Wireless communication for sensors

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***Abstract*—**Today's new standards based ultra-low-power wireless sensor systems allow us to get information from an environment as well as, from the industrial plant more safely and efficiently. Future advances in such sensor systems would demand physical characteristics of the plant. This paper reveals the path loss levels for a site – specific circumstance in a range of from 1 to 8 GHz. Moreover, the study defines a signal – absorption of some materials in the same frequency range.

***Keywords*—** Absorption, path – loss, penetration, propagation, and communication.

I. Introduction

At present there is a rapid expansion of a wireless communication system. Radio wave propagation models are necessary not only for the implementation of a mobile radio system but also, for the wireless sensor network for the various application conditions. Most wireless systems must propagate signals through the nonideal environments [1]. Thus it is urgent to be able to provide detailed characterization of the environmental effects on the different amount of frequency of signal propagation.

A plethora of path loss models have been developed in order to calculate the average path loss (in dBm) [2], for instance, Okumura, Hata, COST-231, Dual – Slope, Ray – Tracing, FDTD, MoM, ANN, ITU, Log – Distance [3] – [6] and others. There are two main approaches for modeling path loss. First, empirical or statistical approach which has a complex mathematical equation, but the predictions are less accurate. Second, site – specific models which are more accurate than the empirical models, but the models highly depend on specific information of the area.

On the other hand, the indoor scenario can easily change its circumstance by changing the position of furniture hence; the indoor propagation modeling is relatively inconsistent. However, there are still steady objects, which should have been investigated and considered for further sensor communication system, for example, signal absorption of doors, walls and floors. Due to a development of a material technology and architecture of a construction various materials might have a different impact.

The most interesting situation is a correlation between a transmitted power and its loss for a different quantity.

Therefore, at the moment aims of this paper are:

A. To define the signal absorption of some materials for the different amount of transmitted power. The materials are:

(a) glass door (Gdoor)
(b) fire resistance wooden door (Wdoor)
(c) wall

B. To study site – specific propagation

II. Theoretical Background

There are a variety of phenomena that occur when an electromagnetic wave is incident. These phenomena are: Reflection, Scattering, Diffraction, Refraction, Absorption, and Depolarization [1].

Path loss is the main constituent of propagation and is a measure of the average radio wave attenuation experienced by the propagated signal when it reaches the receiver, after having navigated through a path of several wavelengths. Path loss is given by [7]:

$$PL_{dB} = 10 \log \frac{P_t}{P_r} \quad (1)$$

Where: P_t and P_r are the respectively transmitted and received powers.

There are number of indoor propagation models are available as mentioned before. Apparently, there are number of the propagation model exist. The most famous or well – known model is Friis transformation equation is given as [8]:

$$P_r = P_t \frac{G_t G_r \lambda_0^2}{(4\pi R)^2} \quad (2)$$

Where: G_t and G_r are the respectively transmitting and receiving antennas gain, R is the distance (m), λ_0 is the free space wavelength (m).

Manuscript received October 18, 2010. This work is supported by grant No. MSM 7088352102: "Modeling and control of processes of natural and synthetic polymers".

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III. MEASUREMENT SITE DESCRIPTION

The measurements are conducted in laboratory room of the Faculty of Applied Informatics of Tomas Bata University. During the measurement procedure the antennas were accurately aligned. The main conditions were a temperature of 25 ^{0}C, and an absolute pressure of 101.325 kPa.

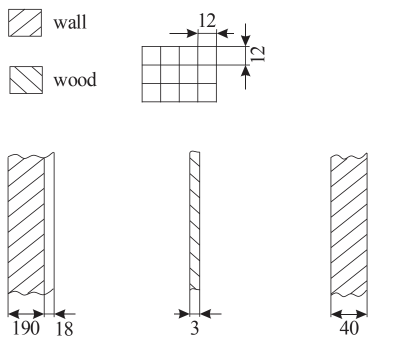
A. Indoor propagation site

The exact topology of the tested room can be seen in the Appendix Section of the present paper. The transmitting and receiver antennas were located on the three different positions, which are:

$$P1 = 4000\ mm$$
$$P2 = 7040\ mm \qquad (3)$$
$$P3 = 5350\ mm$$

B. Absorption measurement of signal

In these cases the three different materials are tested. The antennas were located 0.25 m from the each tested materials. Fig. 1 gives a main geometrical data of tested materials.
As can be seen in Fig.1, the wooden door was fire resistance specific application door, and glass door contains 12x12mm metal wire set.



(a) Wall (b) Gdoor (c) Wdoor

Fig. 1 geometrical characteristic of absorption tested materials

IV. MEASUREMENT SETUP

In study case, a SMR20 microwave signal generator and FSP spectrum analyzers are used. Photo of the measurement set is given by Fig. 2.

The wireless signal with five different power levels in the range from 1 GHz to 8 GHz signal is transmitted from the generator to the receiver. And the data are acquired in PC by using software Agilent VEE Pro version of 7.5. The following constants hold during both propagation and absorption measurement procedure.

Where: Step – 100 MHz
Span – 100 KHz
Resolution Bandwidth – 3000
Sweep Time – 10 s.

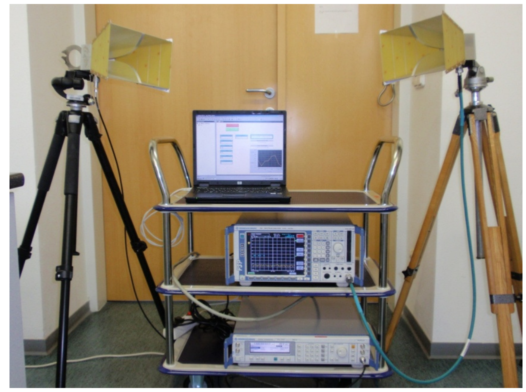


Fig. 2 a photo of measurement set

A. Indoor propagation scheme

During the measurement of the indoor propagation, a following situation can be drawn.

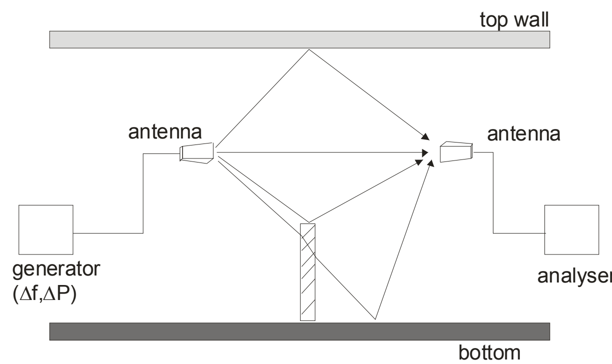


Fig. 3 scheme of the measurement system of propagation

B. Absorption measurement scheme

In contrast to, the scheme of measurement of absorption is given by Fig. 4.

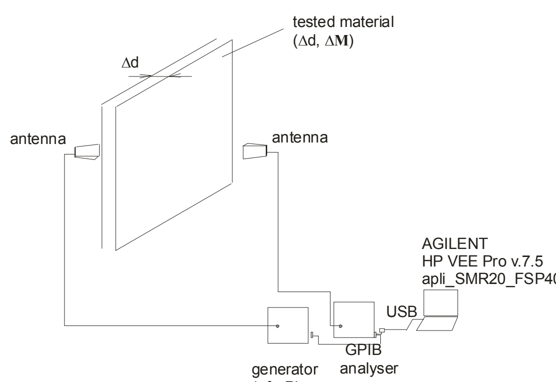


Fig. 4 scheme of the measurement of absorption

V. DATA EVALUATION AND MEASUREMENT ANALYSIS

The measurement site was equipped by some wireless router and laboratory devices, which can add extra noise to the generated signal. Therefore, first we considered a mean value of signal coverage of the measurement site. Second, uncertainties of the measurement devices were subtracted from the measured result in order to get precise loss of the signal. The following equation is used to evaluate the total loss of the signal:

$$P_{TL} = P_R - P_{ref} - P_{SC} - U_S \tag{4}$$

Where: P_R and P_{ref} are the received and reference signal level (dBm), respectively. P_{SC} is the measured signal coverage (dBm), (without signal generator), and U_S is the total estimated uncertainties of the system in dBm. As mentioned former the total estimated uncertainty covers the signal generator, the spectrum analyzer, the coaxial cables, and the antennas as follows:

$$U_S = \sqrt{\sum_{i=1}^{n} u_i^2} \tag{5}$$

Where: U_i is the *i*-th uncertainty of the system unit.

During the measurement of the penetration of the signal trough some material or absorption of signal a following scenario should be considered:

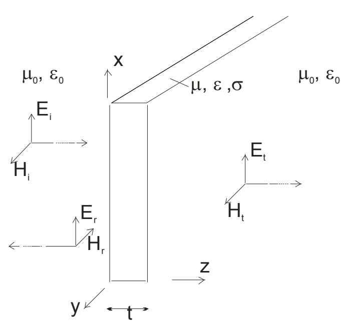


Fig. 5 scheme of penetration

As can be seen, the penetration of the signal to be caused by following parameters: ε_0 permittivity (F/m), μ_0 permeability (H/m), E intensity of electric field (V/m) and intensity of the magnetic field (T/m).

The area of material creates a loss of intensities as K_s :

$$K_s = \left(\frac{E_t}{E_i}\right) = \left(\frac{H_t}{H_i}\right) \tag{6}$$

Alternatively, Shielding Effectiveness (SE):

$$SE = 20\log\left(\frac{1}{K_s}\right) = 20\log\left(\frac{E_i}{E_t}\right) = 20\log\left(\frac{H_i}{H_t}\right) \tag{7}$$

If we derive the above parameters with respect to the to the Maxwell formula:

$$K_s = \left(\frac{1}{\cosh\gamma t\left[1+\frac{1}{2}\left(\frac{Z_0}{Z_M}+\frac{Z_M}{Z_0}\right)tgh\,\gamma t\right]}\right) \tag{8}$$

and

$$SE = 20\log\left\{\left(\frac{(Z_0+Z_M)^2}{4Z_0Z_M}\right)e^{\gamma t}\left[\left(1-\frac{Z_0-Z_M}{Z_0+Z_M}\right)^2 e^{-2\gamma t}\right]\right\} \tag{9}$$

Where: Z_0 is the free space impedance, Z_M is the material impedance which is tested, and γ is the path loss exponent parameter as follows:

$$Z_0 = \sqrt{\left(\frac{\mu_0}{\varepsilon_0}\right)} = 120\pi = 377\Omega$$

$$Z_M = \sqrt{\left(\frac{j\omega\mu}{\sigma}\right)} \tag{10}$$

$$\gamma = \sqrt{j\omega\mu\sigma} = (1+j)\sqrt{\frac{j\omega\mu\sigma}{2}} = \alpha + j\beta$$

The SE formula is:

$$SE = R + A + M \tag{11}$$

Where: R is the reflection (dB), A is the absorption (dB), and M is the penetration (dB).

For the reflection there is the formula:

$$R = 20\log\left(\frac{(Z_0+Z_M)^2}{4.Z_0.Z_M}\right) \Rightarrow$$

$$\Rightarrow 20\log\left\{\left(\frac{(Z_0+Z_M)}{2.Z_M}.\frac{(Z_0+Z_M)}{2.Z_0}\right)\right\} = R_1 + R_2 \tag{12}$$

(R_1 - is the reflection before, and R_2 is the reflection behind the face of area)

The absorption is given by:

$$A = 20\log(e^{\gamma t}) = 20\log\left(e^{\frac{t}{\sigma}}\right) \Rightarrow$$

$$\Rightarrow 8{,}69\,\frac{t}{\sigma} = 0{,}0069\,.t.\sqrt{\omega\mu_r\sigma} \tag{13}$$

VI. Result and Discussion

When a wireless signal hits an object it does not just stop or bounce straight back it could turn, bend, breakup, slow down, or even turn a corner. Reflection happens when the signal completely bounces off the object. The study of the reflection and absorption in wireless signal transmission can result in a more useful wireless sensor network. During the measurement process, the five different level of signals are tested in the frequency range of 1 GHz to 8 GHz.

Fig. 6 shows the different measurement results for propagation in P1 (see appendix).

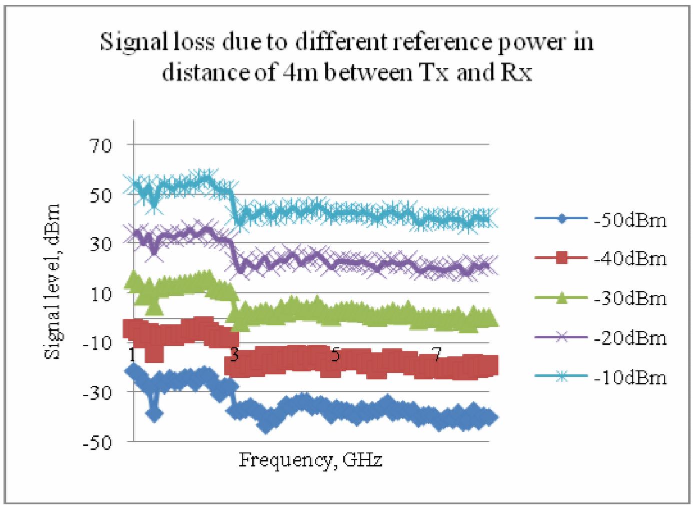


Fig. 6 propagation of signal in P1

As can be seen in Fig. 6, there is a very interesting situation during the transmission of 1.4 GHz signal for all levels of measurement the total loss results a low loss with respect to the other ranges of frequencies. In range of frequency from 3.1 GHz to 8 GHz the total loss curves tend to relatively constant and lower.

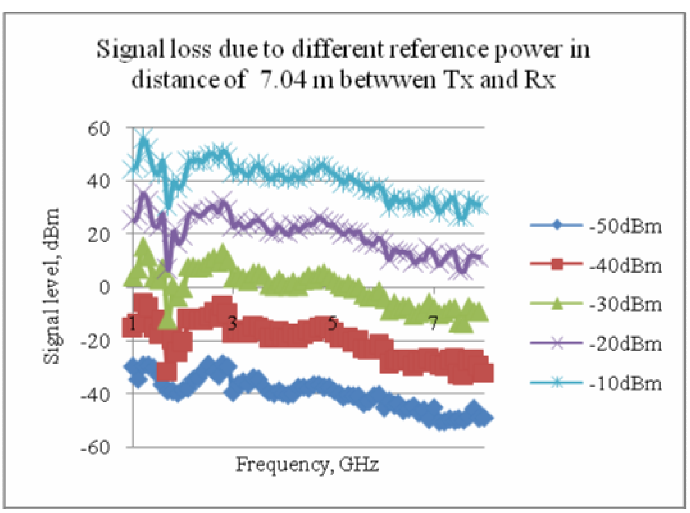


Fig. 7 propagation of signal in P2

Fig. 7 depicts the same result for the next point of measurement. As shown in Fig. 7, in contrast to former result the frequency of 1.7 GHz transmission results more lower than that other ranges of frequencies except of signal level of – 50 dBm. In addition, from the 2.8 GHz frequency transmission the total loss curves tend to gradually decline.

Fig. 8 illustrates the total loss curve for the P3 of measurement of propagation.

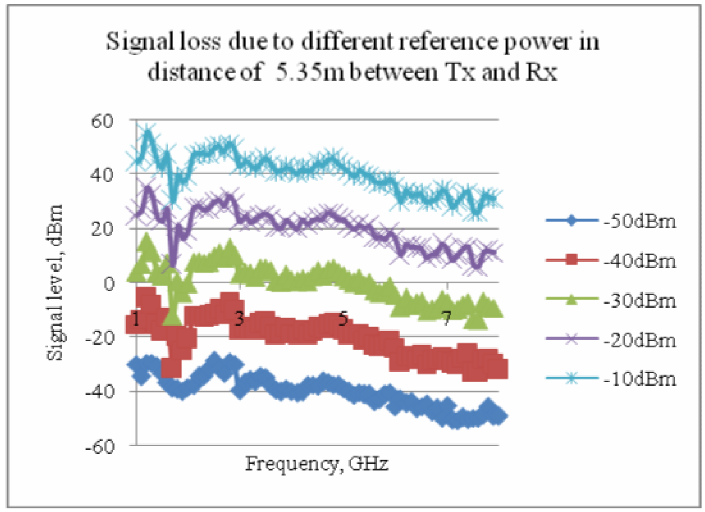


Fig. 8 propagation of signal in P3

As described in Fig. 8, the same situation appears with the P2 result. In order view more precisely, we can combine the graphs.

The following results are obtained during the measurement of penetration. In this case, we will compare with respect to the transmitted signal levels.

Fig. 9 to Fig 13 describe the total loss of the each penetrating material with respect to the transmitted power.

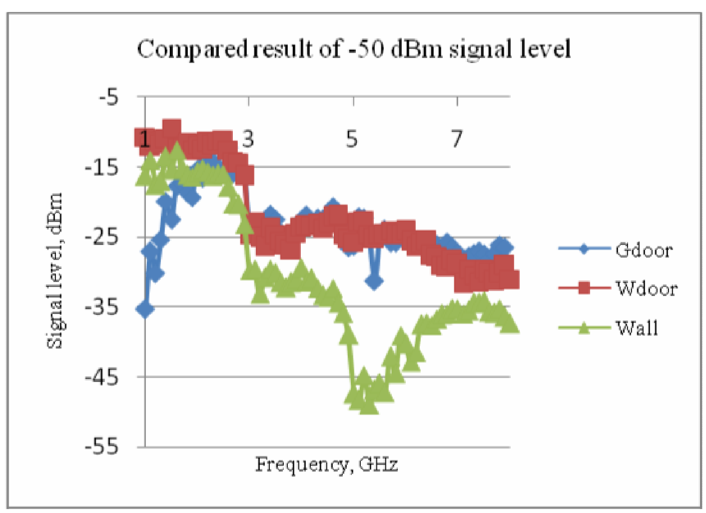


Fig. 9 penetration of signal level of -50 dBm reference

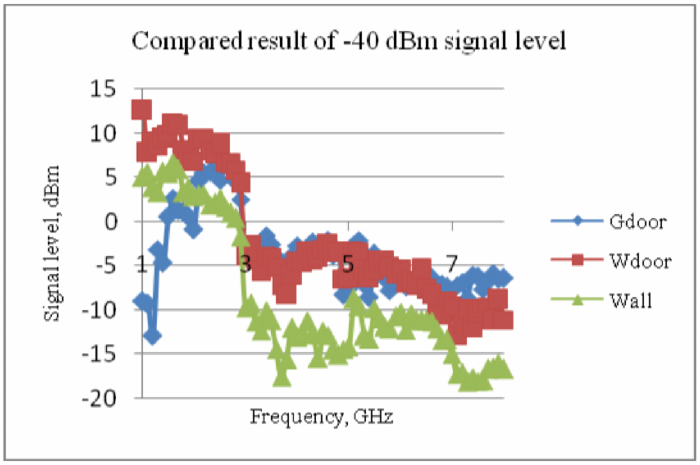


Fig. 10 penetration of signal level of -40 dBm reference

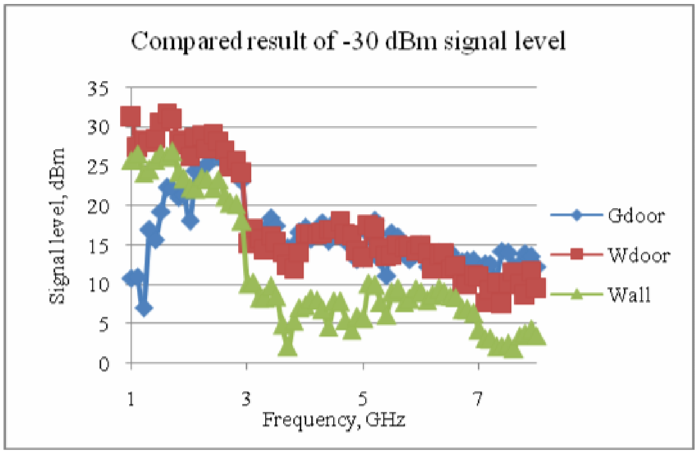


Fig. 11 penetration of signal level of -30 dBm reference

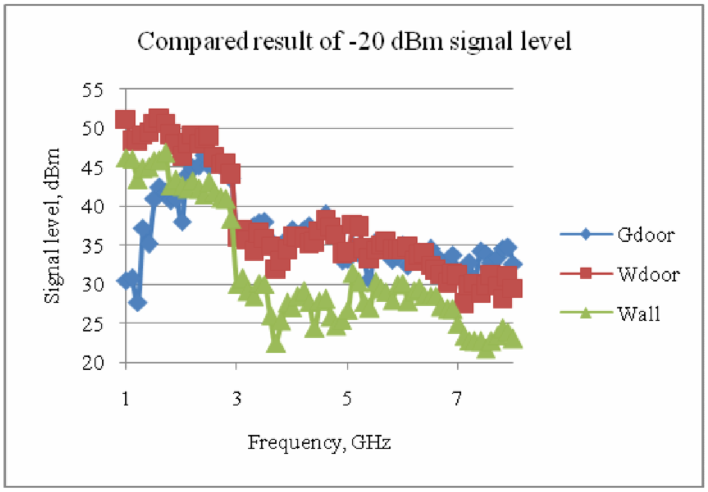


Fig. 12 penetration of signal level of -20 dBm reference

As can be seen in a comparison of the five figures, the penetration of the Gdoor in low frequency ranges from 1 GHz to 1.7 GHz tend to dramatically climb. In the range of 2.2 GHz to 2.9 GHz the total loss was fluctuating by several amounts of loss. In contrast to between 2.9 GHz to 3.0 GHz frequency the curve goes abruptly to downward. In the rest of the frequency band, the curve was changing a shape not by a big amount.

This characteristic of the glass door may can explained by its metal wire for a safety reasons.

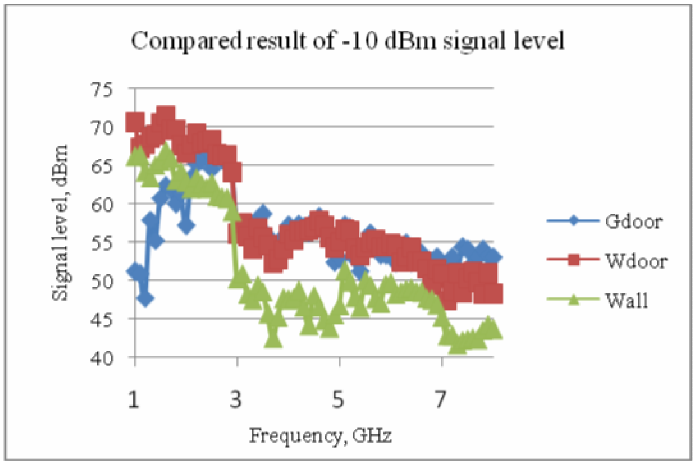


Fig. 13 penetration of signal level of -10 dBm reference

In contrast to the Gdoor, the Wdoor assumed to have a relatively high steady response from 1 GHz to 2.9 GHz range. However, the same situation appears between 2.9 GHz and 3.0 GHz and in residual bands.

The response of the wall penetration measurement curve has the same tendency with the Wdoor but, tends to absorb the more signal than the Wdoor.

VII. Conclusion

From the measured result, it can be concluded that during the propagation of 1.4 GHz frequency measurement shows less signal loss than that other frequency bands. However, when the distance between transmitter and receiver increased simultaneously, when transmitted signal level were -10 dBm the situation disappeared. Therefore, the more investigation may reveal its full behavior. On the second hand, by combining propagation of signal and penetration of signal an accurate signal level may be useful for further sensor communication system.

Appendix

Appendix - The topology of the measurement site is given in next page.

Acknowledgment

This work is supported by grant No. MSM 7088352102: "Modeling and control of processes of natural and synthetic polymers".

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Appendix – The topology of the measurement site