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Effect of the Surface Insulator on UWB 2D-Communication Sheet

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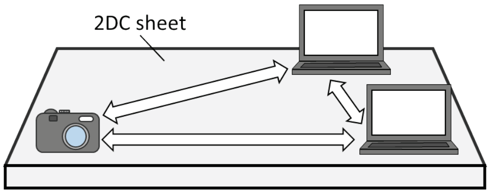
Abstract: In this paper, we evaluate the effect of the surface insulator on ultra-wide band (UWB) two-dimensional communication (2DC) sheet. In practical use of UWB 2DC, an insulator like a carpet would set on the 2DC sheet in the case of the floor implementation. This insulator is supposed to weaken the connection between the 2DC sheet and the device on the carpet. The numerical simulation and the experiment based on this situation are conducted to clarify the effect of the insulator. The both results indicate that the connection between the sheet and the device becomes weak but is kept enough even if several millimeters-thick insulator is inserted between them. We ensure that UWB 2DC is feasible with the 2DC sheet even if a surface insulator is on the sheet.

Keywords: 2D-communication, ultra-wideband (UWB), wireless personal area network (WPAN).

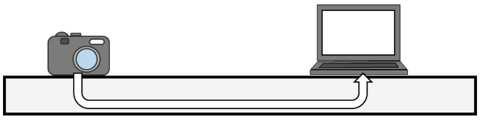
1. INTRODUCTION

Recently, a high-speed data transfer is required in wireless personal area network (WPAN) because a data size handheld devices can operate is becoming bigger. Ultra-wide band (UWB) technology from 3.1GHz to 10.6GHz [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 − 41.3dBm/MHz and signals are easily occluded by objects due to propagation straightness.

Using two-dimensional communication (2DC) [2] is a possible solution for this problem. In 2DC, a microwave propagates along a sheet-like medium on a floor or a desk and the major power of the signal exists inside the sheet as shown in Fig. 1. Information terminals with a dedicated coupler are put on the sheet and connect one another via proximity coupling [3]. Therefore 2DC is free from occlusion problem by general objects and is capable of keeping stable connection against the traveling-wave modes in the air. These are the favorable characteristics for UWB technology.



(a)



(b)

Fig. 1 (a): The conceptual diagram of 2DC. The terminals put on the 2DC sheet can establish the connection among them. (b): the cross-section diagram of the 2DC sheet. Signals propagate mainly in the 2DC sheet.

† Akimasa Okada is the presenter of this paper.

When this sheet is set on the floor, a carpet would be put on the sheet. In this situation, this carpet is supposed to weaken the connection between the sheet and terminals because the gap distance between them are increased. The effect of the thickness of the insulator on the 2DC sheet is evaluated in wireless power transmission (WPT) [4]. However, the case of the UWB communication has not been yet. Therefore, we evaluate the effect of the surface insulator on the 2DC sheet for design of the UWB 2DC sheet.

Numerical simulations and experiments are conducted changing the thickness and the relative permittivity of the insulator. From the simulations, the minimum value of received signal power can be estimated. From experimental results, the received signal power is higher than thermal noise through the high-band (7.25GHz to 10.25GHz) even if the surface insulator is several millimeters thick, and sufficient bandwidth is available in the case of a carpet as the surface insulator. This means that the connection between the sheet and the device is kept enough even if there is several millimeters-thick insulators between them. Therefore we confirm the feasibility of UWB 2DC with the surface insulator.

The rest of this paper is organized as follows. In section 2, the model of the 2DC sheet with the surface insulator is described and the numerical simulation is conducted. In section 3, the experiments with dielectric materials and carpet tiles are also conducted. Finally in section 4, we conclude this paper.

2. UWB 2DC SHEET WITH THE SURFACE INSULATOR

In this section, the model of the UWB 2DC sheet with the surface insulator and the numerical simulations with this model is described

2.1 Model

The model is shown in Fig. 2. The surface insulator is put on all the area of the 2DC sheet because it is corresponding to a carpet on a floor or a laminate on a desk. It has a relative permittivity ε_s and a thickness

h_s. The 2DC sheet consists of three layers, an inductive layer with a conductive mesh pattern, a dielectric layer and a ground layer. The dielectric layer has a relative permittivity ε_i and a thickness h_i. Then the coupler is put on the surface insulator to establish connection with the sheet through the evanescent field that is generated over the sheet.

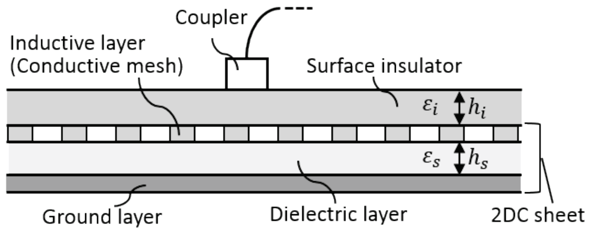


Fig.2 The cross-section view of the model of the 2DC sheet with a surface insulator. The surface insulator is set on all the area of the sheet.

2.2 Simulation Settings

The simulation based on the above model are conducted with the following settings. The simulation model is shown in Fig. 3. The mesh pitch of the inductive layer is 4mm and its line width is 1mm. we assume the material of the inductive layer to be aluminum. The thickness h_s is set at 1mm and the relative permittivity ε_s is set at 2.1. This value of ε_s is the same value as polypropylene. These are the typical values in our previous 2DC system. The thickness h_i is set from 1mm to 6mm by 1mm. The relative permittivity ε_i is set at 1.05, 2.1, 3.15, and 4.2. This means that the ratio $R = \varepsilon_i/\varepsilon_s$ is 0.5, 1, 1.5, and 2.

The UWB coupler proposed in [2] is used to receive signals. The high-band (from 7.25GHz to 10.25GHz) is focused on because this coupler is designed for this band. The side boundary condition is configured as open boundary for avoiding standing wave and the back one is configured as electric boundary that is corresponding to the ground layer. The side of the sheet is set as port1 and the top of the UWB coupler is set as port2. Both ports are modeled as waveguide ports. S-parameter S21 (transmittance) is calculated by CST MICROWAVE STUDIO

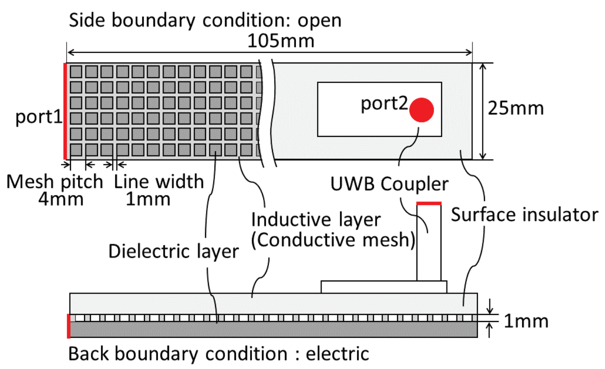


Fig. 3 The schematic diagram of the simulation model. The top view (upper). The cross-section view (lower).

2.2 Simulation Results

Fig. 4 shows the simulation results. The average magnitude of S21 through the high-band is plotted. The results indicate the higher relative permittivity of the surface insulator makes the connection between the sheet and the coupler strong. This is because the leakage energy over the sheet increases with the relative permittivity of the surface insulator [3].

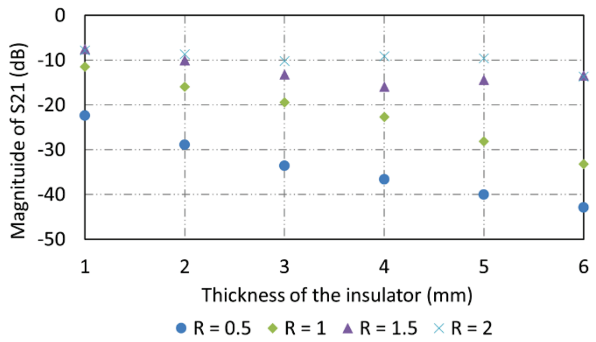


Fig. 4 The magnitude of the average S-parameter S21 (transmittance) through the high-band.

The difference of S21 between R = 0.5 and 1 is about 10dB. Since R = 0.5 corresponds to ε_i = 1.05 that is comparable to the air permittivity, connection can be established for most of the surface insulator materials if S21 at R = 1 is 10dB larger than the minimum connectable value.

In the case of a floor application, a carpet is put on the 2DC sheet. The relative permittivity of the carpet is supposed to be low because it is not a dense material and contains air. We can estimate the possibility that the connection between the 2DC sheet and the coupler put on the carpet can be established with the result of R = 1.

In this simulation, a coupler design developed in a previous research is used to evaluate the magnitude of receiving signals. The general evaluation of the surface insulator effect independent of the coupler design is left as our future work.

3. EXPERIMENT

The results of the numerical simulation is favorable about the UWB 2DC with the surface insulator. In this section, the property of the surface insulator is experimentally examined by inserting four dielectric materials.

3.1 Settings

Fig. 5 shows the schematic diagram of the experimental setup and Fig. 6 shows its overall picture. The size of the 2DC sheet is 500mm × 500mm × 1mm. The composition of the 2DC sheet is the same as the simulation model. The mesh pitch, the line width, and the thickness of the inductive layer are 4mm, 1mm, and 0.01mm respectively. The material of the inductive layer and the ground layer is aluminum. The 1mm-thick polypropylene sheet is used as the dielectric layer. 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 12mm and 80mm. The horn form is exponential horn. The sheet and a SMA connector are connected via two copper plates to excite signals in the sheet. Fig. 7 shows the cross-section view of this part. The UWB coupler proposed in [2] is used to receive signals from the sheet. The coupler is set at the center of the sheet. This experiment is conducted for the high-band as with the simulation and S21 in dB is measured.

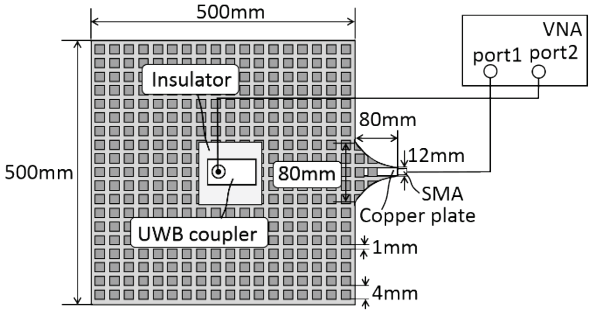


Fig. 5 The schematic diagram of the experimental setup. S21 is measured for the high-band.

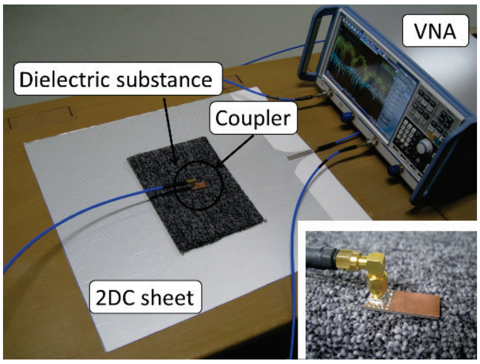


Fig. 6 The overall picture of the experimental setup. The dielectric materials are inserted between the 2DC sheet and the coupler.

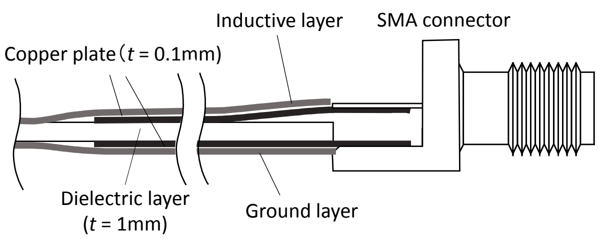


Fig. 7 The cross-section view of the horn section of the 2DC sheet. The sheet and the SMA connector are connected via two copper plates.

The ratio P_R of received power to transmitted power is calculated with the measured S21 to evaluate the signal power received through the 2DC sheet. P_R is calculated as following.

$$\begin{aligned} P_R &= \frac{P_{Rx}}{P_{Tx}} \\ &= \frac{1}{B}\int_B |S_{21L}(f)|^2 df \end{aligned} \tag{1}$$

where P_{Tx} and P_{Rx} denotes the transmitted signal power and the received signal power respectively and S_{21L} is a linear expression of the measured S21. S_{21L} indicates the property of the coupler and sheet.

P_{Tx} and P_{Rx} are the integration of power through the bandwidth B. Therefore they are calculated as following equation with the energy density function of frequency, p_{Tx} and p_{Rx}.

$$\begin{aligned} P_{Tx} &= \int_B p_{Tx}(f)df \\ &= p_{Tx}B \end{aligned} \tag{2}$$

We assumed p_{Tx} in dB is constant because transmitted signal power in UWB technology is defined as −41.3 dBm/MHz.

$$\begin{aligned} P_{Rx} &= \int_B p_{Rx}(f)df \\ &= \int_B |S_{21L}(f)|^2 p_{Tx}(f)df \\ &= p_{Tx}\int_B |S_{21L}(f)|^2 df \end{aligned} \tag{3}$$

Four insulators are inserted between the sheet and the coupler. The relative permittivities of two foaming insulators, Insulator A and Insulator B, are 1.5 and 2.1 respectively. Thickness is examined from 1mm to 12mm by 1mm. The other two insulators are carpet tiles whose thicknesses are about 5mm. These are examined in consideration of implementing UWB 2DC technology on the floor. The case of no insertion is also conducted.

3.2 Results

Fig. 8 shows P_R at each gap distance and the inserted materials. P_R decreases as the gap distance increases or the relative permittivity decreases. This characteristic has the same tendency as that of the simulation results. The highest value is about −25dB at the case of no insertion. S21 of Carpet A is −41dB and that of Carpet B is −44dB. The difference between the highest S21 and that of the carpet tiles is less than 20dB.

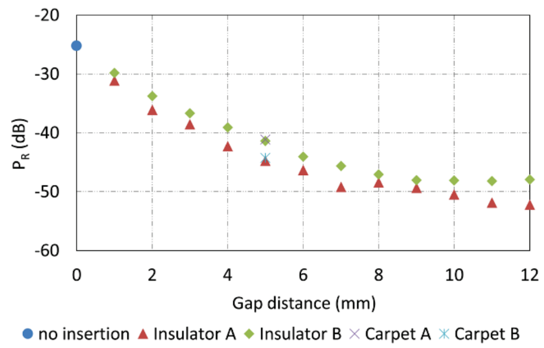


Fig. 8 The ratio P_R of the received signal power to the transmitted signal power. The value of no-insertion case is plotted at 0 mm.

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

$$\mathrm{SNR} = 10\log_{10}\frac{P_{Rx}}{kBT} = 10\log_{10}\frac{P_R p_{Tx}}{kT} \quad (4)$$

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

It is important to clarify the available bandwidth for OFDM. Fig. 9 shows S21 of four insulators at 5mm and S11 through the high-band. S11 is less than −5dB through all the band and less than −10dB at most parts. This indicates the major signals power is successively inputted to the 2DC sheet. The value of S21 is fluctuating mainly between −40dB and −60dB.

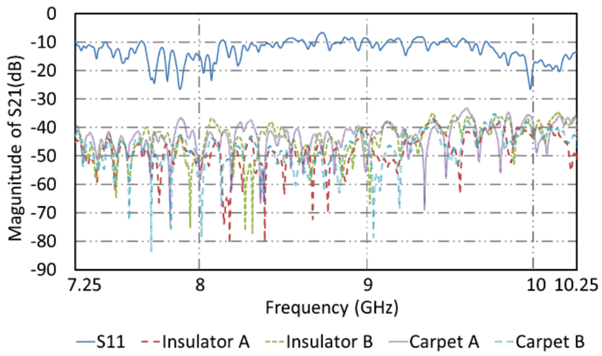


Fig. 9 S-parameter S11 and S21 of four insulators at 5mm through the high-band. S21 is fluctuating mainly between −40dB to −60dB.

Fig. 10 shows the stacked bar graph about S21 at 5mm. 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 1MHz. The results shows S21 is larger than −50dB in more than 60% bandwidth of the high-band. In the case of Insulator B and Carpet A, S21 is larger than −50dB in 80% bandwidth.

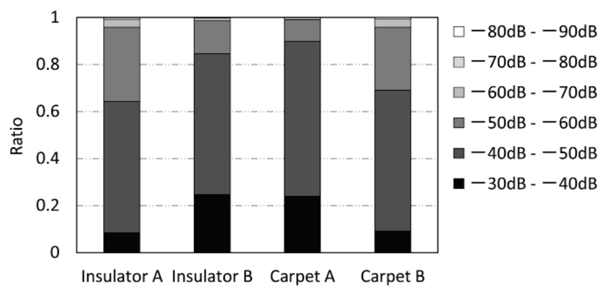


Fig. 10 The stacked bar graph about S21 at 5mm. This figure shows that S21 is larger than −50dB in more than 60% of the high-band.

These results indicate that the sheet and the coupler are well connected for the typical carpet tile materials.

4. CONCLUSION

In this paper, we evaluated the effect of the surface insulator on the 2DC sheet. The simulation and experimental results showed S21 is larger than −50dB in more than 60% of the UWB high-band for the typical carpet tile materials. From these results we ensured the feasibility of UWB 2D-communication.

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