Development of MMW Waveguide Slot Arrays for Gigabit Wireless Access in 5G Cellular Network

Miao Zhang[1, 2], Jiro Hirokawa[2], and Makoto Ando[2]
[1] Department of Electronic Science, Xiamen University
No. 422, Siming South Road, Xiamen, Fujian, 361005 China.
[2] Department of Electrical and Electronics, Tokyo Institute of Technology
2-12-1-S3-19, O-okayama, Meguro-ku, Tokyo, 152-8552 Japan

***Abstract* – Gigabit wireless access in the millimeter-wave band is very essential to the successful realization of 5th generation (5G) cellular network. Two kinds of systems have been developed: a mesh network composed of the 40 GHz-band Fixed Wireless Access system can be applied to realize the outdoor backhauls and fronthauls; on the other hand, a 60 GHz-band short-range wireless access system can be applied to realize the small-cells in the 5G scenarios. The waveguide slot arrays for both systems were designed and fabricated. The performance of antennas and systems will be presented in this paper.**

***Index Terms* —millimeter-wave, waveguide slot array, 5G cellular network, wireless access system, high isolation, signal-to-noise ratio, bit-error-rate.**

1. Introduction

Due to the popularization of smartphones and tablets in recent years, the traffic load in present cellular network is exploding and facing its limitation. As the prediction [1], the network capacity needs to be increased by 1000 times, and the data rate of transmission needs to be increased by 100 times by 2020. The utilization of the millimeter wave (MMW) frequency band is indispensable to the realization of Gigabit wireless access in the 5th generation (5G) cellular network. Fig. 1 shows the schematic outline of a MMW gigabit network to realize a cloud service compatible with mobile users. The key to success is to make full use of wireless technologies in MMW-band. One is a mesh network composed of the 40 GHz-band Fixed Wireless Access (FWA) system for outdoor backhauls as well as fronthauls. A high data rate of 2 Gbps is achieved by in introducing a full-duplex technique named as Directional Division Duplex (DDD) [2], to double the efficiency of frequency reuse. Another is a 60 GHz-band short-range wireless access system with the world's fastest user data rate of 6.1 Gbps [3]. Finally, as illustrated in Fig. 1 the mobile terminals are connected with the 60 GHz-band gigabit access transponder equipments (GATEs) which function as the access points to the 40 GHz-band mesh network.

2. Antennas for the 40 GHz-band DDD system

Rather than the conventional Time Division Duplex (TDD) or Frequency Division Duplex (FDD), a full duplex technique DDD is introduced to the 40 GHz-band FWA system. As shown in Fig. 2, the wireless terminal for DDD adopts two separate antennas for independent transmission and reception. Both of them operate in the same frequency band and with the same polarization to realize bidirectional communication simultaneously. The realization of high performance planar antennas with high isolation of more than 80 dB as well as low sidelobe levels less than -30 dB, is highly required.

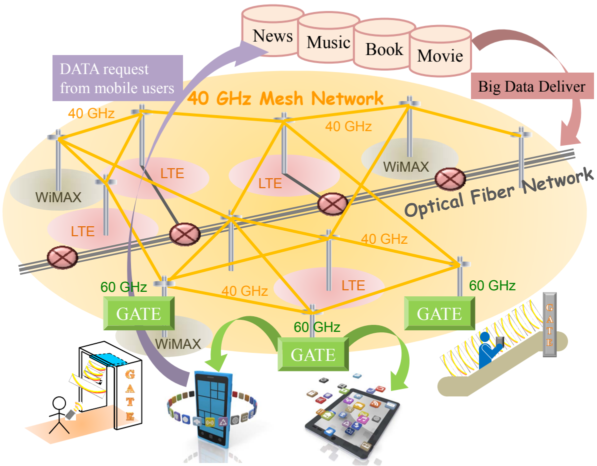

Fig. 1. Measured isolation between two antennas.

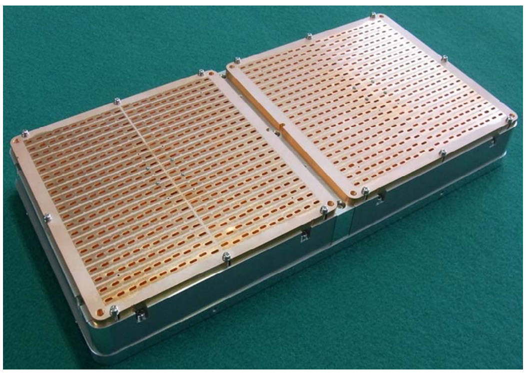

Fig. 2. Wireless terminal for the 40 GHz-band DDD system.

A 22×20-element double-layer waveguide slot array is designed over the frequency range of 39.5 ~ 41.0 GHz [4]. It is fabricated by diffusion bonding of thin copper plates. The antenna gain measured in an anechoic chamber is higher than 30.6 dBi over the desired frequency range. The radiation patterns are also measured in the anechoic chamber. The sidelobes in both *E* and *H*-planes are sufficiently suppressed below -30 dB. The isolation between two antennas arranged in *H*-plane as shown in Fig. 2 is evaluated by connecting them to a Signal Generator and Spectrum Analyzer for sufficiently low noise floor. The high isolation more than 76 dB is achieved as shown in Fig. 3. In addition, a digital canceller is also developed in the baseband circuit to further enhance the isolation to 110 dB.

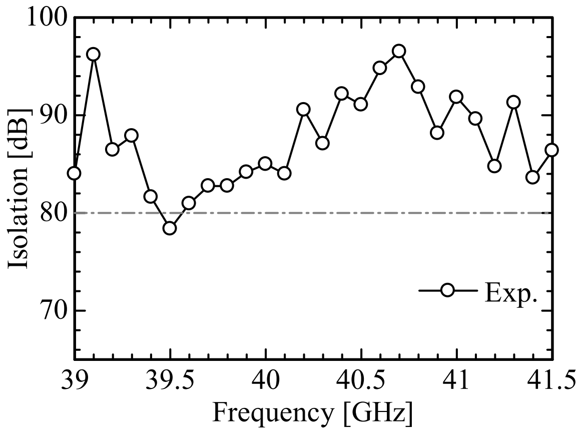

Fig. 3. Measured isolation between two antennas.

3. Antennas for the 60 GHz-band Compact-Range Wireless Access System

A novel indoor short range communication concept is proposed. By introducing the large array antennas in the access point, the GATE realizes communication in the Fresnel zone and also the near-field region of the antennas. As shown in Fig. 4, the 2×2, 4×4, 8×8, 16×16 and 32×32-element circularly-polarized (CP) double-layer waveguide slot antennas have been successfully developed. Especially the 32×32-element array with an aperture size of $(27\ \lambda)^2$ can provide a stable and large signal-reception zone, with an area proportional to the antenna aperture and a communication distance up to 14 m.

A prototype of GATE is realized by installing a BB module and a RF front end on the backside of Tx and Rx antennas. This prototype only covers the global channel 2 ranging from 59.40 to 61.56 GHz. By adopting a low-density parity-check (LDPC) code with a 14/15 rate, the maximum data rate of 3.1 Gb/s can be achieved by the modulation of QPSK [5]. It will be doubled by using 16 QAM. To realize an error-free communication for BER $\leq 10^{-12}$, the condition of SNR > 11dB is required.

The system performance such as the bit-error rate (BER) and signal-to noise ratio (SNR), are evaluated three dimensionally. The relative positions of Tx and Rx are changed to characterize the communication zone as well as the coverage. As shown in Fig. 5, the SNR are measured in the *yz*-plane including the propagation *z*-axis. Here, the 32×32-element array is used as the Tx antenna, while an open-ended waveguide probe is used as the Rx antenna. To testify that the communication zone is clearly defined by the array antenna, the electric field intensity is also calculated in the near-field region. Due to our investigation, the *E*-field intensity higher than -1.3 dBV/A is required for the error-free communication. As shown in Fig. 6, its similarity with the distribution of SNR is certified.

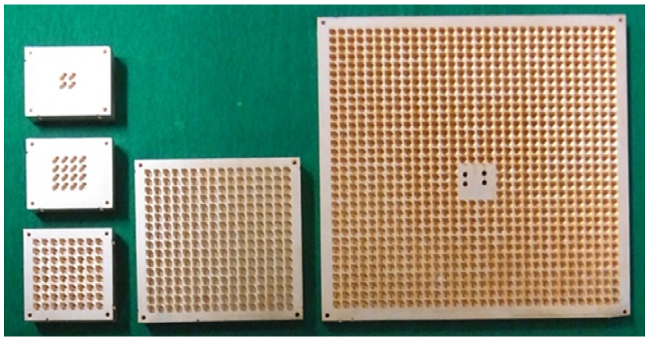
Fig. 4. CP array antennas for 60 GHz-band GATE.

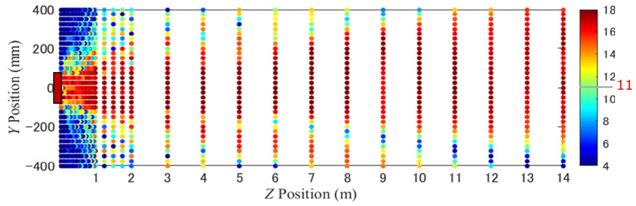

Fig. 5. Measured SNR (dB) in the *yz*-plane.

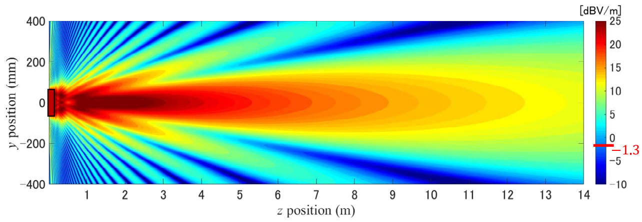

Fig. 6. Calculated *E*-field intensity in the *yz*-plane.

4. Conclusion

The 40 and 60 GHz-band waveguide slot array antennas are successfully developed for the gigabit wireless access systems, which can be fully applied in the 5G cellular network. The antenna characteristics and the system performance are evaluated. The demonstration including those two systems has been established in the campus of Tokyo Tech. The performance of the final demonstration will be presented during the conference.

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