

# Space Diversity Path Loss in a Modern Factory at frequency of 2.4 GHz

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**Abstract:** This paper presents radio wave propagation characteristics of a modern factory at a frequency of 2.4 GHz. Fading deeps from space diversity at transmitting and receiving antennas are proposed with measured data. These models provide both large scale fading and boundary limitation in which almost measured data is contained. There are five path loss categories, namely LOS, NLOS same area, NLOS different area, LOS+NLOS same area and LOS+NLOS all areas. These categories provide different path loss characteristics in each environment. Comparisons between conventional models and purposed models are discussed and show that the purposed models provide prediction with in boundaries for all categories, especially for LOS model and the wall attenuation factor (WAF) model. It is also found that machine arrangements do not affect significantly the path loss characteristics.

**Key-Words:** Space diversity, fading deep, 2.4 GHz path loss, modern factory, one slope model.

## 1 Introduction

Indoor path loss model has been an active area of research in recent years. Various measurement campaigns have been executed to determine propagation characteristics of electromagnetic waves in office and also factory buildings. These measurements resulted in propagation models which support the coverage prediction of wireless networks operating in these environments. For factory applications, monitoring and control of testing between machine and quality control centers requires wireless connection in order to save cost and time consuming comparing with cable connection. While wireless communication between two pieces of machinery is needed for rerouting when production lines are often changed, improved, or moved. On the other hand, energy management centers need to incorporate wireless network in their energy conservation processes.

A popular wireless communication network ZigBee [1], [2] is currently integrated in industrial environments. However, the radio channel in factories will behave much differently with respect to the radio channel of office buildings. This is because of the presence of obstructions such as machinery, law materials and highly reflective materials such as metal including soft and hard walls. These influences on wave propagation are very high. The researchers had been made to

characterize the electromagnetic wave propagation in industrial environment [3], [4] and [5]. Their narrowband measurements in [3] were performed to characterize large-scale, small-scale, and temporal fading in food processing at a frequency of 1300 MHz. The measurements were executed for transmitter and receiver separations ranging from 10 m up to 80 m. Similarly the measurements at 2450 MHz in [4] were done in a chemical pulp factory, a cable factory, and a nuclear power plant at distances up to 95 m from the transmitter. In [5] they performed the measurements in two wood processing and two metal processing factories at frequencies of 900 MHz, 2400 MHz, and 5200 MHz for distances between transmitter and receiver from 15 m up to 140 m. In [6] channel characteristics were obtained and analyzed in a steel plant industrial at a frequency of 1800 MHz. In [7], a WSN testbed emulating realistic industrial environments was constructed and developed for channel testing. The wave propagations were analyzed in 2.4 GHz and 5.8GHz ISM bands. In this paper, wave propagation characteristics in a modern factory which consists of not only machine but also soft and hard walls are presented. The antennas were located with space diversity in order to increase received signal strength. We performed measurement in four categories, namely LOS, NLOS same room, NLOS different rooms, and LOS+NLOS all rooms. Then large scale fading with

fading deep are proposed to characterize propagation path losses.

## 2 Path loss models

### -Single Line Path Loss Model

Indoor path loss is a function of distance to the power  $n$  as below:

$$PL(d) = PL(d_0) + 10n \log_{10} \left( \frac{d}{d_0} \right) \quad (1)$$

where  $PL$  is the path loss approximation at distance  $d$  from the transmitter, and  $PL(d_0)$  is the path loss at the reference distance,  $d_0$  from the transmitter. The value of  $n$  depends on the surroundings and building structure. This reference path loss  $L(d_0)$  is obtained from both measurement called “ non-fixed ” value and calculation called “ fixed ” value as follow:

$$PL(d_0) = 32.4 + 20 \log_{10}(d_{km}) + 20 \log_{10}(f_{MHz}) \quad (2)$$

Because of walls between the transmitter and the receiver, propagation loss as a function of distance and wall attenuations can be calculated as follow:

$$PL(d) = PL(d_0) + 10n \log_{10} \left( \frac{d}{d_0} \right) + \sum_{i=1}^k WA_i \quad (3)$$

where  $WA_i$  is Wall attenuation factors in dB which depend on their structure and material and  $i$  is a number of walls.

### -Boundary Path Loss Model

The multipath fading causes propagation signals swing in a boundary which its lower bound is obtained as follows:

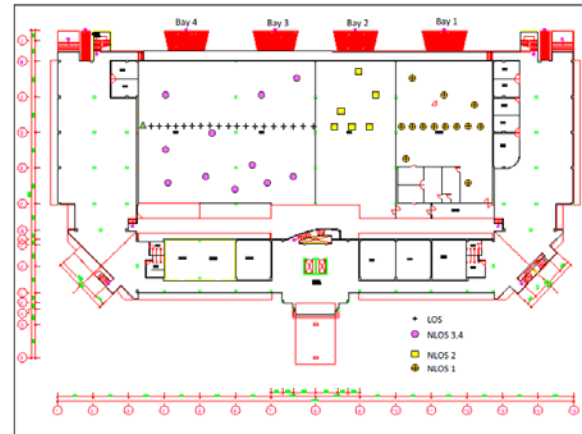
$$PL_{lower}(d) = PL(d_{bp}) + 10n \log_{10} \left( \frac{d}{d_{bp}} \right) \quad (4)$$

Where  $PL(d_{bp})$  is the path loss as a breakpoint distance,  $d_{bp}$  which is calculated in case of indoor communication as follows:

$$PL(d_{bp}) = 20 \log_{10} \left( \frac{\lambda^2}{8\pi(H-h_2)/h_2} \right) \quad (5)$$

Where

$$d_{bp} = 4(H - h_2)h_2/\lambda \quad (6)$$



(a) layout and a photo of the factory



(b) Objects inside the factory

Fig.1. Plant structure of modern factory



Fig.2. the metal grid wall



Fig.3. the solid wall

Where  $H$  is the ceiling height and  $h_2$  is the receiving height. Note that  $n$  in eq.(4) is lower and higher 2 for distance before and after brake point respectively. Because of the fast fading swings in rang of 30 dB in [9]. This make the upper and lower lines of the path loss is spaced and can be written as

$$PL_{upper}(d) = PL_{lower} + 30 \quad (7)$$

### 3 Measurement Procedure

#### A. Description of modern factory

The modern factory is in the faculty of engineering, Mahidol university. It consists of three large rooms which are separated by walls. The first room is a typical Laboratory of Civil engineering which is in Bay3 and Bay4 as shown in Figure 1. This area consists of a large open space where is sorrounded by a machinery laboratory and small rooms with aluminium and glass wall. Fig. 1 shows the layout of the building whose size is 40 m by 32 m. with height of each building was average 11 m. It

consists of concrete walls and cement floors. The second room was a typical retail store room namely, "Bay2". This room is surrounded by metal racks, metal rolls, wooden sheets and machinery within size of 18 m by 32 m. The metal racks walls located at the entrance to the room (Bay2) and isowall walls located at the entrance to the retail store and office room. The third room was a typical retail store and office room manely "Bay1". This room is a large open square area with storage and facilities rooms. The facilities room is called "Cleaning room". This room consists of two types of walls, the isowall walls located between Bay1 and Bay2, concrete walls in the other sides and cement floor with a size of 22 m by 32 m.

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#### B. Measurement apparatus

Propagation experiments in the factory were carried out with the measurement apparatus which consist of a transmitter and a receiver part, as shown in Fig. 4. The transmitter part (see Fig. 4(a)) consists of a transmitting antenna (Tx) and a signal generator. As the Tx, omnidirectional vertically polarized antenna quarter wavelength dipole with ground plan was used. The Tx is mounted on a

telescopic mast at three different heights above the floor in factory building. The Tx is positioned at 1.5 m, 2.0 m and 3.0 m high to perform the space diversity at transmitter as shown in Figure 5. A Hewlett-Packard 83732B synthesized signal generator with a 30 dB low noise amplify (LNA) were used to inject a continuous wave signal with constant power of about 18 dBm into the Tx. The transmitter is placed at a fixed location in the measurement environment. The receiver part (see Fig. 4(b)) consists of a receiving antenna (Rx) mounted on a plastic mast at a height of about 1.71 m above the floor for all measurements. As the Rx, an omnidirectional antenna of the same type as the Tx was connected to a Hewlett-Packard 8593E spectrum analyzer which measured the received power level at the transmitting frequency.

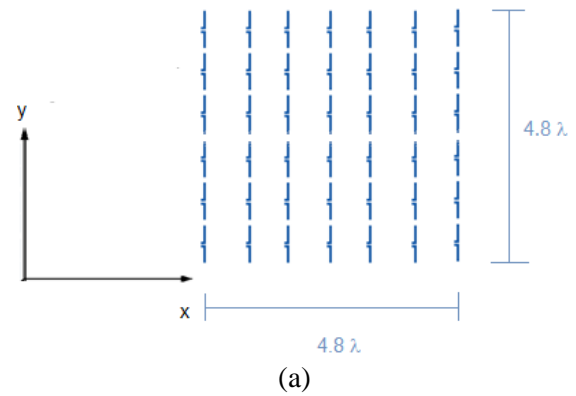


(a)

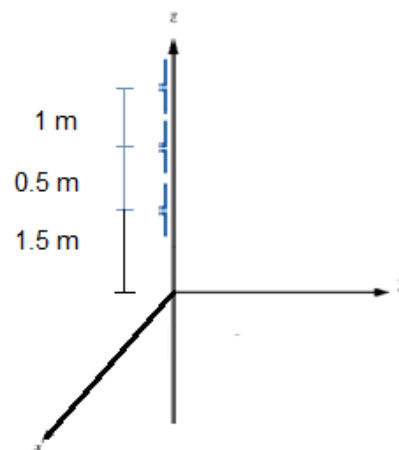


(b)

Fig.4. The equipment apparatus, transmitter unit (a) and receiver unit (b)



(a)



(b)

Fig.5. Space diversity at (a) receiver and (b) transmitter

### C. Measurement procedure

In order to obtain the large scale fading (LSF), The receiver unit was moved to the measurement points where, at total 36 samples from each receiving antenna were taken over 40 wavelengths to perform space diversity at the receiver and averaged to the local average power. Therefore the spacing between two adjacent samples was  $0.8 \lambda$  in order to fulfill Lee's criteria [10] as shown in Fig.5 a). While at the transmitting side, three antenna positions were separated by 1 m at 1.5, 2 and 3 m above floor respectively to perform space diversity as show in Fig. 5 b). The LSF was classified into 3 topography categories, namely 1) LSF1, LOS path, 2) LSF2, NLOS path with light surrounding obstruction and 3) LSF3, NLOS path with heavy surrounding obstruction or complete blocking [5].



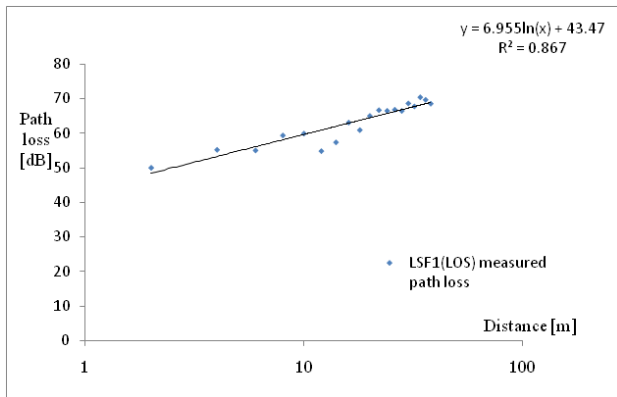


Fig. 6 averaged Non-Fixed LOS path loss and distance with a single transmitting antenna

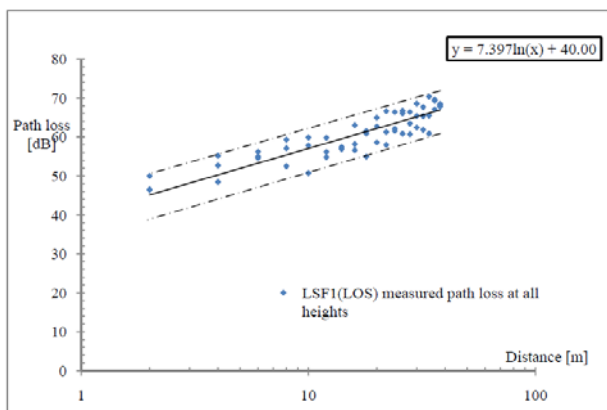


Fig. 7 averaged Fixed LOS path loss and distance with three transmitting antennas

## 4 Path loss Modeling

A number of path-loss samples at 2400 MHz are discussed in five different industrial environments with single slope and fading deep as follows.

### A Single slope modeling

#### 1. LOS

Path loss samples for LOS were done in Bay 3 and 4 at transmitting height of 1.0 m, 2.0 m and 3.0 m above the floor. Figure 6 shows a graph of path loss and distance for non-fixed intercept for a single transmitting antenna. The results show that the path loss as one meter intercept,  $PL(d_0)$  decreases while the path loss exponent increases when the transmitting antenna height increases as shown in Table 1. While path loss from three transmitting antennas provide better received signal strength as shown in Fig. 7.

#### 2. NLOS same room

Path losses increase when radio wave is blocked by objects in the factory. Figure 8 shows a graph of path loss and distance for non-fixed intercept. The results show that the path loss as one meter intercept,  $PL(d_0)$  increases while path loss exponent,  $n$  decreases when the transmitting antenna height increases as shown in Table 1. Note that this relation is same as LOS environment including the NLOS path loss exponents in case of non-fixed and fixed intercepts are very increased comparing with LOS ones. The path losses from three transmitting antennas provide better received signal strength significantly as shown in Fig. 9.

#### 3. LOS with NLOS same room

In order to obtain overall characteristics of radio waves, the measured path losses in the same room (Bay 3 and 4) were classified equally into 11 LOS and 11 NLOS points and distributed over a measurement distance. Figure 10 shows graphs of path loss and distance for non-fixed with single transmitting antenna. The results show that the path loss characteristics provide mixed properties between LOS and NLOS as shown in Table 1. Note that the one meter intercept,  $PL(d_0)$  and the path loss exponent,  $n$  are in range between LOS and NLOS. While path losses from three transmitting antennas confirm better received signal strength as shown in Fig. 11.

#### 4. LOS and NLOS different rooms

Radio waves propagate into different rooms via two different walls, a metal grid wall and a solid wall in Bay 2 and 1 respectively. These make received signal strength decrease because of the WAF. Two categories are considered, NLOS via the metal grid wall and NLOS via the two different walls. It is found that the WAFs are 2.88 dB and 14.53 dB for the metal grid wall (WAF1) and the solid wall (WAF2) respectively as shown in Fig. 12. Note that there are some different path losses between fixed and non-fixed. These show that the  $PL(d_0)$  is not expected and high  $n$  for the non-fixed method. However, this method provides a good standard deviation in order to decrease an error of the prediction as shown in Table 1.

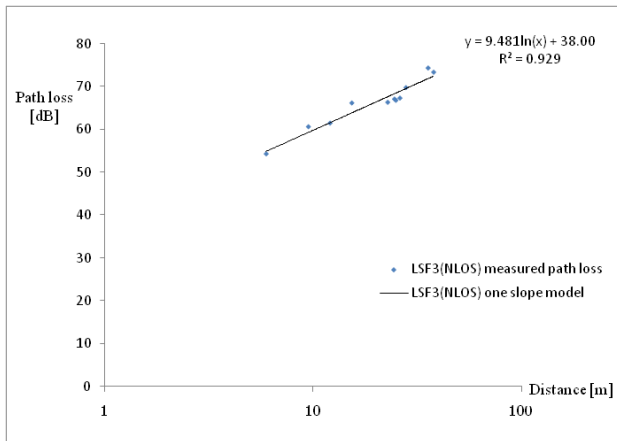


Fig. 8 averaged Non-fixed NLOS path loss and distance with a single transmitting antenna

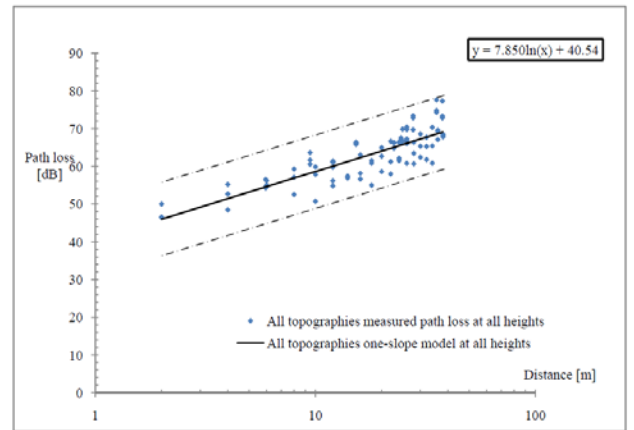


Fig. 11 averaged Non-fixed LOS and NLOS path loss and distance with three transmitting antennas

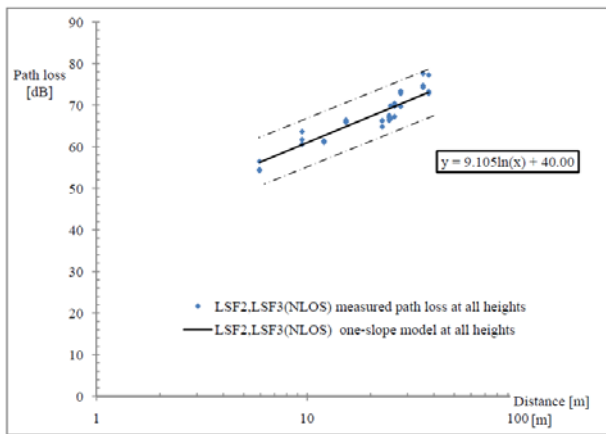


Fig. 9 averaged Fixed NLOS path loss and distance with three transmitting antennas

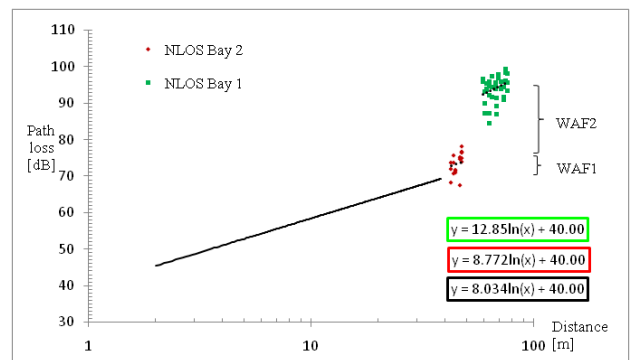


Fig. 12 averaged path loss for wall attenuation factors (WAFs)

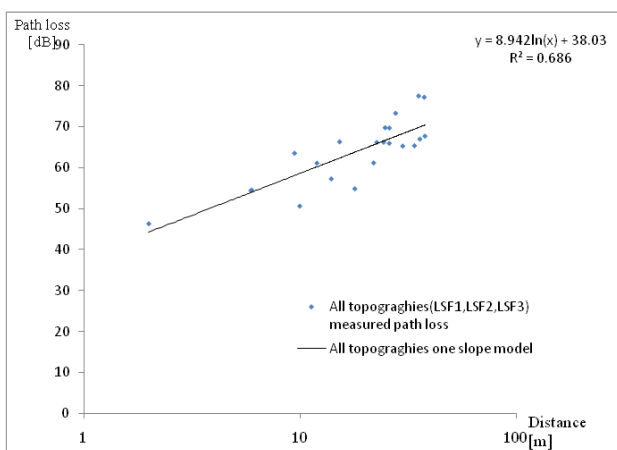


Fig. 10 averaged Non-fixed LOS and NLOS path loss and distance with a single transmitting antenna

Table 1 Summaries of path loss parameters

Factory	LSF/topography	heighted Tx(m)	Nonfixedintercept			Fixedintercept			number of location
			PL(d)[dB]	n	σ(dB)	PL(d)[dB]	n	σ(dB)	
Bay3/4	LSF1(LOS)	15	4034	127	223	4000	164	235	19
		20	4347	160	213	4000	189	235	19
		30	3935	175	233	4000	158	240	19
	LSF3(NLOS)	15	3979	210	189	4000	209	189	11
		20	3801	218	144	4000	203	149	11
		30	3536	252	240	4000	217	255	11
	All topographies Bay3, Bay4	15	4280	158	369	4000	181	376	30
		20	4213	177	224	4000	194	230	30
		30	3570	207	430	4000	180	438	30
Bay2	LSF3(NLOS)	15	-71.71	885	139	4000	211	185	6
		20	-133.75	1241	279	4000	191	340	6
		30	888	391	155	4000	204	159	6
Bay1	LSF3(NLOS)	15	3969	300	287	4000	298	287	13
		20	2870	358	282	4000	295	283	13
		30	6881	135	389	4000	294	388	13
	LSF3(NLOS)	15	1427	415	604	4000	254	757	30
		20	1272	418	680	4000	247	835	30
		30	1678	398	615	4000	252	741	30
Bay3, Bay4	All topographies Bay3, Bay4	15	2229	347	777	4000	225	885	49
		20	2526	330	708	4000	228	800	49
		30	1999	360	730	4000	222	885	49

B Fading deep modeling

The fading deep from spacing between two adjacent samples  $0.8 \lambda$  around the receiving points with no

people moving between the transmitter and the receiver are also discussed in LOS and NLOS categories as follows. Note that these analysis are non-fix interception.

1. LOS with NLOS same room

The fading deep characteristics of radio waves in case of the spacing and the transmitting height variations in the same room (Bay 3 and 4) are shown in Fig. 13. The figure shows that the fading deep in case of LOS and NLOS are 30 and 35 dB respectively. This result confirms with the theory model in eg.(6) for people moving between the transmitter and the receiver especially in case of LOS. The single slope line of LOS is higher than NLOS case. This shows that the fading deep of NLOS is much more than LOS one around 5 dB. This is because of the obstruction in the first Fresnel zone region.

2. NLOS different room

In order to demonstrate the complete obstructions, the radio wave signal measurements in different rooms were performed via walls of Bay2 and Bay1. The fading deep characteristics of radio waves are shown in Fig. 14. The figure shows that the fading deep in case of NLOS Bay 2 and Bay1 are 30 and 35 dB respectively. While the fading deep in case of all topographies will be 45 dB. This confirms complete obstruction from solid wall in Bay1. Note that the fading deep in Bay1 is equal one in NLOS same room. While the fading deep occurred in Bay2 is almost equal the LOS situation. This is because of low attenuation of the metal grid wall.

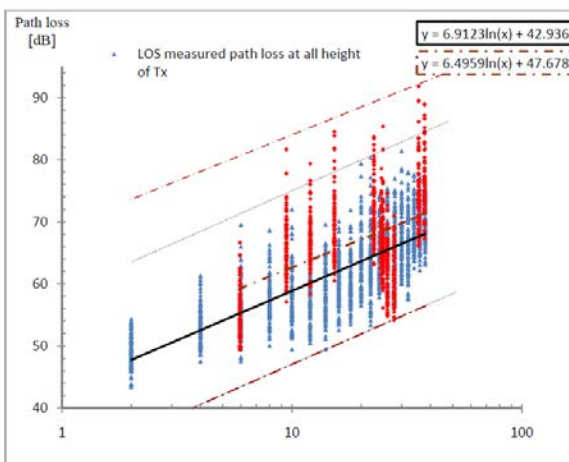


Fig. 13 LOS and NLOS path loss and distance in the same room from all antennas

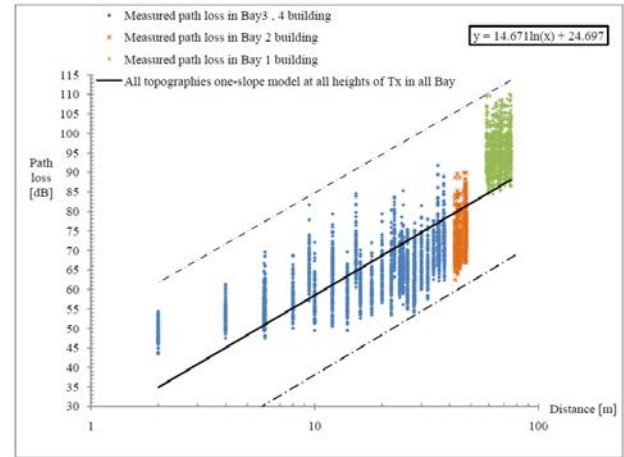


Fig. 14 LOS and NLOS path loss and distance in all Bays from all antennas

5 Conclusion

This paper presented results of path loss characteristics experiments performed in a modern factory at a frequency of 2.4 GHz. The measurements were conducted at several locations in the plant both in the same room and different room.

There are two model types, 1) one slope fixed and non-fixed models and 2) fading deep model. The standard deviations of the non-fixed were generally less than the fixed method. While the fading deeps form space diversity in case of LOS and NLOS are 30 and 35 dB with no walls respectively and 45 in case of all topographies.

The path loss exponent  $n$  for LOS is found to be less than 2, it results from the waveguide effect of the metal machine and roof. While the NLOS path loss exponents are found average to be 2.18 and 2.85 dB for the same room and the all topographies respectively. Also, the transmitting height is not significant to path loss exponent.

Additionally, the wall attenuation factor (WAF) for the metal grid wall and the solid wall are found to be 2.88 dB and 14.53 dB respectively.

Acknowledgment

This research project has received research funding from the Faculty of Engineering, Mahidol University under contract No.53-B104000-051-IO.SS03A300 8088-MU.

*References:*

- [1] K. Islam, W. Shen, and X. Wang, "Wireless Sensor Network Reliability and Security in Factory Automation: A Survey," *IEEE Trans. Systems, Man, and Cybernet—Part C*, vol. 42, no.6, pp. 1243-1256, Nov 2012.
- [2] Faheem Ijaz, Adeel A. Siddiqui, Byung Kwan Im, Chankil Lee, "Remote management and control system for LED based Plant Factory using ZigBee and Internet," *Proc. Of ICACT2012*, Feb. 19~22, 2012
- [3] T. S. Rappaport and C. D. McGillem, "UHF fading in factories," *IEEE J. Select. Areas Commun.*, vol. 7, no. 1, pp. 40-48, Jan. 1989.
- [4] S. Kjesbu and T. Brunsvik, "Radiowave propagation in industrial environments," in *Proc. 26<sup>th</sup> Annual Conference of the IEEE Industrial Electronics Society*, vol. 4, pp. 2425-2430, Oct.2000.
- [5] E. Tanghe, W. Joseph, L. Verloock, L. Martens, H. Capoen, K.V. Herwegen and W. Vantomme, "The Industrial Indoor Channel : Large-Scale and Temporal Fading at 900, 2400 and 5200 MHz" *IEEE Trans. Wireless Commun.*, vol. 7, no.7, pp. 2740- 2750, July 2008.
- [6] K. Mikhaylov, J. Tervonen, J. Heikkila, J. Kansakoski, "Wireless Sensor Networks in Industrial Environment: Real-Life Evaluation Results," in *Proc. BCFIC 2012 Future Internet Communications, 2012 2nd Baltic Congress*, pp. 1-7, Apr 2012.
- [7] Shuiping Luo, Nagesh. Polu, Zhizhang (David) Chen, and Jeff Slipp, "RF Channel Modeling of a WSN Testbed for Industrial Environment," in *Proc. RWS 2011, Radio and Wireless Symposium, Arizona, USA*, pp. 375-378, Jan 2011
- [8] T. S. Rappaport, *Wireless Communications, Principles and Practice*, 2<sup>nd</sup> ed. Prentice Hall PTR, 2002
- [9] Ghaddar M, Talbi L, A Denidni T., "Human body modelling for prediction of effect of people on indoor propagation channel," *Electron Lett.*, vol.40, pp.1592-4, 2004
- [10] Lee, W. C. Y., "Estimate of local average power of a mobile radio signal", *IEEE Trans. Veh. Technol.*, Vol. 34, No. 1, pp. 22-27, Feb. 1985.