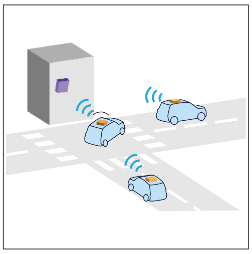


Dynamic Evaluation of Beamforming and Communication Performance of Automotive 5G Millimeter-wave Array Antennas

Yutaro MIKI*, Suguru YAMAGISHI, Ichiro KUWAYAMA, and Hiroshi MURATA

For the realization of autonomous driving, 5G is expected to be used due to its superior features such as high speed, large capacity, and low latency capabilities. To enable large-scale data communication, such as sensing information transmission, it is desirable to use the millimeter-wave band, which has a bandwidth of several hundred megahertz in 5G. 5G millimeter-wave antennas use beamforming technology to transmit radio waves over long distances. We set up a scenario where a vehicle equipped with a 5G millimeter-wave antenna communications with a base station and performs beamforming control while driving, and dynamically evaluated it using 5G signals. This paper reports the evaluation method and results based on the proposed scenario.

Keywords: 5G, automotive antennas, millimeter-wave, beamforming

1. Introduction

In the mobility industry, various technologies are being developed in cooperation with the public and private sectors toward the social implementation of automated driving. In automated driving, a vehicle acquires not only data sensed within its own vehicle, but also various data from other vehicles, roadside equipment, servers, etc., and controls them appropriately by integrating and processing them.(1) For data communication between the vehicle and the other party, communication via cell phone networks and direct communication between devices are being considered.

The 5th generation mobile communication (5G), which is currently gaining popularity, has three characteristics: ultra-high speed/multiple simultaneous connections, low latency, and high reliability.(2) It is expected to be particularly useful in various data communications required for automated driving, including the transmission of large volumes of data such as high-definition 3D maps. The frequency bands used in 5G can be broadly classified into two categories: frequency bands below 6 GHz and millimeter-wave (including quasi-millimeter-wave). The 28 GHz band used for 5G millimeter-wave in Japan has a wide frequency bandwidth of 400 MHz allocated to each telecommunications carrier, and is a frequency band that can take full advantage of the three features of 5G described above.

Our group has been developing automotive antenna technology suitable for 5G millimeter-wave communications.(3)-(5) In this process, in order to evaluate the relationship between the performance of the antenna alone and 5G communication performance as a system, we developed a scenario in which a 5G millimeter-wave antenna mounted on a vehicle communicates with a base station (BS), and conducted dynamic system evaluation experiments along that scenario. As a result, we confirmed that 5G communication can be successfully performed with appropriate beamforming.

2. Onboard 5G Millimeter-wave Antenna

While the millimeter-wave band has the advantage of high-speed data communication due to its wide frequency bandwidth, as mentioned above, it has the disadvantage that radio waves do not reach as far due to greater distance attenuation than the 0.7 GHz to 3.5 GHz frequency band used in the fourth-generation mobile communications (4G long-term evolution). To compensate for this disadvantage, beamforming technology is applied to antennas in the 5G millimeter-wave band. This technology controls and concentrates the radio waves radiated by the antenna in an arbitrary direction by changing the amplitude and phase of the radio waves fed to each element of the array antenna, which is composed of multiple antenna elements, thereby enabling radio waves to travel farther.

The front and top views of the array antenna used in this study are shown in Fig. 1. Four patch antenna elements made of modified PPE resin printed circuit boards (PCBs) are arranged at half-wavelength intervals and configured to control the direction of the horizontal radiation peak by beamforming.

To explain the effect of beamforming, Fig. 2 shows the simulated horizontal directivity of the array antenna at 28 GHz. Figure 2 (a) illustrates the radiation intensity (Amplitude) in the direction directly in front of the antenna

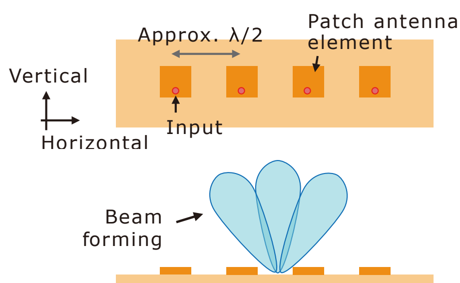
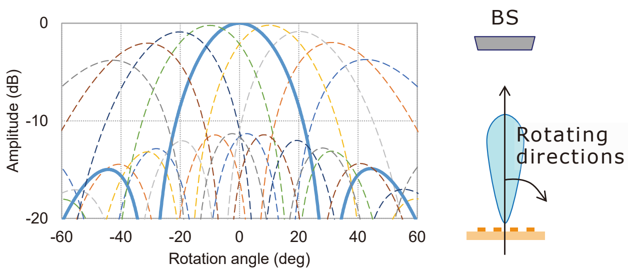
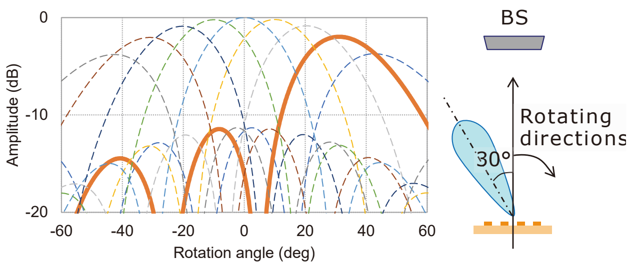


Fig. 1. Four-element array antenna for 5G millimeter-wave

(0°), while Fig. 2 (b) shows the radiation intensity when the peak radiation direction is set at +30° from the front of the antenna. As shown, the solid line represents the radiation intensity in the direction of the base station when the array antenna is rotated clockwise. In Fig. 2 (b), when the antenna is rotated 30° in the direction of the arrow, the peak radiation direction aligns with the base station, resulting in maximum intensity. The dashed lines in Figs. 2 (a) and (b) indicate the directivity when the peak radiation direction is switched at 10° intervals according to the direction of the base station, which is the communication receiver. In Fig. 2 (a), when the antenna is rotated +30° from the 0° peak radiation direction, the base station moves significantly away from the radiation peak, causing the radio wave intensity to drop below -20 dB (1/100), making communication impossible. However, in Fig. 2 (b), when the antenna is rotated +30°, high radiation intensity is obtained, allowing for communication. This control of the peak direction using beamforming enables reliable communication even with base stations located away from the front of the antenna.

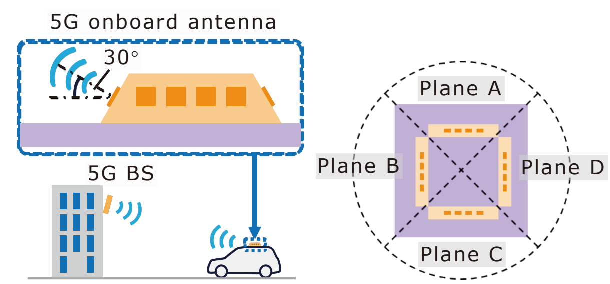


(a) Radiation peak angle: 0°



(b) Radiation peak angle: +30°

Fig. 2. Beamforming characteristics for horizontal plane directivity at 28 GHz



(a) Mounting position on the vehicle (b) Top view of antenna

Fig. 3. Image of array antennas mounted and arranged on vehicle

Figure 3 shows an image of this antenna mounted in an automobile.[3] Millimeter-wave band radio waves are highly susceptible to attenuation by obstructions, and it is desirable for the antenna to be installed in an unobstructed environment (Fig. 3 (a)). The antennas on the roof are placed diagonally upward because BSs are usually located at high locations, such as on top of buildings. In this study, the launch angle from the horizontal directions.

In the horizontal direction, four-element array antennas with a radio wave radiation range of ±45° are arranged in four directions from A to D at 90° intervals by beamforming, enabling coverage in all 360° horizontal directions (Fig. 3 (b)).

3. Evaluation of Beamforming Performance

3-1 Evaluation scenario

In the case where the antennas are placed on the vehicle as described above, the conditions for 5G communication with the BS while performing beamforming are the scenario where the vehicle approaches the intersection where the base station is located, turns right, and leaves the intersection (Fig. 4).[6]

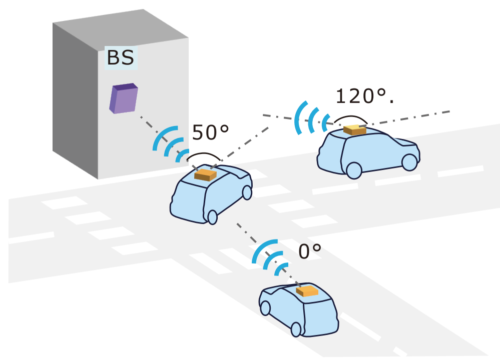


Fig. 4. Experimental scenario

In this scenario, the direction of the BS changes from moment to moment depending on the position of the vehicle, as shown in the figure, and the radiation peak direction changes correspondingly. In this study, using the same modulation signal as in actual 5G communications, we constructed an experimental evaluation system that can perform measurements while changing the radiation peak direction under conditions where the direction of the BS dynamically changes in relation to the antenna.

3-2 Evaluation system

The experimental evaluation system used in this study is shown in Fig. 5. The array antenna to be evaluated is connected to a 5G tester. Between the 5G tester and the array antenna, a beamformer that controls the amplitude and phase feeding of each element is connected to control the radiation peak direction.

In addition, the following points characterize this evaluation system.

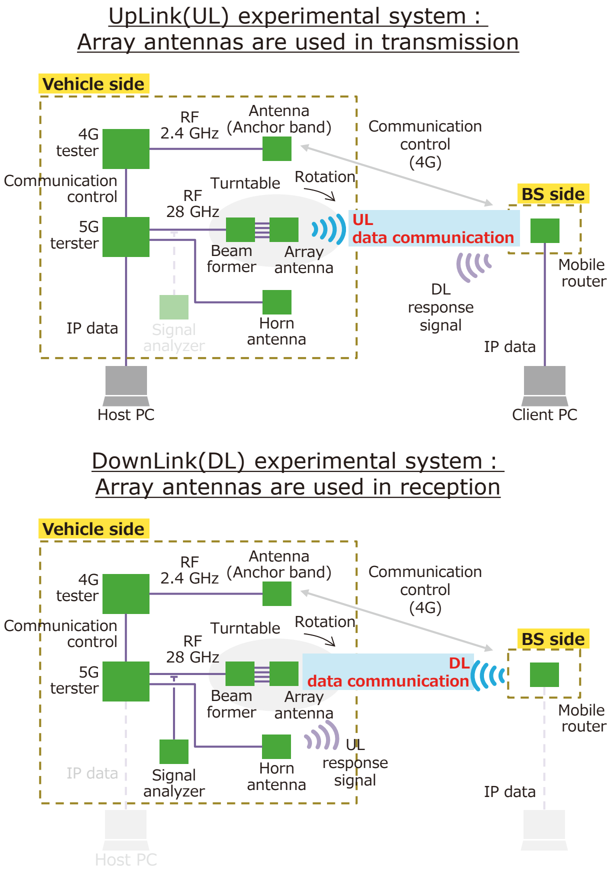


Fig. 5. Experimental evaluation system

• A 4G tester and antenna for 4G will be placed for the anchor band*[1] connection in order to communicate using the anchor band non-standalone method (NSA).*[2]
• As a communication load, a PC is connected to each of the 5G tester and mobile router, and IP data communication is performed between the PCs,
• For Uplink lines (UL, communication direction is from the vehicle (array antenna) to the BS (mobile router)), the throughput*[3] is measured.
• In the Downlink line (DL, communication direction is from the BS to the vehicle), error vector magnitude (EVM)*[4] and received power (Channel Power) in the frequency band used shall be measured.
• The transmission and reception lines on the vehicle side are separated. The line that is not evaluated (the receiving side in the UL experiment, the transmitting side in the DL experiment) transmits the response signal, but a horn antenna is used as an antenna capable of stable transmission and reception.

The experimental evaluation system shown in Fig. 5 was constructed in an anechoic chamber as shown in Fig. 6. The array antenna, which is an onboard 5G antenna, is placed on a turntable, and in the direction angle φ of the array antenna to the mobile router, which corresponds to the role of BS in Fig. 4, is changed by rotating the turntable. Since the array antenna has a launch angle of 30° from the horizontal direction as shown in Fig. 3 (a), the rotation axis of the turntable is tilted by 30° so that radio waves are radiated in the direction of the BS.

4. Beamforming Characteristics

4-1 Static evaluation

First, as a static characteristics evaluation, only one of the four array antenna planes in Fig. 3 (Plane A) was taken out for evaluation, as shown in Fig. 7. The beamforming radiation peak direction was 0°/±20°/±40° under five conditions. In each radiation peak direction, the direction angle φ of the array antenna to the BS was varied, and received power, EVM, and throughput were measured to confirm that communication was possible in each radiation peak direction.

The measurement results are shown below. An explanation of each result is given on the next page.

Figure 8 compares the simulation results of 5G signal Received Power (unit: dB; the maximum value is normalized to 0 dB) and Directivity at each radiation peak direc-

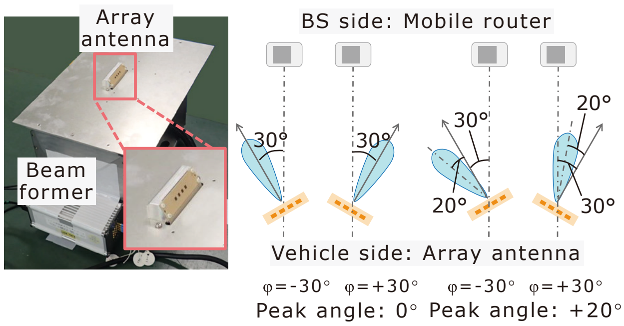


Fig. 7. Array antennas used for static evaluation

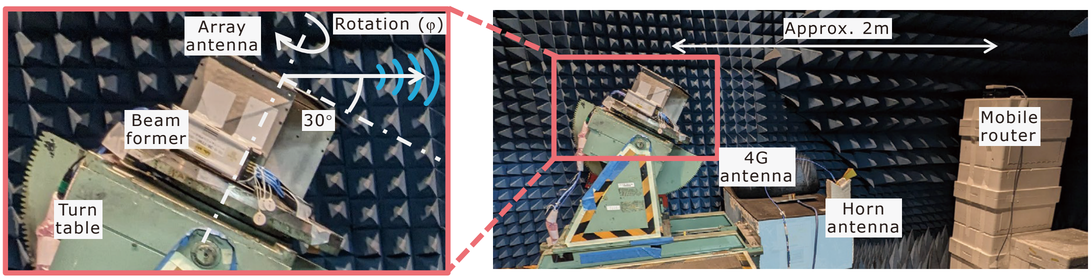


Fig. 6. Experimental view

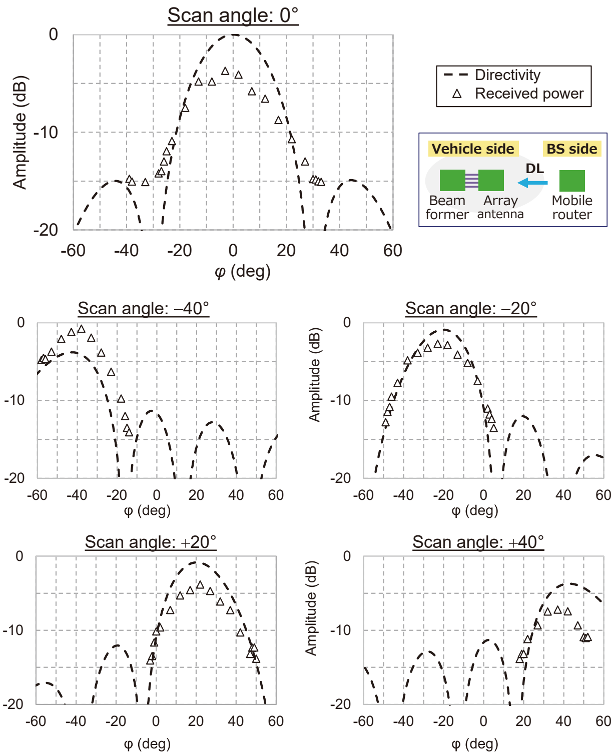


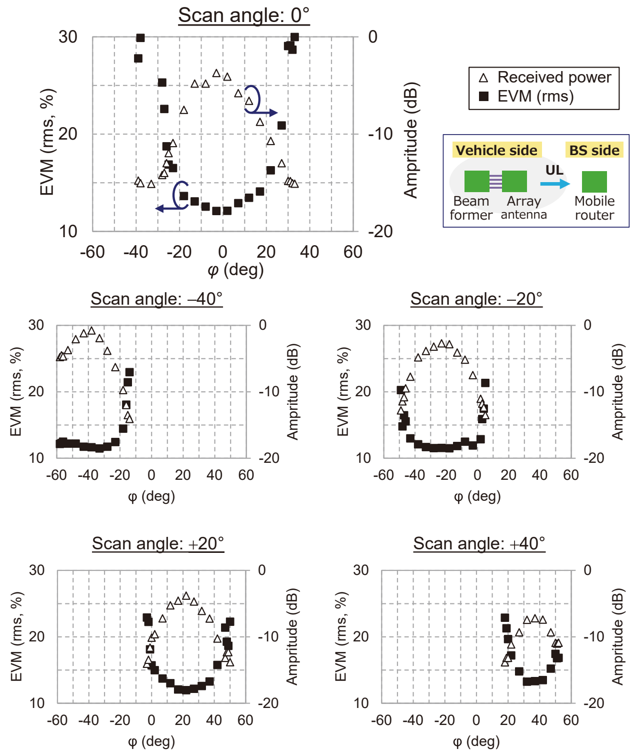
Fig. 8. Comparison of received power intensity and simulation results

tion (Scan Angle). The directivity is plotted by extracting the value for each radiation peak direction from Fig. 2. Although asymmetry is observed, the angles at which the maximum values are taken are the same, and the simulation results of received power and directivity are close to each other.

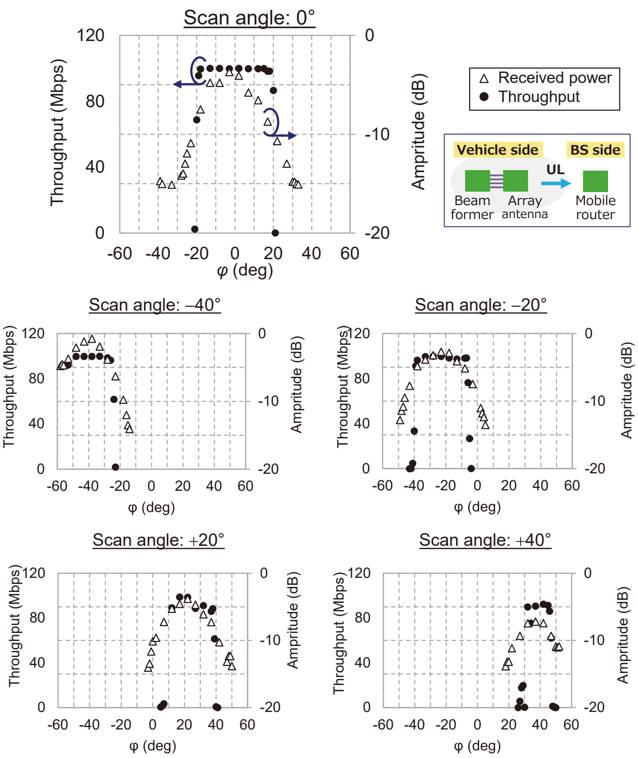
Figure 9 (a) compares the effective value of EVM (rms, unit: %) and received power intensity, showing that the higher the received power intensity, the lower the EVM, i.e., the better the signal quality. (b) compares the throughput (unit: Mbps) with the received power intensity, and shows that the higher the angle of received power intensity, the higher the throughput, although the throughput is at the theoretical value determined by the modulation conditions and other factors. In each measurement result, there was a negative correlation between received power intensity and EVM, and a positive correlation between received power intensity and throughput, as expected.

4-2 Dynamic evaluation

Next, as a dynamic characteristic evaluation to reproduce the scenario shown in Fig. 4, the array antennas were arranged with four planes at 90° intervals as shown in Fig. 10, and a system evaluation including switching of the array antenna planes was conducted. Since the arrangement is rotationally symmetrical, the switching section between planes A and B was excerpted from the four planes, and the range of the direction angle φ of the BS to be measured was set to 0° to 140°. The direction of the peak radiation was controlled to switch by 10° for each 10° rotation of the BS direction angle φ from 5° to 15°, and so on. This confirmed the EVM and throughput during switching of the radiation peak direction and switching of the antenna plane.



(a) EVM vs. received power intensity



(b) Throughput vs. received power intensity

Fig. 9. EVM. throughput vs. received power intensity

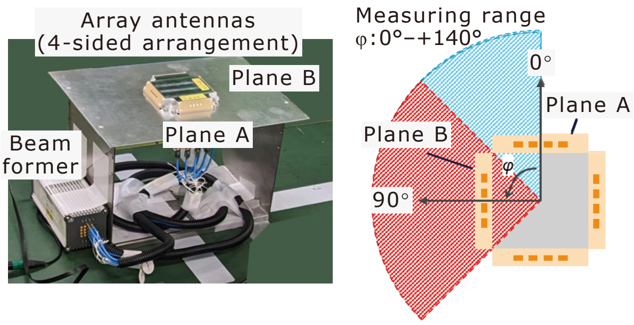


Fig. 10. Array antenna used in dynamic evaluation

Figure 11 shows a view of the throughput measurement on the UL side system. It shows that the directional angle φ is +56.4° and the radiation peak direction is +60°. During the measurement, we monitored the communication status when switching the radiation peak direction, and confirmed that throughput dropped slightly around φ=45° and when switching the antenna between the A and B planes, but data communication was not interrupted and good communication continued.

Figure 12 shows a plot of EVM and throughput values obtained in the above experiment at 5° intervals; although some degradation of EVM was observed around 45°, the theoretical throughput values were obtained over almost the entire measured range, confirming that good communication was achieved under this scenario.

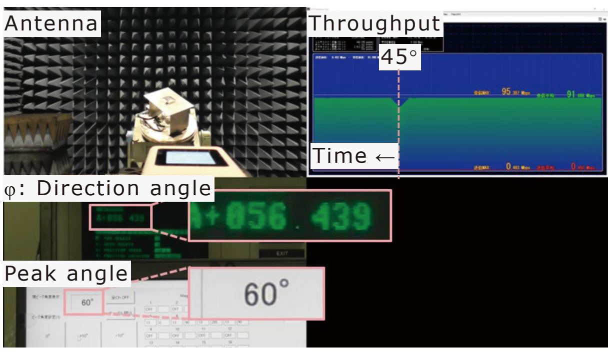


Fig. 11. Measurement view of dynamic evaluation (throughput)

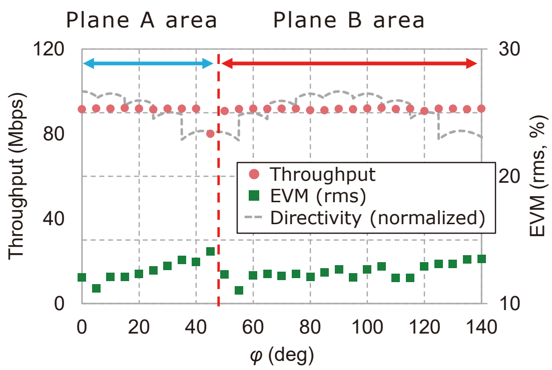


Fig. 12. Measurement results of dynamic evaluation

5. Conclusion

In this paper, an antenna evaluation system was constructed for a scenario in which 5G millimeter-wave array antennas are mounted in an automobile and communicates with a BS, and an evaluation was conducted to measure various characteristics. As a result, it was confirmed that 5G communication is possible without interruption when beamforming is properly performed. By evaluating the entire communication system, we were able to correlate the directivity and beamforming characteristics of the antennas with various communication performance indicators such as signal power, throughput, and EVM. We believe that this will lead to the proposal of a new antenna performance evaluation index.

In the future, we would like to confirm the contribution to the improvement of communication performance through the improvement of antenna properties. Specifically, we would like to verify the improvement effect of antenna directivity using metamaterials*5 technology, which the authors have studied,(3)-(5) and the low-loss effect when the fluororesin flexible PCB FLUOROCUIT(7) developed by Sumitomo Electric group is used as an antenna substrate.

Technical Terms

*1 Anchor band: In the NSA*2 system, wireless connections at 4G used for communication control.

*2 NSA: Abbreviation for Non-Standalone Method. This is a technology that enables both 4G established communication coverage and 5G high-speed communication by using existing 4G networks for communication control and connections for data transmission and reception. In contrast, a method that uses only the 5G network is called the standalone (SA) method.

*3 Throughput: An indicator of the communication speed of a network or communication line, representing the amount of data sent and received per unit of time.

*4 Error vector magnitude (EVM): A metric used to assess the quality of signal modulation. A lower EVM indicates more accurate signal transmission.

*5 Metamaterials: An artificial functional material designed to produce functions that cannot exist in nature (such as having a negative dielectric constant) by periodically arranging structures smaller than the wavelength.

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(7) Fluororesin FPC FLOROCUIT https://global-sei.com/fluorocuit/

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