FTTR-MmWave Architecture for Next-Generation Indoor High-Speed Communications

CHEN Zhe[1], ZHOU Peigen[1], WANG Long[2], HOU Debin[2], HU Yun[3], CHEN Jixin[1], HONG Wei[1]
(1. Southeast University, Nanjing 210096, China;
2. MiSic Microelectronics Co., Ltd., Nanjing 211111, China;
3. Nanjing Ziwei Technology Co., Ltd., Nanjing 211111, China)

DOI: 10.12142/ZTECOM.202504004
https://kns.cnki.net/kcms/detail/34.1294.TN.20251216.1124.002.html, published online December 16, 2025
Manuscript received: 2025-09-15

Abstract: Millimeter-wave (mmWave) technology has been extensively studied for indoor short-range communications. In such fixed network applications, the emerging FTTR architecture allows mmWave technology to be well cascaded with in-room optical network terminals, supporting high-speed communication at rates over tens of Gbit/s. In this Fiber-to-the-Room (FTTR)-mmWave system, the severe signal attenuation over distance and high penetration loss through room walls are no longer bottlenecks for practical mmWave deployment. Instead, these properties create high spatial isolation, which prevents mutual interference between data streams and ensures information security. This paper surveys the promising integration of FTTR and mmWave access for next-generation indoor high-speed communications, with a particular focus on the Ultra-Converged Access Network (U-CAN) architecture. It is structured in two main parts: it first traces this new FTTR-mmWave architecture from the perspective of Wi-Fi and mmWave communication evolution, and then focuses specifically on the development of key mmWave chipsets for FTTR-mmWave Wi-Fi applications. This work aims to provide a comprehensive reference for researchers working toward immersive, untethered indoor wireless experiences for users.

Keywords: Fiber-to-the-Room; millimeter wave; Wi-Fi; cloud virtual reality (cloud VR); beamforming

Citation (Format 1): CHEN Z, ZHOU P G, WANG L, et al. FTTR-mmWave architecture for next-generation indoor high-speed communications [J]. ZTE Communications, 2025, 23(4): 16–26. DOI: 10.12142/ZTECOM.202504004
Citation (Format 2): Z. Chen, P. G. Zhou, L. Wang, et al., "FTTR-mmWave architecture for next-generation indoor high-speed communications," *ZTE Communications*, vol. 23, no. 4, pp. 16–26, Dec. 2025. doi: 10.12142/ZTECOM.202504004.

1 Introduction

Over the past two decades, fixed broadband access technologies have continuously evolved to provide high-speed internet connectivity to end-users worldwide. The rise of new audio-visual media services such as augmented reality (AR), virtual reality (VR), 8K high-definition video, and cloud gaming has created higher demands for network throughput, coverage, and latency from content producers to end-users. The quality of fixed wireless broadband access significantly impacts the end-user experience, affecting factors like maximum service throughput, network stability, ease of installation, and easy management capabilities[1–5].

Currently, mainstream commercial wireless local area networks (WLANs) and cellular networks primarily operate in the sub-6 GHz frequency band, which has limited data transmission bandwidth and struggles to meet the demands of these new services. For example, for highly interactive, extreme cloud VR video transmission, a home network must guarantee a stable rate of at least 4.4 Gbit/s, with round-trip latency and jitter not exceeding 10 ms. High-quality VR headsets are typically connected via High-Definition Multimedia Interface (HDMI) cables, which can transmit up to 40 Gbit/s and require next-generation wireless ultra-high-speed interconnection technologies to provide users with an immersive, untethered experience[6]. The millimeter-wave (mmWave) band offers vast, continuous spectrum, which can provide greater transmission bandwidth. Furthermore, due to the short wavelength of mmWave, the transmitting antennas can be very small, which is conducive to making devices lightweight. To achieve higher wireless communication speeds, researchers across academia and industry have conducted extensive research on mmWave channel characterization, system architectures, software algorithms, hardware circuits, and multiple standards[7–22] over the past two decades. Based on home network scenarios and use cases, the challenges of 60 GHz mmWave transmission have been investigated[17]. Efforts have also been dedicated to channel measurements and modeling at 45 GHz and 60 GHz[19, 21–22]. Similarly, the use of beamforming in short-range communication has been widely studied[14, 18, 20].

The emergence of Fifth-Generation Fixed Networks (F5G) has seen the proposal of Fiber-to-the-Room (FTTR) technology. FTTR extends fiber optic cables to each room, providing gigabit broadband coverage for entire indoor spaces[23–25]. By leveraging the fiber infrastructure laid into each room, FTTR creates a large-bandwidth connection channel for high-speed mmWave communications, enabling efficient mmWave coverage in every room. At the same time, the high wall-penetration loss of the mmWave band creates a favorable condition for eliminating interference between wireless communication systems in different rooms. This allows FTTR to achieve same-frequency networking and ensure information security. To address the demands of new scenarios and services, China Unicom's Ultra-Converged Access Network (U-CAN) hyper-converged access network architecture integrates advanced technologies like 50 Gigabit-capable Passive Optical Network (50G-PON), FTTR, and next-generation Wi-Fi 8 to support the continuous development of indoor tens-gigabit services[26]. New services, such as video production, cloud PCs, and XR computing buses, have stringent requirements including deterministic latency, mobile roaming, and multi-domain networking. Consequently, the architecture proposes a new frequency division duplex access protocol for the next-generation Wi-Fi 8 mmWave air interface, efficient beam management and scanning mechanisms, and a high-low-frequency collaboration mechanism to address mmWave obstruction issues.

Furthermore, a multi-band hybrid networking solution is used to solve challenges like continuous indoor mmWave coverage. The Centralized/Cloud Wireless-Optical Access Network (C-WAN) is a centralized Wi-Fi architecture. It aims to provide full-house network coverage and efficient resource management through the synergy of optical networks and Wi-Fi. Its core features include 1) centralized control, in which a master device collects information and makes decisions, enabling unified and coordinated configuration of optical links and air interface links; 2) seamless roaming, which ensures fast handover of terminals between different access points, thereby enhancing the user experience; 3) interference optimization through Wi-Fi power balancing and interference mitigation. By innovating both the FTTR C-WAN architecture and air interface technology, the system effectively addresses issues of lagging and roaming in home and enterprise Wi-Fi applications, further improving the experience of short-range indoor wireless networks and enhancing efficiency[27–29].

This paper reviews the U-CAN architecture enabled by FTTR-mmWave Wi-Fi technology, with a primary focus on recent advances in Chinese mmWave chips and modules for next-generation FTTR-mmWave Wi-Fi applications. It is organized as follows. Section 2 briefly reviews the evolution of Wi-Fi and mmWave standards and the FTTR-mmWave system architecture. Section 3 focuses on the design of typical millimeter-wave chips, as well as recent Chinese commercial mmWave chip and module developments. Finally, Section 4 concludes the paper.

2 Wi-Fi and MmWave Standard Evolution and FTTR-MmWave Solution

2.1 Wi-Fi and MmWave Standard Evolution

In 1990, the IEEE 802.11 committee was established to promote research and development of standards for WLANs. In 1997, the first version, 802.11-1997, was officially released[30]. The Wi-Fi Alliance was founded in 1999 to apply the 802.11 standard to the industry and facilitate compatibility among different manufacturers. With the growth of WLAN technology and the proliferation of mobile wireless devices, it has become a crucial technology for household network coverage. The release of the 802.11n protocol in 2009 was a major milestone, significantly increasing Wi-Fi network speeds with features like multiple antennas and beamforming that are still used today. Currently, 802.11ax technologies and network devices are widely used, and Wi-Fi 7 (802.11be) is poised to offer a better wireless network experience.

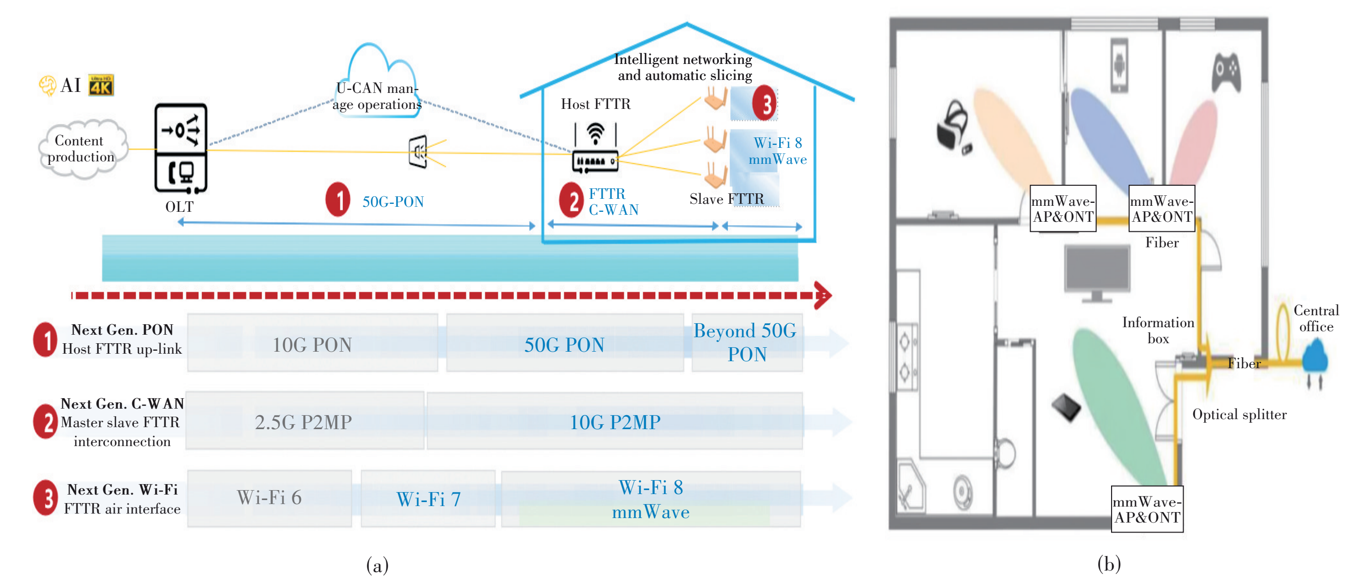
Millimeter-wave refers to electromagnetic waves with a wavelength between 1 mm and 10 mm, corresponding to a frequency range of 30 GHz to 300 GHz. The mmWave band offers vast spectrum resources. According to Shannon's theorem, the communication capacity of the system is proportional to the channel bandwidth, giving mmWave systems a natural advantage in channel capacity. By 2018, several mmWave-related standards had been introduced globally. The ECMA-387 standard primarily defines the characteristics of the physical layer (PHY), protocol adapter layer (PAL) for HD media interfaces, and media access control (MAC) layer in the 60 GHz band, mainly providing high-speed audio and HD video transmission. The IEEE 802.15.3c standard, operating in the 57–66 GHz band, primarily specifies the PHY and MAC layers for Wireless Personal Area Networks (WPANs). WPANs have an effective transmission distance of 10 m and are mainly used for high-speed network downloading. The 802.11ad physical layer supports various modes, including Single Carrier (SC) and Orthogonal Frequency Division Multiplexing (OFDM). As an evolution of 802.11ad, IEEE 802.11ay enhances theoretical speeds (theoretically up to 20 Gbit/s) and expands application scenarios. The IEEE 802.11aj standard is intended for indoor wireless communications, with frequency ranges of 42.3–48.4 GHz and 59–64 GHz. The MAC layer is designed similarly to other IEEE 802.11 protocol standards, while the physical layer introduces analog beamforming and antenna array technologies to improve mmWave coverage. The next-generation Wi-Fi 8 (802.11bq) standard working group has included both the low microwave band (sub-7.25 GHz) and the mmWave Q/V bands (42 – 71 GHz) as candidate working frequency bands.

2.2 FTTR-MmWave System Architecture

The combination of FTTR and mmWave WLAN technology is a recent research topic that is expected to become an optimal solution for service and data transmission in F5G. One such architecture is the U-CAN, which defines a unified access architecture from the cloud to the terminal side and flexibly supports the allocation of transmission resources for industry applications. The U-CAN integrates 50G-PON, FTTR, C-WAN, Wi-Fi 8 (mmWave band), and other technologies to achieve a comprehensive upgrade of the next-generation hyper-converged access network. In this new architecture, fiber optic cables are laid into each room to provide a high-capacity mmWave backhaul channel. With fiber penetrating into each room, using mmWave has two distinct advantages: extremely high speed enabled by more available spectrum and less interference between adjacent networks due to high wall-penetration loss. In this setup, each FTTR terminal can be cascaded with an mmWave access point (AP) on the downlink while connecting to the same Optical Network Terminal (ONT) on the uplink, as shown in Fig. 1. Compared to traditional Wi-Fi, the FTTR-mmWave system can eliminate interference and conflicts between different rooms, effectively improving data rates and transmission reliability while reducing latency. This performance is superior to that of traditional Wi-Fi Mesh network architectures. Currently, a Chinese company has designed an FTTR mmWave prototype using 4×4 multi-input multi-output (MIMO), which has achieved communication rates higher than 10 Gbit/s, validating the performance of the FTTR mmWave system for indoor communications.

3 MmWave Chips for FTTR-MmWave Wi-Fi Applications

FTTR technology is now in large-scale commercial use to address the high-rate transmission requirements of enterprises and homes. However, the bottleneck for even higher transmission rates lies in the fiber-to-wireless transition link. Given its high bandwidth and low latency, the mmWave band is an excellent solution to high-speed wireless transmission. This section focuses on the development of mmWave chips operating in 26 GHz, 40 GHz, and 45 GHz for next-generation indoor high-speed communication applications. While ensuring low cost and high integration, these chips are designed to optimize key metrics such as system bandwidth, power, noise, and linearity to meet the requirements of 16-QAM to 64-QAM modulation schemes to achieve higher transmission rates.



AP: access point
C-WAN: Centralized/Cloud Wireless-Optical Access Network
FTTR: Fiber-to-the-Room
mmWave: millimeter wave
ONT: Optical Network Terminal
P2MP: Point-to-Multipoint
PON: Passive Optical Network
U-CAN: Ultra-Converged Access Network

Figure 1. Schematic diagram of FTTR-mmWave cascading in the U-CAN architecture: (a) overall U-CAN architecture and (b) FTTR-mmWave system

3.1 24 – 29.5 GHz 2×2 Transceiver Chipset in Silicon-Germanium Process

Figs. 2 and 3 show the block diagram and micrograph of the implemented 24 – 29.5 GHz 2×2 transceiver chipset in a 130 nm silicon-germanium (SiGe) bipolar complementary metal-oxide-semiconductor (BiCMOS) process[31]. Each channel contains a quadrature up/down-conversion mixer, a 5-bit variable attenuator, a band-pass filter, an RF driver, a power amplifier (for the transmitter) and a low-noise amplifier (for the receiver). To achieve a low error vector magnitude (EVM), the chipset uses a joint-package design to optimize power and noise performance. It utilizes an image rejection mixer to suppress receiver noise and a direct current (DC) offset calibration circuit in the up-converter for local oscillator (LO) signal leakage calibration. A frequency multiplier chain is also integrated to reduce the requirements on the LO frequency.

The chipset is packaged using a wafer-level chip-scale package (WLCSP) process. The average 1 dB compression point output power for each transmitter channel reaches 20 dBm. The minimum noise figure for the receiver chip is 3.4 dB. The over-the-air (OTA) measurement setup is shown in Fig. 3c. The E8267D signal sources provide the LO signals to the RX and TX chips. For the single-carrier modulation measurement, the TX baseband signal was provided by the Keysight M8190A, and the received IF signal was demodulated using the Agilent DSO91304A. The measured results are presented in Fig. 3d. OTA measurement at 25 GHz with 16-QAM modulation and a distance of 1.1 meters achieved a data rate of up to 8 Gbit/s. Under 64-QAM 5G New Radio (NR) modulation with 400 MHz bandwidth at 25 GHz, the measured EVM remains below −33 dB. Across the 24 – 29.5 GHz band, the EVM level remains below −30 dB.

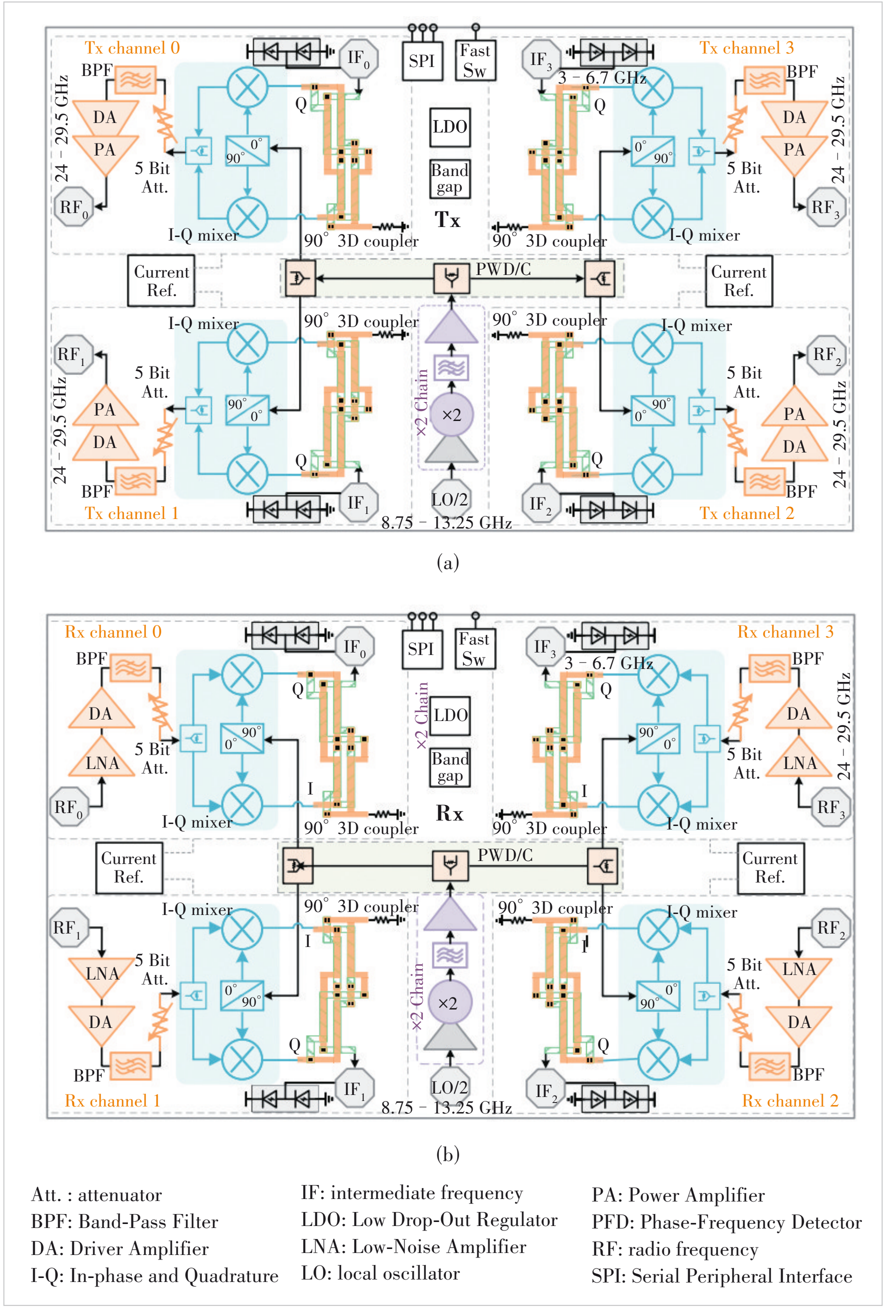
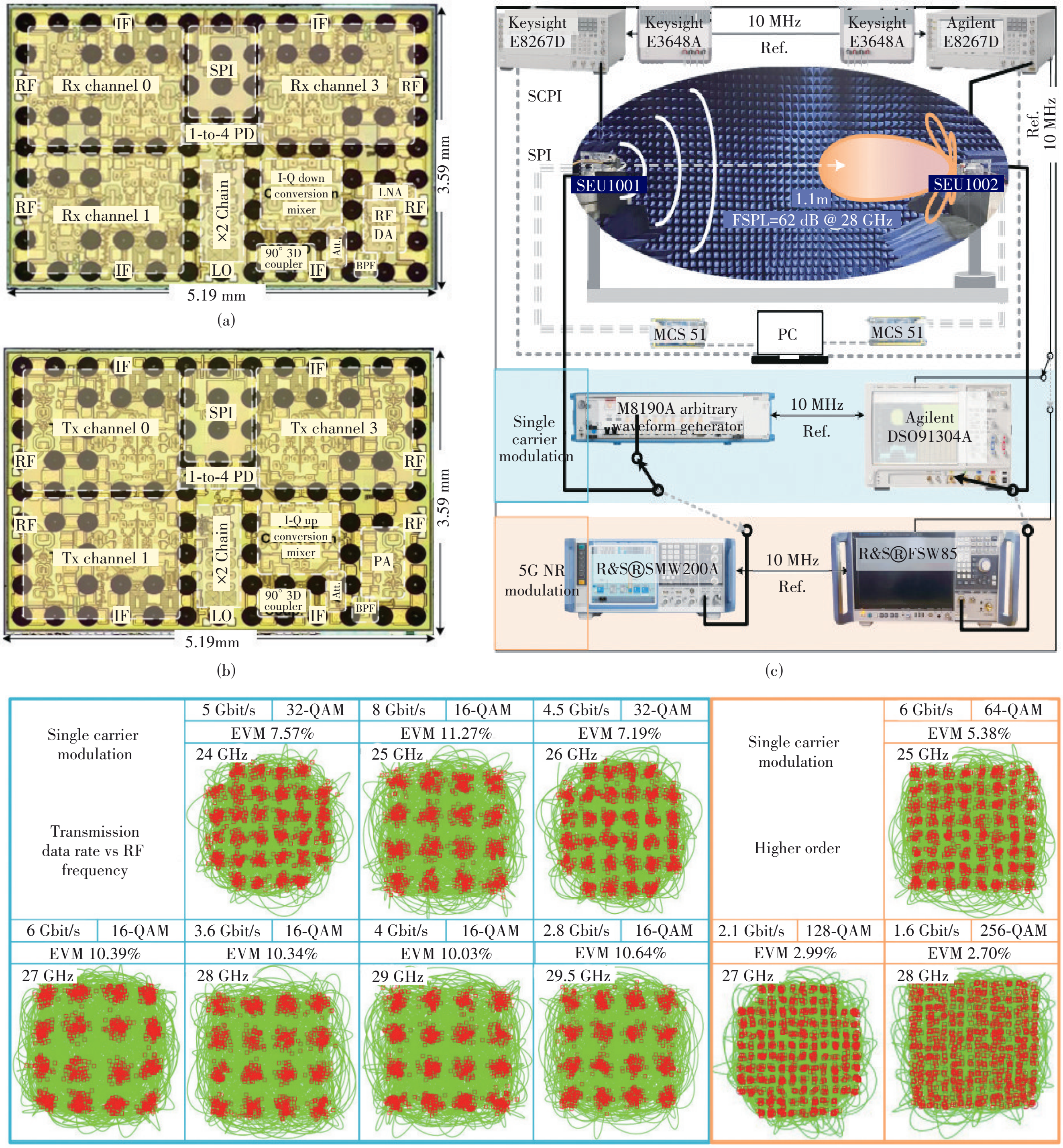


Figure 2. Block diagram of the 24 – 29.5 GHz chipset: (a) Tx chip and (b) Rx chip

3.2 45 GHz IEEE 802.11aj Transceiver in SiGe Process

The IEEE 802.11aj standard is designed specifically for short-range high-speed wireless personal area networks (WPAN). Figs. 4 and 5 show the block diagram and micrograph of a fully integrated IEEE 802.11aj direct-conversion transceiver chipset, fabricated using a 130-nm SiGe BiCMOS process, which includes a transmitter chip and a receiver chip[32]. In the transmitter, the power amplifier output incorporates a T-shaped second-harmonic termination to improve its linearity. Additionally, its output stage employs a power detector based on a self-mixing method to enable precise image signal and local oscillator (LO) leakage calibration.

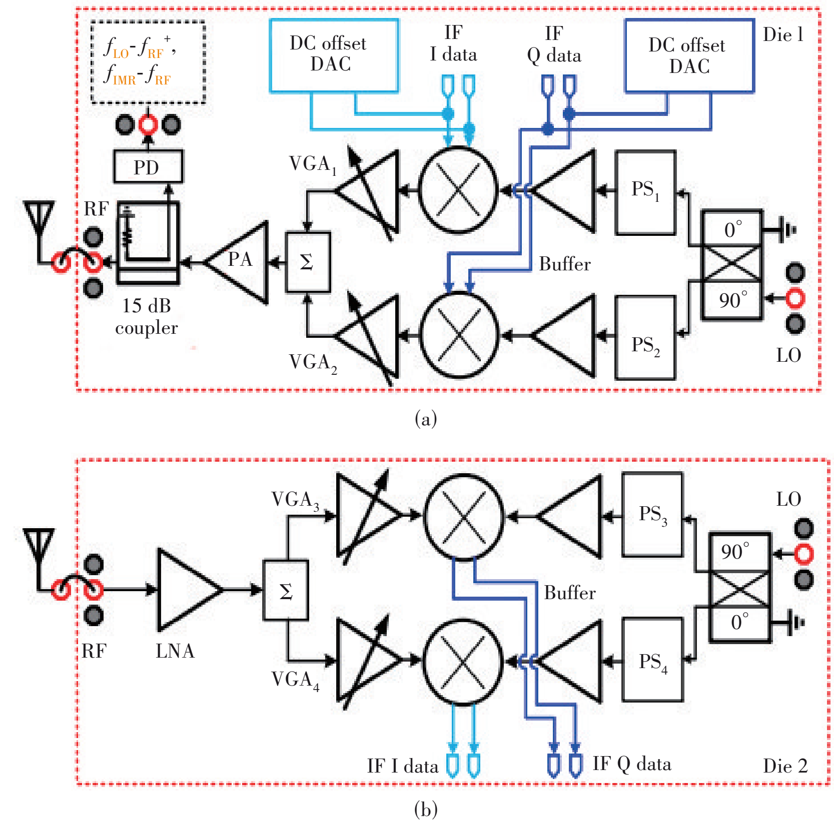
The OTA measurement setup is shown in Fig. 5c. The modulated baseband signals were generated by the M8190A arbitrary waveform generator with a roll-off factor of 0.25. The Agilent DSO 91304A digital oscilloscope with the Agi-



(d)

Att.: attenuator
BPF: Band-Pass Filter
DA: Driver Amplifier
EVM: error vector magnitude
FSPL: Free Space Path Loss
I-Q: In-phase and Quadrature
IF: intermediate frequency
LNA: Low-Noise Amplifier
LO: local oscillator
MCS: Modulation and Coding Scheme
NR: New Radio
PA: Power Amplifier
QAM: Quadrature Amplitude Modulation
RF: radio frequency
SCPI: Standard Commands for Programmable Instruments
SPI: Serial Peripheral Interface

Figure 3. Chip micrograms and measurement results: (a) micrograph of the 24–29.5 GHz Rx chip; (b) micrograph of the 24–29.5 GHz Tx chip; (c) over-the-air (OTA) measurement setup; (d) measured EVM with single carrier modulation signal



DAC: Digital-to-Analog Converter
DC: direct current
I: In-phase
IF: intermediate frequency
LNA: Low-Noise Amplifier
LO: local oscillator
PA: Power Amplifier
PD: Photodiode
PS: Phase Shifter
Q: Quadrature
RF: radio frequency
VGA: Variable Gain Amplifier

Figure 4. Block diagram of the 45-GHz direct-conversion chipset: (a) Tx chip and (b) Rx chip

lent 89600 vector signal analyzer was used to evaluate constellation and EVM performance. During the wireless data transmission measurement, the distance between the transmitter and the receiver was fixed at 1 m. At 42 GHz, 45 GHz, and 48.5 GHz, the measured EVMs of the SC 64-QAM signal (with a baud rate of 100 Mbit/s) were −29.11 dB, −29.44 dB, and −28.56 dB, respectively. As demonstrated in Fig. 5d, the measured 64-QAM constellations over the IEEE 802.11aj frequency band show high quality. Within the IEEE 802.11aj working band of 42.3 – 48.4 GHz, the transmitter achieved an output 1 dB compression point (OP1 dB) of 14.6 – 16.4 dBm, with a conversion gain (CG) exceeding 24 dB. Within the IEEE 802.11aj band, the receiver exhibited a noise figure of 3.8 – 4.1 dB, an input 1 dB compression point ranging from −22 dBm to −18.7 dBm, and a conversion gain greater than 43.8 dB. Overall, the measured transceiver fully meets the IEEE 802.11aj EVM requirements for 64-QAM modulation. In the OTA measurement with a T/R distance of 1 meter, the measured EVM from the transmitter to the receiver is better than −28.5 dB.

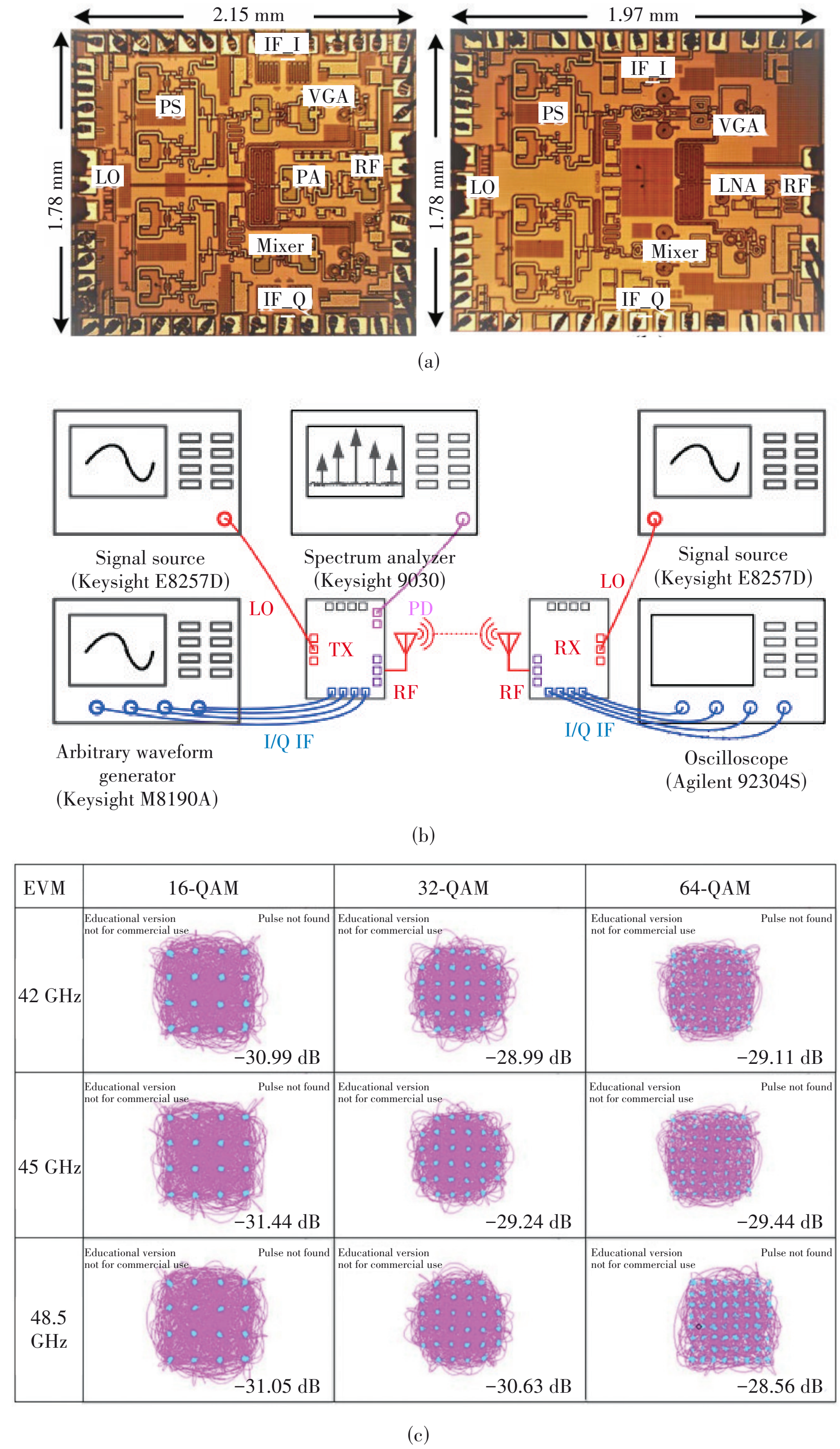
3.3 40 GHz Integer-N Phase-Locked Loop in CMOS Process

This subsection presents a 40 GHz integer-N phase-locked loop (PLL) featuring a linearized CMOS LC voltage-controlled oscillator (VCO), implemented in a standard 90-nm CMOS process. Its block diagram and micrograph are shown in Figs. 6 and 7, respectively[33]. The VCO uses a tri-coupled inductor to couple the varactor diode pairs, achieving gain linearization through mutual compensation. The tri-coupled inductor eliminates the need for a tuning voltage offset circuit or DC-blocking capacitors, making it suitable for high-performance mmWave design.

Measurement results show the linear VCO has a tuning bandwidth of 15.8% and a phase noise of −100.7 dBc/Hz at 1 MHz offset, yielding a figure of merit (FOMT) of −181.8 dBc/Hz. The designed PLL, using this linear VCO, can lock stably from 38.61 GHz to 44.55 GHz. At 40 GHz, it exhibits an in-band phase noise of −81 dBc/Hz at 100 kHz offset and an out-of-band phase noise of −114.5 dBc/Hz at 10 MHz offset, with a total power consumption of 76 mW. Compared with other reported research, the proposed linearization method results in very small variations in VCO gain. The developed PLL demonstrates good stability and minimal loop bandwidth variation across its entire operating frequency range, suitable for wideband mmWave low phase noise LO signal generation.

3.4 Recent Advances in Chinese Commercial Millimeter-Wave Chipsets and Modules

After years of research and development, Chinese RF chip design companies have developed competitive silicon-based millimeter-wave multi-channel beamforming chips and up/down conversion chipsets. For instance, the MSTR111 and MSTR205 chips from MiSic Microelectronics Co., Ltd. integrate eight RF transceiver channels in a single chip at 26/28 GHz (Fig. 8). The P1dB transmit power of a single channel reaches 20.5 dBm. Meanwhile, in Q-band (45 GHz), the MSTR201 (Fig. 9) supports the IEEE 802.11aj (45 GHz) standard. It integrates dual-channel transceivers, frequency conversion units, and a low-phase-noise PLL, with the P1dB of the transmit channel reaching 18 dBm and the noise figure (NF) of the receive channel below 6 dB, making it suitable for high-speed indoor millimeter-wave Wi-Fi application scenarios[34]. The mmWave AP and terminal prototype have also been developed based



EVM: error vector magnitude
I: In-phase
IF: intermediate frequency
LNA: Low-Noise Amplifier
LO: local oscillator
PA: Power Amplifier
PD: Photodiode
PS: Phase Shifter
QAM: Quadrature Amplitude Modulation
Q: Quadrature
RF: radio frequency
VGA: Variable Gain Amplifier

Figure 5. Chip micrographs and measurement results for the 45 GHz transceiver: (a) Tx chip; (b) Rx chip; (c) OTA measurement setup; (d) measured 64-QAM constellation

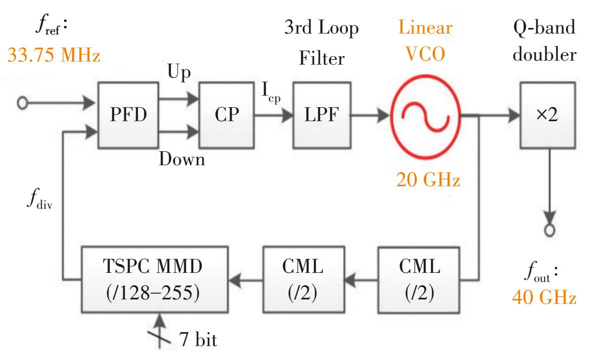
on the millimeter-wave Wi-Fi architecture by Nanjing Ziwei Technology Co., Ltd., as shown in Fig. 10. The system operates in the 24 – 26 GHz frequency band, adopting the millimeter-wave module and the commercial 802.11ax baseband. The system uses active phased array antennas, each containing 2×2 antenna units, which can cover a distance of over 100 meters, with a maximum data rate of 1.6 Gbit/s.

3.5 Challenges in Future MmW-Wi-Fi Applications

Compared to classical sub-6GHz Wi-Fi technology, mmWave Wi-Fi presents distinct challenges that require further research. Beamforming (BF) technologies improve mmWave communication capability by focusing the transmitted signal towards the receiver to provide additional link gain. To enhance coverage in the Q/V-band, the conventional approach is to use a phased array front-end with a moderate 16-element array size, which is a good balance between complexity and performance. In some application cases, the terminals rarely move after deployment, where the real-time BF can be omitted. In other cases, it needs multiple beam coverage for multiple high-throughput terminal users. The analog BF needs multiple subarrays for each beam. However, considering the cost and extra power consumption for multi-beam tracking, it is also a good choice to use several well-planned wider beams from the AP side to the mobile terminals coverage with MIMO techniques. Meanwhile, efficiently coordinating mmWave Wi-Fi with the classical Wi-Fi remains a significant challenge. This requires an advanced digital baseband chipset with integrated analog-to-digital and digital-to-analog converters (ADCs/DACs).

4 Conclusions

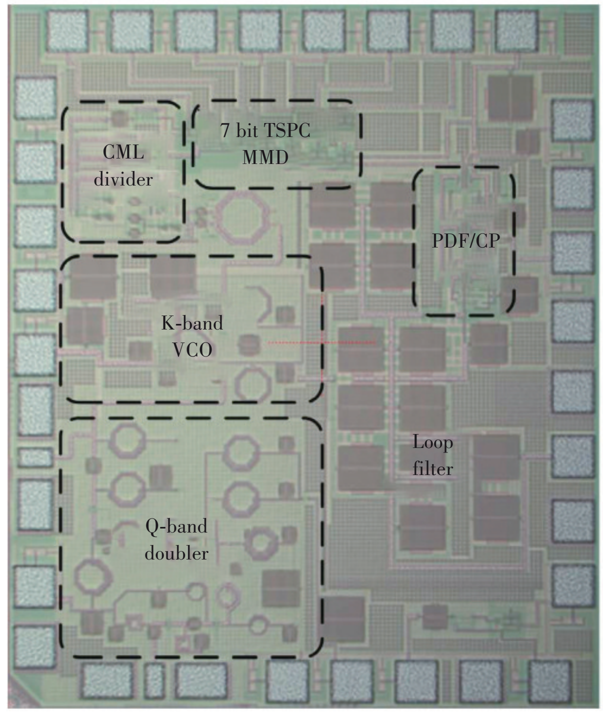
The integration of FTTR and mmWave technologies is a crucial means to achieve highly stable connections and low-latency transmission. The study of mmWave chip technology and system applications under the new FTTR architecture will be a significant research topic for the development of next-generation high-speed wire-



CML: Current-Mode Logic
CP: Charge Pump
I: In-phase
LPF: Low-Pass Filter
MMD: Multi-Modulus Divider
PFD: Phase-Frequency Detector
TSPC: True Single-Phase Clock
VCO: Voltage-Controlled Oscillator

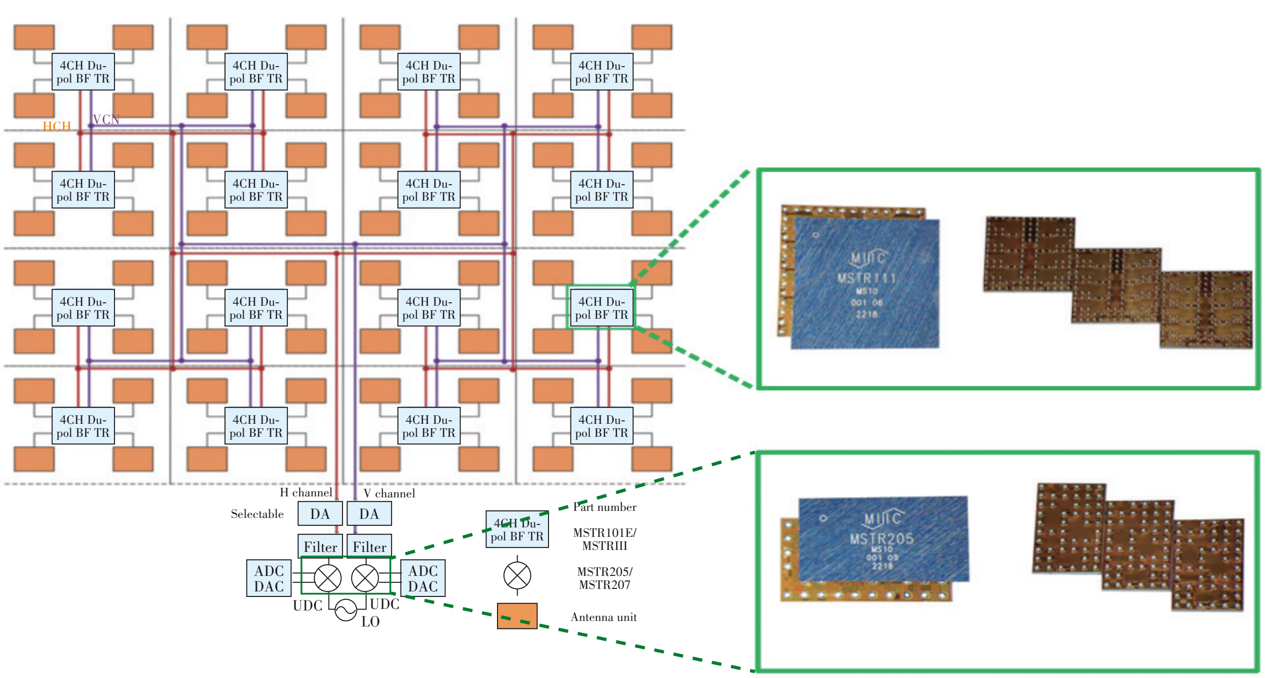
Figure 6. Block diagram of the 40 GHz Integer-N PLL

less access technologies in fixed access scenarios. Based on the advantages of the FTTR-mmWave architecture, it is of great research significance to design mmWave chips and systems with high transmission rates, low latency, high reliability, and low cost, while fully utilizing both sub-7.25 GHz and mmWave Wi-Fi frequency resources to achieve multi-band collaborative transmission. This work briefly reviews the U-



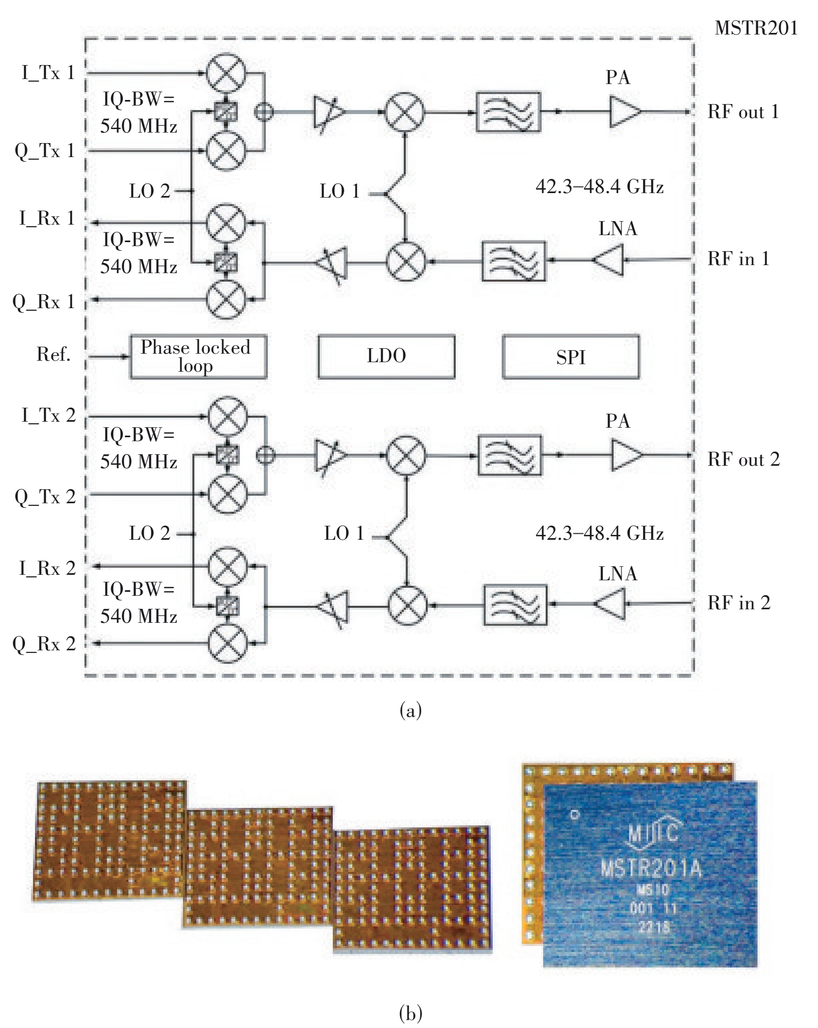
CML: Current-Mode Logic
CP: Charge Pump
MMD: Multi-Modulus Divider
PFD: Phase-Frequency Detector
TSPC: True Single-Phase Clock
VCO: Voltage-Controlled Oscillator

Figure 7. Micrograph of the 40 GHz Integer-N PLL



ADC: Analog-to-Digital Converter
BF: beamforming
CH: channels
DA: Driver Amplifier
DAC: Digital-to-Analog Converter
Du: duplexer
HCH: Horizontal Channel
LO: local oscillator
pol: polarization
TR: Transceiver
UDC: Up/Down-Converter
VCN: Vertical Channel

Figure 8. The 26/28-GHz 8-channel TR and Up/Down-conversion chipsets (Image courtesy of MiSic Microelectronics Co. , Ltd.)



BW: bandwidth
I: In-phase
LDO: Low-Dropout Regulator
LNA: Low-Noise Amplifier
LO: local oscillator
PA: Power Amplifier
Q: Quadrature
RF: radio frequency
SPI: Serial Peripheral Interface

Figure 9. 45-GHz 2-channel transceiver chip for mmWave Wi-Fi (IEEE802.11aj) applications (Image courtesy of MiSic Microelectronics Co., Ltd.)

Figure 10. MmWave Wi-Fi modules for: (a) access point and (b) user terminal (Image courtesy of MiSic and Ziwei Tech., etc.)

CAN architecture with FTTR-mmWave Wi-Fi technology, as well as the recent Chinese mmWave chipset and RF module developments. The combination of fiber optics and mmWave will effectively solve problems related to indoor mmWave signal coverage, high-throughput traffic, and interference between wireless access points. As the key element in this system, the recent mmWave chip and RF module developments have made rapid progress, providing key support for indoor 10-gigabit and higher-speed traffic and millisecond-level transmission services.

References

[1] SCHNEIDER T, WIATREK A, PREUßLER S, et al. Maximum transmittable data rates for millimeter-wave fixed wireless links [C]//Proc. 2012 ELEKTRO. IEEE, 2012: 94 – 98. DOI: 10.1109/ELEKTRO.2012.6225579

[2] GHASEMPOUR Y, DA SILVA C R C M, CORDEIRO C, et al. IEEE 802.11ay: next-generation 60 GHz communication for 100 Gb/s Wi-Fi [J]. IEEE communications magazine, 2017, 55(12): 186 – 192. DOI: 10.1109/MCOM.2017.1700393

[3] KIM M, ROPITAULT T, LEE S, et al. Efficient MU-MIMO beamforming protocol for IEEE 802.11ay WLANs [J]. IEEE communications letters, 2019, 23(1): 144 – 147. DOI: 10.1109/LCOMM.2018.2879476

[4] KIM M S. Deep learning based multiple-beam transmission for IEEE 802.11ay beamforming training [C]//Proc. 27th Asia Pacific Conference on Communications (APCC). IEEE, 2022: 494 – 495. DOI: 10.1109/APCC55198.2022.9943719

[5] ALDUBAIKHY K, WU W, ZHANG N, et al. MmWave IEEE 802.11ay for 5G fixed wireless access [J]. IEEE wireless communications, 2020, 27(2): 88 – 95. DOI: 10.1109/MWC.001.1900174

[6] HE C, REN Z X, WANG X, et al. Millimeter-wave wireless communications for home network in fiber-to-the-room scenario [J]. Frontiers of information technology & electronic engineering, 2021, 22(4): 441 – 456. DOI: 10.1631/FITEE.2000440

[7] IEEE. IEEE standard for information technology—local and metropolitan area networks—specific requirements part 15.3: amendment 2: millimeter-wave-based alternative physical layer extension: IEEE Std 802.15.3c-2009 [S]. 2009

[8] SEYEDI A. On the physical layer performance of ecma-387: a standard for 60GHz WPANs [C]//Proc. IEEE International Conference on Ultra-Wideband. IEEE, 2009: 28 – 32. DOI: 10.1109/ICUWB.2009.5288820

[9] IEEE. IEEE standard for information technology—telecommunications and information exchange between systems—local and metropolitan area networks—specific requirements part 11: wireless LAN medium access control (MAC) and physical layer (PHY) specifications amendment 3: enhancements for very high throughput in the 60 GHz band: IEEE Std 802.11ad-2012 [S]. 2012

[10] IEEE. IEEE standard for information technology—telecommunications and information exchange between systems local and metropolitan area networks—specific requirements part 11: wireless LAN medium access control (MAC) and physical layer (PHY) specifications amendment 3: enhancements for very high throughput to support chinese millimeter wave frequency bands (60 GHz and 45 GHz): IEEE Std 802.11aj–2018 [S]. 2018
[11] IEEE. IEEE standard for information technology—telecommunications and information exchange between systems local and metropolitan area networks—specific requirements part 11: wireless lan medium access control (MAC) and physical layer (PHY) specifications amendment 2: enhanced throughput for operation in license-exempt bands above 45 GHz: IEEE Std 802.11ay-2021 [S]. 2021
[12] AI B, GUAN K, HE R S, et al. On indoor millimeter wave massive MIMO channels: measurement and simulation [J]. IEEE journal on selected areas in communications, 2017, 35(7): 1678 – 1690. DOI: 10.1109/JSAC.2017.2698780
[13] AKDENIZ M R, LIU Y P, SAMIMI M K, et al. Millimeter wave channel modeling and cellular capacity evaluation [J]. IEEE journal on selected areas in communications, 2014, 32(6): 1164 – 1179. DOI: 10.1109/JSAC.2014.2328154
[14] ALKHATEEB A, EL AYACH O, LEUS G, et al. Channel estimation and hybrid precoding for millimeter wave cellular systems [J]. IEEE journal of selected topics in signal processing, 2014, 8(5): 831 – 846. DOI: 10.1109/JSTSP.2014.2334278
[15] CHEN J N, LI S, TAO J Y, et al. Wireless beam modulation: an energy- and spectrum-efficient communication technology for future massive IoT systems [J]. IEEE wireless communications, 2020, 27(5): 60 – 66. DOI: 10.1109/MWC.001.2000021
[16] CUI P F, ZHANG J A, LU W J, et al. Statistical sparse channel modeling for measured and simulated wireless temporal channels [J]. IEEE transactions on wireless communications, 2019, 18(12): 5868 – 5881. DOI: 10.1109/TWC.2019.2940017
[17] GENC Z, DANG B L, WANG J, et al. Home networking at 60 GHz: challenges and research issues [C]//The International Federation for Information Processing (IFIP). Springer, 2008. DOI: 10.1007/978-0-387-77216-5_5
[18] HUR S, KIM T, LOVE D J, et al. Millimeter wave beamforming for wireless backhaul and access in small cell networks [J]. IEEE transactions on communications, 2013, 61(10): 4391 – 4403. DOI: 10.1109/TCOMM.2013.090513.120848
[19] MORAITIS N, CONSTANTINOU P. Indoor channel measurements and characterization at 60 GHz for wireless local area network applications [J]. IEEE transactions on antennas and propagation, 2004, 52(12): 3180 – 3189. DOI: 10.1109/TAP.2004.836422
[20] RANGAN S, RAPPAPORT T S, ERKIP E. Millimeter-wave cellular wireless networks: potentials and challenges [J]. Proceedings of the IEEE, 2014, 102(3):366-385. DOI: 10.1109/JPROC.2014.2299397
[21] SATO K, MANABE T, IHARA T, et al. Measurements of reflection and transmission characteristics of interior structures of office building in the 60-GHz band [J]. IEEE transactions on antennas and propagation, 1997, 45(12): 1783 – 1792. DOI: 10.1109/8.650196
[22] WU X Y, WANG C X, SUN J, et al. 60-GHz millimeter-wave channel measurements and modeling for indoor office environments [J]. IEEE transactions on antennas and propagation, 2017, 65(4): 1912 – 1924. DOI: 10.1109/TAP.2017.2669721
[23] LIU X, LI J W, WU X M, et al. Fiber-to- the-room (FTTR) technologies for the 5th generation fixed network (F5G) and beyond [C]//Proc. IEEE Future Networks World Forum (FNWF). IEEE, 2022: 351 – 354. DOI: 10.1109/FNWF55208.2022.00068
[24] CAI Y. Discussion on the construction of FTTR gigabit full optical network for smart home [J]. Telecom power technologies, 2022, 39(2): 92 – 94. DOI:10.19399/j.cnki.tpt.2022.02.029
[25] CHEN P N, ZHAO Z J, WANG X X. Research on the development and application of FTTR technology in the context of gigabit network development [J]. Telecom power technologies, 2021, 38(17): 85 – 87. DOI: 10.19399/j.cnki.tpt.2021.17.024
[26] SUN L. U-CAN ultra-converged access network architecture and key technologies [C]//2024 National Conference on Microwave and Millimeter Wave. CIE, 2024. DOI: 10.26914/c.cnkihy.2024.019769
[27] NOR A M. Access point selection in beyond 5G hybrid MmWave/Wi-Fi/Li-Fi network [J]. Physical communication, 2021, 46(6): 1 – 11, DOI: 10.1016/j.phycom.2021.101299
[28] SUN X, YAO W B, MAO J H, et al. Research on 5G multi frequency coordination technology [J]. Telecom engineering technics and standardization, 2021, 34(3): 75 – 81. DOI: 10.13992/j.cnki.tetas.2021.03.017
[29] HU T Y, LI L X, CHEN Z. New opportunities for multi-band collaborative communication: Integrated communications and sensing at terahertz band [J]. ZTE technology journal, 2022, 28(4): 14 – 18. DOI: 10.12142/ZTETJ.202204004
[30] IEEE. IEEE Standard for Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: IEEE Std 802.11-1997 [S]. 1997
[31] WANG L, CHEN J X, CHEN Z, et al. A 24 – 29.5-GHz scalable 2 × 2 I-Q TX/RX chipset with streamlined IF interfaces for DBF systems [J]. IEEE transactions on circuits and systems I: regular papers, 2025, 72 (1): 155 – 168. DOI: 10.1109/TCSI.2024.3438555
[32] ZHOU P G, CHEN J X, YAN P P, et al. A −28.5-dB EVM 64-QAM 45-GHz transceiver for IEEE 802.11aj [J]. IEEE journal of solid-state circuits, 2021, 56(10): 3077 – 3093. DOI: 10.1109/JSSC.2021.3057077
[33] CHEN Z, WANG M, CHEN J X, et al. Linear CMOS LC-VCO based on triple-coupled inductors and its application to 40-GHz phase-locked loop [J]. IEEE transactions on microwave theory and techniques, 2017, 65(8): 2977 – 2989. DOI: 10.1109/TMTT.2017.2663401
[34] MiSic Microelectronics Co., Ltd. Product center [DB/OL]. [2025-08-10]. https://www.misic.com.cn

Biographies

CHEN Zhe (zhechen@seu.edu.cn) received his BS degree in microwave engineering from University of Electronic Science and Technology of China in 2006, and his PhD degree in electronic engineering from Southeast University, China in 2014. From 2016 to 2018, he was with The University of Texas, USA. He is currently an associate professor with the State Key Laboratory of Millimeter Waves, School of Information Science and Technology, Southeast University. His research interests include terahertz signal sources and high-speed communications and millimeter wave integrated circuits in nanometer silicon-based technology. He served as the Session Chair for the IEEE International Symposium on Radio-Frequency Integration Technology (RFIT), the IEEE International Wireless Symposium (IWS), and the IEEE International Conference on Microwave and Millimeter Wave Technology (ICMMT).

ZHOU Peigen received his BS degree in radio engineering and PhD degree in electromagnetic field and microwave technique from Southeast University (SEU), China in 2015 and 2020, respectively. From 2019 to 2020, he was a visiting student researcher with Eindhoven University of Technology, The Netherlands. Since 2021, he has been with the State Key Laboratory of Millimeter Waves, SEU, where he is currently an associate professor with the School of Information Science and Engineering. His current research interests include silicon-based millimeter wave/terahertz on chip wireless communication/radar phased-array transceivers.

WANG Long received his BE degree from Hunan Institute of Science and Technology, China in 2015, MS degree from Hangzhou Dianzi University, China in 2018, and PhD degree from Southeast University, China in 2024. From 2018 to 2020, he was with MiSic Microelectronics Technology Company Ltd., Nanjing, as a research engineer. His current research interests include silicon-based millimeter-wave integrated circuits and systems. He was a recipient of the IEEE International Wireless Symposium (IWS) Best Student Paper Award in 2021.

HOU Debin received his BS degree from the School of Physical Electronics, University of Electronic Science and Technology of China in 2007, and his PhD degree from the School of Information Science and Technology, Southeast University, China in 2013. He was with the Blekinge Institute of Technology (BTH), Sweden in 2009, and the Institute of Microelectronics (IME), Agency for Science, Technology and Research (A*STAR), Singapore, as an exchange student, from 2010 to 2012. From 2013 to 2022, he was with the State Key Laboratory of Millimeter Waves, Southeast University, China. He has authored over 20 technical publications. He is now with the MiSic Microelectronics Co., Ltd., China. His current research interests include silicon based/GaAs millimeter wave/terahertz on-chip components, antennas, and integrated circuits. Dr. HOU received the Jiangsu Excellent 100 Doctoral Dissertation Prize in 2014.

HU Yun received his BE degree in electronics and information engineering and ME degree in circuits and systems from University of Electronic Science and Technology of China in 2008 and 2011, respectively, and his PhD degree in electromagnetic and microwave engineering from Southeast University, China in 2019. From July 2011 to February 2015, he was with the Second Academy of China Aerospace Science and Industry Corporation, as a research engineer. He is now with Nanjing Ziwei Tech. Co., Ltd., China. His current research interests include multibeam antennas, antenna arrays, beamforming networks, and RF front-end design. Dr. HU was a recipient of the Student Paper Award of the 2018 IEEE 7th Asia-Pacific Conference on Antennas and Propagation (APCAP 2018).

CHEN Jixin received his BS degree in radio engineering and MS and PhD degrees in electromagnetic field and microwave technique from Southeast University, China in 1998, 2002, and 2006, respectively. Since 1998, he has been with the State Key Laboratory of Millimeter-Waves, Southeast University, where he is currently a professor with the School of Information Science and Engineering and the director of the Department of Electromagnetic Field and Microwave Engineering. His current research interests include the integration technology of millimeter-wave circuits and systems. Dr. CHEN was a recipient of the 2016 Keysight Early Career Professor Award and the 2016 National Natural Science Prize Second Prize of China. He served as the TPC Chair for NCMMW2021 and RFIT2019 and the TPC Co-Chair for HSIC2012 and UCMMT2012.

HONG Wei received his BS degree from University of Information Engineering, China in 1982, and MS and PhD degrees from Southeast University, China in 1985 and 1988, respectively, all in radio engineering. Since 1988, he has been with the State Key Laboratory of Millimeter Waves, has served as the director of the lab since 2003, and is currently a professor at the School of Information Science and Engineering, Southeast University. In 1993, 1995, 1996, 1997 and 1998, he was a short-term Visiting Scholar with the University of California at Berkeley and at Santa Cruz, USA. He has been engaged in numerical methods for electromagnetic problems, millimeter-wave theory and technology, antennas, and RF technology for wireless communications. He has authored and co-authored over 400 technical publications and two books. He has received numerous awards, including the National Natural Science Award of China (twice), the first-class Science and Technology Progress Award from the Chinese Ministry of Education and the Jiangsu Provincial Government (four times), the 2023 CIE Science and Technology Innovation Team Award, and the 2021 IEEE MTT-S Microwave Prize. Dr. HONG is a Fellow of IEEE, a Fellow of CIE, the Vice President of both the CIE Microwave Society and the Antenna Society, and the Chair of the IEEE MTT-S/AP-S/EMC-S Joint Nanjing Chapter. He was an elected member of the IEEE MTT-S Administrative Committee (AdCom) from 2014 to 2016. He served as Associate Editor of *IEEE Transactions on Microwave Theory and Techniques* from 2007 to 2010 and as one of the guest editors for the 5G special issue of *IEEE Transactions on Antennas and Propagation* in 2017.