Technology Reports (Special Articles)

Millimeter-wave Communication Area Deployment / Dielectric Waveguide / Antenna

Special Articles on 5G evolution & 6G (2)

Pinching Antenna —Using a Dielectric Waveguide as an Antenna—

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We propose a method for easily and economically deploying and expanding communication areas in high-frequency bands (millimeter-wave bands) that are now being used in the 5G era and studied for use in the 6G era. This method radiates radio waves from part of a dielectric waveguide—a transmission medium for high-frequency bands—to make the surrounding area a communication area. The ability to radiate radio waves from any point along a dielectric waveguide makes it possible to quickly deploy a variety of communication areas depending on the place and environment.

1. Introduction

In Japan, commercial services for the 5th Generation mobile communications system (5G) were launched in March 2020. As a mobile communications system, 5G marked the first practical use of wideband, high-speed communications using a (quasi-) millimeter-wave band, in particular, the 28-GHz frequency band [1]. The 28 GHz band and higher bands are expected to see expanded use in the future.

In high-frequency bands, it is known that propagation loss*1 is generally high [2]. Furthermore, in a Non-Line-Of-Sight (NLOS)*2 communication environment between the base station and terminal, high-frequency radio waves are more susceptible to electromagnetic shielding than low-frequency radio waves. This creates concern that receiving power at the terminal will dramatically drop and that the communication area will be narrower than that with low frequency bands. Consequently, for 5G and the 6th Generation mobile communications system (6G) for which the use of high-frequency bands of 28 GHz and higher are being studied, the need is felt for securing a Line-Of-Sight (LOS)*3 communication environment between the base station and terminal when pursuing high-speed, large-capacity wireless communications using high-frequency bands [3].

For example, the demand for IoT within factories is expected to grow from here on, and there are great expectations for using 5G to meet this demand from the viewpoints of low-latency and large-capacity transmission. On the other hand, since there are many cases of electromagnetic shielding caused by people and machines in a factory, an NLOS environment tends to form, and on top of this problem, such electromagnetic shielding may move and even factory layout modifications may occur due to changes in the production line. To deal with such fluctuations in the communication environment, a method is needed to quickly and economically provide LOS communication environments.

One method for ensuring a LOS communication environment is to distribute the arrangement of base-station antennas while controlling the directivity*4 of the radio waves radiated from a base-station antenna. This method, in addition to ensuring a LOS communication environment, can be expected to improve spectrum efficiency*5 and communication capacity over the entire system [3]. However, the method is difficult to apply if antenna installation sites and power-supply paths are difficult to set up, and an increase in installation costs accompanying an increase in the number of distributed antennas can also be a problem.

The method proposed in this article for ensuring a LOS communication environment leaks radio waves from part of a dielectric waveguide used as a transmission medium for high-frequency bands and uses these radiated radio waves to deploy a communication area surrounding that point. A waveguide that leaks radio waves is called a "leaky waveguide," which is similar to a Leaky Coaxial Cable (LCX)*6 used for deploying communication areas in underground shopping complexes, tunnels, etc. As such, a leaky waveguide is said to be a high-frequency version of LCX, which suffers from high loss in high-frequency bands. A leaky waveguide also provides new uses not possible with LCX. In the case of LCX, radio waves are leaked from gaps set beforehand in the outer conductor of the coaxial cable, which means that once a LCX is laid, it continues to leak radio waves from those places. On the other hand, the proposed leaky waveguide enables the places for leaking radio waves to be controlled as desired. In this article, we outline "bended antenna" and "pinching antenna" that embody the proposed leaky waveguides and describe verification experiments using a 60 GHz video transmission system.

2. Using a Waveguide as an Antenna

2.1 Waveguides

Media for transmitting signals in high-frequency

*1 Propagation loss: The amount of attenuation in the power of a signal emitted from a transmitting station until it arrives at a reception point.

*2 NLOS: Describes an environment where there are obstacles between the transmitter and receiver. In this case, communication can only take place over waves that have been reflected, refracted, etc.

*3 LOS: Describes an environment where there are no obstacles between the transmitter and receiver, allowing them to communicate via direct waves.

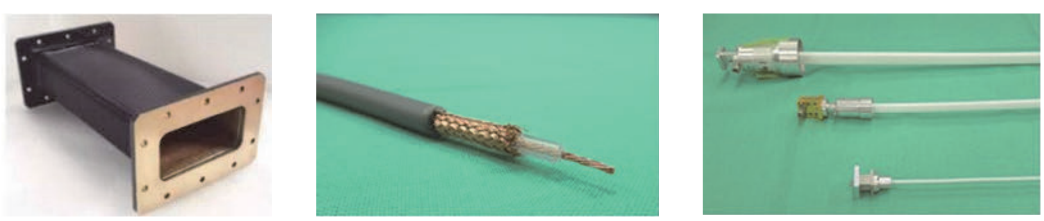
*4 Directivity: An index of direction and intensity of a radio wave radiated in space.

bands include (a) metallic waveguides, (b) coaxial cables, and (c) dielectric waveguides (**Photo 1**).

(a) A metallic waveguide has a cross-sectional shape in which a conductor surrounds a dielectric*7 or air. It is used in satellite earth stations and other applications. Here, the cross-sectional shape of a metallic waveguide determines the target frequency band, and high-frequency radio waves can be transmitted in this way. However, the cross section for transmitting low-frequency waves is large. For this reason and the fact that a metallic waveguide cannot be easily bent, constraints may arise in the handling of this type of waveguide.

(b) A coaxial cable has a cross-sectional shape in which the center conductor and outer conductor are arranged in a concentric manner. It is used widely from direct-current to high-frequency-band applications. It is common to fill the space between both conductors with a dielectric. There is little radio-wave leakage from the outer conductor, and a thin cable features a certain amount of flexibility, but loss in high-frequency bands is higher than that in metallic waveguides, so coaxial cables are mainly used in microwave-and-lower frequency bands. A coaxial cable with gaps set in the outer conductor is called an LCX, and having radio waves radiate from those gaps makes it possible to deploy communication areas in zones normally out of reach of radio waves such as underground shopping complexes and tunnels.

(c) A dielectric waveguide has a structure in which a bar-shaped dielectric is surrounded by a dielectric of different permittivity*8. Making the permittivity of the inner dielectric higher than that of the waveguide periphery makes it possible to confine and transmit high-frequency radio waves mainly through the inner dielectric. The dielectric waveguide targeted in this article uses PolyTetraFluoroEthylene (PTFE)*9 with a relative permittivity*10 of 2.1 for the inner conductor and air with a relative permittivity of nearly 1.00 for the outer conductor. Here, radio waves suffer loss when propagating through the dielectric, and while this loss generally increases as the frequency becomes higher, this increase is smaller than that of a coaxial cable, so dielectric waveguides are used as a transmission medium in high-frequency bands.



(a) Metallic waveguide (b) Coaxial cable (c) Dielectric waveguide

Photo 1 Examples of media for transmitting signals in high-frequency bands

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*5 Spectrum efficiency: The number of data bits that can be transmitted per unit time over a particular frequency spectrum.

*6 LCX: A coaxial cable having a mechanism for leaking radio waves from gaps set in its outer conductor.

*7 Dielectric: An insulator in which direct current cannot flow. Insulators include plastics and other materials.

*8 Permittivity: An index of the ease of polarizing a dielectric.

*9 PTFE: A fluororesin consisting of fluorine and carbon atoms.

*10 Relative permittivity: An index expressing the ratio of a material's permittivity when taking permittivity in a vacuum to be 1.

To establish a means of ensuring a LOS communication environment for high-frequency bands, NTT DOCOMO has been studying a configuration that minimizes the propagation distance and prevents the generation of NLOS communication environments as much as possible by using the low-loss transmission characteristics of dielectric waveguides in high-frequency bands and radiating radio waves in the vicinity of terminals. Up to now, two types of antennas have been proposed in relation to radiating waves from a dielectric waveguide, that is, to using a dielectric waveguide as an antenna: the bended antenna that bends the dielectric waveguide and radiates radio waves from the bent section, and the pinching antenna that pinches the dielectric waveguide with a separate dielectric and radiates radio waves from that location. The following describes these two types of antennas.

2.2 Bended Antenna

The phenomenon of radiating radio waves to the outside occurs at the bent section of a dielectric waveguide. This radiation is accompanied by a corresponding amount of power loss in the waveguide. However, the primary objective of a dielectric waveguide is to deliver radio waves to a distant location with as little loss as possible. Dielectric waveguides have therefore been used in a manner that avoids bending. On the other hand, a bended antenna proactively uses this radiation phenomenon at the bent section of a dielectric waveguide as shown in **Figure 1** [4]. Since the dielectric waveguide can be structured with easy-to-bend materials, it can be bent at a location where radiation is desired as shown in the figure. In other words, radio waves can be radiated at any location along the waveguide to deploy a communication area at that point. In addition, when removing such bending and straightening out the waveguide, this radiation phenomenon ceases to exist, which means that the radio-wave radiation can be terminated at any time and the corresponding communication area removed. On the other hand, since a certain length of waveguide is needed to

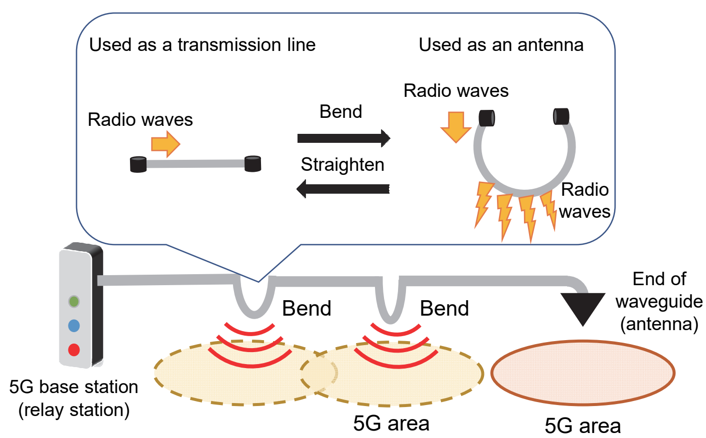


Figure 1　Deploying a communication area with a bended antenna

configure the bent sections for forming bended antennas, a spare amount of length is needed when laying out the waveguide. Attention must also be given to deterioration in waveguide characteristics due to repeated bending and extension.

2.3 Pinching Antenna

Adding a separate dielectric to the dielectric waveguide enables a portion of the radio waves propagating along the waveguide to be induced into that dielectric. As shown in **Figure 2**, a pinching antenna applies the phenomenon of radio-wave radiation from the separate dielectric to form the antenna. Similar to a bended antenna, a pinching antenna allows pinching locations to be selected as desired, which means that radio waves can be radiated at any location along the waveguide to form a communication area as shown in the figure. Here as well, this radiation phenomenon ceases to exist when releasing the pinch so that radio-wave radiation can be terminated at any time and the corresponding communication area removed. It is also possible for a pinching antenna to receive signals from the outside at its radiation (pinching) locations. A pinching antenna is also easy to install since it only involves the attaching of separate dielectrics at some points along the dielectric waveguide.

3. Verification Experiment of Dielectric Waveguide Antenna

We performed a verification experiment to test the radio-wave radiation phenomenon of a pinching antenna. The experiment used High-Definition Multimedia Interface (HDMI) transmitter/receiver units commercially available from Sharp Corporation (VR-WH1). Main radio specifications are listed in **Table 1.** This product consists of wireless transmitter/receiver units conforming to the Wireless HD standard using the 60 GHz band. The transmitter converts the input HDMI signal into

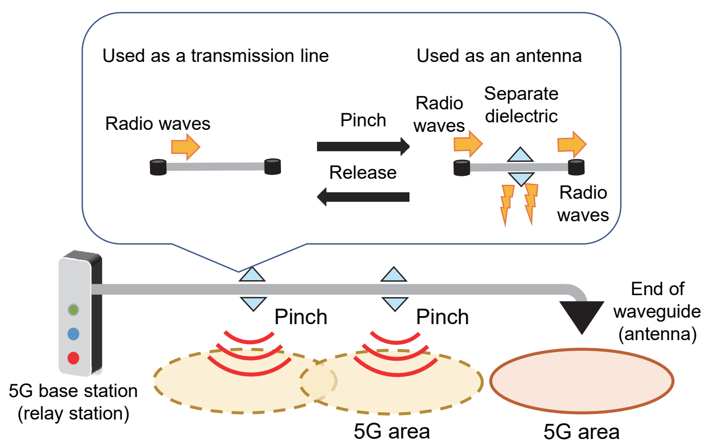


Figure 2 Deploying a communication area with a pinching antenna

radio waves and transmits them using a wide bandwidth (1.76 GHz) in the 60 GHz band, and the receiver generates HDMI signals from received radio waves. In the experiment, spatially radiated radio waves are input into the dielectric waveguide from the transmitter and then radiated from the pinching antenna and received at the receiver.

3.1 Video Transmission Experiment Using a Pinching Antenna

A block diagram of the experimental system is shown in **Figure 3**. In this system, a Personal Computer (PC) plays back the video and converts it into an HDMI signal. A splitter then divides the output HDMI signal inputting one signal into the transmitting monitor and the other signal into the transmitter. The transmitting monitor is used to verify the video played back on the PC. The transmitter, meanwhile, converts the HDMI signal into 60 GHz radio waves and inputs them into the dielectric waveguide. The receiver then inputs the radio waves radiated from the pinching antenna and converts them into an HDMI signal. Finally, the receiver outputs the HDMI signal into the receiving monitor so that the received video can be verified. In addition, the separate dielectric of the pinching antenna is attached to the tips of an ordinary off-the-shelf clothespin.

The states of the transmitting monitor and receiving monitor before and after pinching with the

Table 1 Main radio specifications of wireless HDMI transmitter/receiver units

Compliant standard	Wireless HD 1.1
Transmission system	HRP/LRP
Center frequency	60.48 GHz (Ch2) 62.64 GHz (Ch3)
Bandwidth	1.76 GHz

HRP: High Rate PHY
LRP: Low Rate PHY

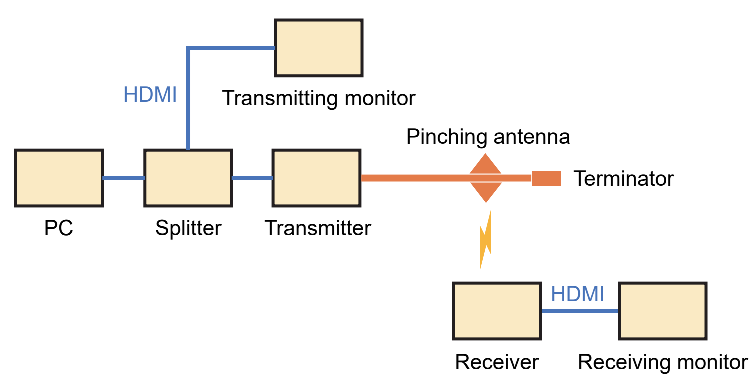
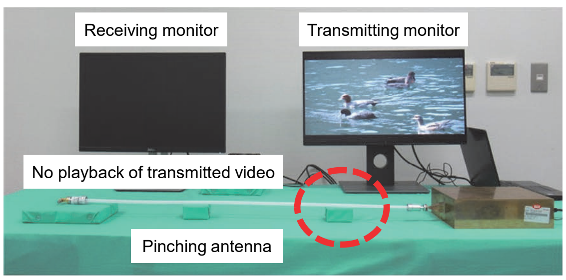


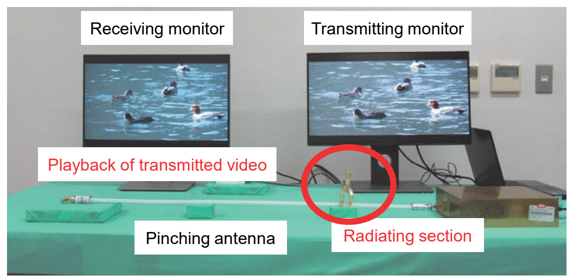
Figure 3 Block diagram of experimental system

clothespin are shown in **Photo 2** (a) and Photo 2 (b), respectively. From Photo 2 (b), it can be seen that pinching the dielectric waveguide with the clothespin attaches the separate dielectric to the waveguide causing radio waves to be radiated from the separate dielectric, and that receiving those radiated waves at the receiver results in playback of the same video as the transmitting monitor on the receiving monitor connected to the receiver. From Photo 2 (a), it can be seen that no pinching with the clothespin results in no radiation and no reception of radio waves so that nothing is displayed on the receiving monitor.

Photo 3 shows the transmitting monitor and receiving monitor when placing a radio-wave shielding plate between the radiating section and receiving section after pinching with the clothespin as shown in Photo 2 (b). The shielding plate loses a LOS environment between the radiating section and receiving section resulting in no reception of radio waves and no display on the receiving monitor as shown in Photo 3 (a). In such a situation, pinching the dielectric waveguide at any other location enables radio waves to be radiated (the dielectric waveguide may be pinched at multiple locations). As shown in Photo 3 (b), pinching the dielectric waveguide at the location where a LOS environment can be created between another radiating section and the receiving section enables radio waves to be received and the same video to be displayed on the receiving monitor and transmitting monitor. If the shielding plate happens to move, changing the pinching location makes it easy to create another new LOS environment.

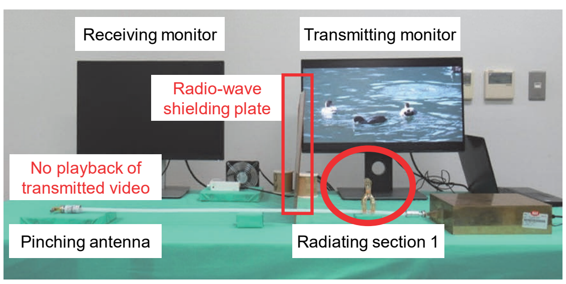


(a) Separate dielectric removed (before pinching)

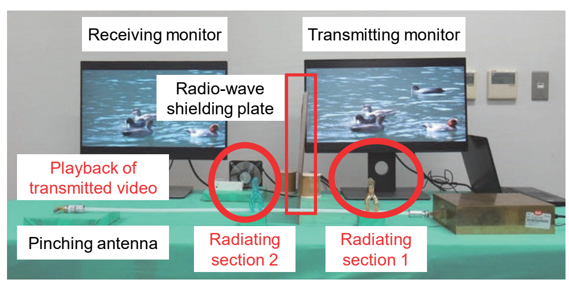


(b) Separate dielectric attached (after pinching)

Photo 2 Video transmission experiment through radio-wave radiation by pinching antenna



(a) Shielding plate installed (one radiating section)



(b) Shielding plate installed (two radiating sections)

Photo 3 Avoiding radio-wave shielding with a pinching antenna

4. Conclusion

This article explained how a dielectric waveguide could be used as a transmission medium for high-frequency bands, described its application to antennas, and presented the bended antenna and pinching antenna as means of flexibly deploying communication areas. Going forward, we plan to perform trials of deploying communication areas in real-world environments.

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