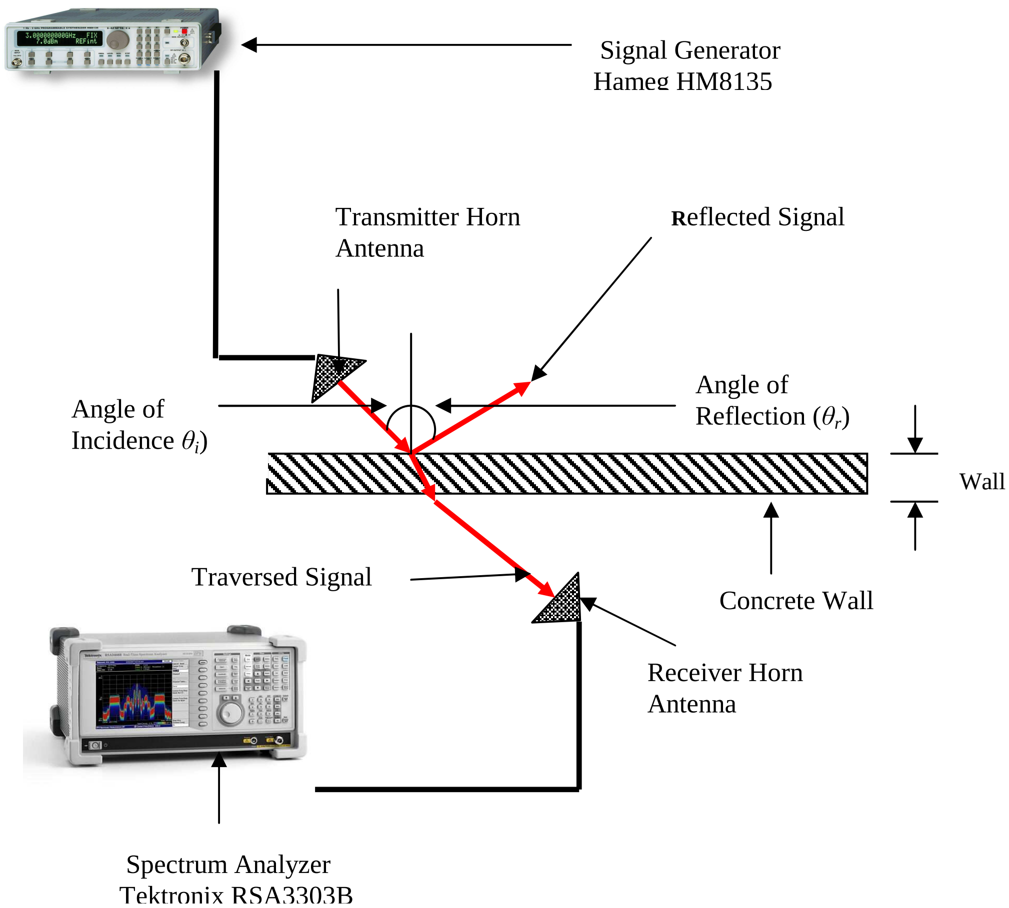


Figure 2. Experimental Setup for Angle of Incidence Tests

3. Results and Discussion:

Scrutinizing graphical responses it can be seen that the signal attenuation levels are lower as the angle of incidence approaches 90^0 and higher as the angle of incidences are at lower values for all the wall thicknesses. Results obtained for tests done in Test Site 2 as shown in graphs of Figures 4 show some attenuation level dips compared to the readings in Test Site 1 shown in Figure 3. These dips observed could have been attributed to heavy reinforcement in Test Site 2 comparative to the walls in Test Site 1.

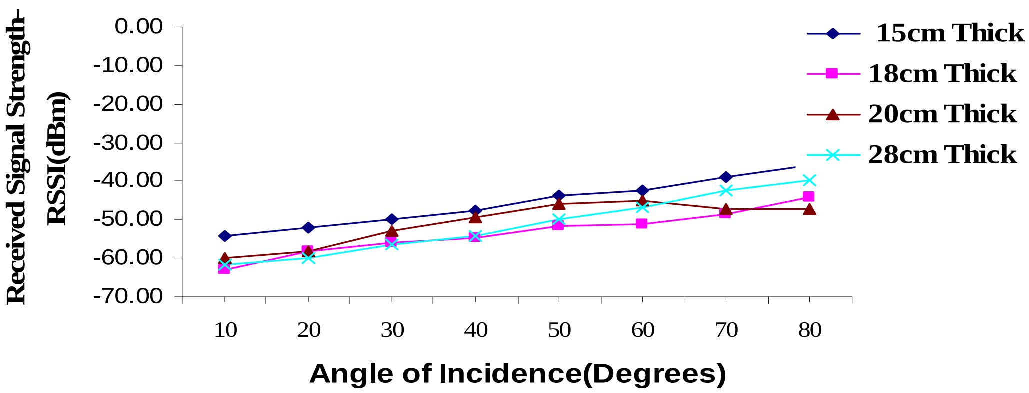


Figure 3. Effects of Angle of Incidence on Signal Strength through 15cm to 28cm Thick Walls in Test Site 1.

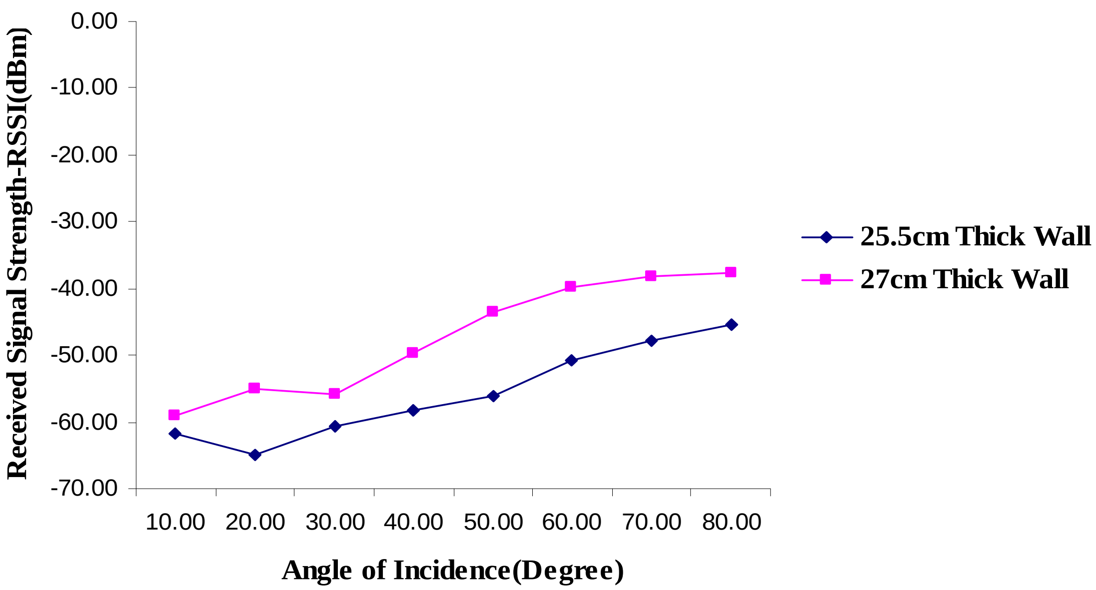


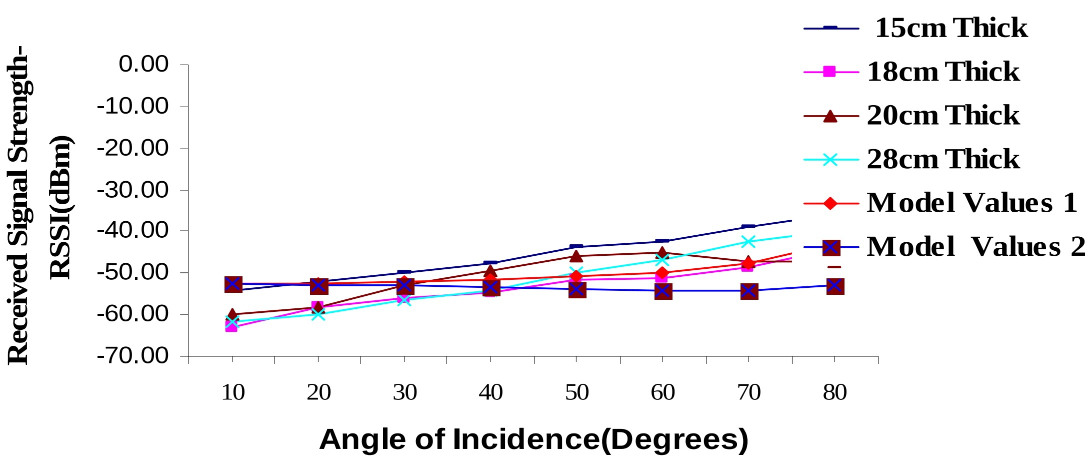
Figure 4. Effects of Angle of Incidence on Signal Strength through 25.5cm and 27 Thick Walls Test Site 2.

4. Testing of Theoretical Model and Measured Signal Strengths:

The Friis free space wireless link modified equation is given by

$$P_r = P_t + G_t + G_r + 20\log_{10} T - 20\log_{10} f - 20\log_{10} r - L_r - L_t + 27.6 \quad (8)$$

therefore 2 model values for transmission coefficient vertical polarization T_{vp} (model values 1) and horizontal polarization T_{hp} (model values 2) were tested.



The results were obtained when the constant value in the model was changed so the model equation modified to

$$P_r = P_t + G_t + G_r + 20\log_{10} T - 20\log_{10} f - 20\log_{10} r - L_r - L_t + 13.0 \quad (9)$$

for a better prediction between the model and measured values.

5. Conclusions:

When experiments were carried out to find the effects of angles of incidence on signal strengths it was found that the orientation of the transmitting and receiving antennas was of perpendicular polarization to the wall surfaces and therefore a strong correlation coefficient realized for all wall thicknesses tested. The errors were found to have varied values depending with the concrete wall tested and the statistical analysis showed there were no significance difference between the model and measured values.

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References

[1] C. Pu and Y. Chung, Mitigation of multipath fading effects to improve indoor RSSI performance, *IEEE Sensors Journal*, 8(11) (2008), 1884-1886.

[2] D. Gupta, WLAN signal characteristics in an indoor environment-an analytic model and experiments, *Msc. Thesis,* University of Maryland, College Park, (2005).

[3] D. Pena, R. Feick, H. Hristov and W. Grote, Measurements and modeling of propagation losses in brick and concrete walls at the 900-Mhz Band, *IEEE Trans., Antenna Propagation*, 51 (2003), 31-39.

[4] D. Puccinelli and M. Haenggi, Multipath fading in wireless sensor networks: measurements and interpretation, *in Proc. IEEE/ACM Int. Wireless Communication Mobile Comput. Conf. (IWCMC'06),* Vancouver, Canada, (2006) 1039-1044.

[5] E. Richalot, M. Bonilla and M. Wong, Electromagnetic propagation into reinforced-concrete walls, *IEEE Journal: Transactions on Microwave Theory and Techniques,* 48(3) (2000), 357-366.

[6] J.L. Chu and Kiang, Multipath effects on beacon performances, *IEEE International Conference on Networking,* Sensing and Control, 1 (2004), 635-638.

[7] J.V.R. Rodriquez, Radio propagation through window panes and reinforced concrete structures-an application of frequency selective surface techniques, *An Msc Thesis, Department of Electroscience,* Lund University, Sweden (2001).

[8] J.W. Jewett and R.A Serway, Physics for Scientists and Engineers with Modern Physics, International Student Edition, Thompson Learning Inc, (2008).

[9] L. Sandrolini, U. Reggiani and A. Ogunsola, Modeling the electrical properties of concrete for shielding effectiveness prediction, *Journal of Physics : Applied Physics*, 40 (2007), 5360-5372.

[10] McGraw-Hill, Absorption of Electromagnetic Radiation, McGraw-Hill Concise Encyclopedia of Physics © 2002 by The McGraw-Hill Companies, Inc., 2002.

[11] M. Lindhe, K.H. Johansson and A. Bichi, An experimental study of exploiting multipath fading for robot communications, *In Proc. Robotics: Science and systems,* Atlanta, GA. 2007, URL:http://www.roboticsproceedings.org/rss03/p37.pdf Accessed 5th, Dec. 2010.

[12] R. Feick, H.D. Hristov, W. Grote and D. Pena, Attenuation measurements for double-mesh reinforced concrete walls at the 900-Mhz cellular band, Department of electronic engineering, universidad technica federico santa maria, Valparaiso, Casilla 110V, Chille, *IEEE Trans. on Antennas Propagation,* (2003).

[13] R. Wu, Y. Lee, H. Tseng, Y. Jan and M. Chuang, Study of characteristics of RSSI signal, *IEEE Journal*, (2008), 13, URL:http://encyclopedia2.thefreedictionary.com/Absorption+(electromagnetic+radiation) (Accessed 8th , January 2011).