5G | Connected Car | Cellular V2X

Collaboration Projects

Vehicle Antenna Technology for Stable 5G Communications without Compromising Vehicle Design —5G Vehicle Glass Antennas—

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To achieve the 5G enabled connected cars of the future, NTT DOCOMO has developed 5G vehicle glass antennas that enable moving vehicles to receive the appropriate base station radio waves. These antennas are 28 GHz-band devices that can be mounted on the windows of automobiles to enable 5G communications without compromising the vehicle design. Installing these antennas in various positions on vehicle windows enables stable transmission and reception of 5G radio waves, and achieves stable high-speed communications. This research was conducted jointly with AGC Inc.

1. Introduction

Currently, the introduction of 5th-generation (5G) mobile communication systems - the communications networks characterized by high-speed, high-capacity, low-latency and multi-device connection set to become commonplace from 2020 onwards - is being studied energetically, because use of the 28 GHz frequency band with 5G will enable ultrawide bandwidth*1 and hence is expected to achieve these high-speed and high-capacity communications [1] [2]. Cellular V2X (Vehicle to everything)*2 to connect cars to various other things has also been discussed in 3GPP, etc., and major groups and corporations in various countries are forging ahead with demonstration experiments [3] [4].

The 28 GHz-band has stronger directionality, due to its wavelengths, which are shorter than those of the frequencies used with the older 4th-generation mobile communications systems (4G). This can cause unstable communications because the radio waves tend to be weakened by the vehicle body when communicating from inside a vehicle. To address this issue, NTT DOCOMO and AGC Inc. (hereinafter referred to as "AGC") have developed the world's first 5G vehicle glass antennas to enable radiowave transmission and reception in

*1 Ultrawide bandwidth: Bandwidth of 100 MHz or greater. In Japan, 400 MHz of bandwidth has been assigned in the 28 GHz band for 5G radio communications.

*2 V2X: V2X is a generic name for radio communications systems for communications between vehicles and other vehicles (V2V: Vehicle to Vehicle), vehicles and infrastructure such as traffic signals and road signs (V2I: Vehicle to Infrastructure) and between vehicles and pedestrians carrying smartphones (V2P: Vehicle to Pedestrian).

the 28 GHz-band and achieve stable 5G high-speed communications with automobiles [5] - [9].

NTT DOCOMO's development partner, AGC, has 40 years experience in design, development and manufacture of vehicle antennas, and possesses technologies to incorporate antennas for AM, FM and TV broadcast and LTE communications, etc. into the glass of vehicle windows. Combining these technologies with the high-frequency (28 GHz-band) 5G technology that NTT DOCOMO has built up through research with major vendors all around the world has enabled the development of these 5G vehicle glass antennas. Using these antenna elements installed on vehicle window glass for transmission and reception of 28 GHz-band radio waves before the radio waves are weakened by the vehicle body enables stable high-speed 5G communications. Also, installing these antennas on the glass surfaces of vehicle windows does not impair vision, and does not compromise vehicle design.

This article describes the 28 GHz-band 5G vehicle glass antennas and related experiments.

This research was conducted jointly with the Automotive Company and Materials Integration Laboratories of AGC.

2. Requirements and Technical Issues of the 5G Vehicle Antenna

Because the 28 GHz-band used with 5G has stronger directionality than the frequency bands used with LTE, etc., it's easier for radio waves to be cut off by the vehicle body and greater propagation loss*3 to occur with communications from the vehicle cabin. To address this issue, methods to compensate for 28 GHz-band propagation loss by the application of beamforming*4 technology using Massive Multiple Input Multiple Output (MIMO)*5 antennas in base stations and achieve high antenna gain*6 are being studied. However, the more the antenna gain is improved, the beam width becomes narrower. During driving, it is desirable to have high gain and omni-directional (non-antenna directivity*7) antennas to enable reception of high-power, multipath waves from structures in the vicinity of the vehicle so that the base station beam can be properly selected. Also, MIMO*8 transmission technology is used with 5G because it improves communication speeds by simultaneously transmitting different data from multiple antennas with horizontally and vertically polarized antennas. For this reason, 5G vehicle antennas must be able to properly receive multiple beams with both polarizations.

Conventional vehicle antennas included antennas for AM, FM and TV broadcast, etc. (**Photo 1**), and antennas for LTE communications printed on vehicle windows surfaces, and designed not to hinder the vision of the driver or compromise vehicle design.

Thus, with requirements including unhindered driver vision and uncompromised vehicle design, NTT DOCOMO began studying development of 5G vehicle glass antennas to support the 28 GHz-band and enable high-speed, high-capacity communications.

3. The 5G Vehicle Glass Antenna Development

3.1 Concept

Structures that use omni-directional antennas

*3 Propagation loss: The amount of power of radio wave decay from their emission from a transmitter to their arrival at a receiver.

*4 Beamforming: A technique for increasing or decreasing the gain of multiple antennas in a specific direction by controlling the phase of the antennas to form a directional pattern of the antennas.

*5 Massive MIMO: MIMO transmission formats use multi-element antennas at both the transmitter and receiver to spatially multiplex the radio signal. Massive MIMO is a technique that enables narrow radio wave beam forming to compensate for carrier losses when using high frequency bands or to transmit more streams at the same time, by utilizing super multi-element antennas with more antenna elements than MIMO. Massive MIMO achieves high speed data communications while securing the desired service area.

have lower antenna gain. Thus, to form omni-directional radiation patterns, achieve high antenna gain and support MIMO transmission without using omni-directional antennas, a distributed array of multiple directional antennas can be used to form beams in all directions around a vehicle. There are vehicle windows facing in every direction of the vehicle that are positioned at intervals longer than the wavelength, and are desirable as antenna mounting positions to lower signal correlation*9 and improve MIMO transmission efficiency.

The mounting positions are shown in **Figure 1**. As shown by the stars in Fig. 1, directional antennas are installed on four windows - the windshield, the rear quarter windows on both sides, and the rear window - to achieve near omni-directionality on the horizontal plane. In the 28 GHz-band, multipath radio waves from structures around the vehicle exist in urban areas, therefore, with this installation method, it's possible to select a directional antenna in the direction of the strongest radio waves among the radio waves arriving from all around, transmit and receive data, and achieve stable high-speed communications in urban areas where radio waves may be easily interrupted.

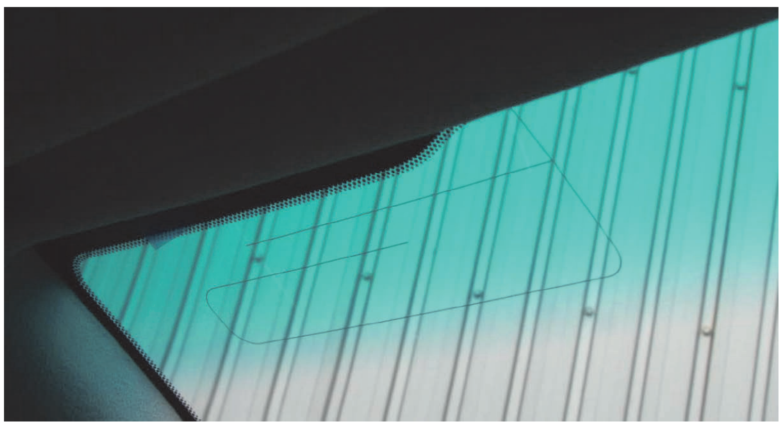


Photo 1　A conventional TV broadcast glass antenna

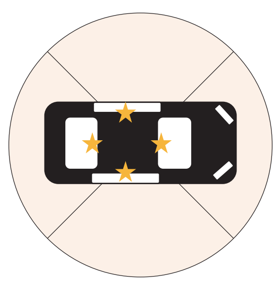


Figure 1　Antenna mounting positions and antenna patterns

*6　Antenna gain: The power radiated in the direction of maximum radiation, usually expressed as the ratio of radiated power to that of an isotropic antenna.

*7　Antenna directivity: The directional characteristics of the strength of radio emission or sensitivity to radio reception of the antenna.

*8　MIMO: A radio communication format in which transmitted data is divided into multiple signals (streams) and then transmitted and received on the same frequency band using multiple antennas at both the transmitter and the receiver.

*9　Correlation: An index expressing similarity between different signals. Expressed as a complex number, its absolute value range from 0 to 1. Similarity increases as the value approaches 1, which makes signal separation at the receiver difficult, and results in degraded throughput in MIMO communications.

3.2 Achieving the Concept through Joint Research with AGC

NTT DOCOMO began joint research to achieve this concept with AGC in June 2018. **Photo 2** shows the 5G vehicle glass antennas we developed.

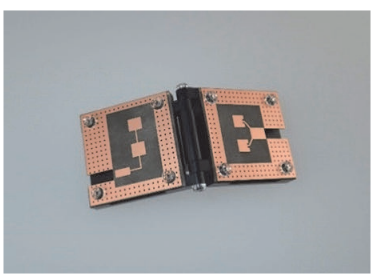
1) On-glass Antenna

Photo 2 (a) shows the glass-mounted antenna (hereinafter referred to as "on-glass antenna") we developed in June 2018. The on-glass antenna is a compact radio unit*10 combining antennas for both horizontally and vertically polarized waves to support MIMO transmission. Two antenna elements are used respectively to perform electrically tilting*11 of the vertically oriented beam so that it comes horizontal. To improve radio emission efficiency in the 28 GHz-band, we designed the on-glass antenna using fluoropolymer resin because of its low dielectric constant*12 and low dielectric loss tangent*13. Also, the antenna has a three-dimensional structure which makes it easy to orient to optimize antenna directionality. Although this antenna can only be mounted on the places where it will not interfere with the driver's field of vision, it is easy to orient for directionality to enable efficient radio wave reception and high communication speeds.

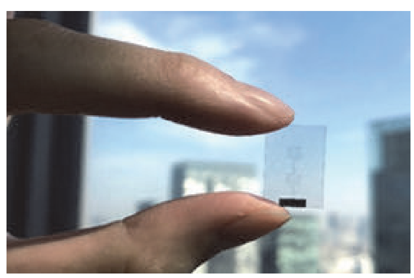
2) Glass-integrated 5G Antenna

Photo 2 (b) shows the glass-integrated 5G antenna we developed in May 2019. This antenna is a compact, thin and clear glass antenna, and similar to the on-glass antenna, it has two antenna elements for horizontal and vertical polarization to perform electrically tilting of the vertically oriented beam so it becomes horizontal. This antenna has been designed with a synthetic fused silica glass substrate that has low dielectric constant and dielectric loss tangent properties similar to the on-glass antenna. This antenna is integrated with glass and less visible than the on-glass antenna, and will not hinder vision when multiple antenna elements are installed on vehicle windows. However, the flat structure of this antenna limits the directionality of the antenna pattern, which causes inferior communications speeds compared to the on-glass antenna.

Photo 3 shows examples of on-glass antenna installation. Installing four on-glass antennas on the car windows in the four places - the windshield, the right and left rear quarter windows, and the rear window - enables omni-directionality for data transmission and reception. We also installed glass-



(a) On-glass antenna



(b) Glass-integrated 5G antenna

Photo 2 The 5G vehicle glass antenna we developed

*10 Radio unit: Part of the equipment comprising a base station, which performs transmission and reception by converting digital signals to a radio signals, amplifying them and sending or receiving them to or from the antenna elements. It also performs the processing required to generate beam forming for Massive MIMO.

*11 Tilting: Inclination of an antenna's main beam direction in the vertical plane. There are mechanical tilt systems that physically tilt the antenna and electrical tilt systems that control the amplitude and phase of antenna array elements to tilt the main beam.

*12 Dielectric constant: A material-specific quantity related to the distribution of an electric field when a current is passed through a circuit. While it's possible to make antennas small if their dielectric constant is high, their operational frequency bandwidth tends to become narrow.

integrated 5G antennas in four places in the same way as the on-glass antennas.

4. Demonstration Experiment

4.1 Overview of Experiment

We performed the experiments in urban small cell[*14] environments around Sumida Ward in Tokyo. **Photo 4** shows our experimentation vehicle with on-glass and glass-integrated 5G antennas installed on the windows, which were connected to 5G equipment installed inside the vehicle. 5G base station radio equipment was installed on the roof of another experimentation vehicle, and throughput[*15] was obtained while driving in the urban area at a speed around 30 km/h while using the 28 GHz-band between the 5G base station and the 5G equipment connected to the 5G vehicle glass antennas. For bandwidth, the maximum transmission bandwidths for the experimental equipment of 800 MHz and 400 MHz were used.

Table 1 shows the main specifications of the 28 GHz-band 5G base station and terminal equipment used in this experiment. The 5G base station uses a 128-element horizontally and vertically polarized antenna panel for beamforming, transmits a maximum of four streams, and has beam tracking functions for following the movement of the experimentation

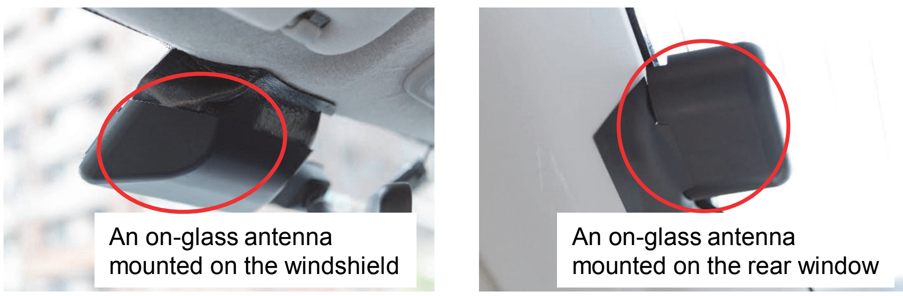


Photo 3　Example on-glass antenna installations

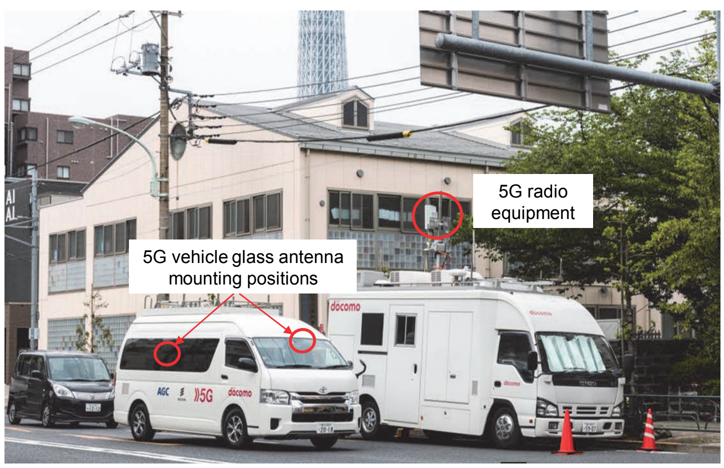


Photo 4　A scene during demonstration testing

*13 Dielectric loss tangent: A material-specific value used as an indicator of the amount of leakage that does not reach the antenna when a current flows through a circuit. If the value is high, less of electric energy intended for communications is transmitted to the antenna, which deteriorates its radiation efficiency.

*14 Small cell: A cell smaller than a macro cell, and covering a relatively small area. Also called a microcell.

*15 Throughput: The amount of data transferred through a system without error per unit time.

vehicle. The 5G terminal equipment was installed in the backseat of the experimentation vehicle and connected to the on-glass and glass-integrated 5G antennas. With the experimental equipment, because the 5G base station must precisely and quickly select the optimal antenna beam to perform beam tracking, a suitable base station antenna beam was selected in response to the driving position of the experimentation vehicle using a mobility reference signal (MRS) to reference the reception power of each beam. The terminal feeds back several candidates with favorable reception power from among the base station antenna beams, and then based on this feedback, the base station determines which base station antenna beam to use for transmission. This enables beam tracking by optimal selection of base station antenna beams for the driving position of the experimentation vehicle.

4.2 Experimental results

Table 2 shows the throughput obtained for the on-glass and glass-integrated 5G antennas in the urban area.

800 MHz of bandwidth was used for the on-glass antenna experiment. When using the on-glass antennas, the throughput was a maximum of 7.9 Gbps

Table 1 Main specifications

5G base station equipment	Frequency	27.9 GHz
	System bandwidths	732 MHz, 366 MHz
	Duplex method	TDD (UL:DL = 2:48)
	Radio access method	OFDMA
	Antenna structure	Vertical and horizontal polarization, 2 per polarization x 128 elements
	Max. no. of MIMO streams	4
	Modulation method	QPSK, 16QAM, 64QAM
5G terminal equipment	Antenna structure	Vertical and horizontal polarization, 8 elements per polarization x 2 elements in a sub array

OFDMA: Orthogonal Frequency Division Multiple Access
QAM: Quadrature Amplitude Modulation
QPSK: Quadrature Phase Shift Keying
TDD: Time Division Duplex

Table 2 Experimental results

Antenna type	Bandwidth	Throughput obtained from experimental equipment
On-glass antenna	800 MHz	Max 7.9 Gbps Average* 3.0 Gbps
Glass-integrated 5G antenna	800 MHz	Max 7.5 Gbps Average* 2.5 Gbps
	400 MHz	Max 3.8 Gbps Average* 1.3 Gbps

*Calculated with an area 100 m in radius from the base station downlink, with an average of 3 Gbps within a 100 m radius of the base station, and a maximum communications distance of 232 m.

For the glass-integrated 5G antenna experiment, both the 400 MHz and 800 MHz bandwidths were used. With the 400 MHz bandwidth the maximum downlink was 3.8 Gbps, with an average of 1.3 Gbps within a 100 m radius of the base station. With the 800 MHz bandwidth, the maximum downlink was 7.5 Gbps, with an average of 2.5 Gbps within a 100 m radius of the base station, and the maximum communications distance was 178 m.

These experimental results showed that the use of the 5G vehicle glass antennas enabled stable, high-speed 5G communications. Also, on comparison of the antennas, the on-glass antenna enabled higher throughput and longer distance communications. The 3-D structure of the on-glass antenna enables easy optimization of antenna patterns and hence improvements in communication performance, whereas the flat structure of the glass-integrated 5G antenna makes optimizing antenna patterns more difficult with the same number of antenna elements, which accounts for the differences in throughput.

5. Conclusion

This article described 5G vehicle glass antennas and related experiments. NTT DOCOMO and AGC will continue these studies to further improve communication speeds with Massive MIMO with these antennas. We also plan to advance initiatives to enlarge 5G areas and expand applications using these antennas in environments where base station installation is problematic or 5G demand is temporary.

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