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Signal Connection among Two-Dimensional Communication Tiles by Direction-Dependent Frequency Shift

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Abstract: In this paper, we aim to construct a communication environment all over the room floor by using two-dimensional communication (2DC) sheets. A scheme that realized such an environment by laying the 2DC sheets on all over the floor like carpet tiles have been proposed. In the system, oscillation loop can be formed due to the amplifier built in the 2DC tiles for compensation of signal attenuation. In this paper, we propose, to avoid oscillation loop, a 2DC tiles connection scheme based on FDD system that divides frequency into two frequency bands assigned for the uplink and for the downlink, and present an implementation example.

Keywords: two-dimensional communication, ultra wideband, wireless communication, frequency division duplex,

1. INTRODUCTION

Recently, as use of wireless communication increases, radio frequency resources are getting more and more crowded. Especially in the 2.4-GHz and 5-GHz bands, the Wi-Fi data transmission speed obviously drops in the densely populated section like a business district. Ultra-wideband (UWB) technology from 3.1 GHz to 10.6 GHz [1] is expected to compensate this lack of bandwidth. However, UWB has physical connectivity problems because signal transmission power is restricted to -41.3 dBm/MHz, and signals are easily occluded by objects in the air, due to propagation straightness. Received power density P_R in free-space is given as follows by Friis's law [2].

$$P_R = \left(\frac{\lambda}{4\pi r}\right)^2 G_T G_R P_T \qquad (1)$$

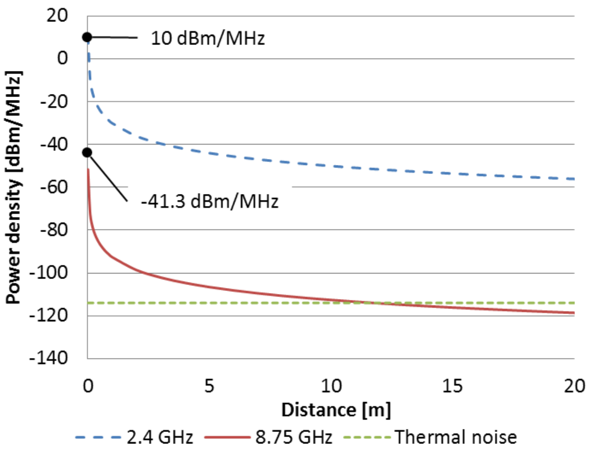


Fig. 1: Signal power density of free-space propagation at 2.4 GHz and 8.75 GHz. Transmitted power densities at 2.4 GHz and 8.75 GHz are assumed to be 10 dBm/MHz and -41.3dBm/MHz, respectively. 10 dBm/MHz is the maximum transmitted power of IEEE802.11b/g transmitters in Japan. Thermal noise is calculated at 290 K.

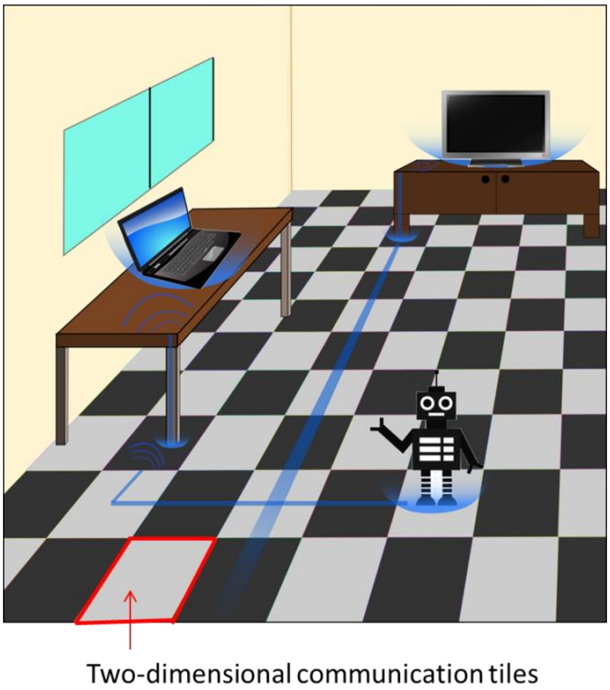


Fig. 2: The concept of 2DC tiles environment.

where P_T, G_T, G_R, λ, and r denote transmission power, transmitter antenna gain, receiver antenna gain, wavelength and distance between the transmitter and the receiver. Fig. 1 shows signal power density attenuations of Wi-Fi signal (2.4 GHz) and UWB signal (8.75 GHz), calculated by (1), where $G_T = G_R = 1$ is assumed. 2.4-GHz Wi-Fi signals can be received at a distance of tens of meters with 50-dB or larger signal-to-noise ratio (SNR). On the other hand, UWB signals decay as low as the thermal noise level at a distance of 10 m.

Using two-dimensional communication (2DC) [3] can be effective for reliable UWB signal transmission. 2DC is realized with a waveguide sheet and proximity couplers. The waveguide sheet guides microwaves along itself and generates evanescent field around its surface. The sheet can be attached to surfaces such as

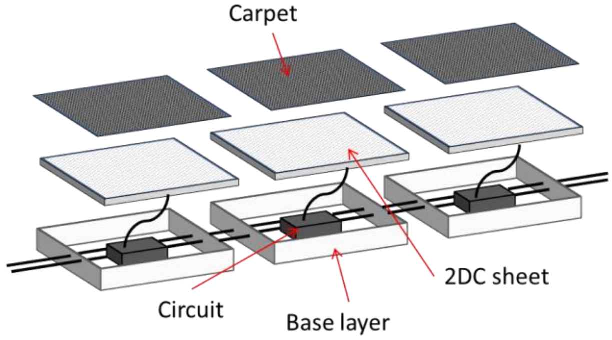


Fig. 3: The structure of 2DC tiles.

desks, shelves and floors. Proximity couplers laid on the sheet transmit/receive microwaves into/from the sheet across the sheet surface without electrical contacts.

Currently, it has been studied to construct a communication environment in the entire room such as an office room and a living room, by covering the floor with 2DC sheets. To reduce costs and workloads of initial installation and of repairment of a damaged part of sheets, laying the sheet of manageable size on the floor as shown in Fig. 2 has been proposed [4.5.6]. We call this sheets 2DC tiles. 2DC tiles consist of a carpet, a 2DC sheet and a base layer as shown in Fig. 3. The base layer includes a circuit for establishing the connection with the neighbor tiles. Signals must be amplified to compensate the signal attenuation due to the connection part between adjacent tiles, in order to transfer signals across a large number of tiles.

Here we have a problem: how to prevent oscillation by the amplifiers. As the circuit has amplifiers, an oscillation loop can be formed if there is a positive feedback path in the tiles. In this study, we propose the circuit design to amplify signals without oscillation loops in 2DC tiles, and we aim to transmit signals of UWB High-band, 7.25-10.25 GHz.

The rest of this paper is organized as follows. Section 2 describes the proposed circuit operation. Experimantal measurement setups and the results are presented in Sections 3. The paper is concluded in Section 4.

2. THE PROPOSED METHOD

To transmit signals to all tiles while being amplified, we propose separating the transmission line into the uplink (UL) and the downlink (DL), and transmitting signals only in one direction respectively. The UL and the DL are connected at one end of the tiles arranged in a row, as shown in Fig. 4. In the UL, each tile receives signals from the sheet on itself and transfers those signals toward the connecting point. In the DL, signals leave the connection point and transferred toward the opposite end of the row of tiles and every sheet on the tile receives the signals.

In this system, we need a way to avoid an oscillation loop. If the UL and the DL are directly connected to each other, there are two situations in which an

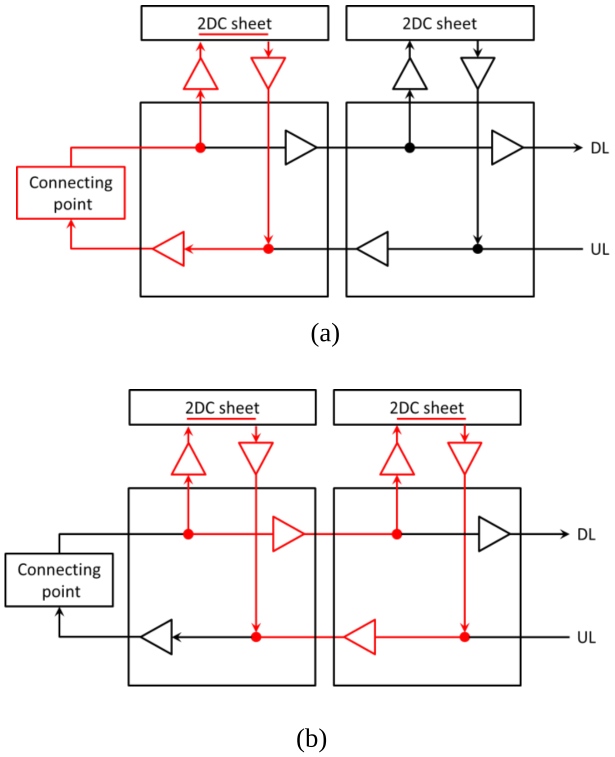


Fig. 4: The UL and DL are connected at the one end (left-hand side end in this figure) of the tiles arranged in a row. There are two possible oscillation loops: (a) a path including a tile and the connecting point, (b) a path including two tiles.

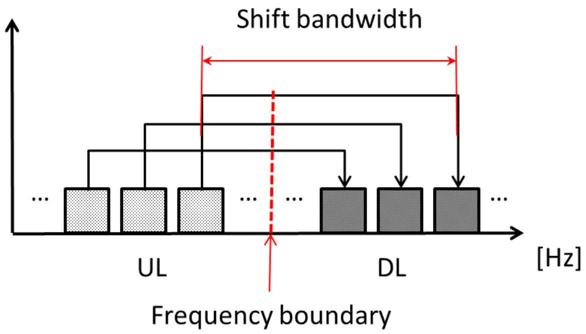
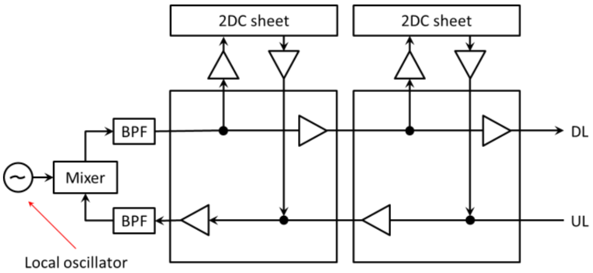


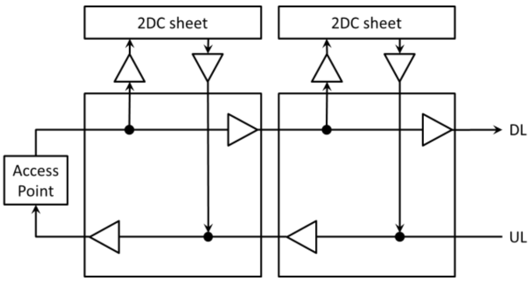
Fig. 5: How to separate frequency band.

oscillation loop will be formed. One is the route from sheet A to sheet A through the connecting point at the end of tiles as shown in Fig. 4 (a). The other is the route between sheet A and sheet B as shown in Fig. 4 (b). We must consider connection between the tiles not to occur those loops that have the loop gain greater than 1. In Fig.4 (b), the loop gain will be less than 1, because signals pass through amplifiers in reverse direction, which usually has a significantly high isolation. Thus we discuss about avoiding the loop in shown Fig. 4 (a).

There are two methods to avoid the oscillation loop while connecting UL and DL at the end of tiles: frequency division duplex (FDD) system and time



(a)



(b)

Fig. 6: Two methods to avoid the oscillation loop.
(a) FDD and (b) TDD.

division duplex (TDD) system.

FDD system is the technology that performs full-duplex transmission by dividing frequency into two frequency bands assigned for the UL and for the DL. For instance, the lower frequency band is used as the UL band and the higher frequency band as the DL band, as shown in Fig. 5. Since the passbands of the two bandpass filters (BPFs) are different, the loop gain at any frequencies can be less than 1. To apply FDD scheme to the 2DC tile system, a frequency shift function is required at the connection point between the UL and the DL. This can be achieved by using a mixer and a local oscillator (LO), as shown in Fig. 6 (a)

On the other hand, TDD system is the technology that allows half-duplex transmission by switching UL and DL using an Access Point (AP). It uses same frequency for UL and DL. The AP is used at the connecting point between the UL and the DL, as shown in Fig. 6 (b). The UL and the DL transmission lines are always separated by the AP, therefore oscillation loops will be never formed. The TDD 2DC enables communications only between the AP and a transceiver on tiles. Direct communications between an arbitrary pair of transceivers on tiles are not possible.

In this paper, we propose a 2DC tile connection scheme based on FDD. The FDD-based scheme is suitable for a UWB system, because a frequency band wide enough to accommodate the separated UL/DL bands. By attaching a frequency converter to

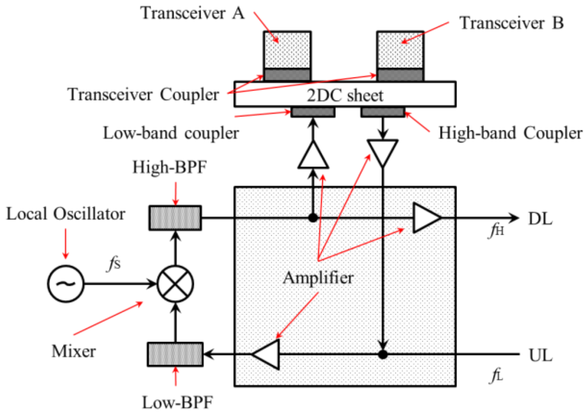


Fig. 7: The schematic diagram of the 2DC tiles system.

transceivers on the tiles, TDD-based communication such as Wi-Fi can be also supported by the FDD-based 2DC.

3. EXPERIMENT

The schematic diagram of a 2DC tile system is shown in Fig. 7. This tile is the end of tiles in a row and the UL and the DL are connected by a mixer. f_S denotes the shifting frequency, f_L denotes a frequency in the lower band and f_H denotes one in the higher band. The operation of 2DC tiles is as follows.

1. Transceiver A on a 2DC tile transmits f_L signals into the 2DC sheet.
2. The low-band coupler below the sheet receives signals.
3. Signals except f_L component are obstructed by the low-BPF.
4. f_L is shifted to f_H via the mixer.
5. Signals except f_H component are obstructed by the high-BPF.
6. Signals are fed into the sheet again, and transceiver B on the tile receives f_H signals.

Communication among 2DC tiles is realized by those operations. Note that both transceivers A and B are not essentially required to be placed on the same tile. This situation is just one example and is shown here for a purpose to simplify the description of the operation.

3.1 Conversion Loss Measurement

Setting

Fig. 7 shows the circuit of conversion loss measurement. The measurement procedure is as follows.

1. Signal generator outputs f_L signal.

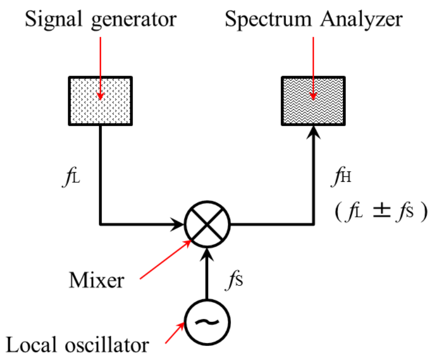


Fig. 8: The schematic diagram of conversion loss measurement.

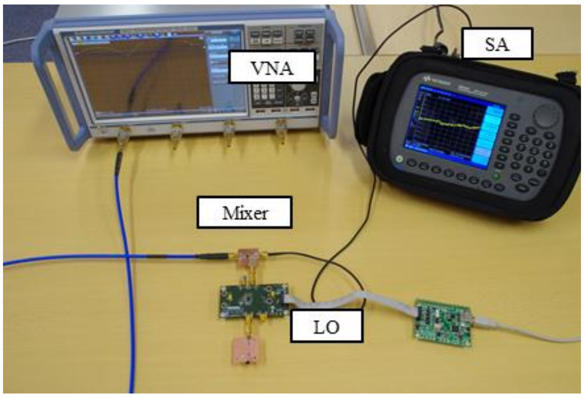


Fig. 9: The overview of conversion loss measurement.

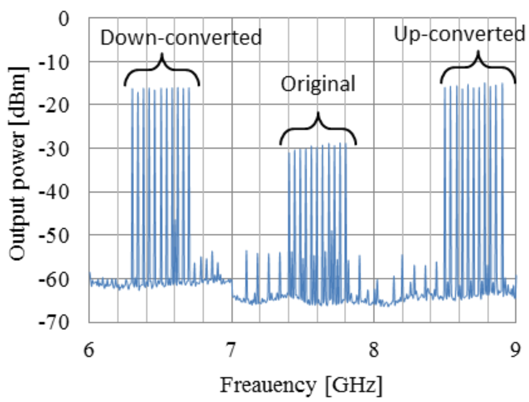


Fig. 10: Mixer-output power.

2. Oscillator outputs f_S.
3. The mixer multiplies f_L signal and f_S signal.
4. Output signal spectrum from the mixer is measured with a spectrum analyzer (SA).

From the measured output spectrum and the input spectrum, conversion loss from the f_L signals to the f_H signals can be calculated. The isolation from the input port to the output port of the mixer at the original frequency, f_L, is also calculated.

Note that we used stimulus signals of a vector network analyzer (VNA) as f_L input signals.

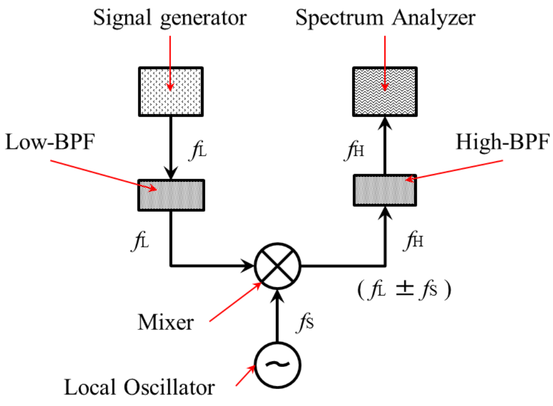


Fig. 11: The schematic diagram of the filtering loss measurement.

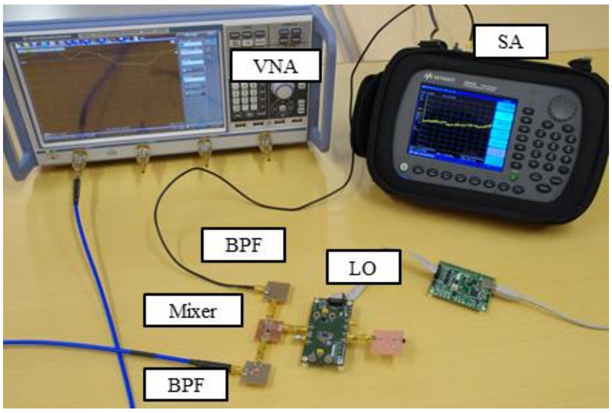


Fig. 12: The overview of filtering loss measurement.

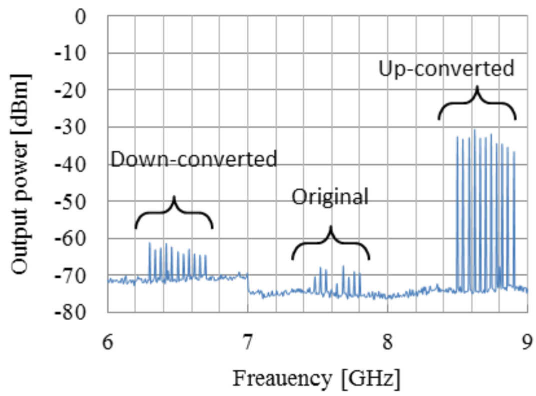


Fig. 13: Output power through the mixer and BPFs.

Result

Fig. 9 shows the overview of the experimental system and Fig. 10 shows the measured mixer output power spectrum. The original signals from signal generator consist of 11 frequency components, from 7.4 GHz to 7.8 GHz with a step of 40 MHz, and the magnitude of each component is 0 dBm.

Signals of f_L are converted to f_H by mixer and are weaken by 15 dB. Other frequency f_L-f_S components, down-converted signals, are also generated with almost the same power as up-converted signals by multiplying.

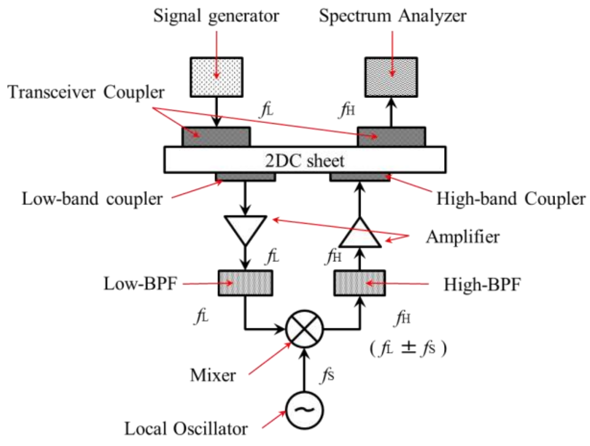


Fig. 14: The schematic diagram of the implementation example.

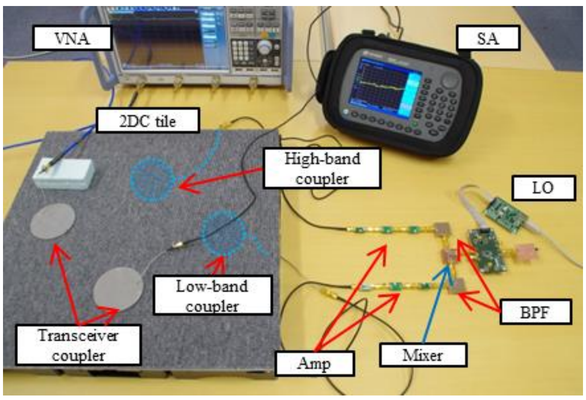


Fig. 15: The overview of implementation example.

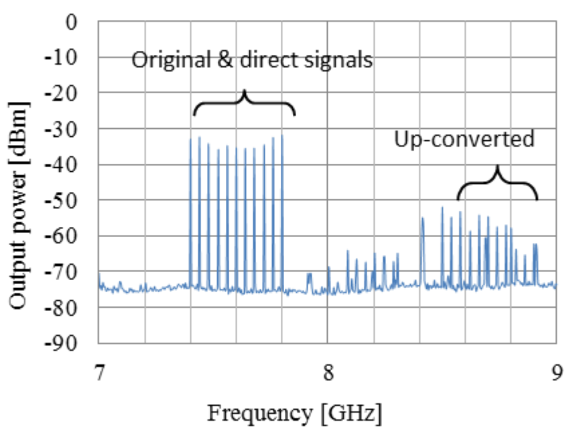


Fig. 16: Output power through the 2DC tiles system.

Original frequency components are suppressed by 30 dB.

3.2 Filtering Loss Measurement

Setting

Fig. 11 shows the circuit of measurement of the overall conversion loss with bandpass filters. The measurement of the overall conversion loss with bandpass filters. The measurement procedure is as follows.

1. Signal generator outputs f_L signals.
2. That signals pass through low-BPF.
3. Oscillator outputs f_S signals.
4. The mixer multiplies f_L signals and f_S signals.
5. Signals except f_H signals are obstructed by the high-BPF.
6. Output signal spectrum from the mixer through the BPF is measured with the SA.

We investigated the signal spectrum before the sheet. From the measured output spectrum and input spectrum, insertion loss of this conversion system, can be calculated.

Result

Fig. 12 shows the overview of the experimental system of 3.2 and Fig. shows the result of that experiment. f_H signals are 30 dB larger than that of f_L by the BPF. Moreover, Signals of f_H is 25 dB larger than a frequency below f_L. The result indicates that amplifiers with up to 60-dB gain can be inserted in the signal path while maintaining the gain of the original frequency component less than 0 dB.

In the following subsection, an amplifier-integrated 2DC tile system implementation will be presented.

3.3 Implementation Example Measurement

Setting

The schematic diagram for implementation is as shown Fig. 14. This circuit simulates an actual implementation of the communication system. The measurement procedure is as follows.

1. Signal generator outputs f_L signals into the sheet.
2. Low-band coupler receives that signals.
3. That signals pass through low-BPF.
4. Oscillator outputs f_S signals.
5. The mixer multiplies f_L signals and f_S signals.
6. Signals except f_H are obstructed by High-BPF.
7. Signals passed the high-BPF are fed into the sheet.
8. Coupler receives signals from the sheet and inputs those signals to SA.

Result

Fig. 15 shows the overview of the experimental system of actual communication. As attenuation of a coupler connecting the sheet is large, amplifiers are inserted between the sheet and the filter. As a portion of f_L signals are bypassed through the sheet and propagate to spectrum analyzer directly, f_L is larger than f_H.

Note that we fabricated the BPFs [7] in accordance with UWB high-band. Fig. 16 shows characteristics of the filters. 7.4-7.8 GHz and 8.5-9.1 GHz are passband of the low- and high-BPFs, respectively. In this experiment, we use 7.4-7.8 GHz for UL, 8.5-8.9 GHz for DL and 1.1 GHz for shift bandwidth in accordance with filters.

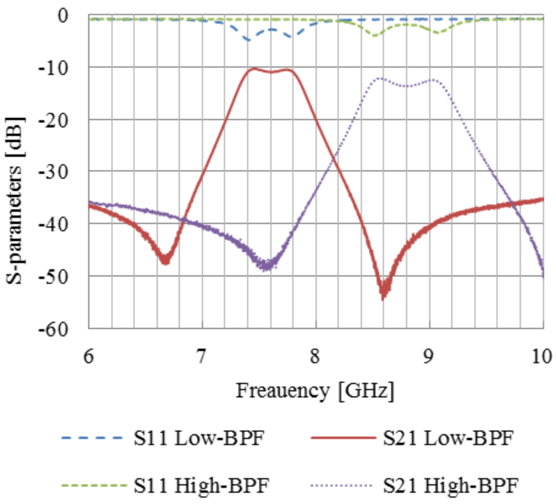


Fig. 17: Low-and high-BPF characteristics.

4. CONCLUDION AND PROSPECTS

We proposed a signal transmission scheme in 2DC tiles systems based on FDD that separated UL and DL by frequency, and presented a practical implementation. Oscillation loop is not formed because signal gain of the transmit frequency is less than 0 dB, while the FDD communication is enabled with 7.4-7.8-GHz transmitted band and 8.5-8.9-GHz received band.

In addition, we mention BPF separating frequency. In this study, we used the bandwidth of 400 MHz in 7.4-7.8 GHz and 8.5-8.9 GHz. That bandwidth was determined by the characteristics of the BPFs. Wider passband of each BPF and narrower overlapping transition bandwidth are required for effective use of UWB high-band. As shown in Fig. 18, the boundary between the UL and the DL bands should be set at the center frequency of UWB high-band for symmetric bandwidths configuration of UL and DL. To maximize the available bandwidth, the bandwidth of the transition between the passband and the stopband should be minimized.

ACKNOELEDGMENT

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