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Future of 300-GHz-Band Wireless Communications and Their Enabler, CMOS Transceiver Technologies

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Abstract

Post-5G or 6G is expected to expand the range of services by enabling seamless connections between wireless and optical communications at ultrahigh transmission speeds beyond 100 Gbps. This evolution of wireless systems could be driven by technological trends moving from millimeter wave to terahertz. The 300 GHz band, just at the boundary between millimeter wave and terahertz, can provide a wide range of frequencies above 40 GHz continuously and is suitable for ultrahigh speed communications. In this paper, we will discuss techniques for achieving 300-GHz-band communication in CMOS integrated circuits suitable for mass production and the direction of technology for practical 300 GHz communication.

1. Introduction

In Japan, 5G service was launched in 2020. The mobile generation has been evolving every decade so far. If this trend continues, post-5G or 6G is expected to be realized in 2030. On the other hand, as shown in Fig. 1[1], both optical communications (wired communications) and wireless communications have been evolving exponentially in terms of data rates. It takes 7.5 years for optical communications to increase the communication speed tenfold, and it takes four years for wireless communications to do so. If the rate of evolution continues at the current pace, the speed of wireless communications is expected to catch up with the speed of wired communications by 2030. This means that ultrahigh-speed transmissions beyond 100 Gbpse will enable seamless connections between wireless and optical communications, expanding the range of services.

Such an evolution of wireless systems could be brought about by technological trends moving from millimeter wave to terahertz. The most recent focus has been on the 300 GHz band, which is right on the border between millimeter wave and terahertz: in WRC-19, footnote 5.564A was added to the wireless communications regulations to identify 275-296 GHz as land mobile and fixed operations[2]. This frequency band, together with the 252-275 GHz band that had been available for wireless communications in the past, will now provide a wide range of 44 GHz for continuous use. This paper discusses techniques for achieving 300 GHz communication in CMOS integrated circuits suitable for mass production and the direction of the technology for the practical application of 300 GHz communication.

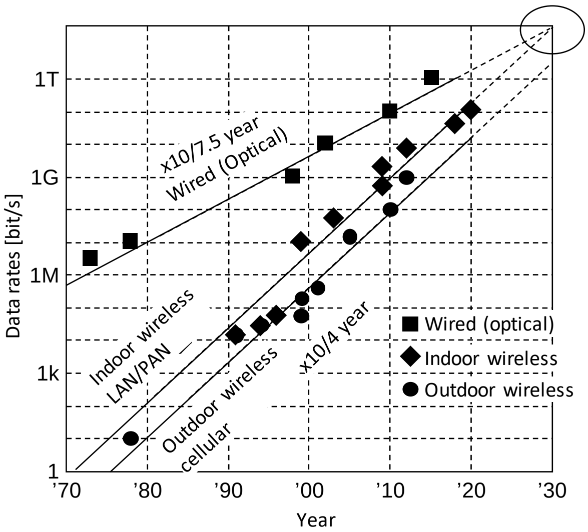


Fig. 1. Evolution of data rates for wired and wireless communications. Wireless data rates are evolving faster than wired communications and are expected to reach 100 gigabits per second by 2020. Furthermore, at this rate of evolution, by 2030, wireless data rates will be on par with wired communications.

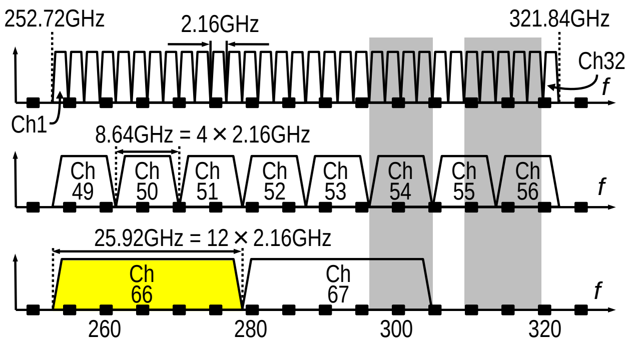


Fig. 2. IEEE 802.15.3d allocates multiple bands of channels in the frequency band of 252.72 GHz to 321.84 GHz. The above is an example of the channels allocated in IEEE 802.15.3d. We have realized a transceiver that uses channels 49, 50, and 66.

2. 300-GHz-Band Transceiver with CMOS Technology

Why Choose CMOS Technology?

Terahertz has the disadvantage that it is difficult to generate a high-power signal. In recent years, improvements in both device and circuit technology are resolving this problem. Silicon integrated circuits, especially CMOS circuits, were considered unsuitable for terahertz communications because the high-frequency performance of silicon transistors is lower than the high-frequency performance of compound semiconductor transistors. However, wireless circuits used in mass-produced cell phones and personal computers (PCs) are now made with inexpensive CMOS integrated circuits due to improvements in circuit and device technology. Advanced signal processing is essential for infrastructure devices spread across satellites and the terminals connected to them. CMOS integrated circuits are important to achieve terahertz communication and advanced signal processing on a single chip at a low cost. We have deliberately chosen CMOS integrated circuits because we believe that the performance of silicon transistors can be overcome by modifying the circuitry.

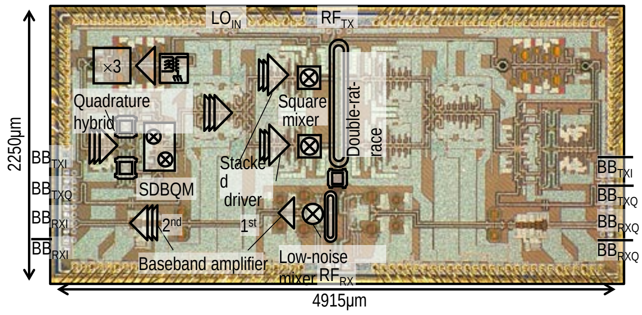
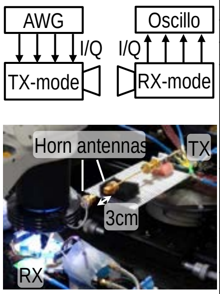


Fig. 3. A chip micrograph of a 300 GHz single-chip CMOS transceiver.



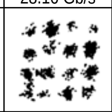
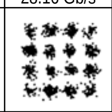
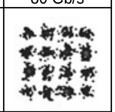
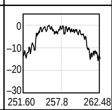
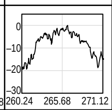
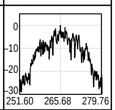
Channel	Ch. 49	Ch. 50	Ch. 66
Center freq.	257.04 GHz	265.68 GHz	265.68 GHz
Modulation	16 QAM	16 QAM	16 QAM
Data rate	28.16 Gb/s	28.16 Gb/s	80 Gb/s
Constellation (Equalized)			
Spectrum			
EVM	10.9%	11.3%	12.0%

Fig. 4. Overview of measurements for communication experiments and results of constellation and output spectrum measurements using a 300 GHz CMOS transceiver.

300-GHz-Band CMOS Transceiver

We have realized a single-chip CMOS transceiver that operates [3] as a target for the channel 49, 50, and 66 frequency bands of IEEE 802.15.3d, shown in Fig. 2 [4]. It is important to support quadrature amplitude modulation (QAM) as envisioned in IEEE 802.15.3d for mass production transceivers for general consumer use. Therefore, a single-chip transceiver was developed by combining the technology of a QAM-capable 300 GHz CMOS transmitter and receiver, which have been developed in the past. The transceiver has an architecture without a power amplifier for the transmitter and low noise amplifier for the receiver.

The 40-nm CMOS process was used to fabricate the transceiver. The chip micrograph of the transceiver is shown in Fig. 3. The size is 4.92×2.25 mm^2. The power consumption of the transmitter and receiver modes is 890 and 897 mW, respectively. Figure 4 shows the wireless communication measurements. A pair of 24 dBi horn antennas was used for the wireless communication experiments. The output baseband signal from the receiver was analyzed using a real-time oscilloscope with vector signal analysis. Constellation and power spectra corresponding to channels 49, 50, and 66 of IEEE 802.15.3d are shown in Fig. 4. A data rate of 80 Gbit/second over 3 cm was achieved at 16 QAM.

3. The Future of 300-GHz-Band Communications

Research into terahertz communications will make it possible to provide high-speed communications everywhere. This will completely change the lifestyles of people around the world if it becomes a reality. When the speed of the infrastructure using wireless communications rivals that using fiber-optic communications, we will be able to get all kinds of Internet information just as quickly as we do in the office, regardless of whether we are actually in the sky, on a satellite in space, or in the ocean. The most promising future of post-5G or 6G is said to be earth-wide communication using a huge number of satellites. Free space optical communication is considered advantageous for satellite-to-satellite communications because of its ability to provide high-speed links, but it cannot link satellites with the ground because it cannot pass through clouds. However, terahertz can pass through clouds while attenuating, so it can link the satellite to the ground. Terahertz communication can form a strong link, as if optical fiber were connecting satellites and the ground to satellites.

4. Conclusions

We have realized a single-chip transceiver in CMOS integrated circuits that can transmit and receive modulated signals in the 300 GHz band. Although there are still some problems to be overcome before commercialization, we have demonstrated that terahertz communication is possible in CMOS. As a result, we believe that CMOS integrated circuits are a candidate for terahertz transceivers in 6G.

There are potential new applications for terahertz communications in all areas where fiber optic speed is expected but not connected by fiber optics. Terahertz communications would be an ideal application for aviation or maritime high-speed communications. The deployment in infrastructure such as satellites, airplanes, and ships will probably be paralleled by the deployment in a variety of mobile devices.

Acknowledgements

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References

[1] T. Kürne, IEEE 802.15-10-0320-02-0000-Tutorial_Igthz.

[2] “Sharing and compatibility studies between land-mobile, fixed and passive services in the frequency range 275-450 GHz,” Report ITU-R SM.2450-0, June 2019.

[3] S. Lee et al., "An 80-Gb/s 300-GHz-Band Single-Chip CMOS Transceiver," *IEEE Journal of Solid-State Circuits*, vol. 54, no. 12, pp. 3577-3588, Dec. 2019.

[4] IEEE Standard for High Data RateWireless Multi-Media Networks, Amendment 2: 100 Gb/sWireless Switched Point-to-Point Physical Layer, IEEE Computer Society sponsored by the LAN/MAN Standards Committee.