

# UWB 2D Communication Tiles

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**Abstract**—This paper proposes “2D communication (2DC) tiles” for practical implementation of UWB 2D communication. Each tile is a 50-cm square which is the standard size of carpet tiles. The tiles can be easily connected and the covered area is extendable freely. If the surfaces of the desks, walls and floors have 2DC tiles, wide-band connection to the network is established everywhere in a room. As the most fundamental problem of this system, we examine the physical connection property between the standing waves produced in the tile and a coupler put near the surface. The results in the simulations and the experiments show stable UWB communication based on OFDM is achieved with the proposed system.

**Index Terms**—UWB, wireless communication, physical layer, 2D communication, 2DC tile

## I. INTRODUCTION

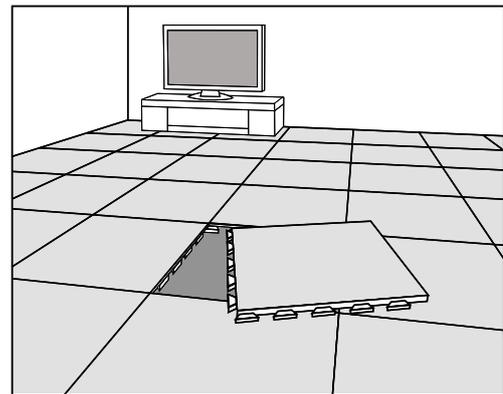
Ultra-wideband (UWB) from 3.1GHz to 10.6GHz [1] enables high-resolution video streaming [2] and high-speed transfer of data storage in wireless personal area network (WPAN), at least theoretically. Such a wide band can potentially provide stable and high-speed connections for the people in a crowded area. The use of UWB, however, is confronted with the physical connectivity problem since UWB signal amplitude is restricted under -41.3dBm/MHz and easily occluded by general objects due to the propagation straightness of high frequency waves.

A possible solution for the problem is use of 2D communication (also called 2D signal transmission) proposed in [3] where microwaves propagate in a sheet-like medium located on desks and floors, and information devices put close to the surfaces establish connection [4]. Since the major power of the signal propagates in the sheet, the communications are

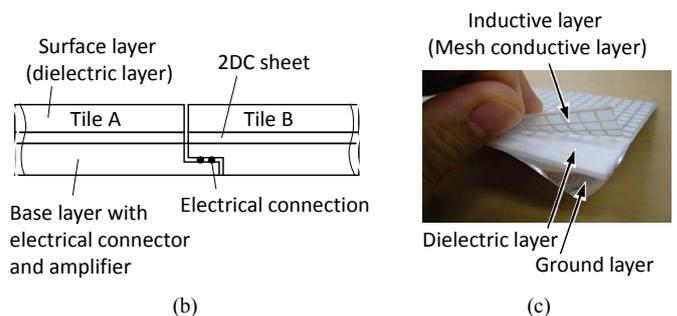
- free from occlusion problem by the general objects on the 2DC sheet,
- robust against interference with the traveling-wave modes in the air,

which results in more stable connections with higher SN ratios than the connections in the air.

In addition, 2DC enables not only signal transmission but also wireless power transmission (WPT) through the identical 2DC sheet. WPT using 2D medium has already been developed in previous works [5] using 2.4GHz band and the



(a)



(b)

(c)

Fig. 1. (a): The conceptual diagram of 2DC tiles. 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 with the network. (b): The cross-section of a pair of connected tiles. (c): The structure of the “2DC sheet” used in the experiment. The photo is reprinted from [5].

standardization using 2.4GHz band is currently proceeding in Japan.

This paper proposes “2D communication tiles” as shown in Fig. 1 as a practical way to achieve the UWB 2DC concept. The dimensions of the tile follow the standard configuration of a carpet tile. The tiles can be easily connected and the covered area is extendable freely. If the surfaces of the desks, walls and floors have 2DC tiles, wide-band connection to the network is available everywhere in the room. It is also straightforward to connect the floor tiles and desk tiles through the desk legs.

The rest of this paper is organized as follows. The overview of the proposed system is explained in Section 2. The feasibility in the physical layer is examined in numerical simulations and experiments in section 3 and 4, respectively. In section 5, the expected applications using the proposed system are described. Finally, we conclude this paper in section 6.

## II. SYSTEM OVERVIEW

The conceptual diagram of 2DC tiles is described in Fig. 1. The configuration of a 2DC tile follows the standard carpet tile whose side length is 50cm. Each tile has a surface layer, a 2DC sheet, and a base layer with mechanical and electrical connectors. The dielectric material of the surface layer is selected to suit the application scene. If it is used on the floor, the layer would be a carpet. For desk use, a flat, smooth and rigid surface should be selected.

The second layer, 2DC sheet (= 2DST sheet in [4]), consists of three layers, a ground layer, a dielectric layer and an inductive layer with a conductive mesh pattern. Typically the pitch of mesh is 4mm and the line width of it is 1mm. These values are used in our previous work for achieving both high efficiency and safety in 2.4GHz power transmission [5]. The ground layer and the inductive layer are shorted at the boundary of the tile so that power transmission can be realized effectively, which means the neighbor tiles are independent of each other in microwave propagation. Since the tile edge is reflective for the microwaves running in the sheet, the inputted microwave forms a standing wave. In 2DC tile system, the signal transmission should be based on OFDM (Orthogonal Frequency Division Multiplexing) for obtaining the best performance in this communication environment.

The base layer has mechanical and electrical connectors for binding the neighbor tiles. This layer has electrical wires for transmitting DC power used for UWB signal amplification. UWB signals of a tile are transmitted to the neighbor tile through the amplifier embedded in the base layer. The base layer design also includes mechanical connection and electrical connectors for DC-line and UWB signal between neighbor tiles. In the future, the DC power supplied to each tile will also be used for wireless (proximity) power supply to the items on the tile surface. The protocol of the signal transmission to the neighbor tiles is also an important design issue in the next step.

In the following sections, we examine the physical connection properties between a tile-size 2DC sheet and a coupler put close to the 2DC sheet.

## III. SIMULATIONS

In the 2DC sheet, TEM waves propagate between the upper conductive mesh layer and ground layer. Since the edge of the tile is shorted, the inputted microwaves in the sheet is reflected at the sheet edges and forms a standing wave.

The upper mesh layer of the 2DC sheet produces an evanescent wave over the sheet surface. A coupler put close to the surface establishes the connection through the evanescent field. Since standing waves are induced in the sheet, the connectivity between the 2DC sheet and a coupler depends on

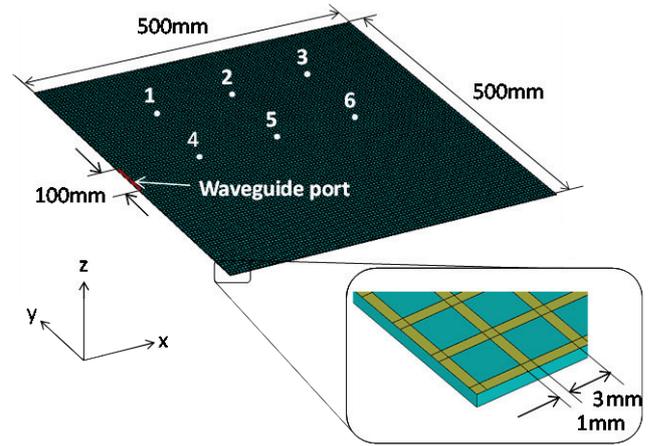


Fig. 2. The overall simulation model of 2DC sheet (upper) and the magnified figure of the mesh configuration (lower right). The 2DC sheet model consists of an inductive layer and dielectric layer. The back-side boundary condition of the dielectric layer is “electric” since a conductive layer, ground layer, exists on the back of the dielectric layer. The side boundary condition of the dielectric layer is also “electric” since the sheet edge is shorted as shown in Fig. 5(b). Signals are inputted from the 100mm-wide waveguide port.

the coupler position relative to the nodes of the standing waves. For examining this property, we conduct the following simulations.

### A. Simulation Setting

Fig. 2 shows the overview of the simulation model. In this simulation, we use CST Microwave Studio. The dimensions of the 2DC sheet are 500mm in side length and 1mm in thickness. The mesh pitch of the inductive layer is 4mm and the line width of the mesh is 1mm. The thickness of the mesh is 0.01mm. We assume the mesh material to be Aluminum. The thickness of the dielectric layer is 1mm, and the relative permittivity is set at 2.1. These are the typical values in the previous 2DST (2DC) system [5]. We apply the electric boundary condition to the boundary face since the sheet edge is shorted as shown in Fig. 5(b). Input signals are excited at the waveguide port set at the boundary. The waveguide port size is 100mm for the lower frequency bound of 3.1 GHz.

### B. Simulation Results

Fig. 3 shows the amplitude distribution of the electric field at the center height of the dielectric layer, for frequencies  $f = 3\text{ GHz}$ ,  $6\text{ GHz}$ ,  $8\text{ GHz}$  and  $10\text{ GHz}$ . The standing wave is generated at each frequency.

Fig. 4 shows the amplitude of electric field at the six sample points of 1 – 6 shown in Fig. 2. Position 5 is located at the origin of the  $xy$  coordinate. The vertical line of the figure is normalized by the largest value in the 2DC sheet. The lowest value is about  $-35\text{ dB}$  at  $(x,y) = (0,0)$  and  $f = 3.8\text{ GHz}$ . The lowest value among the high-band (from  $7.25\text{ GHz}$  to  $10.25\text{ GHz}$  in Japan) is about  $-32\text{ dB}$  at  $(x,y) = (126, 126)\text{ mm}$  and  $f = 10.2\text{ GHz}$  in our spatial resolution of simulation. These results show the frequency range of UWB is well covered and a desired condition for OFDM is achieved.

## IV. EXPERIMENTS

### A. Experimental Setting

Fig. 5(a) is the overview of the experimental system. The size of 2DC sheet is the same as the simulation model, 500 mm square with the thickness of 1 mm. The pitch of the mesh is 4 mm and the line width is 1 mm. The thickness of the mesh is  $10\mu\text{m}$ . The material of the mesh is aluminum. The dielectric layer is made of a 1mm-thick polypropylene plate. In this experiments, the inductive layer and the ground layer are not shorted but open since they are both reflective and the difference is not critical in this basic experiment. The open and short edges are illustrated in Fig. 5(b). Input signals are excited in the sheet through the 0.1 mm-thick copper plates attached to the inductive layer and the ground layer as shown in Fig. 5(c). A horn-shaped pattern is used at the connection between the cable and the 2DC sheet for avoiding reflection.

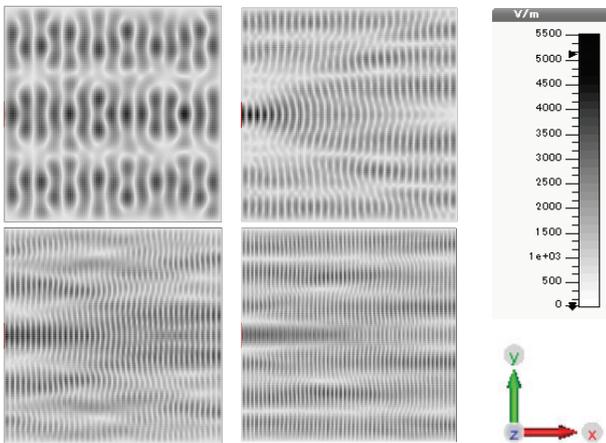


Fig. 3. The amplitude distribution of electric field at the center height of the dielectric layer for  $f = 3\text{ GHz}$  (upper left),  $6\text{ GHz}$  (upper right),  $8\text{ GHz}$  (lower left), and  $10\text{ GHz}$  (lower right). Each figure shows a standing wave is generated.

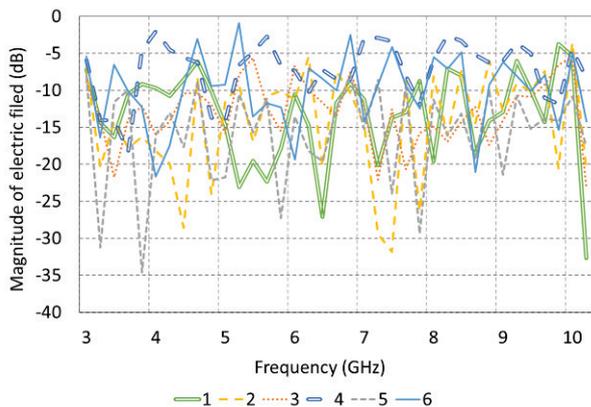


Fig. 4. The amplitude of electric field at the six sample points in a 2DC sheet. The amplitude is normalized by the maximal value in the 2DC sheet at each frequency.

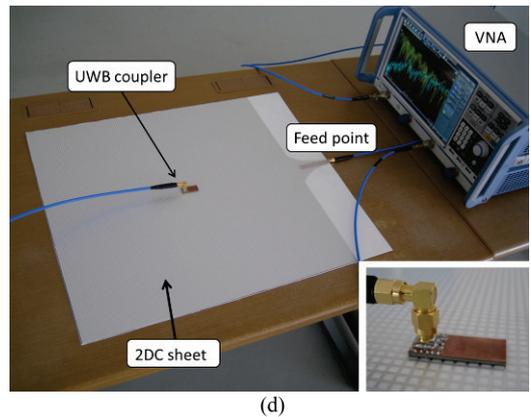
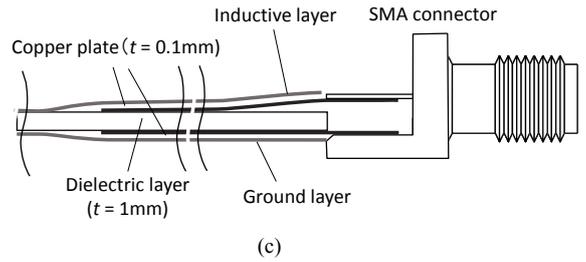
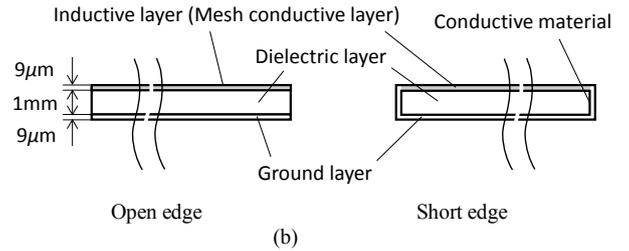
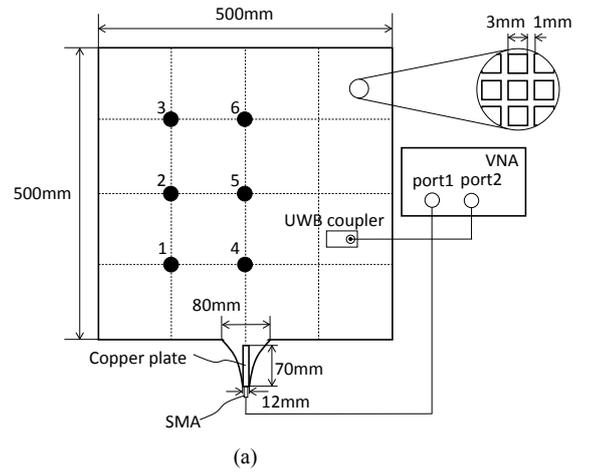


Fig.5. (a): The schematic of the experimental settings. We measured  $S_{21}$  at the six sample points of 1~6 between the UWB coupler and the feed point of the 2DC sheet. (b): Illustration of Open edge (left) and Short edge (right). (c): The cross-section of the feed point. Two 0.1mm-thick copper plates connected to a SMA connector are attached to the inductive layer and the ground layer. (d): The overview of the experimental settings. The coupler identical to that of [3] shown in the lower right photo was used as the UWB coupler. The coupler is a rectangular plate of 32 mm by 14 mm.

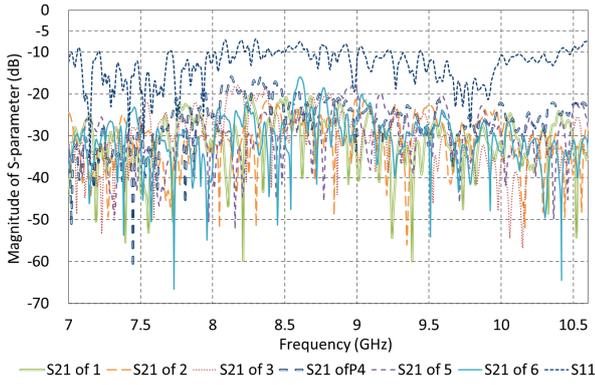


Fig. 6. S-parameter S21 (transmittance) and S11 (reflection) through the high-band. S21 is fluctuating mainly between  $-20$  dB and  $-40$  dB. S11 of port1 (the feed point) is smaller than  $5$  dB through the band.

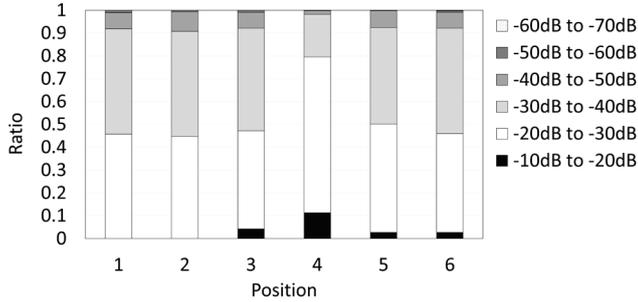


Fig. 7. Stacked bar graph on the experimental data of S21 at each position. This figure shows S21 is larger than  $-40$  dB in more than  $90\%$  bandwidth of UWB high-band.

The widths of horn pattern are  $80$  mm in the sheet side and  $12$  mm in the cable side, and it forms an exponential horn. The UWB coupler proposed in [3] for covering the high band is used to receive/send signals from/to the sheet. The coupler is a simple rectangular plate of  $32$  mm by  $14$  mm as shown in Fig. 5 (c), with simple patterns of two copper layers. We measure S-parameter at the six sample points of 1 – 6 by using a vector network analyzer (VNA), Rhode & Schwarz ZNB-20. The experimental setting is shown in Fig. 5(d). The positions of the measured points are the same as those of the simulation analysis.

Although the final system has a surface layer as shown in Fig. 1, the following basic experiments are conducted without a surface layer. There exists a  $50\mu\text{m}$  PET film between the UWB coupler surface and the inductive layer of the 2DC sheet.

### B. Signal transmission at each coupler position

Fig. 6 shows S11 (reflection) at the feed point of the 2DC sheet and S21 (transmittance) for each coupler position. Since S11 is less than  $-5$  dB, the major signal power is successively inputted to the 2DC sheet in the high-band. The value of S21 is fluctuating due to standing waves mainly between  $-20$  dB to  $-40$  dB in the band.

Fig. 7 shows the stacked bar graph for S21 at each sample point to present the total band width for well-conditioned communication.

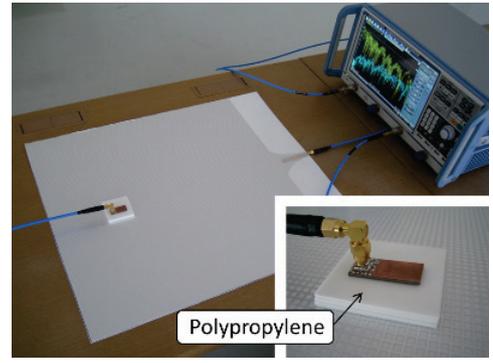


Fig. 8. The experimental setup. S21 is measured at position 6. The distance between the 2DC sheet and the coupler is changed from  $0$  mm to  $5$  mm by inserting the polypropylene sheet.

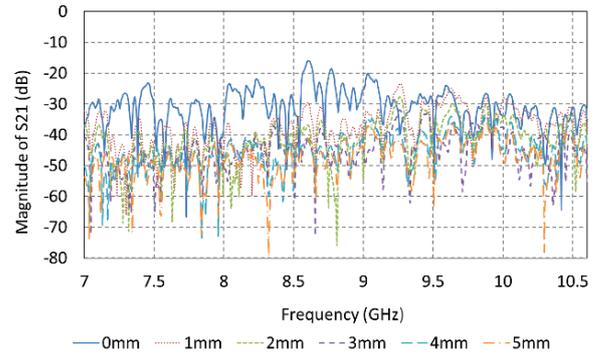


Fig. 9. Plot of S21 for various gap distances between the UWB coupler and 2DC sheet.

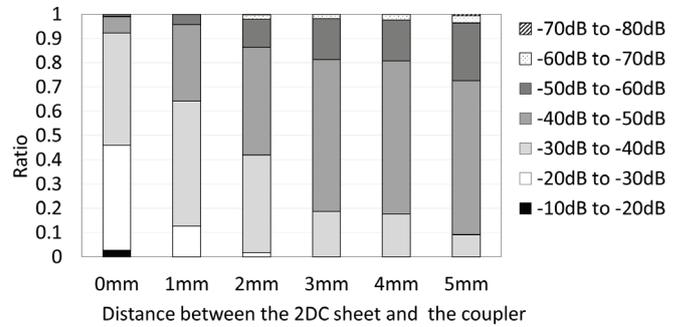


Fig. 10. Stacked bar graph on the experimental data of S21 at each gap distance.

All the S21 data are sampled with  $3$  MHz interval for each point. The ratios of the S21 data number of  $-n$  dB  $\sim$   $-(n+10)$  dB to the total data number are shown for  $n = 10, 20, 30, 40, 50,$  and  $60$ . The result shows S21 is larger than  $-40$  dB in more than  $90\%$  bandwidth of the high-band. The transmission coefficient of  $-40$  dB can be considered to enable stable UWB communication under the signal-amplitude restriction of  $-41.3$  dBm/MHz in OFDM-based UWB communication.

### C. Effect of the gap distance between the 2DC sheet and the coupler

In floor applications, carpet clothes exist between the coupler and 2DC sheet. On a desk, a decorative laminate would be put on the 2DC sheet. For evaluating the effect, we measure S-parameter at position 6 under the following condition. The distance between the 2DC sheet and the coupler is changed from 0 mm to 5 mm by inserting a piece of polypropylene sheet. The distance 0 mm means the same condition as the former experiments. Fig. 8 shows the experimental setup.

The experimental results are showed in Fig. 9. The transmission coefficient S21 is fluctuating between  $-30$  dB and  $-50$  dB. Fig. 10 shows the statistical analysis of S21 through the high-band by the same procedure as Fig. 7. This figure shows S21 decreases as the gap distance increases. But even for the distance 5 mm, S21 is larger than  $-50$  dB in more than 70% bandwidth.

## V. APPLICATIONS

The stable UWB connection by the proposed 2DC tiles combined with future wireless power supply will extend the applications of UWB communication. As Fig. 11 illustrates, the function of 2DC tiles is summarized as follows.

### A. Configuring the communication area

The communication area can be configured and extended by connecting the 2DC tiles on a floor, wall and desk. It is also possible to set communication areas at different heights. In the case of Fig. 11, the desk with a UWB coupler at the leg is connected to the floor network through the coupler. Then a TV, PC and camera are connected to the identical network.

### B. Connecting devices to the network

Information devices can connect to the network by touching the 2DC tiles on the desks or floors. If we take up the devices, the connections are terminated automatically. For keeping the connection between a handheld device and 2DC tiles, various forms of Diffuser might be useful, where Diffuser is a coupler device between the radiation mode from the device and the evanescent mode around a 2DC tile. A small and thin Diffuser pasted on a general object around us can produce a 3D zone of coverage around it.

## VI. CONCLUSION

In this paper, we proposed “2D communication tiles” for practical implementation of UWB 2D communication (2DC). The tile is a 50-cm square which is the standard size of carpet tiles. The tiles can be easily connected and the covered area is freely expanded. Many application in a room can be realized by implementing these tiles on desks, floors and walls. It is also straightforward to connect the floor tiles and desk tiles though the desk legs.

The 2DC tile consists of three layers, a surface layer, a 2DC sheet and a base layer. In this paper, we focused on the 2DC

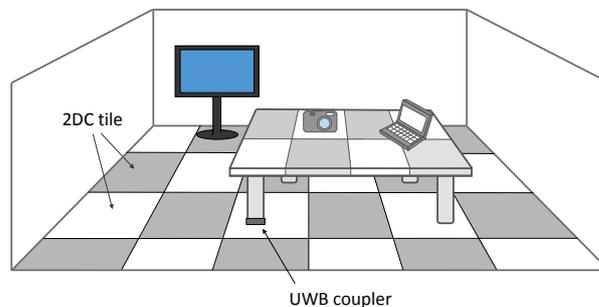


Fig.11 A typical usage of 2DC tiles. The communication area on the desk and floor are connected through the UWB coupler at the desk foot. PCs and TVs with the couplers are connected to the network by touching the 2DC tiles.

sheet and examined the physical properties in numerical simulations and experiments.

From the preliminary experimental results without the surface layer, the value of S21 was larger than  $-40$  dB for 90% of the total bandwidth of UWB high band, where S21 was measured between a UWB coupler and the 2DC sheet connector with 3 MHz interval. Although the surface layer degrades the connection, S21 was larger than  $-50$  dB in 70% of UWB high band in an experiment simulating a surface layer of 5 mm polypropylene. This result shows the 2DC tile system enables OFDM-based UWB communication in a physically good condition though standing waves are generated in each tile.

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## REFERENCES

- [1] Federal Communications Commission, “First report and order, revision of part15 of the commission’s rules regarding ultra-wideband transmission systems,” ET Docket No. 98-153, 2002.
- [2] W. Cui, P. Ranta, T. A. Brown and C. Reed, “Wireless video streaming over UWB,” Proc. ICUWB, pp. 933-936, 2007.
- [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] A. Noda and H. Shinoda, “Selective Wireless Power Transmission Through High-Q Flat Waveguide-Ring Resonator on 2-D Waveguide Sheet,” IEEE Transactions on Microwave Theory and Techniques, vol.59, no. 8, pp. 2158-2167, 2011.