UWB Sensor Network on 2-D Waveguide Sheet

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***Abstract*—In this paper we propose a room-size ultra-wideband (UWB) wireless communication system for fast data transmission of sensor networks. We use two-dimensional signal transmission (2DST) for wireless communication. In the proposed system, planar waveguide sheet is used as a medium guiding microwave and receiver couplers on the sheet extract microwave across the sheet surface. We design the UWB coupler and demonstrate the validity by numerical simulation. Experimental results show that the fabricated couplers can mediate sufficient power for UWB communication.**

Keywords*—Wireless Multimedia Sensor Network (WMSN), Ultra-wideband (UWB), Two-dimentional Signal Transmission (2DST)

I. Introduction

High-throughput and low-latency wireless connection of sensors is one of key issues in wireless multimedia sensor network (WMSN) [1]. If we want to gather and process video and audio data stream from a lot of sensor devices in real time, significantly large channel capacity is required. It is desirable that sensor devices send data streams wirelessly to host computer, but there is bandwidth limitation on wireless communication protocols.

Ultra-wideband (UWB) technology is expected to realize high data rate wireless communications within tens of meters [2]. UWB signals use the spectrum from 3.1 GHz to 10.6 GHz, which enables sufficiently large channel capacity. However, radiation of UWB signals in air includes some problems. UWB signals are easily shielded by obstacles because of following reasons:

- Signal strength of UWB communication is restricted to -41.3 dBm/MHz.
- The signal propagates more straightly as frequencies get higher.

We suppose that proposed UWB communication system in this paper can be the solution for the existing problems.

In this paper, we propose a room-size UWB wireless communication system using two-dimensional signal transmission (2DST) technology [3]. In the proposed system, room-size, planar waveguide sheets embedded on the floors and walls are used as a medium guiding microwave and receiver couplers on the sheet extract microwave across the sheet surface by non-contact coupling using near-field connection. The sensors put on the sheet-like waveguide can communicate stably with a wide-band.

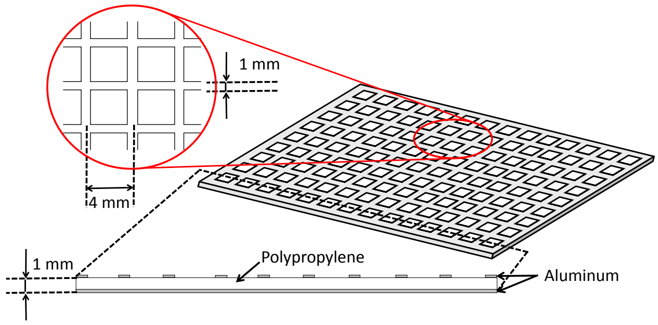

Fig. 1. Structure of 2D waveguide sheet. It has three layers. The bottom is conductor, the middle is dielectric, and the top is inductive impedance layer (conductive mesh).

Since the transmitted microwaves are confined in 2D medium and external areas of the sheet are physically separated, there are mainly two advantages in UWB communication using 2DST as follows:

- In the 2DST sheet we can use higher power density than radiation in air.
- Signals in the sheet are free from occlusion by external objects and interference from external signals.

We suppose that these advantages will lead to realization of more convenient UWB communication environment using 2DST technology.

Wireless power transmission (WPT) using 2DST sheet is also available with a different setup. We have already developed the WPT system using 2.5 GHz signal transmission in our previous work [4]. In the WPT system, a thick insulator layer on the sheet is required in order to maximize the transmittable power by reducing the unwanted power extraction from the sheet surface. However, because of the insulator layer, the WPT system only allow for narrowband signal transmission using high-Q resonance coupling. In this paper, we develop the system without the insulator layer for specializing in UWB communication. Therefore only limited power is transmittable in this paper's system.

In the proposed system, transmitter/receiver couplers on the sheet feed/extract UWB signals across the sheet surface,

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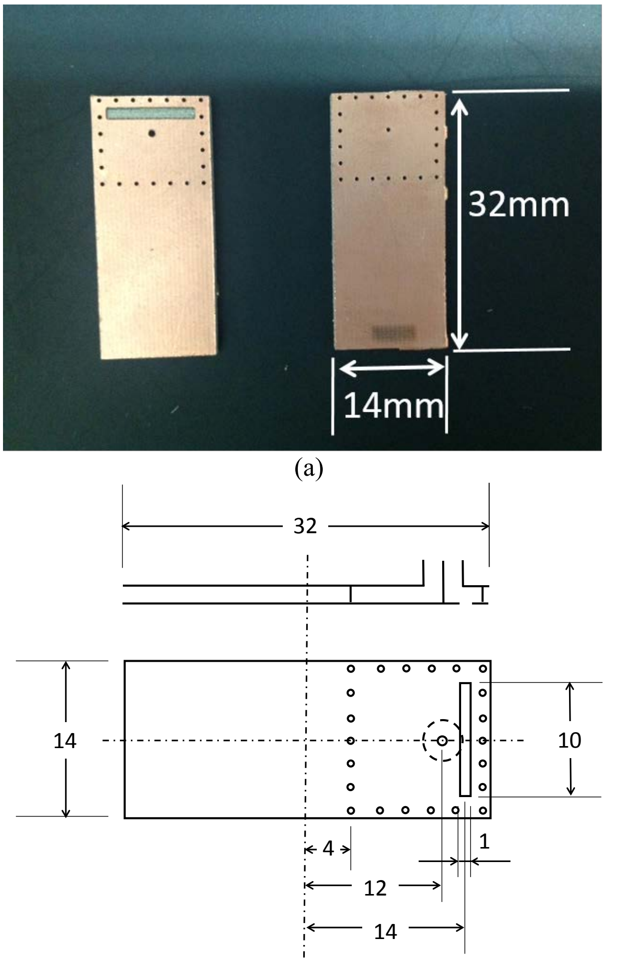

Fig. 2. (a) Fabricated UWB coupler and (b) its design parameters. A double-sided copper clad board is used as a conductor plate which extracts UWB signals from a slot formed on lower conductor put close to the sheet surface (left).

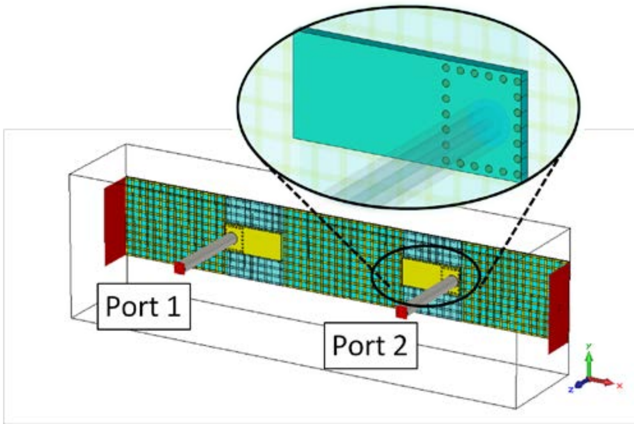

Fig. 3. Simulation model where two UWB couplers touches on surface of the 2DST sheet. To feed/extract the UWB signals, coaxial cables are attached to each coupler.

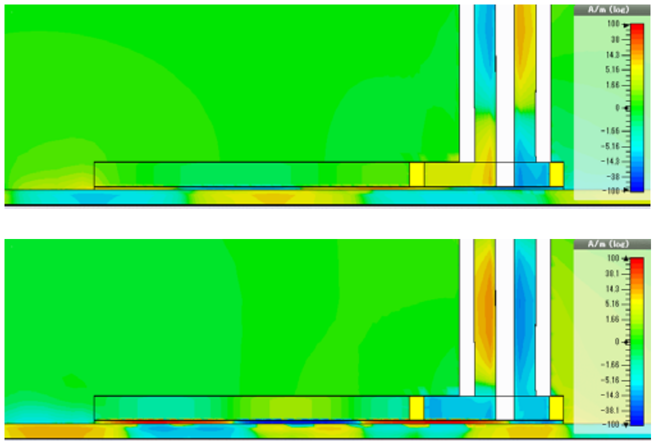

Fig. 4. Simulated electromagnetic field distribution on 8.75 GHz (upper) and 9.284 GHz (lower) when microwaves are fed from a coaxial cable to the sheet. Colors represent the phase of microwave. Lower image is at a resonance frequency of the coupler.

but such a wideband coupler have not yet been realized. Our main results in this paper are 1) designing and fabricating UWB couplers, 2) measuring characteristics of the couplers on the sheet and demonstrating validity of our proposed UWB communication system in the physical layer.

In the following section, we show the design and prototype of the proposed UWB communication system. The rest of this paper is organized as follows. The system overview is explained in Section II, and full wave simulation for designing UWB coupler is presented in Section III. Developed UWB couplers and its experimental results are shown in Section IV. Finally, we conclude this paper in Section V.

II. System Description

A. 2-D Waveguide Sheet

Structure of 2-D waveguide sheet is shown in Fig. 1. It has three layers. The bottom is conductor, the middle is dielectric, and the top is inductive impedance layer (conductive mesh). We assume that mesh pitch of the top layer is sufficiently smaller than the wavelength in the sheet. Then, mesh-patterned conductor of top layer having a certain inductance for the mesh-current generates evanescent field. The evanescent fields above the mesh exponentially decay with respect to distance from the sheet surface [3]. If a conductor plate is put close to the sheet surface, signal in the waveguide is extracted. As the signal propagates through the sheet, we can use all area of the sheet surface as communication interface.

B. UWB Coupler

In this section we show a design of UWB communication couplers which extract microwave across the sheet surface. Since popular small antennas are designed to maximize a gain at resonance frequency, UWB antennas are designed to have a lot of resonance frequency to cover wideband [5]. On the other hand, since the UWB coupler in the paper extracts signals from the sheet surface using near-field connection, we are able to attain such a wideband characteristics over the UWB

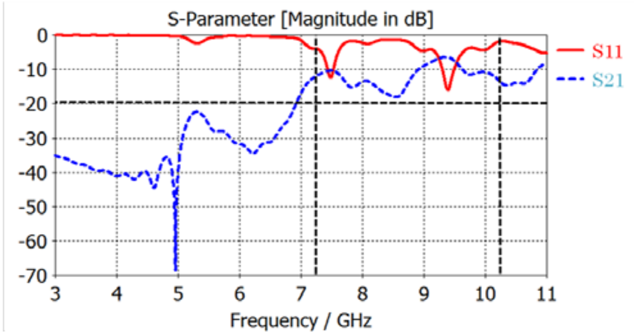

Fig. 5. Simulation results of the produced sheet and coupler. Calculated S21 (transmittance) between two couplers are over -20 dB from 7.25 GHz to 10.25 GHz.

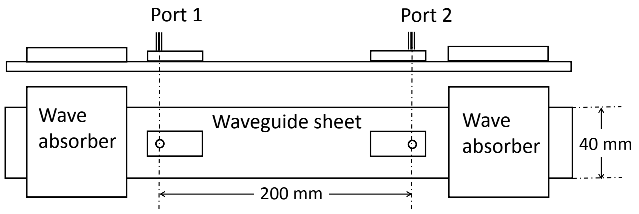

Fig. 6. Schematic diagram of the experimental setup. Two couplers are attached to a network analyzer. Wave absorbers are put on edges of the sheet in order to remove the effect of reflection.

frequencies without complex design. This extraction is attained by the interference of propagating modes in the sheet and the coupler [6].

Fig. 2 shows the fabricated UWB coupler. The coupler extract signals from a slot formed on lower conductor patch put close to the sheet surface. 50 ohm coaxial cable is connected to the upper conductor patch as shown in Fig. 3. The impedance matching between the coupler and coaxial line can be performed by tuning the patch dimensions and the slot dimensions. It is desirable that the size of the UWB coupler is as small as possible to be embedded in wireless communication devices, but if the coupler is much smaller than wave length in the sheet, sufficient impedance matching cannot be attained. We decide the coupler dimensions under an assumption that the UWB coupler is used at 7.25 – 10.25 GHz, which is legally available in Japan as UWB high-band.

III. Simulations and Results

In this section we confirm the above discussions by simulation analysis using software CST Microwave Studio.

Fig. 3 shows the simulation model, which includes narrow segment of the sheet and two UWB couplers. The 2DST sheet is modeled as we fabricated in our previous work [4]. The thickness of upper and lower conductive layers are 0.01 mm, and that of dielectric layer is 1mm. Each waveguide port is set at a coaxial cable connected on a slit formed on the lower conductor of the coupler. The distance between the two couplers is 20 cm. For clarifying the basic property, a strip-shaped 2DST sheet with the width of 40 mm is supposed. We set the open boundary condition to each end of the strip 2DST sheet so that the reflection at the boundaries is negligible.

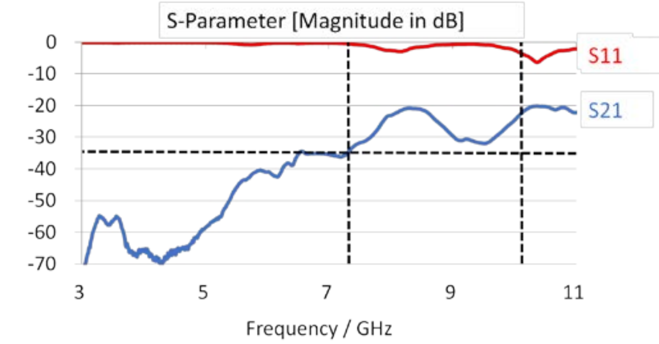

Fig. 7. Measurement result of the produced sheet and coupler. Measured S21 (transmittance) between two couplers are over -35 dB from 7.25 GHz to 10.25 GHz.

Fig. 4 shows electromagnetic field distribution of the simulation. A standing wave of an electromagnetic wave is formed in the space between the lower conductor of the coupler and the sheet surface. The standing wave excites propagation modes in the sheet.

Fig. 5 shows calculated S21 (transmittance) and S11 (reflection) at frequencies of UWB communication. The calculated S21 is larger than -20 dB in the frequencies from 7.25 GHz to 10.25 GHz (UWB high-band). Though the antenna's shape is very primitive and has not been optimized, the value of calculated S21 by the simulation is already larger than the S21 between two isotropic antennas placed at a distance of 20 cm i.e. -35.7 dB (7.25 GHz) to -38.7 dB (10.25 GHz) theoretically given by Friis transmission equation.

The calculated S11 shows that significant portions of signal (larger than -3 dB at almost all the frequencies) are reflected to the feeding coaxial cable. This should be improved technical before practical uses, and also shows there is a room of improvement of S12 by reducing this reflection. At the same time, we should notice that the main signal transmission path is inside the 2DST sheet. We can input a stronger signal into the sheet than the case of antenna radiation under the restriction of UWB signal strength.

IV. Experiments

In this section we demonstrate the validity of our concept through experiment.

A fabricated prototype of UWB coupler is shown in Fig. 2. The UWB coupler was 32 mm by 14 mm, with the same parameters as those in the simulation. The coupler is fabricated using 1.524-mm thick double-sided copper clad boards, Arlon DiClad-880 (relative permittivity, and loss tangent are 2.17 and 0.0009 at 10 GHz, respectively). Aluminum (9 μm)/PET (50 μm) laminated sheets are used for the ground plane and mesh conductor plane. The dielectric waveguide layer is a 1-mm-thick polypropylene (PP) sheet. As the PP sheet has a relative permittivity of about 2.1, the wavelength in the medium is about 30mm – 100mm at UWB frequency, which is sufficiently larger than mesh pitch of the top layer.

We show the experimental setup in Fig. 6. The sheet width is 40 mm, the same as the simulation model shown in Fig. 3. Two couplers touches on surface of the 2DST sheet 20 cm apart. We put wave absorber (Takechi ES-88) on the edge of the sheet in order to remove the effect of reflection. Although the signal transmission using such a narrow sheet is insufficient to consider practical situations, it is reasonable for the fundamental coupler evaluation.

Fig. 7 shows measured S21 (transmittance) and S11 (reflection) at frequencies of UWB communication. The S-parameters were measured by vector network analyzer. In the frequencies from 7.25 GHz to 10.25 GHz (UWB high-band), the S21 is larger than -35 dB. The value of S21 is supposed to be sufficient for high quality UWB communication under the strength limitation of the radiated power as we have discussed in the former section.

V. CONCLUSION

In this paper we proposed a room-size ultra-wideband (UWB) wireless communication system using two-dimensional signal transmission (2DST) technology. In the proposed system, two-dimensional waveguide sheet is used as a medium guiding microwave and transmitter/receiver couplers on the sheet feed/extract microwave across the sheet surface. We designed the simplest structure of the UWB coupler and demonstrated the validity by numerical simulations. We showed by experimental results that the 2DST system can mediate sufficient power for UWB communication.

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