Ultra-high-speed Transmission of 5G High-frequency Signals and Large-bandwidth Integrated Circuits

Zhengyu Chen *

School of Electronic and Information Engineering, Anhui University, Anhui, 230601, China

* Corresponding Author Email: P124302005@stu.ahu.edu.cn

Abstract. With the continuous advancement of the communications field and the constant updates and iterations of communication technologies, the development of 5G communication technology has accelerated the speed at which people can access information. Integrated circuits capable of ultra-high-speed signal transmission form the foundation for the reliable delivery of information, yet they also present a significant challenge. The high bandwidth and other factors in integrated circuits ensure high-speed, low-latency, and highly stable transmission of high-frequency signals. This study is based on existing communication module integrated circuits, summarizing the characteristics of high-frequency signal transmission within integrated circuits and the advantages of transmitting signals through wide-bandwidth integrated circuits. Communication module integrated circuits suffer from drawbacks such as low integration levels and significant signal transmission losses in the manufacturing technique. Additionally, they exhibit disadvantages in high-frequency signal transmission, including susceptibility to obstruction and interference, slow transmission speeds, and insufficient spectrum resources. To address these shortcomings, methods such as employing chemical plating technology, optimizing transimpedance amplifier chips, and designing impedance-matched self-calibration circuits have been proposed to enhance the bandwidth of integrated circuits and improve their capability to transmit high-frequency signals. Thereby optimizing the performance of integrated circuits. The research findings will accelerate data processing in integrated circuits and enhance communication speeds. Meanwhile, provide insights for the future realization of 6G and satellite communication technologies.

Keywords: 5G Communication, Integrated Circuit Manufacturing, High-frequency signal, High bandwidth, High-speed signal transmission.

1. Introduction

The constant digitization of information has become an unstoppable trend. With the continuous advancement of the electronic communications industry and the ever-increasing demand for faster information transmission. Rapid, high-volume, and accurate data signal transmission has become a major challenge in the field of communications. 5G advanced technology has a wide range of applications across many different fields. For instance, in the medical field, Lu Kaixin explored how 5G technology, the Internet of Things, AI technology, and wearable devices enable real-time transmission of patient conditions, ensuring the smooth execution of remote surgeries and monitoring [1]. In the field of satellite positioning and navigation, Ren Zhengdongxie discovered that the high bandwidth and low latency advantages of 5G technology can provide reliable signal transmission support for BDS positioning technology, and this assists BDS in enhancing the accuracy of data surveying while reducing the impact of environmental factors on BDS positioning [2]. In the field of signal transmission rates and coverage range, Li Mian et al. investigated the framework of the RWMMSE algorithm based on a large-scale MIMO downlink model to maximize the energy efficiency of communication modules [3]. To achieve ultra-high-speed signal transmission for 5G, existing communication module integrated circuits can be optimized for bandwidth and frequency bands using high-frequency transmission technology, new multi-antenna transmission techniques, and simultaneous full-duplex transmission on the same frequency [4]. The high bandwidth and high-frequency transmission bands in integrated circuits are prerequisites for ensuring signal transmission speed and integrity, which ensures the quality of signal transmission. The appropriate combination of the two approaches mentioned earlier can achieve the requirements for high-speed, low-latency transmission and greater user capacity in integrated circuits.

At present, the manufacturing of communication module chips, such as RF chips, communication interface chips, and baseband chips, has reached maturity in certain areas. As of August 2025, the most advanced communication chips include the MM8108 chip, the ADI 5G mmWare chipset, and the highly integrated Si4735-D60 chip supporting global channel reception launched at CES 2025 [5]. However, obstacles remain in the manufacturing of certain types of chips. Among these, the most critical areas requiring optimization are signal transmission speed, transmission stability, and information privacy.

This paper investigates the factors influencing the manufacturing of high-bandwidth integrated circuits and the transmission of high-frequency signals, summarizing their advantages and disadvantages along with improvement methods addressing their shortcomings. This study aims to optimize 5G technology and communication module integrated circuits through the investigation and analysis of bandwidth and high-frequency bands in integrated circuits.

2. Ultra-high-speed Signal Transmission

2.1. Principles of Signal Transmission in Integrated Circuits

Signals are transmitted in the form of electrical signals within integrated circuits. Electrical signals come in two forms: analog signals and digital signals, and these two forms can be converted into one another, and they are transmitted through metallic materials and conductors on integrated circuits. When electrical signals are transmitted to the transistor, they control its cutoff and conduction states, enabling the integrated circuit to recognize the electrical signals. Next, the electrical signals undergo processing and manipulation through logic gate circuits and are finally transmitted to other modules. In addition, there are other technologies for signal transmission in integrated circuits; for example, optical interconnect technology converts electrical signals within integrated circuits into optical signals [6]. These optical signals are transmitted through optical transmitters to optical receivers, where they are ultimately reconverted into electrical signals [6].

2.2. Influencing Factors of Ultra-High-Speed Signal Transmission

The factors affecting ultra-high-speed signal transmission primarily include the bandwidth of integrated circuits and the frequency band of signals, each with distinct characteristics. As shown in Fig. 1.

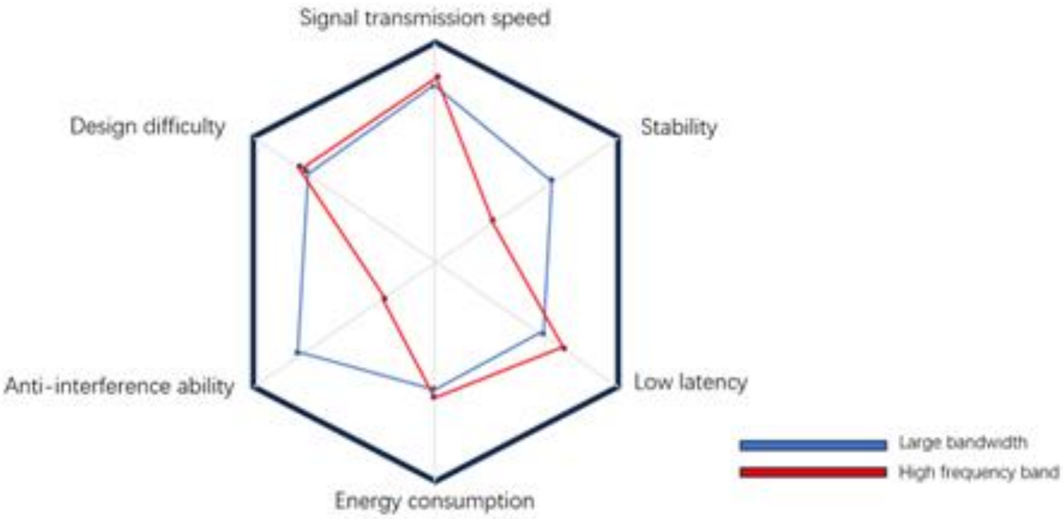

Fig. 1 Characteristics of Wide Bandwidth and High Frequency Bands.

Fig. 1 illustrates that the greater the bandwidth of an integrated circuit, the better the stability of signal transmission, the faster the signal transmission speed, and the stronger the resistance to interference. However, it also has drawbacks such as high design complexity and high power consumption. The higher the signal frequency, the faster its transmission rate and the greater the signal bandwidth it can carry. However, it exhibits poorer stability and interference resistance and poses greater design challenges. Beyond the bandwidth of integrated circuits and the frequency range of transmissible signals, numerous factors also determine signal transmission quality. These include the interconnect materials and structures used in manufacturing, process precision, signal integrity and power consumption control, as well as resistance to noise and electromagnetic interference [7].

2.3. The Advantages of Ultra-high-speed Signal Transmission

Ultra-high-speed signal transmission can enhance the data transfer rate of integrated circuits, improve system integration and reduce size. It also supports signal transmission over longer distances, reduces signal loss during transmission, and enhances stability. Additionally, ultra-high-speed signal transmission technology is applicable to numerous other scenarios, such as cloud computing, industrial automation, autonomous driving, and aerospace [8]. Zhang Yongyong's research demonstrates that technologies such as high-frequency electronics and ultra-wideband (UWB) can enable ultra-high-speed signal transmission, thereby enhancing the anti-interference capabilities of communication chips and meeting requirements for high-efficiency, low-power signal transmission [9]. Enhanced the user experience and met user needs.

3. High Bandwidth

3.1. Characteristics of High-Bandwidth Integrated Circuits

Bandwidth can be used to determine the frequency range of signals that a circuit can handle. Increased bandwidth means the upper limit of the frequency range that the circuit can handle will be raised, thereby improving its high-frequency characteristics. The bandwidth range of high-bandwidth integrated circuits generally refers to frequencies above 50 GHz. The primary characteristics of high-bandwidth integrated circuits often include high chip integration density and high material purity [10]. Different integrated circuits also utilize various bandwidth-expansion techniques for optimization, such as resistive feedback technology, distributed amplifier technology, and parallel peak-shaving technology [10].

3.2. Advantages of High-Bandwidth Integrated Circuits

High-bandwidth integrated circuits can be used to transmit and process high-speed signals, and can also handle signals at higher frequencies, enabling the chip to accommodate a broader range of signal frequencies. Its advantages are primarily reflected in faster data transmission speeds, greater stability, lower latency, and strong resistance to environmental factors and noise, thereby enhancing the interactive experience. High-bandwidth communication integrated circuits can also accommodate a wider range of application requirements. For example, providing high-bandwidth memory interfaces for high-performance servers and enabling real-time processing of high-frequency raw data for radar systems. Additionally, by optimizing this chip, the power foldback efficiency of power amplifiers in 5G communications can be effectively enhanced, reducing heat generation and thereby improving energy utilization efficiency and device performance [11].

3.3. Optimize Integrated Circuit Bandwidth

During the manufacturing process, high-bandwidth designs can be achieved by substituting raw materials with those possessing lower resistivity, typically below the micro-ohm-centimeter level. Employing more advanced lithography techniques in the manufacturing process, for example, etching using extreme nanoscale ultraviolet lithography technology. Moreover, while numerous techniques exist to increase bandwidth, each comes with certain drawbacks, such as negative feedback, inductive peaking, and capacitive de-emphasizing [12]. While inductive peaking technology can increase the bandwidth of the output signal, it leads to an increase in chip area, thereby raising manufacturing costs [12]. A currently effective approach is the design and optimization of transimpedance amplifier chips proposed by Ban Yu, which are applied to high-speed transceiver modules in integrated circuits. By introducing a spike at high frequencies, the bandwidth is enhanced to meet the 25Gbps requirement [12]. His experimental results indicate that beyond 105Hz, the gain enters relatively stable phases of 63.3626dB and 66.3626dB, demonstrating that the circuit gain remains relatively stable within this frequency band [12]. The frequency range where the gain declines from its peak to 3dB has a lower limit of approximately 40.0654kHz and an upper limit of approximately 27.4686GHz, reflecting the effective frequency range over which the circuit amplifies signals [12]. Meanwhile, if current compensation is added to enhance the transconductance of the main amplifier tube at low currents, thereby increasing bandwidth [12].

4. High-frequency Signal

4.1. High-frequency Signal Characteristics

The frequency band of an integrated circuit refers to the range of electrical signal frequencies that the circuit itself can effectively process, and its range is one of the key factors determining the transmission speed, distance, penetration capability, and interference resistance of the signal. High-frequency signals typically refer to those within the 3MHz to 30MHz range. Characterized by their short wavelengths, the manufacturing of integrated circuits for such signals often requires controlling line widths and spacings within extremely narrow tolerances—typically achieving atomic-level precision [13]. Additionally, during the manufacturing process, factors such as film thickness and doping concentration must be strictly controlled to prevent significant deviations that could compromise chip performance.

4.2. High-Frequency Signal Transmission Characteristics

High-frequency integrated circuits utilize more spectrum resources to achieve greater bandwidth, thereby meeting the requirements for high-speed signal transmission. At the same time, it can reduce environmental interference through methods such as frequency hopping and spread spectrum. Besides, within the 0–300 GHz range, the rectangular micro-coaxial transmission structure enables ultra-wideband operation with extremely low loss by transmitting in a near-pure TEM mode. It is more effective than traditional microstrip and coplanar waveguide transmission lines, with signals transmitted in an almost completely enclosed manner and isolation between adjacent transmission lines exceeding 60 dB [14]. However, high-frequency signal transmission also has numerous drawbacks and limitations. The higher the frequency of the signal, the greater the loss during transmission, the weaker the resistance to interference and crosstalk, and the more prone the signal is to distortion [14].

4.3. To Optimize High-frequency Signal Transmission

During high-frequency signal transmission, signal integrity is affected by impedance mismatch. Yin Yongsheng et al. designed an impedance-matching self-calibration circuit integrated within an integrated circuit based on TSMC's 0.18μm CMOS process, which comprises two current source modules, a comparator module, a digital control module, and a resistance trimming module [15]. As shown in Fig. 2.

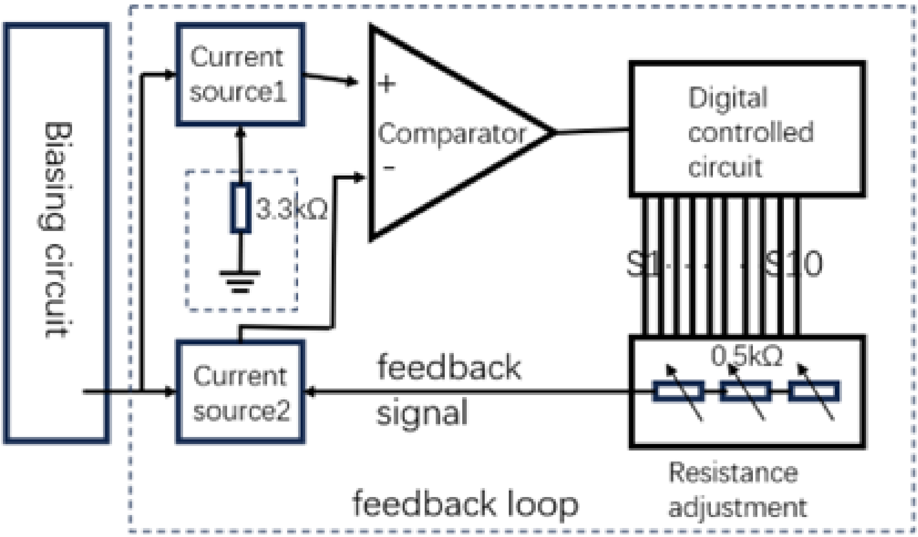

Fig. 2 Self-Calibrating Impedance Matching Circuit Diagram.

This circuit uses rnhpoly resistors for calibration (The process deviation of rnhpoly resistors is only 6.82%) [15]. This circuit ensures that the two current sources have the same output voltage by adjusting the ratio between current source 1 and current source 2, as well as the ratio between the two resistors [15]. The comparator's output is then transmitted to the digital control module to adjust the total resistance value of the resistor trimming module. Meanwhile, one signal path is extracted and transmitted to current source 2 to form a closed-loop system, thereby achieving impedance self-calibration [15].

5. Manufacturing Optimization for High-Bandwidth Integrated Circuits Used in Ultra-High-Speed Transmission of High-Frequency Signals

5.1. Optimization of Chip Manufacturing Materials

During the process of manufacturing, select thin-film materials with low dielectric constants and high performance. Low dielectric constant typically refers to values less than 3.9. During this process, Diethoxymethylsilane(DEMS) can be used to fabricate silicon-based semiconductor films with low dielectric constants [16]. The organic purity of the DEMS must reach 0.9999 by mass fraction, the total metal ion impurity content must be less than 5.000 μg/L, and the content of any single metal impurity must not exceed 0.500 μg/L [16]. Moreover, Han L integrated novel optoelectronic materials such as graphene and lithium niobate films onto a silicon photonics platform, achieving an integrated circuit bandwidth of 100GHz while simultaneously reducing chip energy consumption and enhancing the extinction ratio [17].

5.2. Optimization of Chip Manufacturing Processes

In terms of manufacturing processes, Ye Chunyi and colleagues investigated the application of chemical plating technology in chip manufacturing, which deposits metal ions from the solution onto only the desired substrate to form a metal coating. This process offers low cost, simple operation, and strong conformal plating capability, addressing the issue of uneven deposition of barrier layers in chip-to-chip interconnects and 3D packaging TSVs, simultaneously reducing the chip size enables more efficient transmission of high-frequency signals [18]. Hou Wenqiang et al. proposed using backpropagation neural networks (BPNN) and a fast non-dominant sorting genetic algorithm (NSGA-II) with an elite retention strategy to optimize bismuth-doped fiber amplifiers(A device for expanding the communication wavelength range and increasing transmission capacity), establish a BPNN model to clarify the relationship between structure and performance, thereby enabling multi-band signal transmission [19].

6. Challenges and Development Directions in Electronic Communication Technology

4G, 5G, and 6G technologies differ significantly in various aspects. The following Table 1 provides a brief overview:

Table 1. Comparison of 4G, 5G, and 6G

	4G	5G	6G
Download speed	5Mbps-100Mbps	50Mbps-10Gbps	>100Gbps
Time delay	10-50ms	1-10ms	0.1-1ms
Base station coverage area	1000-3000m	100-300m	global
Safety Mechanism	VoLTE	5G-AKA	

With the continuous advancement of mobile communication technology, data transmission speeds have significantly increased, latency has steadily decreased, base station coverage has expanded, and data transmission security has been continuously enhanced. However, as technology continues to advance, the costs associated with equipment construction and maintenance also increase accordingly. Meanwhile, the 5G industry still faces numerous challenges, including difficulties in integrating with traditional industries' information infrastructure and fragmented solutions.

Currently, 5G networks are evolving toward intelligent site selection, concealed deployment, and comprehensive coverage in base station construction. In the realm of the Internet of Everything, 5G technology is advancing toward non-terrestrial networks to achieve global coverage. And in the realm of artificial intelligence, 5G technology is actively integrating with AI, advancing toward the development of an integrated network that unifies connectivity, sensing, computing, and intelligence.

7. Conclusion

This paper analyzes and illustrates the current state of integrated circuit development in the field of communications, as well as its existing shortcomings. Clarify the principles of electrical signal transmission in integrated circuits. By describing the characteristics and advantages and disadvantages of high-frequency signal transmission, as well as the impact of bandwidth on signal transmission, this paper summarizes methods and conclusions for optimizing it. And the paper also explores how to improve material selection and manufacturing techniques in the integrated circuit manufacturing process. It provides direction for technological advancement in the field of communications, holding significant importance for the early realization of ultra-high-speed signal transmission and the evolving communications industry. Although significant progress has been made in 5G high-frequency signal transmission technology, further optimization is still required in specialized areas such as radio frequency and baseband processing. Currently, artificial intelligence continues to advance and empower the communications sector. In the future, 6G communications and satellite communications will gradually permeate people's lives, offering greater convenience to humanity.

References

[1] Lu Kaixin. Analysis of 5G Communication Technology Applications in Telemedicine [J]. China New Communications, 2023, 25(20): 68-70.

[2] Ren Zhengdongxie. Application of 5G Communication Technology in Satellite Navigation and Positioning [J]. Communications World, 2025, 32(04): 151-153.

[3] Li Mian, Li Yang, Zhang Zonghui, et al. Efficient Distributed Precoding Design for Massive MIMO Communications [J]. Transactions of the Institute of Communications of China, 2023, 44(08): 37-48.

[4] Wang Yangyi, Tian Yi. 5G Standards and Key Technologies [J]. Information Technology and Standardization, 2016, (06): 47-51.

[5] Zhang Kaiwen, Pan Zicheng, Pan Xinyu, et al. Research on All-Band Intelligent Communication Receivers [J]. Internet of Things Technology, 2024, 14(04): 46-49. DOI: 10.16667/j.issn.2095-1302.2024.04.012.

[6] Chen, L. P. Research on the Development of Metal Interconnects and Their Wet Electronic Chemicals [J]. Research and Progress in Solid-State Electronics, 2024, 44(04): 343-350.

[7] Vijeswaran D, Manikandan V. Stability Analysis of Cyber-Physical Micro Grid Load Frequency Control System with Time-Varying Delay and Non-Linear Load Perturbations[J]. Computer Modeling in Engineering & Sciences,2019,121(3):801-813.

[8] Dai Baoxiang, Cui Yuan, Zhu Lei, et al. Design and Implementation of a High-Speed Digital Signal Transmission System Based on FPGA and Fiber Optic Transmission [J]. Home Appliance Maintenance, 2025, (02): 77-79+76.

[9] Zhang Yongyong. Research on Complete Technology for High-Speed Railway Signal System Upgrade and Transformation [C]// Chongqing Big Data and Artificial Intelligence Industry Association. Proceedings of the Academic Symposium on Artificial Intelligence and Economic Engineering Development (II). China Railway Electrification Bureau Group North Engineering Co., Ltd.; 2025: 1246-1249. DOI: 10.26914/c.cnkihy.2025.013860.

[10] Gao Yang. A Bandwidth Extension Technique for CMOS Amplifiers [J]. Popular Science and Technology, 2010, (10): 33-34.

[11] Kumari T, Senapati A, Ghazali N A. F-Slotted Multiple-Input Multiple-Output Antenna with High Gain, High Isolation, and Expanded Bandwidth for Ultra-Wideband Wireless Applications[J]. Wireless Personal Communications,2025, (prepublish):1-26.

[12] Ban Yu. Design of a High-Speed Transimpedance Amplifier Chip with Wide Bandwidth and High Gain [J]. Journal of Terahertz Science and Electronics, 2025, 23(01): 35-39.

[13] Oupeng L, Jia H, Kun Z, et al.Integrated sensing and communication in 6G: a prototype of high resolution multichannel THz sensing on portable device[J]. EURASIP Journal on Wireless Communications and Networking,2022,2022(1):

[14] Yu Jiabing, Zhang Chao. Application and Development of High-Frequency Signal Amplification Technology in Information and Communication Engineering [J]. Digital Technology and Application, 2025, 43(04): 52-54.

[15] Yin, Y. S., Zhao, P. C., Deng, H. H., et al. A High-Frequency Impedance-Matching Self-Calibration Circuit. Microelectronics, 2017, 47(03): 367-371. DOI: 10.13911/j.cnki.1004-3365.2017.03.017.

[16] Shi, Z., Ding, Q. Y., Yuan, Z. J., et al. Study on Purification Technology of 4N Electronic-Grade Diethoxymethylsilane [J]. Acta Chimica Sinica, 2025, 76(05): 2186-2197+2419.

[17] Han L. Vision and trend analysis for transport networks in 5G era[C]. Present on ACP, 2020.

[18] Ye, C.Y., Wu, X.X., Zhang, Z.B., et al. Research Progress on Electroless Plating Technology in Chip Manufacturing [J]. Acta Chimica Sinica, 2022, 80(12): 1643-1663.

[19] Hou Wenqiang, Pei Li, Wang Jianshuai, et al. Design of Bismuth-Doped Fiber Amplifiers Based on Neural Networks and Multi-Objective Optimization Algorithms [J]. Acta Optica Sinica, 2024, 44(02): 120-127.