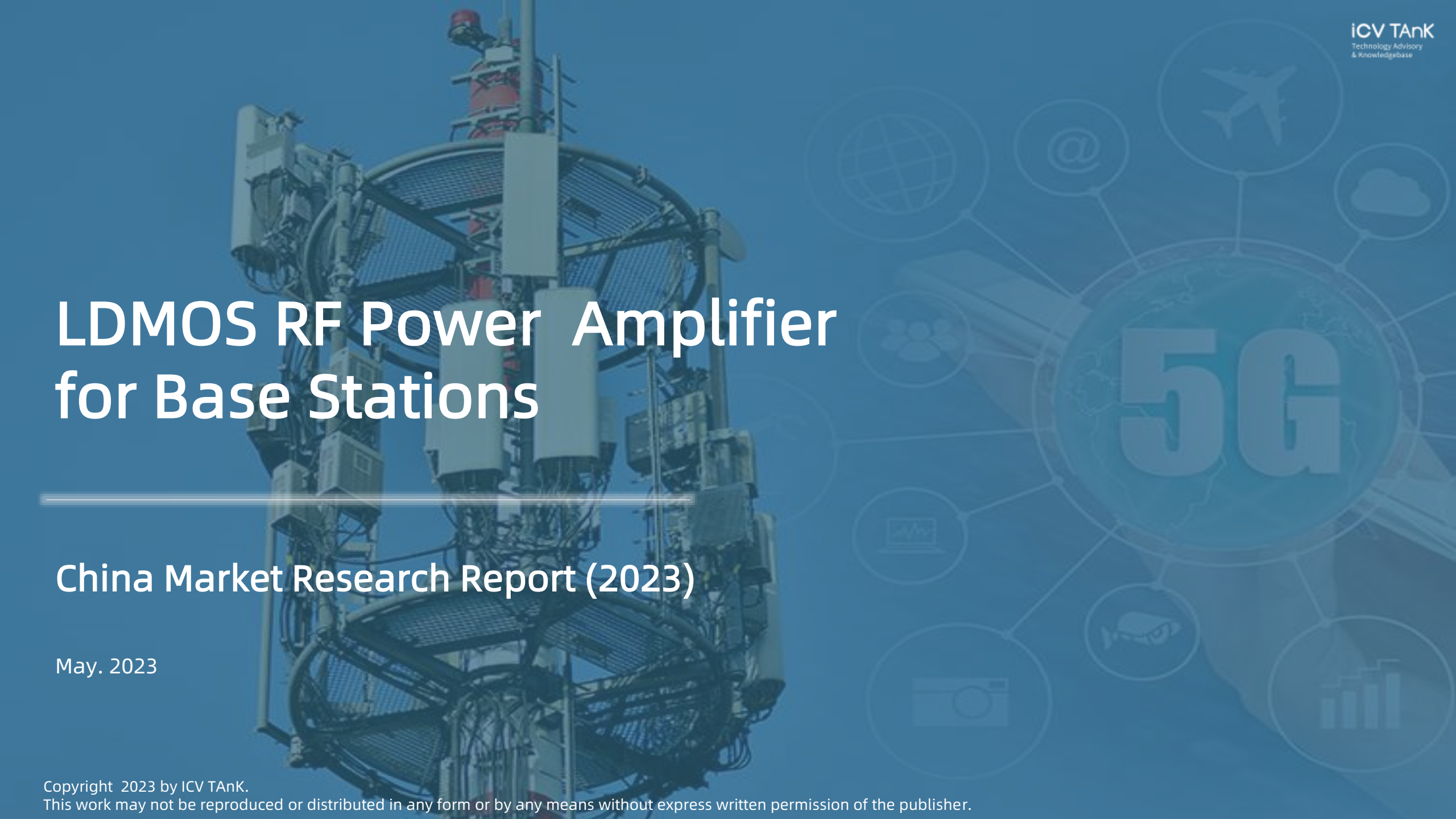

LDMOS RF Power Amplifier for Base Stations

China Market Research Report (2023)

May. 2023

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Methodology

Industry research: By conducting interviews with relevant companies, consumers, and industry experts, we aim to understand the demand, trends, and scale of the market.

Data analysis: By collecting, organizing, and analyzing market data, including market size, growth rate, pricing trends, consumer preferences, and more, we aim to understand the current status and development trends of the market.

Competitive analysis: By analyzing information such as competitor's products, prices, and market share, we aim to understand the competitive landscape in the market and our own strengths and weaknesses.

Technical analysis: By evaluating the technical requirements and development trends of the market, including the advantages and disadvantages of single photon detector technology characteristics, we aim to gain insights into the market's direction.

Regional analysis: By understanding factors such as local consumer demands and policy environments, we aim to identify regional differences in markets and potential for development.

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1.1 Overview

LDMOS is an enhanced mode N-channel MOSFET commonly used in RF power circuits to meet the requirements of high voltage tolerance and power control. In the field of telecommunications, LDMOS RF power amplifiers are widely used in communication base stations and mobile radios due to their advantages of low cost, high integration, and better compatibility with DPD (Digital Pre-Distortion). Among them, communication base stations are currently the largest application area for LDMOS.

In the global mobile communications industry, early technologies and markets were primarily dominated by European companies. However, with the upgrade and iteration of communication technologies from 2G to 5G, Chinese companies have gradually risen and become major participants in the global mobile communications industry.

As a high-tech industry in the upstream of the industrial chain with high technical barriers, European manufacturers such as NXP and Ampleon have a long history of development, and they have advantages in terms of capital investment, research and development innovation, and technological accumulation, which contributes to the recognition and industry awareness of LDMOS RF power amplifier products. In China, as the region with the largest investment in mobile communication infrastructure worldwide, domestic companies started relatively late in the field of LDMOS. However, they have persisted in independent innovation and effectively improved their technical capabilities, leading to the development of competitive enterprises that can rival well-known European manufacturers. The self-sufficiency rate of their products has steadily increased.

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1.2 Significance of Researching the Chinese Market (1)

The industry data in the Chinese region is relatively transparent and publicly available, providing a solid foundation for industry research.

Unlike other countries or regions where the telecommunications industry is primarily driven by private enterprises, China's telecommunications infrastructure construction and operation are government-led, and the telecommunications operators are all state-owned enterprises. A large amount of fundamental data is officially collected and published by the authorities. The Ministry of Industry and Information Technology (MIIT) is the regulatory authority responsible for the Chinese mobile communications industry. It is primarily responsible for industry planning, coordinating network construction, formulating tariff policies, and industry regulation. MIIT regularly releases relevant data on the Chinese telecommunications industry, including key information such as the number of base stations, user subscriptions, and data traffic. In addition, Chinese telecommunications operators such as China Mobile, China Unicom, and China Telecom are publicly listed companies, and they provide comprehensive data disclosures.

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1.2 Significance of Researching the Chinese Market (2)

China holds a leading position in mobile communication technology. In the 1G/2G era, the industry's technical systems and standards were dominated by European countries and companies. However, starting from the 3G era, the Chinese government and enterprises began investing in the field and emerged as industry leaders in the 4G/5G era. Prominent communication equipment suppliers such as Huawei and ZTE have emerged. Despite facing sanctions from the United States, Huawei still maintains a market share of approximately 30% in the global base station market, making it the global leader. In terms of patent quantity, as of the end of 2022, Huawei holds a 14.59% share of the global effective patent families, ranking first. ZTE, Datang, OPPO, and Xiaomi are also among the top ten in terms of patent quantity.

In terms of investment in ICT infrastructure, China is far ahead. According to public data from Chinese government agencies and telecommunications operators, China ranks first globally in the number of base stations deployed. Taking 5G base stations as an example, China accounts for over 60% of the global total. In economically developed regions such as North America and Europe, the adoption rate of 5G is far lower compared to China, with mobile network coverage primarily dominated by 4G, and 5G deployment is still in the early stages. In some economically disadvantaged regions like the Middle East and Africa, signal coverage still relies primarily on 2G/3G, and 4G deployment is at its peak.

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1.2 Significance of Researching the Chinese Market (3)

There are two main reasons for China's leadership in this area. Firstly, the construction of China's communication infrastructure is government-led and receives significant financial support. Moreover, the allocation of spectrum is more efficient. Secondly, China has a large population with strong market demand. Compared to regions like Europe and the Americas, China has a higher population density. The network characteristics of mobile communications indicate that areas with higher population density exhibit more pronounced economic benefits in terms of communication infrastructure construction. This is particularly evident in the initial massive investment in 5G deployment, where private telecommunications operators in other regions bear the responsibility for profit and loss.

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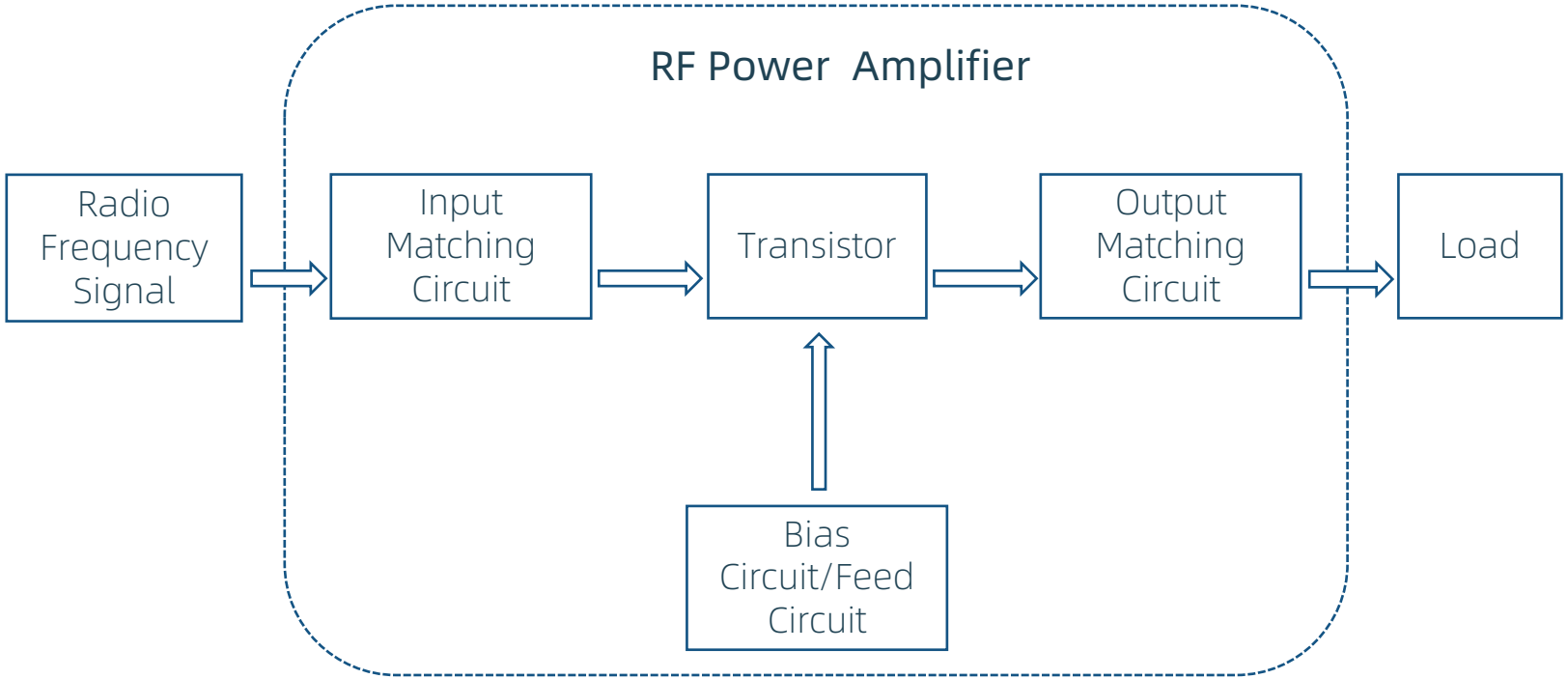
2.1 Principles of RF Power Amplifiers



RF power amplifiers are used to amplify RF signals, allowing weak modulated signals to be amplified to a sufficient power level at the output. They typically consist of transistors, input/output matching circuits, biasing circuits, and feed circuits. The principle behind them is to convert the power from the power supply into a current that varies according to the input signal, utilizing the current/voltage control function of the transistor, thereby achieving current/voltage amplification.

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2.2 Applications of RF Power Amplifiers

Compared to traditional power amplifiers, RF power amplifiers have the following characteristics within higher frequency bands: higher output power, higher efficiency, and higher reliability. They serve as a core component in RF front-end architectures for applications such as base stations, mobile phones, WiFi, NB-IoT, and other wireless communication fields. They can also be integrated into RF power sources for industrial, medical, scientific, and other domains.

This research primarily focuses on the application of RF power amplifiers in the field of base stations.

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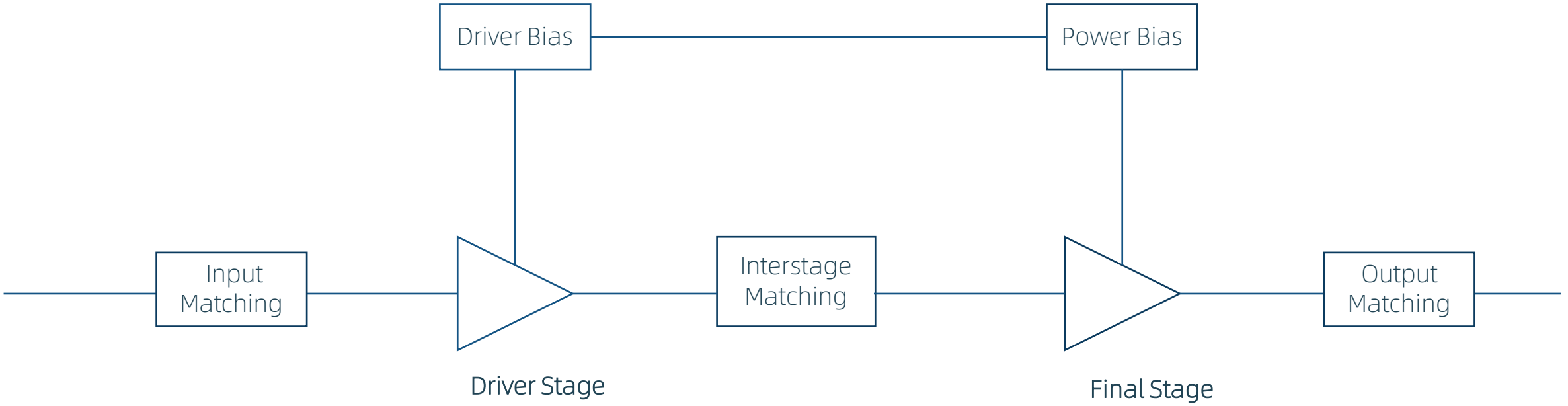
2.3 Structure of Base Station RF Power Amplifiers



RF power amplifiers are crucial components in the RF front-end of base stations, as their performance directly affects important factors such as signal strength and stability, ultimately influencing the end-user experience. In the transmission link of a base station, RF power amplifiers are utilized to amplify the signal gradually from the pre-driver stage/driver stage to the final stage, converting weak signals into higher-power signals, which are then fed to the antenna for radiation outward. This process achieves gain amplification of the input excitation signal and converts DC power into microwave power output.

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2.4 Main Types of Base Station RF Power Amplifiers

Since the introduction of 2G mobile communication technology, LDMOS has gradually become the market mainstream in communication base station applications and has maintained its position to this day. With the development of 4G and 5G mobile communication technologies, GaN has been widely adopted in communication base stations due to its excellent performance in high-frequency applications. However, in medium and low-frequency applications, LDMOS remains the mainstream choice due to its advantages of low cost, high integration, and better compatibility with Digital Pre-Distortion (DPD). In power-limited scenarios such as pre-driver stages and small base stations, GaAs is still used, albeit with a smaller and smaller market share, and thus it is not the main focus of this discussion.

GaN RF Power Amplifier

LDMOS RF Power Amplifier

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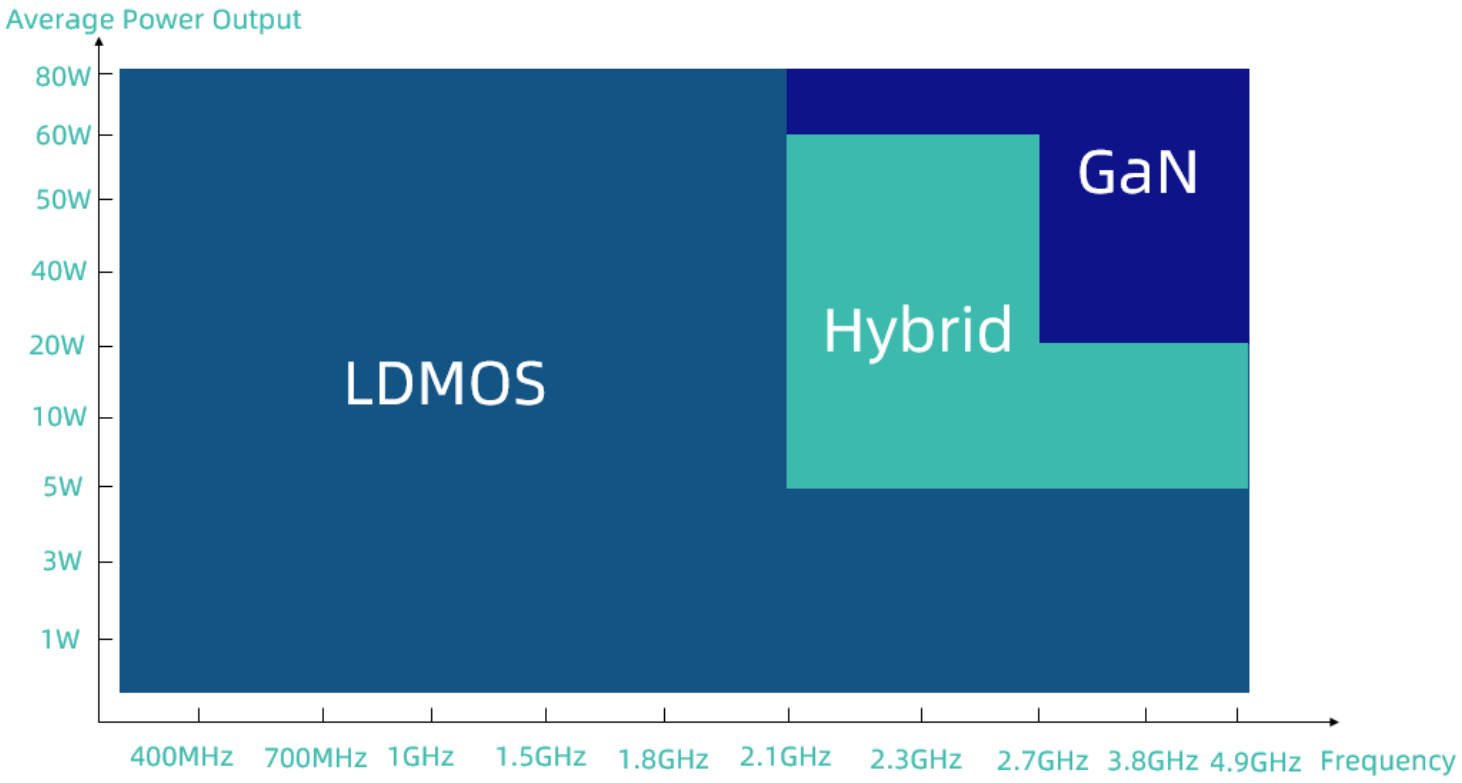
2.5 Different Application Ranges of LDMOS and GaN Based on Frequency and Power



Based on their respective advantages, LDMOS and GaN have different primary application areas. GaN is primarily concentrated in high-frequency, high-power scenarios, while LDMOS is mainly used in medium and low-frequency scenarios. Additionally, LDMOS also finds application in some high-frequency, low-power scenarios.

The choice between GaN and LDMOS is not always straightforward, which is always dynamic and dependent on OEM's strategy.

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3.1 Classifications of Base Station

Type	Coverage Radius	Applications
Macro Base Stations	Above 200 meters	Primarily utilized for outdoor wide-area network signal coverage
Small Base Stations	50-200 meters	Primarily deployed in areas such as urban streets, residential neighborhoods, and large-scale industrial parks where macrocell base stations are unable to provide coverage
Indoor DAS	10-50 meters	Primarily deployed indoors to provide network signal coverage in environments such as shopping malls, office buildings, hotels, and other similar settings

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3.2 The Advancement of 5G Technology Has Resulted in an Increase in The Deployment Density of Base Stations

Frequency is a scarce resource in mobile communication, and it is crucial to plan and allocate it properly to prevent interference between different communication systems. While frequency allocation varies across countries and regions, the development of wireless communication technology has led to the occupation of low-frequency bands, driving the shift towards higher-frequency bands. In China, 5G primarily operates in frequency bands such as 2.5GHz-2.7GHz, 3.3GHz-3.6GHz and 4.8GHz-5GHz, whereas the United States predominantly focuses on higher-frequency millimeter waves.

In ideal conditions (without considering losses), the formula for wireless signal transmission distance is as follows:

$$d = \frac{1}{4\pi} \cdot \sqrt{\frac{Pt \cdot Gt \cdot Gr}{Pr}} \cdot \lambda$$

d: wireless radio wave transmission distance Pt: the base station's transmit power Pr: the terminal's receive power
λ: the wavelength of the electromagnetic wave Gt: the base station's transmit antenna gain Gr: the terminal's receive antenna gain

Therefore, in order to achieve the same coverage effect, 5G base stations require a higher density of construction.

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3.3 Comparison of Construction Density between 5G and 4G Macro Base Stations

4G Macro Base Stations

5G Macro Base Stations

The distribution density of 4G macro base stations in urban centers is approximately 500 meters per station, whereas 5G macro base stations require an estimated density of around 250 meters per station. In general, the demand for 5G macro base stations in urban centers is two to three times higher than that for 4G macro base stations.

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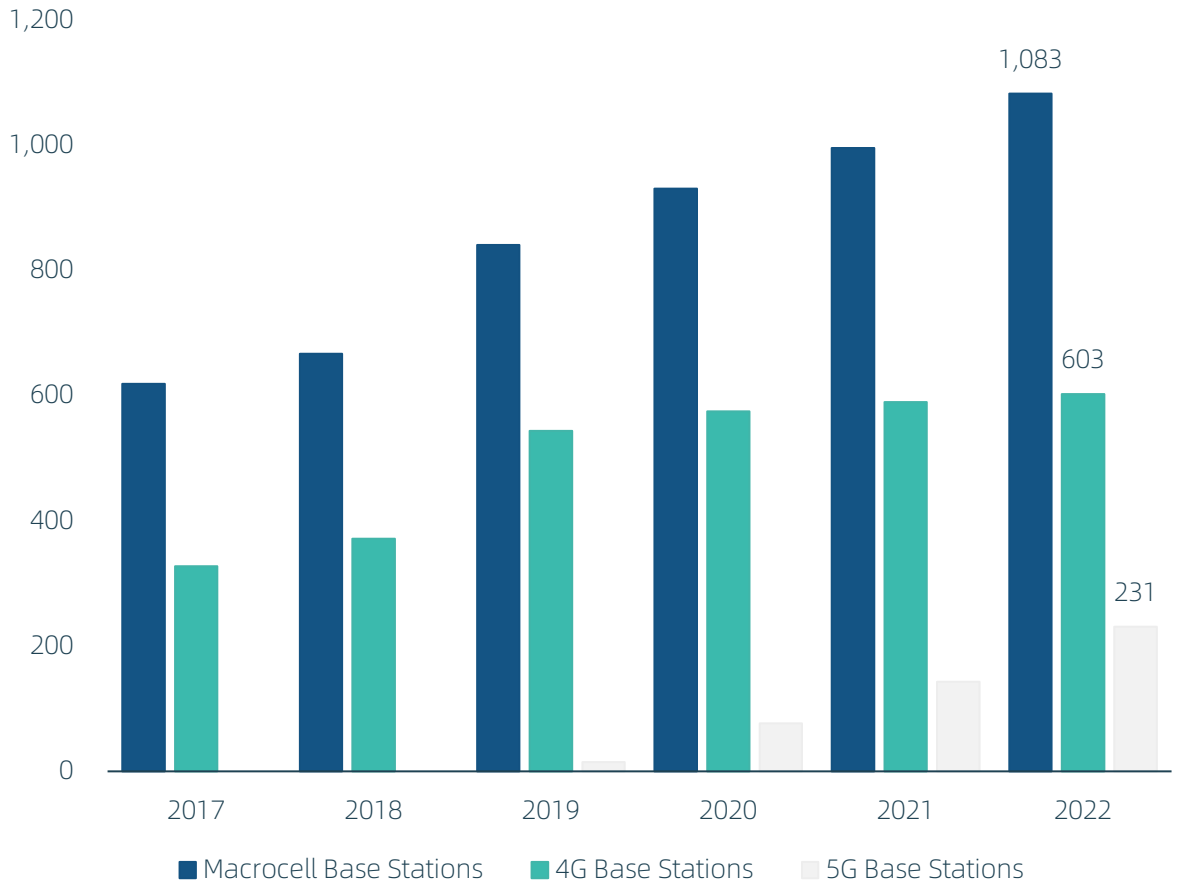
3.4 Increasing Number of Base Station Deployments(1)

Total Number of Base Stations in China (in 10 Thousand Units)



According to the 2022 Telecommunications Industry Statistics Report released by the National Ministry of Industry and Information Technology of China, the total number of mobile communication base stations in the country reached 10.83 million by the end of 2022, with a net increase of 870,000 throughout the year. Among these, there were 2.312 million 5G base stations, with 887,000 new 5G base stations deployed during the year, while the number of 4G base stations amounted to 6.03 million, with 130,000 new 4G base stations added during the same period.

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3.4 Increasing Number of Base Station Deployments(2)

According to the "14th Five-Year Plan for the Development of the Information and Communication Industry" proposed by the National Ministry of Industry and Information Technology of China, by 2025, there will be 26 5G base stations per 10,000 people in China.

While the final stage of the RF power amplifier in high frequency 5G macro base stations primarily utilizes GaN technology, the driver stage still has a significant proportion of LDMOS usage due to its advantages of low cost, high integration, and better compatibility with DPD (Digital Pre-Distortion).

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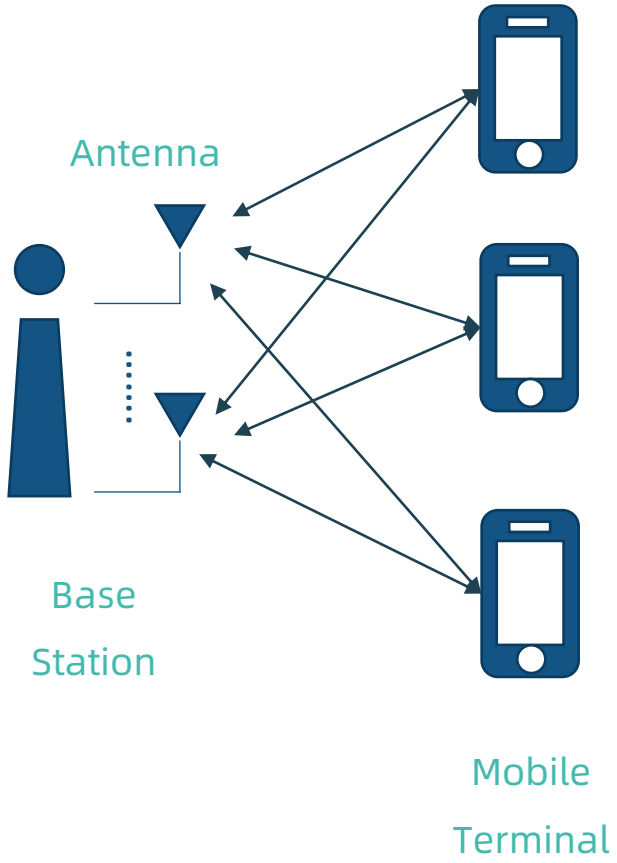
3.5 Popularization of MIMO Technology



Traditional SISO (Single Input Single Output) involves data transmission between base stations and mobile terminals through a single channel. In order to improve data upload and download speeds, MIMO (Multiple Input Multiple Output) technology has emerged. It allows multiple antennas to simultaneously transmit and receive signals, significantly increasing the system's channel capacity without the need for additional spectrum resources or increased antenna transmit power.

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3.6 Significant Increase in Communication Base Station Antenna Channels with Massive MIMO

	5G Macrocell Base Stations				
Single-sided Channels	64	32	8	4	2
Total Channels	192	96	24	12	6

	4G Macrocell Base Stations		
Single-sided Channels	8	4	2
Total Channels	24	12	6

Note: Macro base stations typically have three antennas

To meet the high transmission speeds of 5G, Massive MIMO has been widely adopted, surpassing MIMO with 2/4/8 antennas. Massive MIMO systems can have 32/64 antennas, greatly increasing the number of channels. As each transmission channel requires a power amplifier, the demand for power amplifiers has multiplied.

With a constant power output per individual base station, having more transmission channels results in lower power per channel, thereby increasing the demand for LDMOS.

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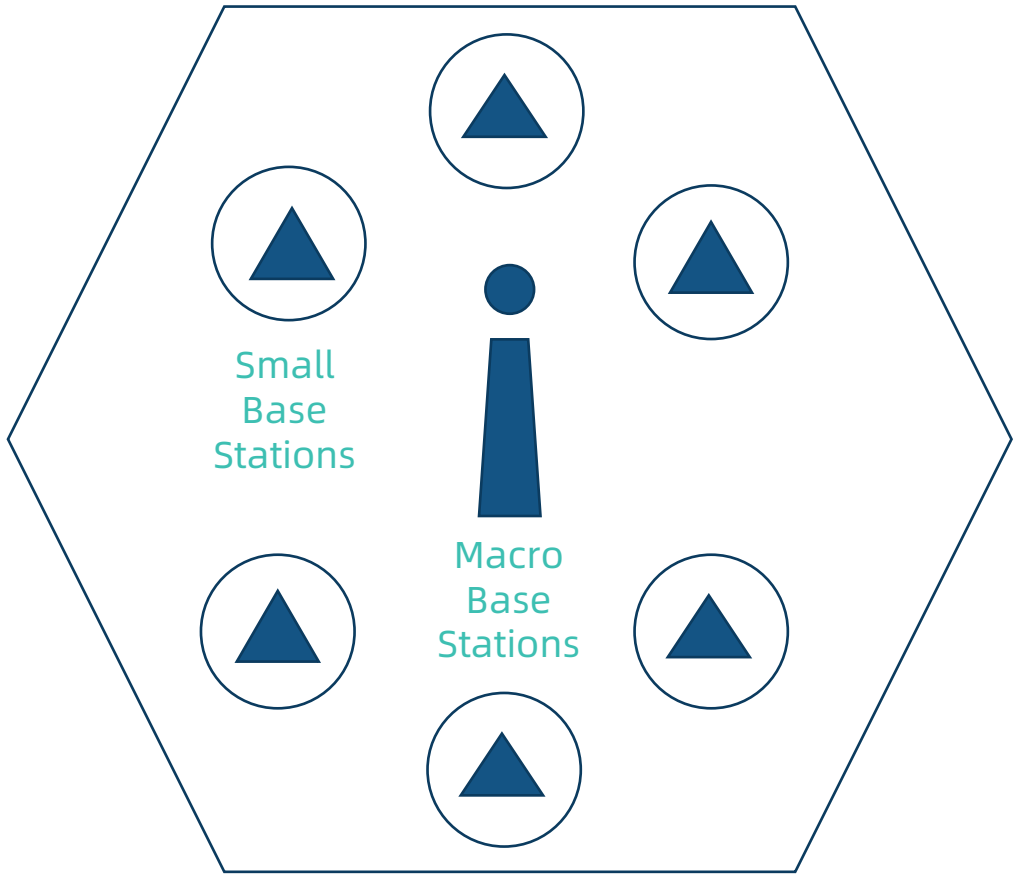
3.7 Small Cell Deployment as a Cost-effective and Enhanced Coverage Network Solution



Small cell deployment demands higher chip integration, making silicon-based LDMOS the mainstream choice. However, there are a few companies that opt for GaAs technology.

Due to the higher frequency of 5G signals, they have weaker wall penetration and diffraction capabilities, resulting in coverage blind spots. Macro base stations, due to their large footprint and impact on the urban environment, are not feasible for widespread deployment. To address the coverage gaps, small cell deployment has emerged as a cost-effective and enhanced coverage network solution, allowing for increased base station density.

Given the higher frequency of 5G, a denser deployment of small cells is required to achieve network coverage. Typically, one 5G macro base station requires 2-10 small cells to form a network and ensure signal coverage. Initially, the focus of 5G deployment is often on macro base stations, and as the construction reaches a certain scale, the demand for small cells emerges.

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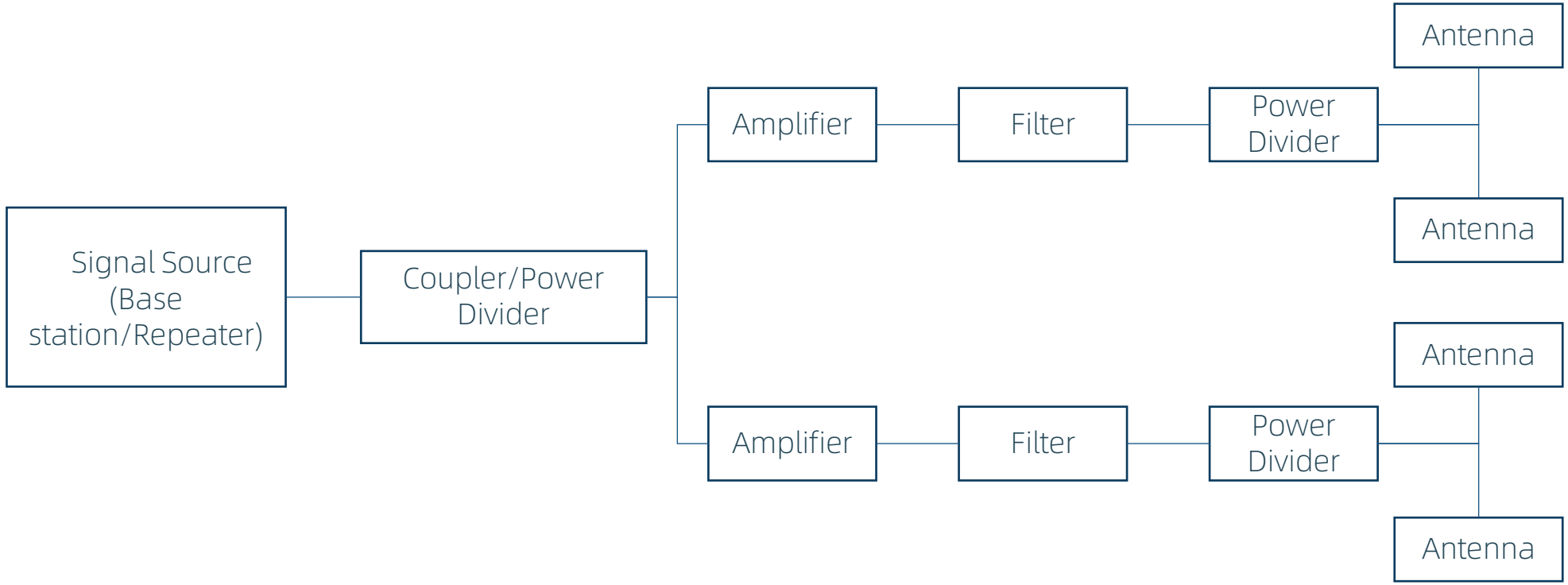
3.8 Indoor Distributed Systems as Essential Solutions for Indoor Signal Coverage



In indoor environments such as shopping malls, office buildings, and hotels, the network signals transmitted by base stations often face obstacles such as walls and windows, resulting in uneven coverage. To address this, various indoor distributed systems are used to evenly distribute the base station signals to every corner of the indoor space. LDMOS is the mainstream choice in Indoor distributed systems.

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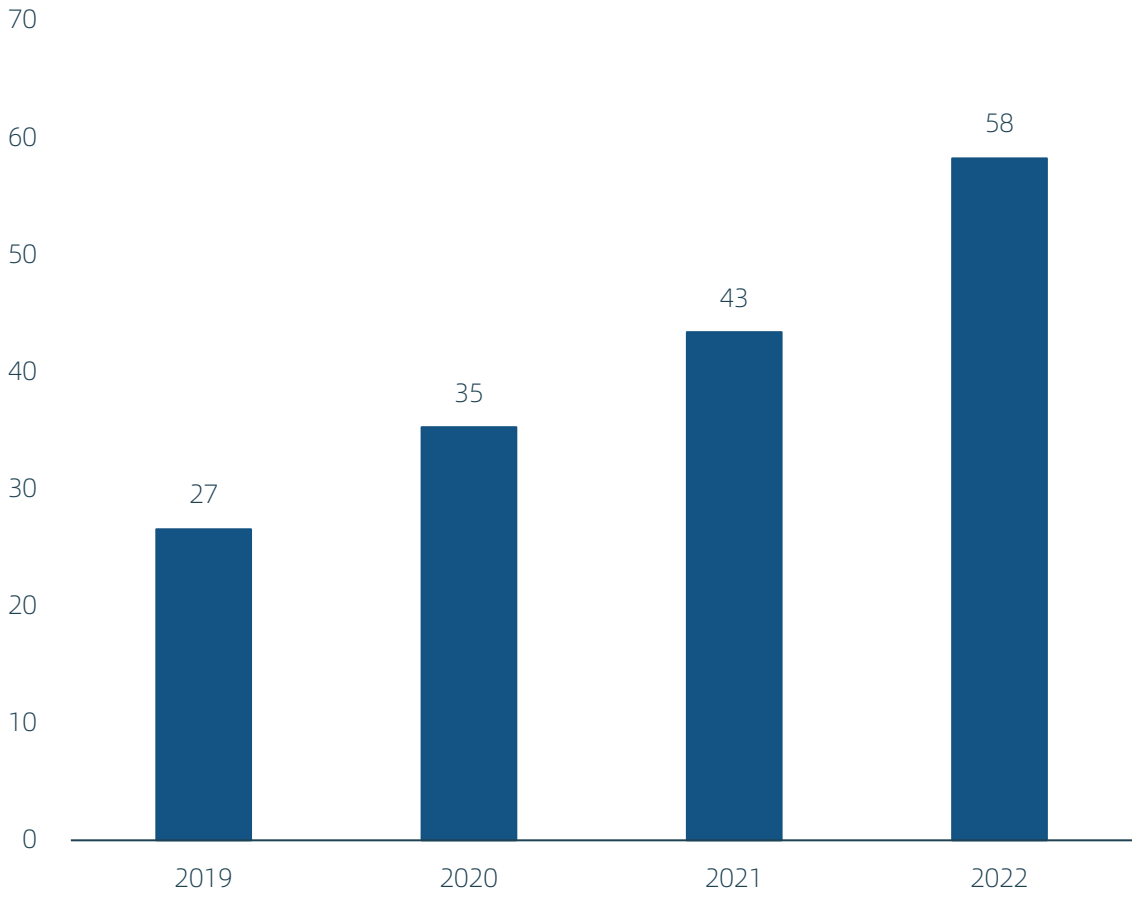
3.9 China Tower's Rapid Revenue Growth in Indoor Distributed Systems Business

China Tower's Indoor Coverage Business Revenue (in 100 Million RMB)



China Tower, with major shareholders including China Mobile, China Unicom, and China Telecom, is responsible for the construction, maintenance, and operation of a significant portion of communication towers and associated infrastructure, as well as the development of public network coverage for high-speed railways, subways, and large-scale indoor distributed systems.

According to the annual report released by China Tower in 2022, their indoor distributed systems have achieved a cumulative coverage of 7.39 billion square meters, representing a year-on-year growth of 48.1%. The total coverage of high-speed railway tunnels and subways has reached 20,040 kilometers, showing a year-on-year growth of 18.5%. The indoor distributed systems business has maintained a high-speed growth trend in terms of revenue.

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3.10 Spectrum Refarming Enables Low-Frequency Bands for 5G

Operator	Frequency Range
China Mobile/ China Broadcast Network	700MHz
China Unicom/China Telecom	900MHz

To address the scarcity of frequency resources and reduce the cost of 5G deployment, the Ministry of Industry and Information Technology of China allocated the 700MHz frequency band for 5G use in 2020. It was jointly constructed by China Broadcasting Network and China Mobile. In 2022, the 900MHz frequency band was further allocated for 5G use, and it is being jointly developed by China Unicom and China Telecom. The above low-frequency base stations will be set up more in the near future.

These low-frequency bands were originally used by 2G/3G/4G technologies. The reallocation of frequency bands has reduced the cost of 5G deployment, making it economically viable to provide 5G coverage in rural and remote areas with lower population densities. As older communication technologies like 2G are phased out, there is a continuous expectation of releasing low-frequency spectrum resources, which will further drive the market demand for LDMOS.

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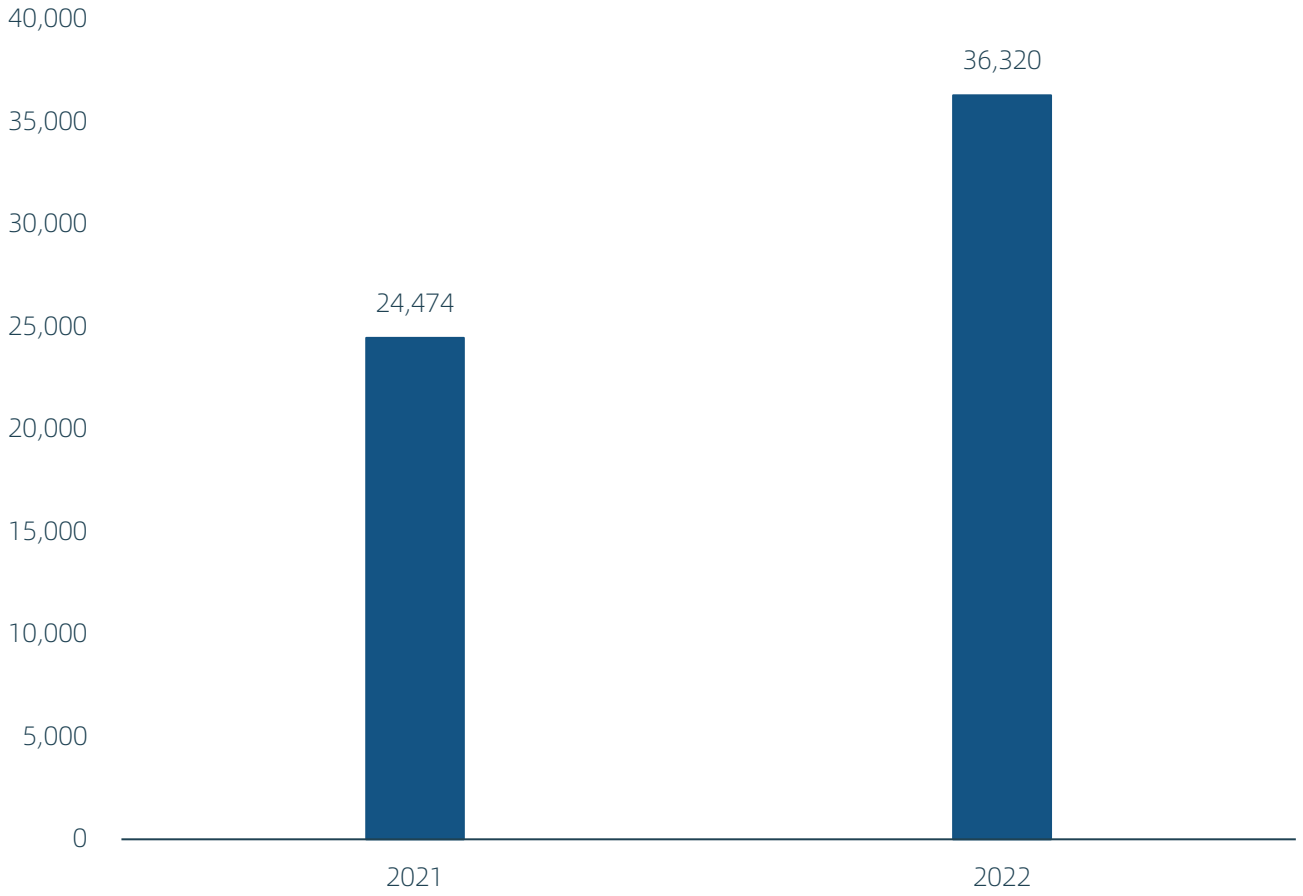
4. Steady Increase in Demand for LDMOS in RF Power Amplifiers for New Base Stations in China

Demand for LDMOS RF Power Amplifiers in Newly Constructed Base Stations in China (2021-2022) (in Thousands)



LDMOS has been the mainstream choice for applications in the mid-to-low frequency range and power levels, and it cannot be replaced by GaN. Furthermore, driven by factors such as spectrum refarming, small cell deployment, and indoor distributed systems, the market demand has been steadily increasing.

In 2021 and 2022, the quantities of LDMOS RF power amplifiers used in new base stations in China were 24,474 thousand units and 36,320 thousand units, respectively.

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5250 Fairwind Dr. Mississauga, Ontario, L5R 3H4, Canada
(+1) 929 530 5901
infer@icvtank.com

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