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Evaluation of Isolation Property of UWB 2DC Tile for Coexistence with Radio Signals

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***Abstract*—In this paper, we evaluate isolation property of an ultra-wide band (UWB) two-dimensional communication (2DC) tile. The UWB 2DC tile is based on 2DC technology and enables a room-size and high-speed network. In 2DC, radio waves are confined in a sheet-like waveguide. An evanescent field is generated above the waveguide and used to establish the connection between the devices with a dedicated coupler. Energy radiated from the waveguide is so small that coexistence between signals in the tile and in the air with little interference in the same room is possible. To evaluate the interference between an over-the-air communication path and an on-tile communication path, the transmittance between an antenna in the air and a feeding coupler on the tile is measured with a vector network analyzer. The measurement is conducted with two typical boundary conditions of the waveguide: a short boundary and an open boundary. The experimental results show that the transmittance is about −60 dB or less at 600 mm above the tile in each boundary. This value is lower than that of free-space propagation. Therefore, the UWB 2DC tile system can keep the stable and high-speed network even if the same frequency band is shared with in-air UWB communication.**

Keywords*—*infrastructure; factory automation; communication system; coexistence; 2D communication (2DC)

I. Introduction

In a modern industrial factory, people, equipment, and many devices are required to be networked to improve the efficiency of manufacturing and fabrication. Wireless communication is a key technology to establish such a high density network with no wires that restrict the motions of the devices and increase installation cost. One problem of wireless connection is the instability caused by electromagnetic interferences. The network in factory automation often requires high reliability and low latency compared with daily life communication [1]-[7]. A wireless PROFIBUS [8], an extensive communication system of an existing field bus, is one of solutions. Moreover, the coexistence of multiple wireless networks is also desired in the use of unlicensed band [9][10] and the IEC standard for coexistence management of wireless industrial system has been developed [11].

The ultra-wide band (UWB) two-dimensional communication (2DC) tile [12] can be a solution for these requirements. 2DC is the communication technology that confines signal propagation area to two dimensional plane by using a sheet-like waveguide called a “2DC sheet” [13]. The concept diagram of 2DC and the picture of the sheet, which is similar to a parallel plate waveguide, is shown in Fig. 1(a). An evanescent field is generated above the sheet if the top layer called an inductive layer, has a metal-mesh structure to provide the sheet inductance. A dedicated coupler is put on the top layer to transmit/receive signals to/from the sheet with proximity connection.

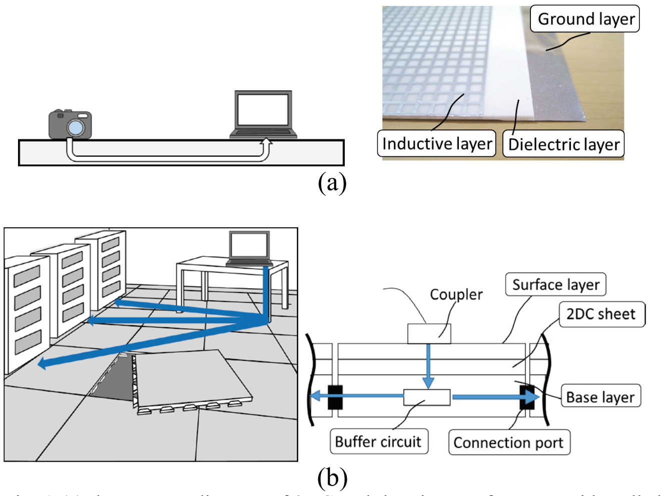

Fig. 1 (a) the concept diagram of 2DC and the picture of a waveguide called 2DC sheet. Signals propagate in the sheet, not in the air. This sheet consists of three layers with the top layer of a mesh structure. (b) the concept diagram of UWB 2DC tile system. The network is established and freely extended by connecting the tiles that have signal propagation and transmission function. This tile consists of a surface layer like a carpet tile, the 2DC sheet, and a base layer including a buffer circuit to transmit/receive signals. The tile size is 500 mm square that is the standard carpet-tile size.

The UWB 2DC tile is a practical way to implement the 2DC infrastructure. The concept diagram and the cross-section diagram of the tile is shown in Fig. 1(b). This tile is a tile-like communication unit that includes the 2DC sheet and non-contact interfaces to connect the tiles. A network area is freely extended by connecting the tiles on a floor. A buffer circuit is also included to maintain signal intensity. Though the additional implementation cost is needed to establish the network compared to wireless communication, the installation

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process is almost the same as a standard OA floor that is necessary for a modern room.

The characteristics of the system with 2DC are as follows

- Signals are always in line-of-sight (LOS) environment because they propagate in the sheet.
- Data communication and wireless power transmission [14] can be integrated.
- The power density can be larger than free-space radiation.

In addition to the above characteristics, the 2DC system is expected to have high-isolation property to signals propagated in the air. This is because microwaves are generated as the evanescent field only in the vicinity of the sheet and little energy is radiated in the far field. The isolation property is important to enable the stable tile-system communication even under frequency overlapping with the over-the-air communication. In our previous works [12][15][16], we ensured the connection between the tile and the coupler. However the feasibility of the coexistence with radio signals in the air has not been yet ensured. In this paper, we evaluate the physical isolation property of the tile to enable the coexistence with radio signals. Moreover the effect of two typical boundary conditions of the tile, open and short, that is involved with fabrication of the tile is also clarified.

The rest of the paper is organized as follows. In the next section, the characteristics of the boundary conditions are examined by a numerical simulation. In the section Ⅲ and Ⅳ, the experiments to evaluate the isolation property between the signals propagated in the air and in the tile are conducted. After the discussion section, we finally conclude this paper.

II. Boundary Condition of UWB 2DC Tile

In this section, the boundary conditions of the UWB 2DC tile are described and the characteristics of them are examined by the numerical simulation.

A. Type of Boundary Condition

There are two boundary conditions of the UWB 2DC tile: open and short. As shown in Fig. 2, the difference is whether the inductive layer and the ground layer of the 2DC sheet are shorted at the boundary or not.

In the case of the open boundary, the sheet is expected to have reflective characteristics, but some amount of energy are radiated due to the gap between the inductive layer and the ground layer at the edge. The open boundary, however, is useful because of easier fabrication than shorted one if the isolation performance is acceptable. The shorted boundary makes the 2DC sheet electromagnetically isolated from the neighbor sheets.

The radiation of both boundaries has been examined in a preceding research in different conditions [17]. We will clarify the property in UWB and the current typical sheet parameter.

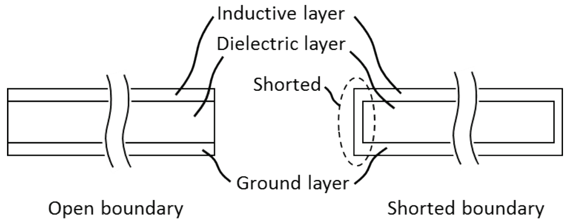

Fig. 2 Boundary condition of the UWB 2DC tile. The difference is whether the inductive layer and the ground layer of the 2DC sheet is shorted at the boundary or not.

B. Simulation

The numerical simulation is conducted to compare the difference of signal propagation of both boundaries with one 2DC sheet model shown in Fig. 3. The size of the 2DC sheet is 150 mm ×150 mm. This size is smaller than the tile but the difference is not critical to simulate the signal propagation at the boundary. A line width and a pitch of the mesh in the inductive layer is 1mm and 4mm, respectively. A material of the inductive layer and the ground layer is set as perfect electric conductor (PEC). The dielectric layer is 1mm thick and its relative permittivity is 2.1. These values are typical in our previous works. A UWB coupler model [18] is used to feed microwaves to the sheet. The center of the model is the origin of the coordination. The simulation is conducted with CST Microwave Studio.

Fig. 4 shows the simulation results. The amplitude of electrical field Ez of around the boundary, (x, y) = (−75, 10), at 8.2 GHz. Leak from the open boundary of the sheet is larger than the case of the shorted boundary. This leaked energy density is localized around the sheet edge.

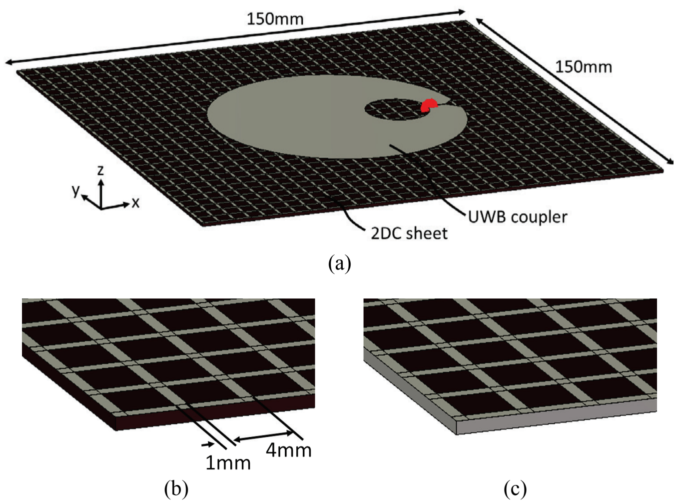

Fig. 3 Simulation model. (a) the overview of the model. The composition of the sheet model is typical in our previous works. A UWB coupler is used to excite signals to the sheet. (b) the enlarged figure of the open boundary sheet model. (c) the enlarged figure of the shorted boundary model

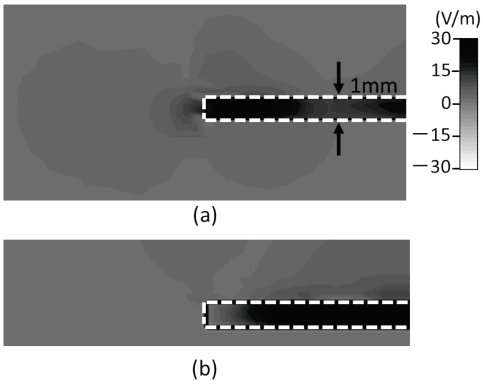

Fig. 4 Simulation results. The amplitude of electric field Ez of around the boundary, (x, y) = (−75, 10), at 8.2 GHz is shown. (a) open boundary, (b) shorted boundary. Dashed line shows the outline of the model. The results show that a certain amount of energy leaks from the open boundary and this energy is localized around the sheet edge while little from the shorted boundary.

III. Isolation along Vertical Direction

In this section, the isolation property of the 2DC sheet along the vertical direction is experimentally examined by measuring the transmittance between the sheet and an antenna in the air. The experiment is conducted only at 8.2 GHz, as a representative frequency of UWB high-band (7.25 GHz – 10.25 GHz in Japan).

A. Setup

Fig. 5 and Fig. 6 show a schematic diagram and a picture of the experiment. In this experiment, one tile is examined to clarify the tile property. The feeding coupler set to the tile and a whip antenna whose return loss at 8.2 GHz is about −12 dB are connected to the vector network analyzer, Rhode & Schwarz ZNB-20. The transmittance is measured by changing the vertical distance between the tile and the antenna from 0 mm to 1000 mm. The position of 0 mm from the tile corresponds to that of 6 mm from the 2DC sheet in the tile because thickness of the surface layer is 6 mm. Both the open boundary sheet and the shorted one shown in Fig. 7 are examined. The short boundary sheet is experimentally fabricated by shorting the inductive layer and the ground layer of the open boundary sheet with copper tapes. In this experiment, the base layer is not implemented because only one tile is examined.

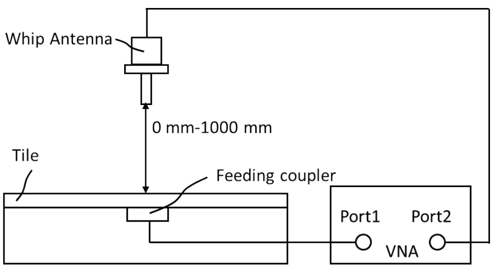

Fig. 5 The schematic diagram of the experimental setup. The gap distance between the whip antenna and the tile are changed from 0 mm to 1000 mm. The transmittance is measured with a vector network analyzer. A feeding coupler is set under the ground layer to excite/extract signals to/from the sheet. The rod of the antenna is perpendicular to the sheet. The antenna and the feeding coupler are designed to resonate at 8.2 GHz.

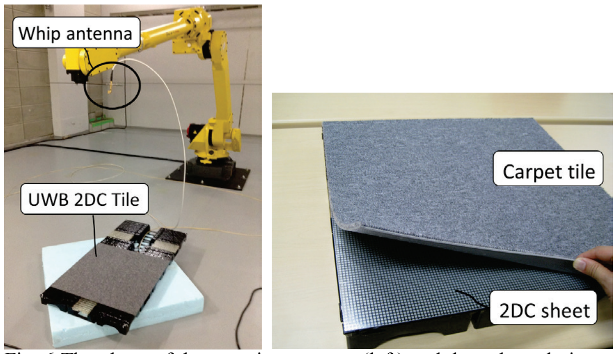

Fig. 6 The photo of the experiment setup (left) and the enlarged picture of one tile (right).

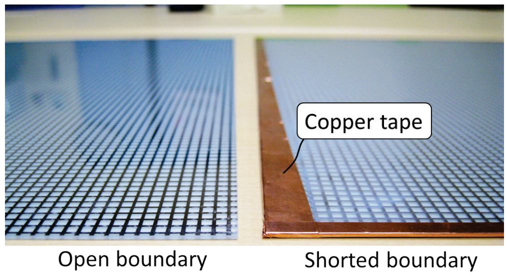

Fig. 7 The photo of the open-boundary 2DC sheet and the shorted one. Copper tapes are used to short the inductive layer and the ground layer.

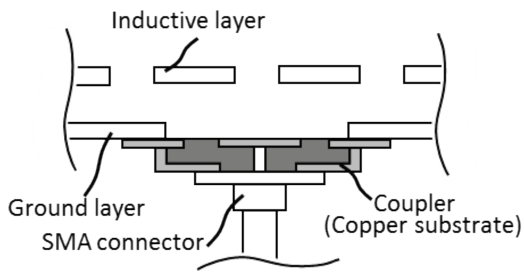

Fig. 8 The schematic diagram of the feeding coupler. The coupler is set under the ground layer. A part of the ground layer around the coupler is eliminated to resonate between the coupler and the sheet.

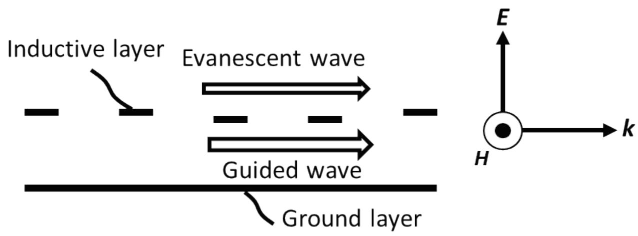

Fig. 9 The fields of waves propagated in the 2DC sheet. The electric field ***E*** of signals in the sheet is normal to the sheet and the magnetic field ***H*** is tangential. The wavenumber vector ***k*** is perpendicular to both fields.

The composition of the 2DC sheet of the tile is as follows. The size of the sheet is 500 mm × 500 mm × 1 mm. The line width and the pitch of the inductive layer are 1mm and 4 mm respectively, which are the same as the numerical simulation. The material of the inductive layer and the ground layer is aluminum. The 1 mm-thick polypropylene sheet is used as the dielectric layer. The feeding coupler is set under the ground layer to excite/extract signals to/from the sheet. The return loss at 8.2 GHz of this coupler is about -18 dB. The aluminum sheet around the feeding coupler is eliminated to establish the proximity connection between the sheet and the feeding coupler as shown in Fig. 8.

The carpet tile, the model number YS 1004 manufactured by Teijin Limited, is employed as the surface layer. The size of this carpet tile is 500 mm×500 mm×6 mm.

As the attitude of the antenna is shown in Fig. 5, a rod is perpendicular to the tile to match polarization so that the antenna and the sheet can be easy to resonate. The electric field ***E*** and the magnetic field ***H*** in the 2DC sheet are normal and tangential to the sheet, respectively and the direction of the wavenumber vector ***k*** is perpendicular to both fields as shown in Fig. 9.

B. Result

Fig. 10 shows the experimental results. Each plot indicates an average of ten measurements. The transmittance decreases rapidly from 0 mm to 100 mm and gradually from 100 mm to 1000 mm in both boundaries. The former characteristics are derived from near field radiation and the latter are derived from far field radiation. The transmittance at more 600 mm gap distance is about −60 dB or less while about −20 dB at 0 mm. Based on Friis transmission equation, propagation loss of 8.2 GHz signals in free-space is −46.3 dB at 600 mm between measurement points. In the case that the directivity of the whip antenna is 0 dBi in a radiation plane, the antenna gain of the sheet is calculated as −13.7 dBi, which indicates the sheet has the high-isolation property.

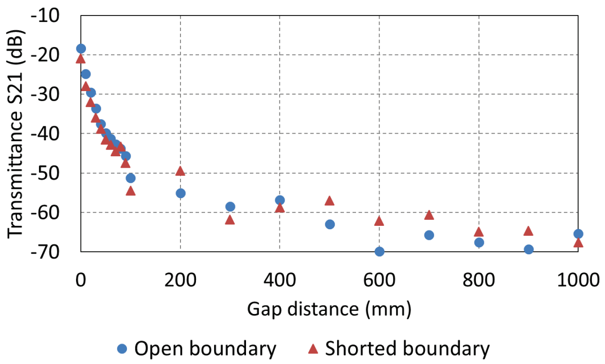

Fig. 10 The transmittance S21 between the 2DC tile and the antenna along vertical direction.

IV. Isolation along Azimuth and Elevation angle

In this section, the isolation property between the free-space propagation waves and the tile involved with azimuth angle and elevation angle is examined. The transmittance between the tile and the antenna is measured.

A. Setup

Fig. 11 shows the experimental condition. The antenna and the tile are the same as the former experiment. The connection of them to the VNA is also the same. The antenna is set at 1000 mm from the center of the tile where the radiation pattern can be considered as far field based on the result of the former section because the radio signals arriving to the tile via the air are the far-field signals. The attitude of the antenna is controlled so that the rod can be perpendicular to the line between the antenna and the center of the tile.

Elevation angle θ is changed from 0 degree to 90 degree. Azimuth angle φ is set to 0 degree or 45 degree. More than 45 degree in azimuth angle is unnecessary due to the symmetric property of the tile.

B. Result

Fig. 12 and Fig. 13 show the experimental results for $\varphi = 0$ degree and 45 degree respectively. Both results show that there is not a strong relationship between the transmittance and the boundary condition, and the transmittance is about −60 dB or less at almost all angles in both boundaries. Therefore UWB 2DC tile also has high-isolation performance along azimuth and elevation angle with both boundaries.

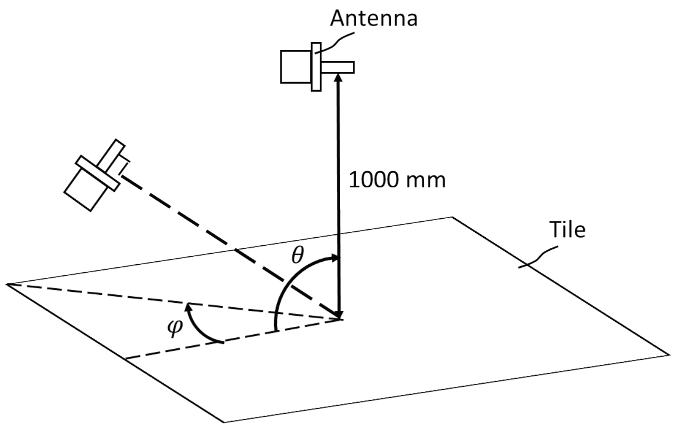

Fig. 11 The schematic diagram of the experimental setup. The antenna is set at 1000 mm from the center of the tile. The transmittance is measured with 0 degree and 45 degree of azimuth angle φ and elevation angle θ from 0 degree to 90 degree. The attitude of the antenna is changed so that the rod can be perpendicular to the line between the antenna and the center of the tile.

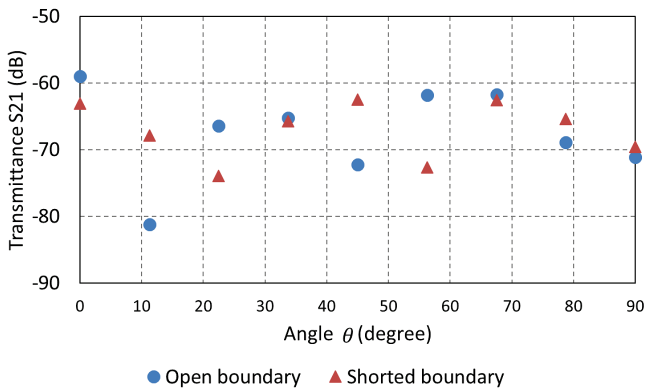

Fig. 12 The transmittance S21 between the 2DC tile and the antenna at $\varphi = 0$ degree.

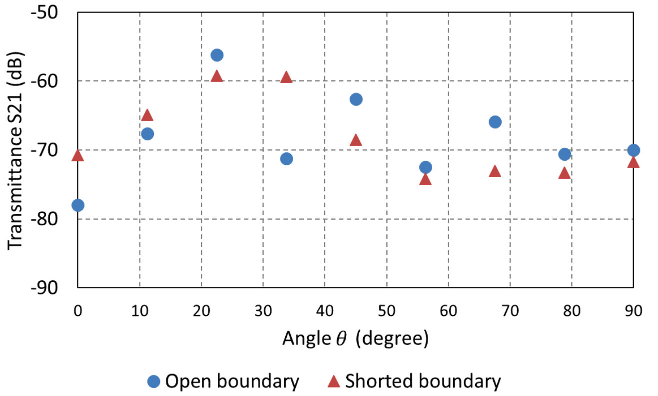

Fig. 13 The transmittance S21 between the 2DC tile and the antenna at φ = 45 degree.

V. DISCUSSION

The experimental results show that there is not the clear difference of the isolation performance in the far field between both boundaries. This seems inconsistent with the simulation result that microwaves leak from the open boundary sheet in near field. The reason should be clarified in our future work.

The experimental results also show that the transmittance between the sheet and the antenna is −60 dB at 600 mm and −20 dB at 0 mm from the tile. Signals from the surface of the tile has the margin of 40 dB from the signals at 600m above the tile. If the dedicated coupler is put on the tile instead of the antenna, more margin can be obtained. This high-isolation property of the sheet makes coexistence with radio signals feasible.

The tile system enables the coexistence but the far field characteristics as well as the near field are observed as shown in Fig. 9. In 2DC, theoretically little microwaves are radiated in the far field because only the evanescent field is generated from the sheet. This is considered that the sheet is finite size and has the edge. The suppression of the far-field radiation is our future work.

VI. CONCLUSION

In this paper, we evaluated the isolation property of one UWB 2DC tile to signals propagated in the air with two boundary conditions of the 2DC sheet: open and short. From the numerical simulation, the difference of the boundary condition was shown. In the case of the open boundary, some microwaves are radiated from the boundary. This radiation is major only in near field.

In order to evaluate the isolation property of the tile, the transmittance between the antenna in midair and the feeding coupler under the UWB 2DC tile was measured by changing gap distance, azimuth and elevation angle. The transmittance is less than −60 dB at gap distance of more than 600 mm and −20 dB at the surface of the tile. These values indicate that the signals from the surface of the tile is stronger by 40dB than signals over the air and the antenna gain of the tile is about −13 dBi, based on Friis transmission equation and the gain of the antenna in the air. The transmittance is also less than −60 dB at almost all the angles at the 1000 mm distance from the center of the sheet, with the both boundaries. Therefore, 2DC signal can be received with stronger intensity than a mid-air UWB signal with sufficient margin.

From these results, we ensured that the UWB 2DC tile has high-isolation property to signals propagated in the air with both sheet-boundary conditions and enables coexistence with radio signals in UWB frequencies.

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