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Active Tile for Room-Size UWB 2-D Communication

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***Abstract*— This paper presents a practical scheme to enhance a two-dimensional communication (2DC) system to the entire floor of a room. The 2DC uses a waveguide sheet as a physical communication medium. Covering an entire room floor with a large single piece of sheet is impractical in terms of fabrication, delivery, and installation. An alternative scheme, in which the floor is covered with waveguide sheet tiles, has been proposed. This paper proposes an active tile system as a specific implementation of the scheme. A circuit configuration is presented and the feasibility is demonstrated through measurements on an experimental system.**

I. INTRODUCTION

Ultra-wideband (UWB) is one of the promising technologies for short-range, high-speed wireless communications. UWB systems are allowed to use extremely wide spectral ranges from 3.1 to 10.6 GHz, at the expense of reducing the transmitted power density at most -41.3 dBm/MHz [1]. The wide spectral range potentially enables large channel capacity. The low power density can be acceptable for some indoor short-range applications. Thus, UWB is attractive for high-speed short-range wireless communication systems.

In practical use, some objects in the communication environment can obstruct the radio waves propagating over the air. Such obstruction can be more critical in the UWB communications than in conventional Wi-Fi systems using the 2.4-GHz and the 5-GHz bands, because of the high-frequency, low-power transmitted signals. The diffraction effect of the radio waves is reduced at higher frequency, and path loss from a transmitter to a receiver behind the obstacle will increase. Due to the extremely low transmitting power as mentioned above, the path-loss degradation can be fatal for UWB wireless links.

Two-dimensional communication (2DC) [2] can be an alternative scheme for the conventional over-the-air wireless communications. The 2DC uses a waveguide sheet as a physical communication medium. Communication devices put on the sheet can transmit/receive the radio waves into/from the sheet across the surface, at arbtrary points on the sheet. In exchange for this geometrical restriction in the device position, the 2DC provides some advantages as follows.

- The major propagation paths of radio waves are inside the sheet and are not obstructed by any objects outside the sheet.

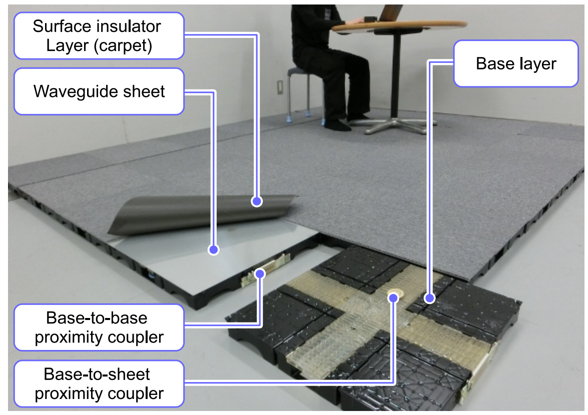

Fig. 1: An image of the active tile 2DC system implementation.

- The power density transmitted into the sheet can be increased while the equivalent isotropically radiated power (EIRP) is kept complying with the UWB spectral mask.
- Wireless power transmission can be supported by the same wave guide sheet as well as the signal transmission.

The 2DC system development started from tabletop-size systems, and recently an idea of room-size, floor-embedded system has been proposed [3]. The room-size 2DC will provide above mentioned advantages and will be suitable for indoor UWB communication systems.

Although the concept of the 2DC tile system was proposed in [3], any actual implementations to realize the system have not been presented. In this paper, we present an implementation example of the 2DC tile concept. Fig. 1 shows an image of the system.

The rest of the paper is organized as follows. Realization of the 2DC tile concept will be overviewed in Section II. Signal transmittance mesurement result will be shown in Section III. Conclusions and prospects will be presented in Section IV

II. OVERVIEW OF 2DC TILE SYSTEM REALIZATION

This section presents an overview of 2DC tile system realization schemes.

To cover the entire floor of a room with small (e.g., 50-cm square) 2DC tiles, two-dimensional (2-D) tiling is required. Actually, the 2-D tiling of the 2DC tiles can be internally connected as a single 1-D meander tile chain (shown in Fig. 2(a)) or as a several parallel 1-D tile chains (Fig. 2(b)). In this paper, the 1-D tile chain is assumed, and 2-D networks

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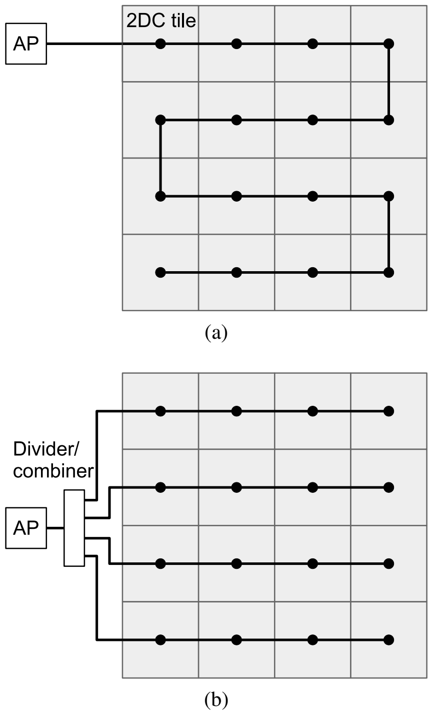

Fig. 2: Internal connection topologies of 2DC tiles. (a) Single 1-D meander tile chain topology and (b) parallel 1-D chians topology. The arrows show the signal flow from the access point (AP) to each tile.

of tiles, e.g, a mesh network and a star topology, are not considered.

Signals can be distributed to every tile by dividing the input signal into two outputs in each tile, as shown in Fig. 3(a). Conversely, transmitted signals from every sheet can be combined and be transferred to the same destination, as shown in Fig. 3(b).

Some representative signal distribution schemes are illustrated in Fig. 4.

As the simplest scheme, the identical dividers can be used in every tile, as shown in Fig. 4(a). Suppose that the power fed into the common port, p, is devided into ap $(0 < a < 1)$ and $(1 - a)p$. In this case, the available signal power p_k at the waveguide sheet of the kth tile is

$$p_k = (1 - a)a^{k-1} p_0,$$

where p_0 is the available power at the input port of the tile chain. The available signal powers at the first and the Nth tiles are different by a ratio of a^{N-1}.

This unbalance of the available power among the tiles can be avoided by tuning the dividing ratio of each divider correspondingly to the tile number k, as shown in Fig. 4(b). To achieve the uniform power distribution, the scattering parameters (S parameters) of the kth divider should be

$$|S_{\mathrm{sc},k}|^2 = \frac{1}{N - k + 1} \quad (1)$$

$$|S_{\mathrm{bc},k}|^2 = \frac{N - k}{N - k + 1}, \quad (2)$$

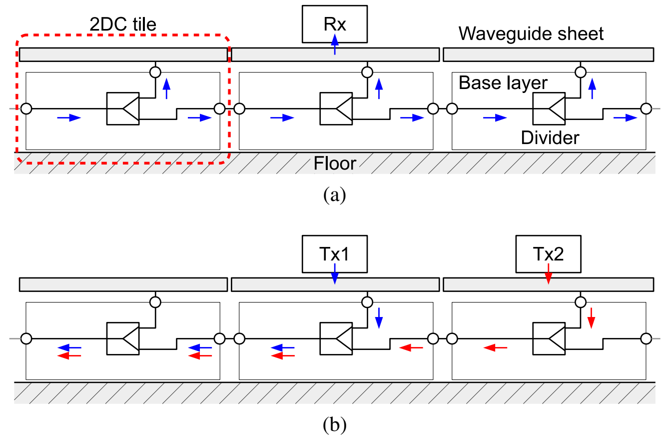

Fig. 3: (a) A primitive scheme to distribute signals to every sheet by using dividers. (b) Signals transmitted from any sheet can be transferred to the same destination (the left hand side end in this figure).

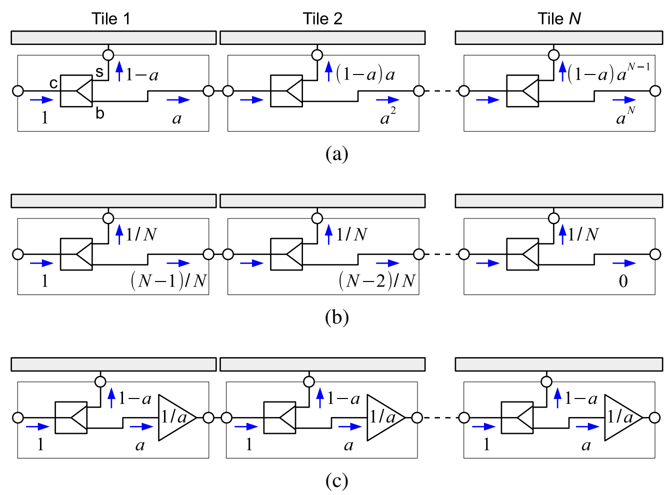

Fig. 4: Some representive schemes for distributing a signal to N tiles by using dividers. (a) All dividers have the identical dividing ratio. As the tile number increases, the signal power available at the tile decays exponentially. (b) The available signal power at every tile is identical. The dividing ratio of the divider have to be tuned correspondingly to the tile number. (c) Identical signal power is available at every tile while using identical dividers and identical amplifiers.

where S_{sc} is the S parameter from the common port to the output port connected to the sheet, and S_{bc} is that from the common port to the other output port connected to the base layer of the next tile. The requirement of the S parameters specific to the tile number will significantly reduce the system flexibility.

As suggested in [3], each tile can contain amplifiers to compensate the signal loss. While using identical dividers, uniform power distribution can be achieved by using amplifiers, as shown in Fig. 4(c). The gain of amplifiers used in every tile is also identical. Even if the circuit contains significantly lossy components, the signal loss can be compensated

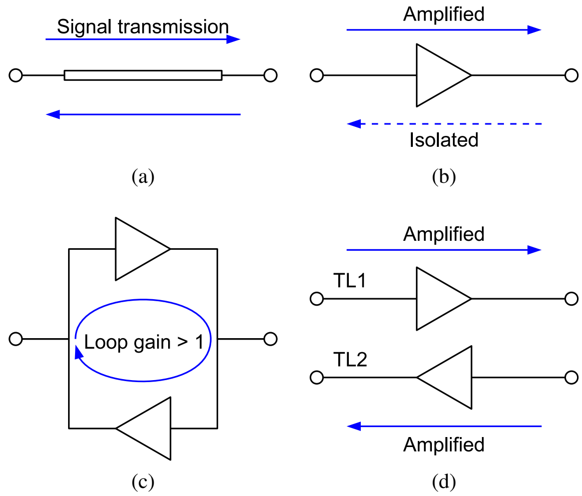

Fig. 5: (a) A passive TL is a bidirectional TL. (b) An amplifier is a unidirectional TL. (c) Two amplifiers connected in the opposite direction to each other form a positive feedback loop with the loop gain greater than 1. (d) Two separated amplifiers operate as a pair of unidirectional TLs opposite to each other.

and the signal strength can be uniform across every tile by choosing the amplifier gain properly. We refer to this type of tile as an "active tile." On the other hand, we refer to a tile not containing amplifiers as a "passive tile."

The major advantage of the active tile system is the scalability. The system is composed of identical tiles and each of them has no parameter to be tuned uniquely. Adding new tiles to an existing system as well as removing some of the tiles from the system are possible, while the signal power available on each tile is kept unchanged.

As a significant difference between the active and the passive tile systems, the active tile needs internally separated two transmission lines (TLs). Fig. 5 illustrates the reason for this requirement. In a passive TL, signals are transferred in the both directions. With an amplifier, the forward direction signals are amplified and the backward signals are isolated. Thus, a TL containing amplifiers is unidirectional. Connecting two amplifiers in the opposite directions to each other will fail to transfer signals, because they will form a positive feed back loop with the gain greater than 1, which will oscillate. Therefore, in order to transfer singals in the both directions in the tile chain, two isolated TLs are needed.

Thus, for scalable 2DC tile systems, the active tiles consisting of two isolated TLs are required.

III. Prototype of Active Tile System

Based on the discussions in the previous section, ptorotype active tiles were fabricated. Fig. 6 shows an evaluation experiment system consisting of 10 active tiles. The system was designed to operate in 500-MHz bandwidth around the center frequency of 8 GHz.

In order to reduce the additional workload of 2DC floor tiles installation compared with conventional raised floor panels, non-contact couplers [4] should be used for inter-tile connection. The insertion loss of the inter-tile coupler proposed in [4] is approximately 10 dB. In the evaluation system, 10-dB fixed attenuators were used instead of the non-contact couplers .

Connection between the base layer and the waveguide sheet should also be contactless. In the evaluation system, non-contact couplers shown in Fig. 7 were used.

The 2-way equal power divider/combiner used in the prototype circuit was Mini-Circuits ZX10-2-98+. The insersion loss was 3.4 dB for each. Bandpass filters (BPFs) were used for rejecting unwanted frequency signals and for avoiding saturations of amplifier outputs. The insertion loss of BPF in the passband was 2.5 dB. In order to compensate the losses due to these lossy components, the apmlifier gain was chosen as 16 dB in the pass band. Avago Technologies VMMK-3803 was used for the amplifier.

In the evaluation system, a UWB 2DC coupler [5] was used as a mobile station (MS) coupler. The active tile chain was scanned with the MS coupler while S parameters were measured by vector network analyzer (VNA). S_{31}, the transmittance from the MS coupler to the uplink (UL) port of the tile chain, and S_{23}, that from the downlink (DL) port to the MS coupler, are shown in Fig. 8. For each data point, S parameters measured at 81 points (50-mm pitch 9×9 points) on each tile are averaged. At each position, S parameters were measured at 501 frquency points in the 500-MHz span centered at 8.2-GHz, and they were averaged.

The result shows that the difference between the S parameters at the first tile and the tenth tile is approximately 12 dB, for both the UL and the DL. The average attenuation for every tile is calculated as approximately 1.3 $(= 12/9)$ dB. As the number of the tiles connected in series increases, the signal loss increases with 1.3 dB per tile. The loss for the 5-meter long 10-tile chain is significantly lower than the free space path loss with isotropic antennas at 8 GHz for 5-m distance, -64.5 dB.

Ideally the difference should be 0 dB, i.e., the S parameters should be constant value regardless of the tile number. The difference between the actual loss and the ideal zero loss is due to the unbalance between the amplifier gain and the insertion losses of the lossy components including the divider/combiner, the BPF, and the inter-tile connection. If the loss significantly exceeds the amplifier gain, the available power at the further end of tile chain will be reduced. On the other hand, if the amplifier gain exceeds the losses significantly, the amplifier will saturate and the signal will be distorted. Thus, the balance between the gain and loss should be properly designed to avoid those problems. The almost ideal balance between the gain and the loss will be achieved by using a amplifier with the gain slightly higher than the loss and a additional attenuator that offsets the excess gain.

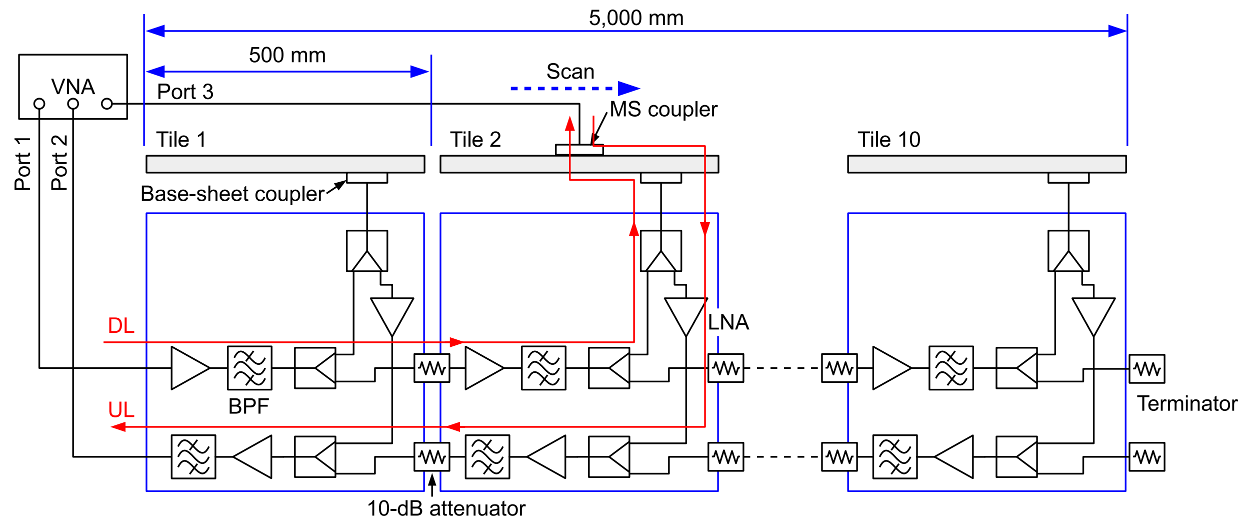

Fig. 6: Evaluation system schematics. In an actual communication system, ports 1 and 2 correspond to the AP, and port 3 corresponds to the mobile station (MS).

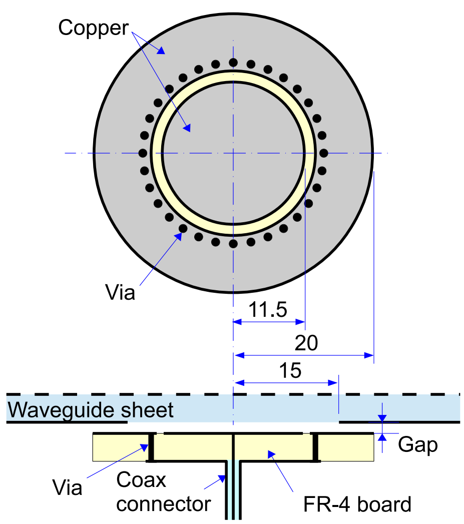

Fig. 7: Top view and cross-sectional view of a non-contact coupler for connection between the base layer circuit and the waveguide sheet.

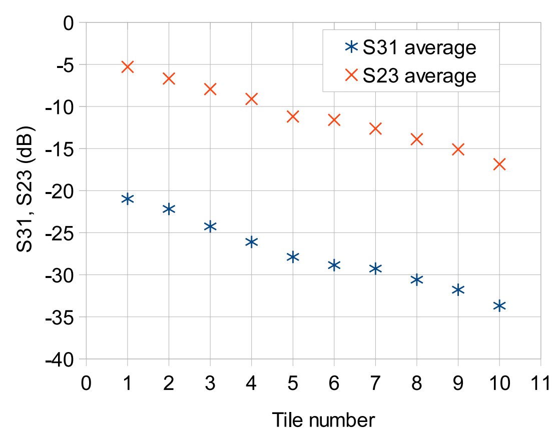

Fig. 8: Measured S parameters. S_{31} is the UL (from the MS to the AP) transmittance, and S_{23} is the DL (from the AP to the MS) transmittance. The approximately 16-dB difference between them is due to the gain of the low noise amplifier (LNA) used in UL, for avoiding signal-to-noise ratio degradation.

IV. CONCLUSION

This paper proposed an implementation of active-tile 2DC systems. In the fabricated system, the transmittance between the AP and the MS decreases by 1.3 dB every tile. At the further end of the 10-tile chain, i.e., 5-m distant from the input port of the tile chain, the input signal is transferred with 13-dB net attenuation. The loss is significantly lower than the free space path loss at 8 GHz for 5-m distance, -64.5 dB. The net attenuation/gain can be reduced to 0 dB, by balancing the amplifier gain and the insertion losses of the lossy components. Thus, the proposed active tile implementation is effective to transferring UWB radio's significantly low power signals across the entire floor of a room.

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