Proceedings of the 2014 IEEE/SICE International Symposium on System Integration, pp.376-380, December 13-15, 2014

Feasibility Study on OFDM Signal Transmission with UWB 2D Communication Tile

Akimasa Okada, Akihito Noda, and Hiroyuki Shinoda

Abstract—**The concept of UWB 2DC tile as a practical implementation of UWB 2DC was proposed in the previous research. In this paper, we evaluate the feasibility of OFDM signal transmission through a two-dimensional communication (2DC) sheet in the high-band of ultra-wide band (UWB). First, we examine the effect of a thick surface insulator put on the sheet that weakens the connection between the 2DC sheet and the device on the surface insulator. Experiments are conducted to clarify the physical property of the connection. Second, we examine signal transmission via the 2DC sheet with a pair of UWB communication devices. Based on the both experimental results, we ensure that OFDM UWB 2DC is feasible with a practical carpet material on the sheet.**

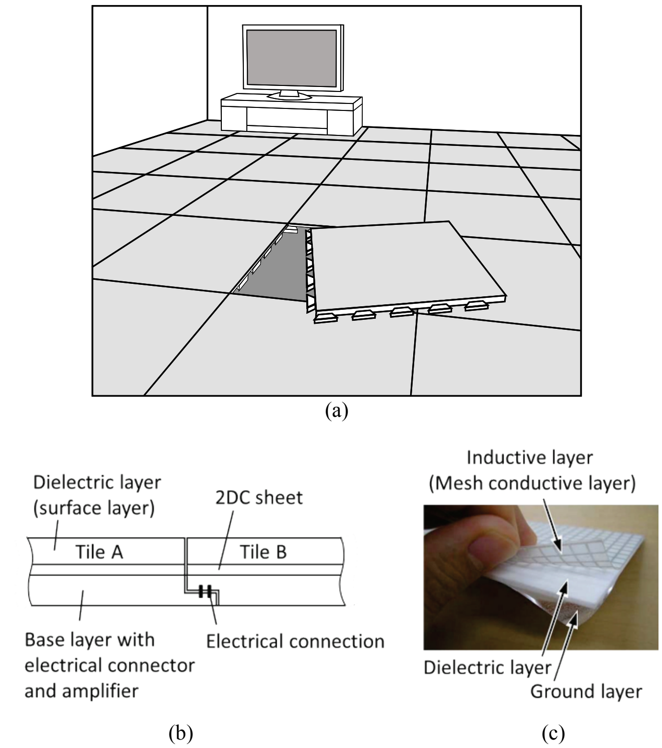

Fig. 1. (a) Conceptual diagram of 2DC tiles proposed in [4]. The figures are reprint from [4]. (b) Neighbor tiles are connected both mechanically and electrically. Each tile is independent of the neighbors in microwave propagation. Information terminals put close to the surface can connect to the network. (c) A photo of the 2DC sheet. This sheet consists of an inductive layer, a dielectric layer, and a ground layer.

I. INTRODUCTION

DEMANDS for higher-speed data transfer is growing in wireless personal area network (WPAN) for various purposes. As well as the mobile devices and home information appliances, vision-based high speed sensor networks and robot communication need a large-throughput data transfer channel with short delay. Ultra-wideband (UWB) technology from 3.1 GHz to 10.6 GHz [1] is expected to satisfy this requirement with such an enough bandwidth. UWB technology, however, is confronted to a physical connectivity problem since signal transmission power is restricted to −41.3 dBm/MHz and signals are easily occluded by objects due to propagation straightness.

Channel estimation [2] is an effective way to improve the quality of UWB communication with signal processing. Using two-dimensional communication (2DC) [3] is also an effective solution for this problem by localizing a microwave propagation area. In 2DC, a microwave propagates inside the sheet with an evanescent wave on the surface. Information terminals are put on the sheet and connected via proximity coupling [4]. Therefore 2DC is free from occlusion problem by general objects, in short, signals are always in line of sight (LOS). It is also capable of keeping the signal to noise ratio better than that in over-the-air communications, because the communication path is inside the sheet and the outside space are almost isolated. These favorable characteristics for UWB technology enables the stable connection against free-space propagation with a simple receiver. As a practical form of ind-oor 2DC implementation, we proposed “UWB 2DC tile” in [5] as shown in Fig.1. The tile is a 50 cm square which is the standard size of a carpet tile and consists of three layers: a surface layer, a 2DC sheet, and a base layer. The surface layer is the dielectric material put on the 2DC sheet, for example a carpet tile. The base layer has a function of transmitting signals to neighboring tiles with buffer circuits.

In this system, a device with a UWB coupler is put on the surface layer and establishes a connection with the 2DC sheet. Therefore it is necessary to keep connection between the coupler and the sheet even with a surface layer supposed to be several-milimeters thick. In previous researches, the surface insulators on the 2DC sheet were evaluated with some foaming materials and a part of carpet material in [5] and [6].

In this paper, we evaluate the transmission property of more practical surface layers, carpet tiles actually used in a floor.

The authors are with Graduate School of Frontier Sciences, Department of Complexity Science and Engineering, The University of Tokyo, 5-1-5, Kashiwanoha, Kashiwa-shi, Chiba, Japan, (corresponding author to provide phone: 81-4-7136-3777; fax: 81-4-7136-3777;
e-mail: okada@hapis.k.u-tokyo.ac.jp, Akihito_Noda@ipc.i.u-tokyo.ac.jp, hiroyuki_shinoda@k.u-tokyo.ac.jp)

We also examine the fundamental experiment of signal transmission with OFDM signals using a pair of UWB high-band OFDM devices developed for this system.

The rest of this paper is organized as follows. In Section Ⅱ, the evaluation of the surface layer is described. In Section Ⅲ, the fundamental experiments of signal transmission via the sheet is conducted. Finally in Section Ⅳ, we conclude this paper.

II. EFFECT OF THE SURFACE LAYER ON THE 2DC SHEET

A. Contents of Experiment

In this section, two properties of the surface layer are experimentally examined by inserting dielectric materials between the 2DC sheet and the coupler.

One is the ratio of received power to transmitted power. This ratio P_R is defined as following.

$$P_R \equiv \frac{P_{Rx}}{P_{Tx}}, \quad (1)$$

where P_{Tx} and P_{Rx} respectively denote the transmitted and received signal power. They are respectively calculated by integrating the power spectral densities, p_{Tx} and p_{Rx} through the bandwidth of interest B.

$$P_{Tx} \equiv \int_B p_{Tx}(f)df \quad (2)$$

$$P_{Rx} \equiv \int_B p_{Rx}(f)df \quad (3)$$

Using the transmittance S_{21} from the transmitter to the receiver. P_{Rx} is expressed as

$$P_{Rx} = \int_B |S_{21}(f)|^2 \ p_{Tx}(f)df \ . \quad (4)$$

Suppose that the transmitted power density is constant across the bandwidth because transmitted signal power in UWB technology is defined as −41.3 dBm/MHz.

$$p_{Tx}(f) = \overline{p}_{Tx}, \quad (5)$$

where $\overline{p}_{Tx}$ denotes the constant value. Substituting (4) and (5), we can rewrite (2) and (3) as follows.

$$P_{Tx} = B\overline{p}_{Tx} \quad (6)$$

$$P_{Rx} = \overline{p}_{Tx}\int_B |S_{21}(f)|^2 \ df \ . \quad (7)$$

Substituting (6) and (7) into (1), we obtain

$$P_R = \frac{1}{B}\int_B |S_{21}(f)|^2 \ df \ . \quad (8)$$

The other property is the available bandwidth in high-band (from 7.25 GHz to 10.25 GHz in Japan). This is analyzed with S-parameter S21 (transmittance).

B. Settings

Fig. 2 shows the schematic diagram of the experimental setting and Fig. 3 shows its overall picture. In this experiment, the 2DC sheet and the surface layer of one tile are examined.

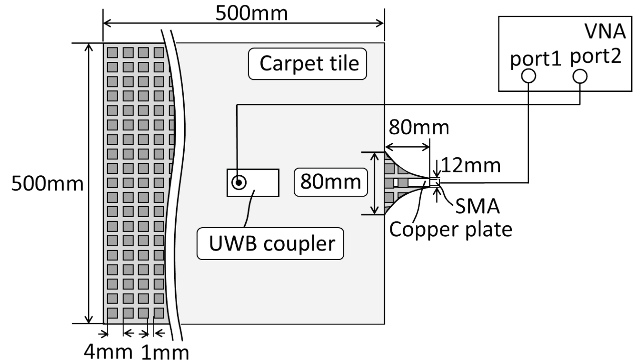

Fig. 2 The schematic diagram of the experimental setting. S21 is measured for the high-band. Two insulator and two carpet tiles are inserted between the 2DC sheet and the UWB coupler as the surface layer.

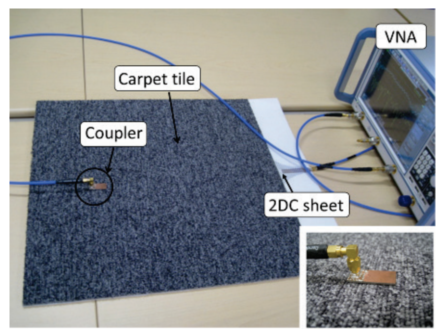

Fig. 3 The overall picture of the experimental setup. The dielectric materials are inserted between the 2DC sheet and the coupler. This figure shows the case of a carpet tile.

The size of the 2DC sheet is 500 mm ×500 mm× 1 mm. The sheet consists of three layers, an inductive layer with conductive mesh, a dielectric layer, and a ground layer. The mesh pitch, the line width, and the thickness of the inductive layer are 4 mm, 1 mm, and 0.01 mm respectively. This composition of the sheet is typical in our research. The material of the inductive layer and the ground layer is aluminum. That of the dielectric layer is the 1mm-thick polypropylene sheet. The relative permittivity of the polypropylene is 2.1. There exists a 50 μm PET film on the inductive layer for protection. This sheet is connected to a vector network analyzer, Rhode & Schwarz ZNB-20 via a horn-shaped connection part of the 2DC sheet for obtaining the flat frequency characteristic. The widths of the cable side and the sheet one of the horn part are 12 mm and 80 mm. The horn form is an exponential horn. The sheet and a SMA connector are connected via two copper plates to excite signals in the sheet. The UWB coupler proposed in [3] is used. It is set at the center of the sheet. This experiment is conducted for the high-band. S21 in dB is measured.

Two foaming insulators and two carpet tiles are examined as the surface layer and inserted between the sheet and the coupler. The relative permittivities of two insulators, Insulator A and Insulator B, are 1.5 and 2.1, respectively. Thickness is examined from 1 mm to 12 mm by 1 mm. The size of two carpet tiles are 500 mm ×500 mm ×6 mm. These carpet tiles are commercial products used in a floor. The model number of one tile, Carpet A is YS1004 and the other one, Carpet B is CT1420. Both are manufactured by Teijin Limited. The case of no insertion is also conducted. In this case, the coupler is put on the 2DC sheet directly.

C. Result

Fig. 4 shows P_R measured with the surface materials described above. P_R decreases as the thickness increases or the relative permittivity decreases. The highest value is about −25 dB at the case of no insertion. S21 of Carpet A is −41 dB and that of Carpet B is −44 dB. The difference between the highest S21 and that of the carpet tiles is less than 20 dB.

As the minimal requirement, the received power must be higher than thermal noise. In this case, the ratio of signal to noise SNR is calculated as below

$$SNR = 10\log_{10}\frac{P_{Rx}}{kBT} = 10\log_{10}\frac{P_R \bar{p}_{Tx}}{kT}. \qquad (4)$$

If SNR for the thermal noise should be 20 dB or larger and $\bar{p}_{Tx}$ in dB is −41.3 dBm/MHz, the minimal value of P_R in dB is about −82 dB. From these results, our system has a sufficient margin from the thermal noise.

Fig. 5 shows S21 of four materials at 6 mm and S11 through the high-band. S11 is less than −5dB through all the band and less than −10 dB at most parts. This indicates the major signals power is successively inputted to the 2DC sheet. The value of S21 is fluctuating mainly between −40 dB and −60 dB. Fig. 6 shows the stacked bar graph about S21 at 6 mm. The ratios of the S21 data number of $-n$ dB − $-(n+10)$ dB to the total number of the data are shown when n is from 30 to 80. All the data are sampled at every 1 MHz. The results shows

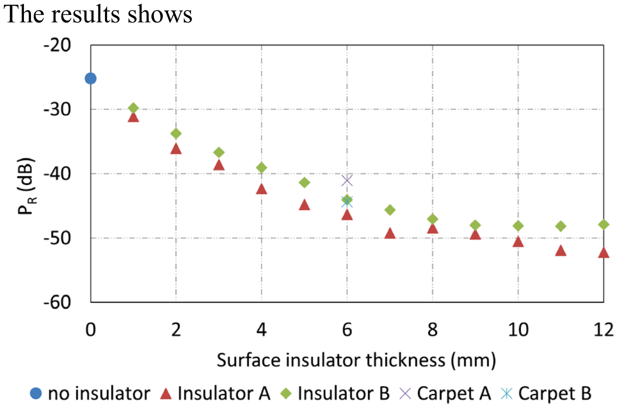

Fig. 4 The ratio P_R of the received signal power to the transmitted signal power. The value of no-insertion case is plotted at 0 mm.

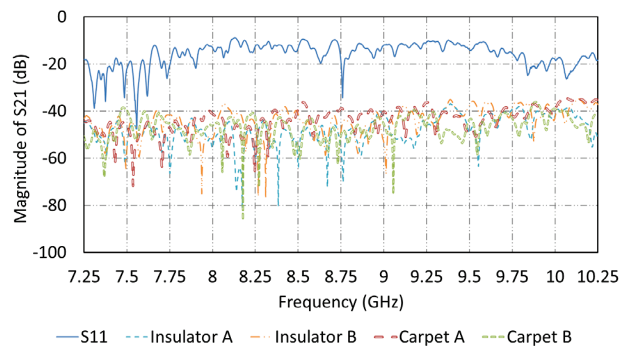

Fig. 5 S-parameter S11 and S21 of four materials at 6 mm through the high-band. S21 is fluctuating mainly between −40 dB to −60 dB.

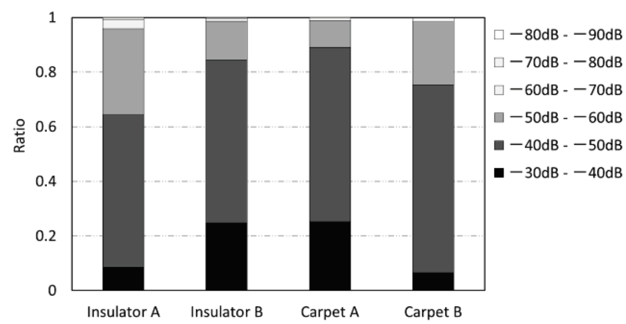

Fig. 6 The stacked bar graph about S21 at 6 mm. This figure shows that S21 is larger than −50 dB in more than 60% of the high-band.

S21 is larger than −50 dB in more than 60% bandwidth of the high-band. In the case of Insulator B and Carpet A, S21 is larger than −50 dB in 80% bandwidth. For all the cases, S21 is larger than −60 dB in more than 95% of UWB high-band, with 22 dB margin form the thermal noise.

III. SIGNAL TRANSMISSION EXPERIMENT

The results in the former section shows UWB communication with the UWB 2DC tile is physically feasible. In this section, signal transmission using a pair of UWB communication devices is examined. The devices were developed by Apollo Giken Co.,Ltd.

A. Setting

Fig. 7 shows the experimental diagram and Fig. 8 shows the overall picture. Signals are inputted to the 2DC sheet and received via the coupler put on a carpet tile. The carpet is Carpet A used in Section II. The coupler is the one proposed in [7]. This coupler can extract more power from the 2DC sheet for the high-band than the coupler used in the former section.

The transmitter outputs OFDM signals whose carrier frequency is 8 GHz and bandwidth is 125 MHz. The specifications of OFDM signals are as follows. The number of FFT point is set as 64. Therefore the bandwidth of a subcarrier

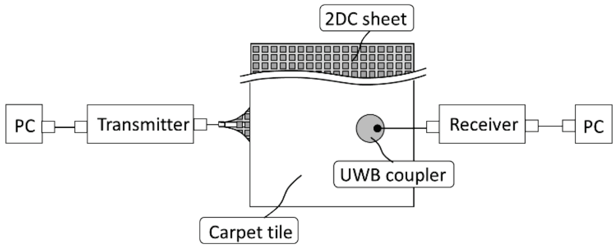

Fig. 7 The schematic diagram of the experimental setting.

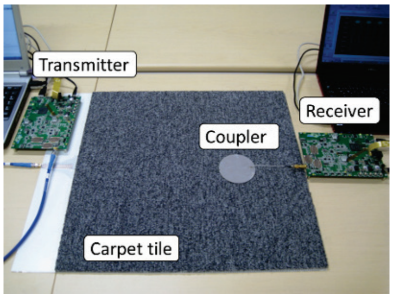

Fig. 8 The overall picture of the experiment

is about 1.95 MHz. The length of a guard interval (GI) is 64 ns. No signals are transmitted for 1,024 ns after 1 symbol (576 ns) is transmitted. In this experiment, only one subcarrier is used so that it can be easy to understand a waveform of signals. Three subcarrier frequencies, 1.95 MHz, 19.5 MHz, and 39 MHz in the 125 MHz bandwidth are examined.

B. Result

Fig. 9, 10, and 11 shows one symbol of the transmitted waveform and the received one whose frequencies of the subcarrier are 1.95 MHz, 19.5 MHz, and 39 MHz, respectively. The amplitudes of both waveforms are normalized by the maximum one. Some noises are added to signals, but almost all the signals are received correctly.

In the UWB 2DC tile, multipath signals are generated [5]. However, that influence is negligible since the signal storage duration in a tile is just several nanoseconds which is corresponding to a few times reflections in a tile. The length of the guard interval is much longer than the storage duration.

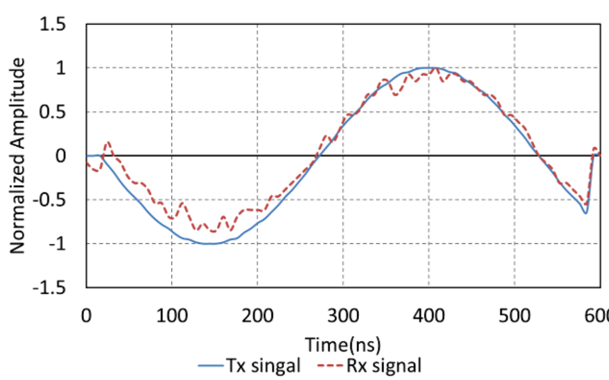

Fig. 9 The transmitted waveform and received one of 1.95 MHz subcarrier. The length of signals are 512 ns and that of guard interval is 64 ns in this waveform. The obtained data are lined smoothly.

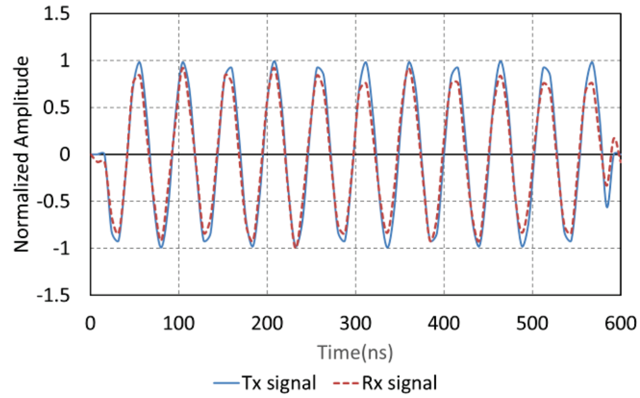

Fig. 10 The transmitted waveform and received one of 19.5 MHz subcarrier.

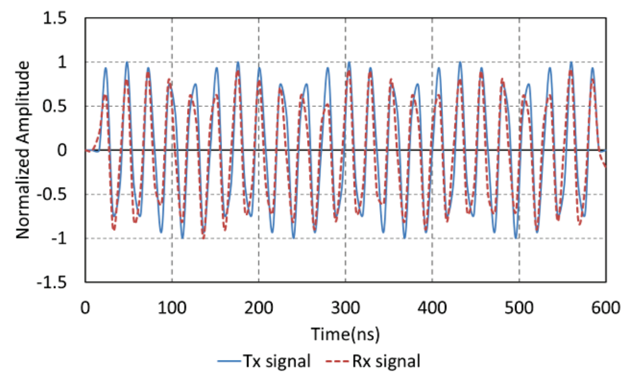

Fig. 11 The transmitted waveform and received one of 39 MHz subcarrier.

IV. Conclusion

In this paper, we examined the signal transmission with a UWB 2D communication tile. First, we evaluated the effect of the surface layer. The experimental results show S21 is larger than −50 dB and −60 dB in more than 60% and 95% UWB high-band, respectively, for the typical carpet tile materials. This result shows that OFDM UWB communication is possible with enough margin from the thermal noise.

We also examined the signal transmission at 8-GHz band using a pair of UWB OFDM communication devices. Three subcarrier frequencies, 1.95 MHz, 19.5 MHz, and 39 MHz in the 125 MHz bandwidth were individually examined and were received with negligible errors. The influence of the multipath signals was negligible.

These results indicate that the UWB communication based on OFDM is feasible with 2D communication tiles.

Acknowledgment

We thank Yoshiaki Hirano and Machiko Oouchida, Teijin Limited for providing the sheet materials. This work was supported in part by the Strategic Information and Communications R&D Promotion Programme (SCOPE) 135003009.

REFERENCES

[1] "First report and order, revision of part 15 of the commision's rules regarding ultra-wideband transmission systems," FCC, Washington, DC, ET Docket 980153, 2002

[2] Y. Li, A. F. Molish, and J. Zhand, "Practical Approaches to Channel Estimation and Interference Suppression for OFDM-Based UWB Communications," IEEE Transactions on Wireless Communications, Vol.5, No. 9, pp. 2317-2320, 2006

[3] Y. Kudo, A. Noda, and H. Shinoda, "UWB Sensor Network on 2-D Waveguide Sheet," Proc. IEEE Sensors Applications Symposium, pp. 339-342, 2014.

[4] H. Shinoda, Y. Makino, N. Yamahira and H. Itai, "Surface sensor network using inductive signal transmission layer," Proc. INSS 2007, pp.201-206, 2007.

[5] H. Shinoda, A. Okada, and A. Noda, "UWB 2D Communication Tiles," Proc. IEEE International Conference on Ultra-Wideband 2014, to be published in September 2014

[6] A. Okada, A. Noda, and H. Shinoda, "Effect of the Surface Insulator on UWB 2D-Communiation Sheet," Proc. SICE Annual Conference 2014, to be published in September 2014

[7] A. Noda, Y. Kudo, and H. Shinoda, "Circular planar coupler for UWB 2-D communication," Proc. IEEE International Conference on Ultra-Wideband 2014, to be published in September 2014