POLITECNICO DI TORINO

Master's Degree Automotive Engineering

MASTER FINAL PROJECT

Research on China's Base Station Antenna Industry

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December 2021

ABSTRACT

The wireless communication network brings great convenience to people's daily life, and makes the information exchange between people faster, more efficient, and safer. However, with the rapid growth of user demand, 4G is becoming more and more congested, and the fifth-generation mobile communication system represented by the efficient use of spectrum resources and the intelligent allocation of individual needs has begun to arise. The rapid development of the fifth-generation mobile communication technology has put forward higher requirements and challenges for base station antennas. This thesis reviews the development of China's base station antenna industry. This thesis will discuss the opportunities and challenges that the arrival of 5G will bring to China's base station antenna industry, such as industry upstream materials. This thesis will also discuss the factors that promote and restrict the development of China's base station antenna industry.

Key words: base station, antenna, 5G, materials

ACKNOWLEDGEMENTS

I would like to express deepest appreciation to everyone who helped me during my thesis.

Firstly, I am extremely thankful to my Supervisor, Prof. Ladislau Matekovits for his constant encouragement and guidance.

In addition, I would like to thank my friends for their continued supports and valuable suggestions.

Finally, I would like to thank my parents for their loving considerations and confidence in my all through these years. Without their invaluable motivation and help, I would not be who I am today.

Table of contents

List of Figure

List of Table

CHAPTER I

I. Introduction of base station antenna

In the era of information explosion, mobile communications and networks have been widely promoted, and at the same time they have become the most active areas of development in the life of the society.

The base station antenna is a converter that converts the guided wave propagating on the line and the electromagnetic wave radiated in space, and acts as an intermediate component for transmitting or receiving signals. According to the purpose, antennas can be divided into communication antennas, broadcast antennas, television antennas, radar antennas, etc. According to the function, communication antennas can be divided into three categories: network coverage antennas, communication transmission antennas and terminal antennas. The three types of antennas can be further subdivided according to different purposes. Base station antennas are a subdivision of network coverage antennas and are mainly installed on communication base stations. The performance of base station antenna affects the signal reception quality of the entire communication system and affects the communication quality.

I.1. Antenna Glossary

There are many important properties of antenna. This paper we only mention four fundamental properties: directivity, gain, radiation pattern and polarization.

I.1.1. Directivity

Antennas have different radiation or receiving strengths in different directions. This is the directivity of the antenna. A radiation pattern is usually used to measure the directivity of an antenna.

I.1.2. Gain

Gain is one of the most important parameters. It quantitatively describes the degree to which an antenna concentrates the input power, and is used to measure the ability of the antenna to radiate or receive electromagnetic waves in a specific direction. Antenna gain usually refers to the gain in the direction of maximum radiation. Under the same conditions, the higher the gain, the better the directivity, and the farther the radio wave travels, that is, the coverage distance increases. However, the width of the wave speed will be compressed, and the narrower the lobe, resulting in poorer coverage uniformity.

I.1.3. Radiation pattern

Antenna radiation pattern, also known as antenna pattern and far-field pattern, is a graphical description of antenna radiation.

I.1.4. Polarization

Antenna polarization is a vector parameter that describes the electromagnetic wave radiated by the antenna in a certain direction. Polarization usually describes the direction of the electric field. Antennas usually have several polarization modes such as horizontal polarization, vertical polarization, ± 45° polarization. For example, when the electric field direction is perpendicular to the ground, it is called vertical polarization. There are several examples of polarization methods as shown in Figure 1 [1].

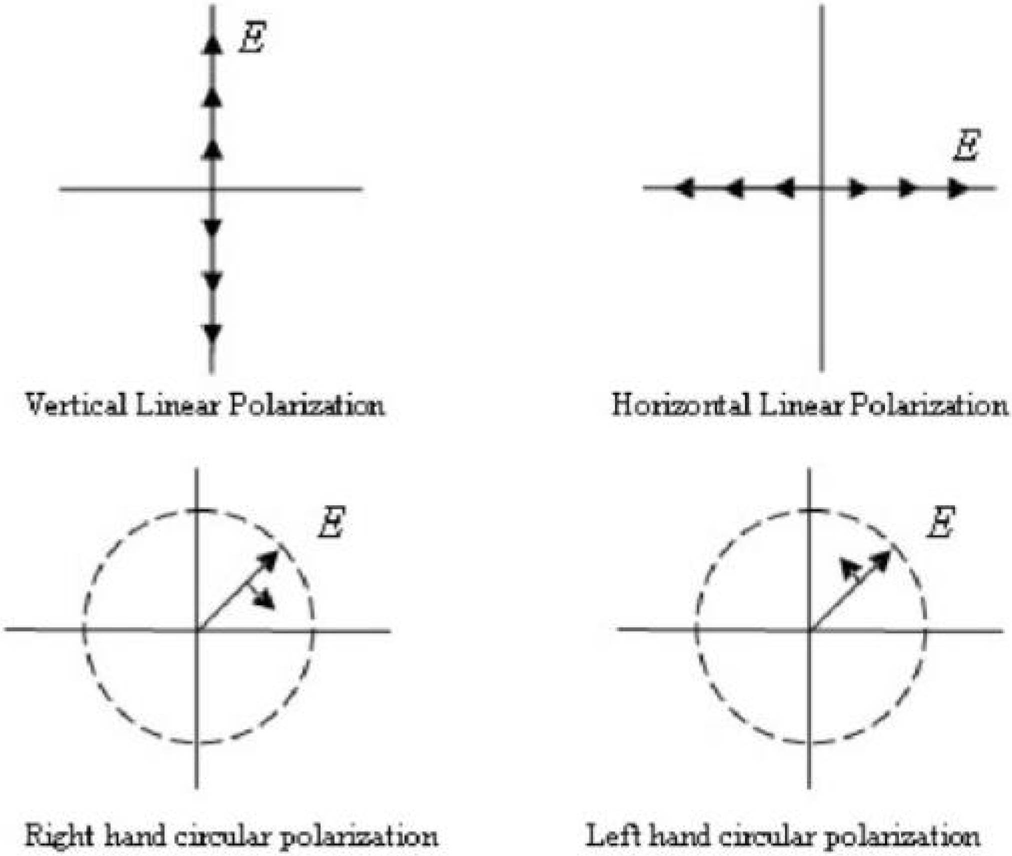


Figure 1: Examples of polarization [1].

I.2. Classification of base station antenna

According to the directionality, base station antennas can be classified as omnidirectional and directional antennas. According to the polarization, base station antennas can also be classified as unipolar and bipolar antennas.

I.2.1. Omnidirectional antenna

The omnidirectional antenna shows uniform radiation in 360° on the horizontal pattern. There is an example of radiation pattern of the omnidirectional antenna as shown in Figure 2 [2].We can clearly see the omnidirectional antenna has a large coverage area in the horizontal direction, but the coverage area is small in the vertical direction. In areas with many obstructions, the omnidirectional antenna may not be able to achieve effective coverage in all directions, and is generally suitable for indoor signal transmission, such as ceiling-mounted omnidirectional antennas and wall-mounted omnidirectional antennas. In the mobile communication system, this type of antenna is generally used in the suburbs.

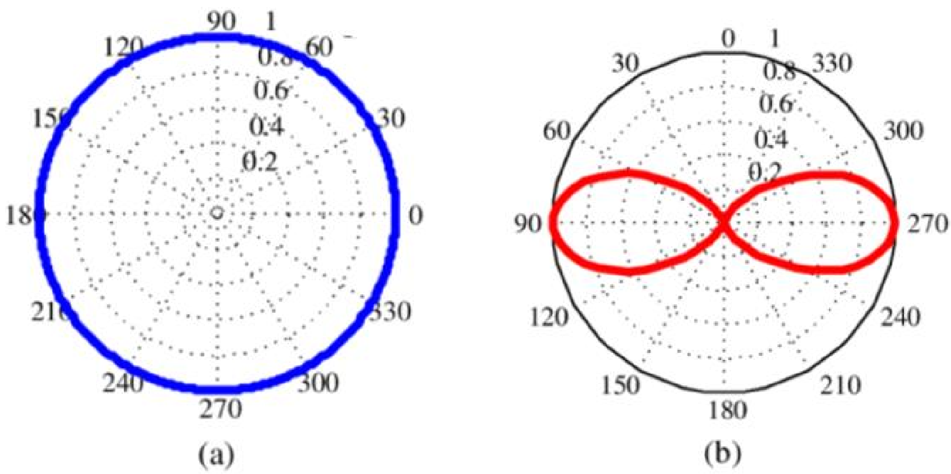


Figure 2: The radiation pattern of the omnidirectional antenna (a) The H-plane. (b) The V-plane [2].

I.2.2. Directional antenna

A directional antenna refers to an antenna that transmits and receives electromagnetic waves particularly strong in one or several specific directions, while transmitting and receiving electromagnetic waves in other directions is zero or very small. There is an example of the radiation pattern of a directional antenna, as shown in Figure 3 [1]. Its coverage is smaller than that of an omnidirectional antenna, but the transmission distance is longer. Generally, in base station systems, the use of directional antennas is very common. Generally, there are three types of directional antenna lobe widths: 60°, 90° and 120°, and they correspond to different sectors. For example, a base station is divided into 3 sectors, covered by 3 antennas, and each antenna covers a range of 120 degrees.

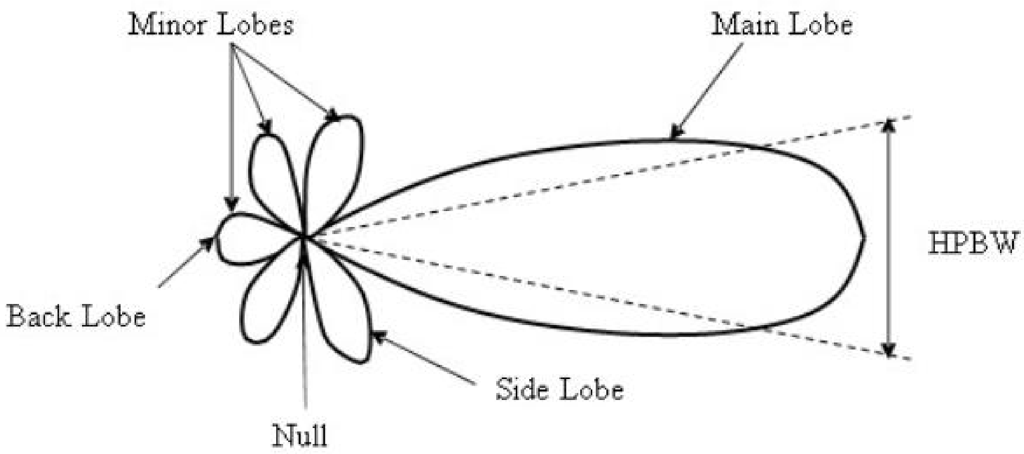


Figure 3: The radiation pattern of the directional antenna [1].

I.2.3. Unipolar antenna

The unipolar antenna uses 3 or 2 antennas as a radio frequency group. In the case of 3 antennas, two antennas are responsible for receiving, and one antenna is used as transmitting; when there are two antennas, one antenna is used as a pure receiving antenna, and one antenna combines transmitting and receiving functions. For example, In CDMA2000, generally uses two antennas, one antenna is used for transmission, the other is responsible for receiving and transmitting. So, more installation space and more overhead for routine maintenance is needed. Because the unipolar antenna is not as cost-effective as the bipolar antenna, and the location and installation are more cumbersome, it only used in the occasions that the bipolar antenna can't be used, such as in rural or suburban areas.

I.2.4. Bipolar antenna

The bipolar antenna that combines +45° and -45° polarization directions orthogonal to each other antenna and works in the transceiver duplex mode at the same time, so its most prominent advantage is to save the number of the antennas of a single directional base station. The ±45° polarization orthogonality can ensure that the isolation between the two antennas meets the requirement of intermodulation for the isolation between antennas (≥30dB), so the installation space of the dipolar antenna is smaller, and it is more suitable for use in urban areas. In addition, bipolar antennas have the advantages of electrically adjustable antennas.

CHAPTER II

II. Evolution of China's base station antenna

China's base station antennas have all been imported from abroad from the beginning, and now they have basically realized the local production of the entire antenna industry chain. According to the development of communication standards, the development history of base station antennas can be divided into 5 stages.

II.1. 1G

The first generation of mobile communication technology (1G) was formulated in the 1980s. In the 1G era, the number of mobile communication users was relatively small, and the antenna form was relatively simple, and rod-shaped omnidirectional antennas were mostly used.

In 1987, China's first-generation mobile communication system was established in Guangdong, and China officially entered the era of mobile communication. China's base station antennas mainly relied on imports and had no independent production capacity, the price of antenna was high.

II.2. 2G

As the 2G era enters the cellular era, the frequency increases and the radiation distance become shorter. At this time, in order to increase the radiation distance, the antenna radiation is gradually directional, divided into sectors, and the general lobe widths are 60°, 90°, and 120°. In the 2G era, antennas are still dominated by single-polarized antennas, but arrays have appeared, and the arrays are dominated by the vertical direction. In 1997, dual-polarized antennas (±45° crossed dual-polarized antennas) began to take the stage of history.

In 1994, China built the first GSM (Global System for Mobile Communications) communication network, meaning the beginning of China Mobile's 2G era. In the early stage of 2G, due to the lack of technology, China's base station antennas still rely on imports and have not yet achieved localization. In 2000, the Ministry of Information Industry promulgated the "Technical Conditions for Base Station Antennas for Mobile Communication Systems", indicating China's determination to enter the field of antenna manufacturing and promoting the localization of base station antennas.

II.3. 3G

In the 2.5G and 3G era, many multi-band antennas have appeared. Because the system at this time is very complicated, such as GSM, CDMA, etc., need to coexist, so multi-band antennas are an inevitable trend. In order to reduce costs and space, multiple frequency bands have become mainstream at this stage.

In January 2009, China's Ministry of Industry and Information Technology issued 3G licenses to the three major operators (China Mobile, China Unicom, and China Telecom), and China officially entered the 3G era. At this stage, Chinese base station antenna manufacturers have gained an advantage in the Chinese market. Most of the base station antennas of China's three major operators are supplied by Chinese manufacturers. Some head enterprise antenna technology has reached the international advanced level, but the core components of the industry chain still rely on imports.

II.4. 4G

In 4G era, with the introduction of MIMO technology, antennas have gradually evolved from single antennas to array antennas and multiple antennas.

In December 2013, China's Ministry of Industry and Information Technology issued 4G licenses to the three major operators (China Mobile, China Unicom, and China Telecom), and China officially entered the 4G era. In the 4G era, the international status of Chinese base station antenna manufacturers has further improved, with total shipments accounting for approximately 50% of global supply.

II.5. 5G

The 5th Generation Mobile Communication Technology (5G) is a new generation of broadband mobile communication technology with high speed, low latency, and large connection characteristics. 5G has a significant impact on the realization and improvement of smart driving, smart agriculture, smart home, and other fields. As 5G uses millimeter wave, beamforming, and Massive MIMO technology, 5G base stations have higher requirements for antennas. The antenna changes from a passive antenna to an active antenna.

In June 2019, China's Ministry of Industry and Information Technology issued 5G licenses to the three major operators (China Mobile, China Unicom, and China Telecom), and China officially entered the 5G era. On September 13, 2021, the Minister of Industry and Information Technology stated at a press conference that China has built the world's largest optical fiber and mobile communications network. 5G base stations and terminal connections accounted for more than 70% and 80% of the world's connections respectively. The 5G industry accelerates development, and the penetration of 5G mobile phone products is accelerated. The data released at the conference showed that from January to August this year, domestic 5G mobile phone shipments were 168 million units, an increase of 80% year-on-year.

Conclusion

The evolution of base station antenna is shown in Figure 4. Before the 2G era, China's base station antennas were basically completely dependent on imports, and there was no independent production capacity. In the 3G era, China's base station antenna industry has developed rapidly and has a high domestic market share, but the global base station antenna market is still occupied by the United States and Germany. In the 4G era, the international status of Chinese base station antenna manufacturers has further improved, with total shipments accounting for approximately 50% of global supply. In the 5G era,5G base stations and terminal connections accounted for more than 70% and 80% of the world's connections respectively.

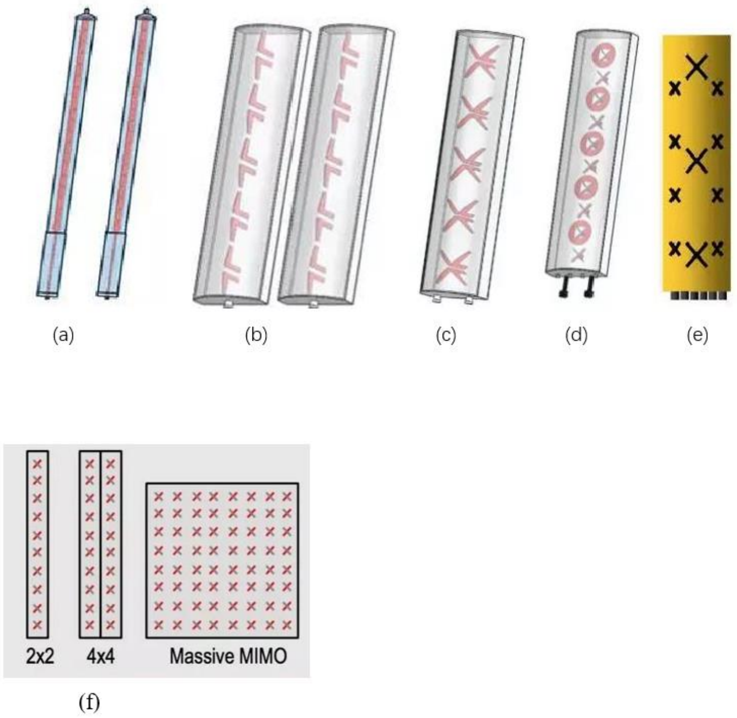


Figure 4 : The evolution of base station antenna. (a) Omnidirectional antenna; (b) Directional single polarization antenna; (c) Directional dual-polarized antenna; (d) Multi-array dual-polarized antenna;(e) LTE&MIMO antenna; (f) Massive MIMO antenna [3].

CHAPTER III

III. Overview of China's base station antenna industry

III.1. Base station antenna market size

According to data from ABI Research, the current global base station antenna market is stabilizing. The world's top 3 antenna manufacturers Huawei, Katherine, and CommScope account for nearly 70% of the base station antenna market share. In 2020, Huawei has the highest market share, reaching 35.1%.

In 2020, China base station market size reached RMB30.4 billion, as shown in Table 1 [4]. The total number of base stations reached 9.31 million. Among them, the total number of 4G base stations reached 5.75 million, achieving deep coverage in urban areas. The total number of 5G base stations reached 718,000, achieving coverage in above Prefecture-Level city and key counties. The number of 5G base stations reached 1.037 million by the August 2021, achieving coverage in all Prefecture-Level city, as well as more than 95% of county towns and 35% of towns and townships [5].

Year	#4G BS (Ten thousand)	#5G BS (Ten thousand)	#Others BS (Ten thousand)	4G BSA market size (100 million RMB)	5G BSA market size (100 million RMB)	Others BSA market size (100 million RMB)	BSA market size (100 million RMB)
2015	177	0	289	42.48	0	23.12	66
2016	263	0	296	63.12	0	23.68	87
2017	328	0	291	78.72	0	23.28	102
2018	372	0	295	89.28	0	23.6	113
2019	544	13	284	130.56	26	22.72	179
2020	575	71.8	284.2	138	143.6	22.736	304

NOTE: BS: Base station

BSA: Base station antenna

Table 1: 2015-2020 China's base station antenna market size (100 million RMB) [4].

III.2. Base station antenna industry chain

The base station antenna industry chain can be divided into three parts: upstream, midstream, and downstream. The upstream of the base station antenna mainly includes hardware material, cable and plastic material suppliers, electronic components, etc.; the midstream is antenna manufacturers; and the downstream is mainly telecom operators and equipment integrators, as shown in Figure 5. The development of 5G brings changes and opportunities to the industry chain.

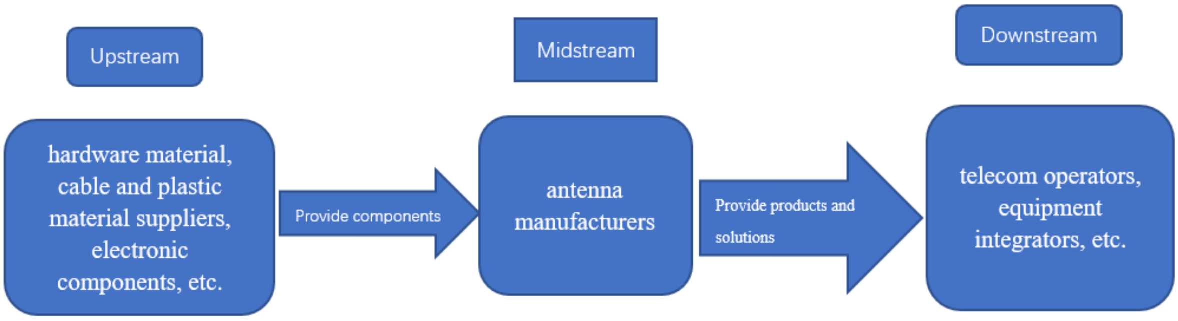


Figure 5: Base station antenna industry chain

III.2.1. The upstream

Before introducing the upstream of the base station antenna industry, I would like to introduce the 4G/5G base station structure. The basic principles of 4G and 5G base stations are similar, but there are certain differences in specific designs. 4G base station mainly consists of three parts: Building Base band Unit (BBU), Remote Radio Unit (RRU) and antenna. At present, in 4G communication base stations, both the antenna system and RRU use high-frequency & high-speed PCBs, and the BBU mainly uses high-speed PCBs. The antenna and RRU in the 5G base station are integrated in the AAU (Active Antenna Unit). From 4G to 5G, the base station structure and substrate requirements have not undergone essential changes, but the usage and parameters have been significantly upgraded. AAU contains antenna system (radiating element & feeder network), transceiver unit (DSP; DAC/ADC; PA; LNA; Filter and other devices), in which the radiating element (self-contained PCB material) is integrated on a PCB (including feeder network), The area of the transceiver unit is mainly based on two PCBs, PA and TRX. So, the needs of PCB in 5G base station are much higher than the 4G base station.

The 4G base station antenna is mainly composed of radiating element (radiation units), reflector (base plate), power distribution network (feeder network), and package protection (radome), as shown in Figure 6 [6]. The antenna radiation unit is the basic element of the antenna, which has the function of guiding and amplifying the electromagnetic wave, making the electromagnetic signal received by the antenna stronger. The reflector serves to modify the radiation pattern of the antenna, increasing gain in a given direction. The main function of feeder network is to realize the energy transmission between the port and the radiating element and the amplitude and phase distribution between the radiating elements. The radome is a structure that protects the antenna system from the external environment.

This thesis focusses on the materials of radiating element, radome and PCB.

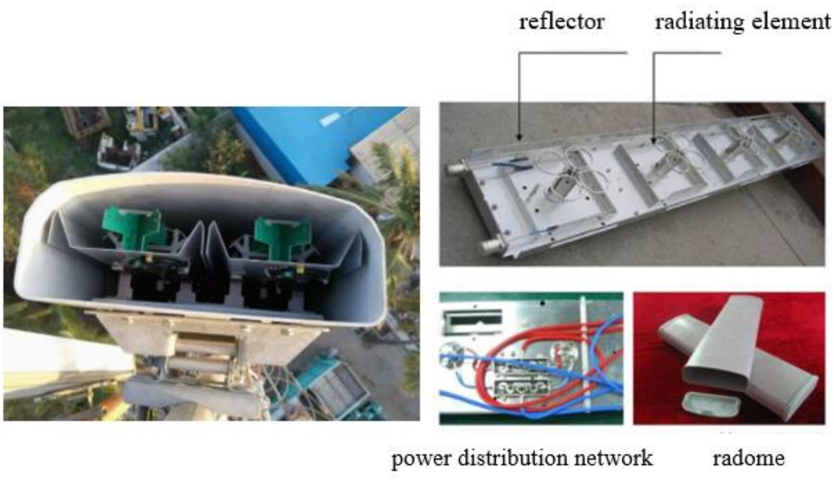


Figure 6: 4G base station antenna architecture [6].

III.2.1.1 The radiating element

The traditional antenna radiation unit is made of metal with good conductivity. In the 3G and 4G era, metal radiation units are mainly used. 5G Massive MIMO technology has increased the number of antennas geometrically. The antenna architecture has evolved from 4G multi-port antennas to dense arrays, requiring antennas to be light in weight, small in size and cost-effective. So, the lightweight, high-precision, high-integration, strong plasticity, and low-cost plastic radiating element have become popular in 5G base station antennas.

Plastic antenna radiating element materials include PPS, LCP, PPO and so on. At present, PPS antenna radiating element are the mainstream. As a special engineering plastic with excellent comprehensive performance, PPS has excellent high temperature resistance, dielectric properties, dimensional stability, flammability, chemical stability, and electroplating performance [7]. It is one of the few materials that can meet the requirements of 5G base station antenna applications with a linear expansion coefficient of less than 20 at -40°C to -130°C. For example, the antenna radiating element is made of PPS+40% glass fiber as the main material and uses 3D plastic + selective laser electroplating process. Compared with metal radiating element and LDS plastic radiating element, the weight is greatly reduced. PPS plastic radiating element is suitable for macro base station antennas and has more advantages in terms of product performance and processing efficiency. It is currently the mainstream technical solution for 5G antenna radiating element. The global PPS industry is highly concentrated, and production companies are mainly located in Japan, the United States, and China. Among them, Japan's production capacity accounts for about 45% of the world's total production capacity. At present, China's PPS material suppliers mainly include: SABIC, DSM, Celanese, Tongyi, etc.

The following is to introduce some radiating element materials developed by several companies. CGN Juner has developed PPS, LCP, and PPO materials that can be applied to base station antenna elements, as shown in Table 2 [8]. The LNP ™OFC08 (as shown in Figure 7) modified material developed by SABIC has high modulus, low warpage, stable dielectric properties, can meet the requirements of SMT process, has good coating adhesion, and can be used for antenna radiating element. AUSTON®PPS (polyphenylene sulfide modified material) independently developed by ORIDA has excellent dimensional stability, low linear expansion, high modulus, high strength, excellent weather resistance, and excellent chemical resistance, and can be used for antenna radiating element, as shown in Figure 8.

Type	L1NW-09S/L	S2G8-16S/L	O2G2-08S/L
Substrate material	LCP	PPS	PPO
Dielectric constant,1GHz	3.2	3.8	3
Dissipation factor, 1GHz	0.027	0.002	0.001
HDT,°C at 1.82 MPa	234	265	155
Density, g/cm³	1.4	1.65	1.06

Table 2 : Materials for base station radiating element [8].

Figure 7: LNP ™OFC08 [9].

Figure 8: AUSTON®PPS [10].

III.2.1.2 The radome

The function of the antenna cover is to protect the antenna system from the external environment (such as wind and snow, sunlight, organisms, etc.), and to extend the life of the antenna. At the same time, it is necessary to ensure the permeability of electromagnetic waves, so there are high requirements for the dielectric properties, mechanical properties, and weather resistance of the materials. In addition, in order to meet the design requirements of 5G antennas for lightweight, miniaturization and integration, radome materials also need be lightweight. The traditional radome based on thermosetting glass fiber reinforced plastic cannot meet the requirements of lightweight. In recent years, as people's awareness of environmental protection has increased, the requirements for environmental protection at home and abroad have become higher and higher. Environmentally friendly is an important direction for the development of 5G materials, which are easy to use, easy to recycle, and easy to handle. Facing the higher requirements of 5G for antenna cover materials, companies are now actively researching and developing low-dielectric, low-loss reinforced modified materials that are cost-effective, environmentally friendly, and lightweight, such as PC, PP, ASA and so on.

Polycarbonate (PC) has the advantages of high strength and elasticity, high impact resistance, excellent electrical properties, strong insulation, good dimension, wide operating temperature range, etc. The application range of ordinary PC materials has certain limitations. Through modification, it has low dielectric, low loss, high impact resistance, good flame retardancy, weather resistance, dimensional stability, and other characteristics, and can be used as a 5G base station radome. The global PC production companies are mainly concentrated in North America, Western Europe and Northeast Asia. The growth of demand in Asia has driven the rapid growth of global PC production capacity, and the global production center has also shifted to Asia, especially China.

Polypropylene (PP) has excellent mechanical properties, good insulation properties, high heat resistance, low density, low water absorption, low price, and high-cost performance. Polypropylene is a non-polar polymer with extremely low dielectric constant and dielectric loss. Its dielectric properties remain stable under temperature and frequency changes, which can ensure that the base station radome has good wave permeability and heat resistance. The excellent properties of polypropylene make it very suitable for making base station radomes. PP radome generally adopts glass fiber reinforced PP preparation method. Filling materials such as PP resin, low-dielectric glass fiber, hollow glass microbeads, and toughening modifiers, etc. are mixed uniformly, and then extruded and pelletized. The base station radome is made by injection molding, extrusion or molding process. In recent years, the development of propane dehydrogenation (PDH) technology and the improvement of methanol to propylene technology have accelerated the expansion of PP production capacity. China's PP production companies are mainly Sinopec, PetroChina and Shenhua Group, and their production capacity accounts for 35.0%, 15.9% and 11.4% respectively.

ASA (Acrylonitrile styrene acrylate) has similar structure and performance to acrylonitrile-butadiene-styrene (ABS) but has high weather resistance. When the ASA resin material is used as the 5G antenna cover material, it needs to undergo a certain modification treatment. Modified resins, tougheners, compatibilizers, fillers, flame retardants and processing aids are added to the ASA resin, and through optimized combination, the mechanical properties, dielectric properties, flame retardancy, weather resistance, impact resistance and UV resistance of the material all meet the requirements of the antenna cover. At present, the global ASA resin manufacturers mainly include: South Korea's LG, South Korea's Lotte, Ineos, SABIC, Japan's Toray, Japan's Aiyulong, Taiwan's Chi Mei Industrial, and other companies. Among them, LG Chem, Chi Mei Industrial, Ineos, and SABIC have the highest market share. In 2019, the global market share was 19.35%, 17.51%, 16.24%, and 13.04%. At present, the production technology of ASA resin in China is relatively backward, mostly dependent on imports, and high-end technology is still in the hands of multinational companies.

The following is to introduce some radome materials developed by several companies. The SABIC® PP Compound material developed by SABIC have low dielectric constant, excellent weather resistance, light resistance, low temperature resistance and impact resistance, meeting the requirements of 5G antenna covers. The 5G project team of WANHUA chem has developed a series of 5G radome materials with excellent dielectric properties, chemical resistance, impact resistance and short molding cycle, as shown in the Table 3. ORINKO has developed a series of radome materials, such as glass fiber reinforced PP materials, weather-resistant, cold-resistant and flame-retardant PC/ABS materials, which have passed the certification of Huawei products.

parameter	Unit	WanBlend® STC3711	Wancom® PPG0616H	Wancom® PPG0616H	Wancom® PPG0412H
Density	g/cm3	1.20	1.13	1.05	1.01
Bending Modulus	MPa	2200	5000	6400	4700
Bending strength	MPa	90	95	110	100
23°C Cantilever notch impact	kJ/㎡	65	23	6.0	6.5
-40°C Cantilever notch impact	kJ/㎡	24	15	5.5	6.0
Heat distortion temperature(0.45MPa)	°C	145	158	150	150
Flame retardant	UL 94	VO	HB	HB	HB
Dielectric constant	2.5GHz	2.7	2.5	2.4	2.4

Table 3: Examples of randome materials that devolved by WANHUA chem [11].

III.2.1.3 The PCB

PCB (Printed Circuit Board) is an important electronic component, a support for electronic components, and a carrier for electrical interconnection of electronic components. Due to the larger data volume and transmission frequency of 5G, higher working frequency band, and the structure tends to be multi-layered and highly integrated design, PCB substrate materials are required to meet the requirements of high heat resistance, high heat dissipation, miniaturization, and light weight. 5G high-frequency/high-speed PCB substrate resin materials require low dielectric constant, low dielectric loss, low thermal expansion coefficient and high thermal conductivity. At present, most of the high-frequency/high-speed PCB substrates are represented by polytetrafluoroethylene (PTFE) thermoplastic materials and hydrocarbon resin (PCH) thermosetting materials.

PTFE has excellent dielectric properties and is the most mature high-frequency/high-speed substrate resin material. It is currently one of the very few materials that can be applied to ultra-high frequency millimeter wave band circuit substrates, and has good thermal stability and self-flame retardant functions. The preparation methods of PTEE resin in industry mainly include suspension polymerization and emulsion polymerization. Among them, products made by emulsion polymerization are more widely used. At present, PTFE resin emulsion polymerization technology is mainly monopolized by foreign companies, and China's output is extremely low, and a large amount of imports from abroad are needed every year.

PCH is an unsaturated polymer with only two elements of C and H. It has excellent dielectric properties and belongs to a thermoplastic polymer. When preparing high-frequency copper clad laminates, low-dielectric ceramic powder and glass fiber cloth need to be added for reinforcement and modification. And through cross-linking to a thermosetting transition. At present, the PCH systems that can be used to manufacture high-frequency copper clad laminates mainly include polybutadiene system, styrene/divinylbenzene copolymerization system, polybutylene styrene (SB, SBS) copolymerization system, EPDM copolymerization system, SI and SIS Copolymerization system, PPO modified SI and SIS copolymer system, PPO modified polystyrene butadiene system, cycloolefin copolymer (COC, DCPD) system, etc. The PCH resin of each system is monopolized by a few foreign companies. There is no similar PCH resin in China, and there is still a big gap between the research and development level of PCH substrate and foreign countries.

III.2.2. The midstream

The midstream is antenna manufacturers. China's antenna manufacturing companies mainly include Huawei, Comba Telecom, Tongyu Communications, Mobi, etc. It can be seen from the report released by EJL Wireless Research in 2017 that the top companies in the global base station antenna market are Huawei 32%, Comba Telecom 13%, Mobi Development, CommScope 12%, Kathrein etc., as shown in Figure 9.

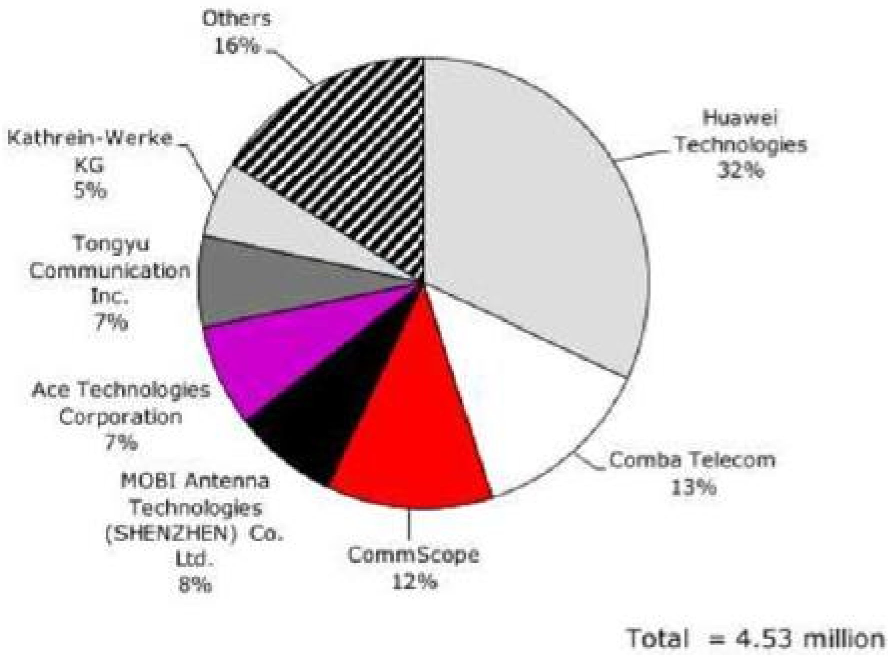


Figure 9: Global base station antenna shipment market share in 2017 [12].

III.2.3. The downstream

The downstream is mainly telecom operators and equipment integrators. Telecom operators are the main consumers of base station antennas. Operators such as China Mobile, China Unicom, China Telecom, and China Radio and Television have absolute weight in the purchase of base station antenna products.

The application of 5G technology has made the traditional BBU and RRU separation solution evolved into an integrated active antenna solution (AAU) that integrates antennas and radio frequency modules. The degree of antenna integration has become higher, and the downstream customers of antenna manufacturers have shifted from telecom operators to equipment integrators. The purchase proportion of equipment integrators increased. The model that equipment integrators purchase antennas and integrate them into communication equipment systems before selling them to telecom operators will become the mainstream.

CHAPTER IV

IV. Driving Factors of China's Base Station Antenna Industry

IV.1. The development of 5G

The communication network makes the information exchange between people more and more fast and efficient. With the increase in the number of users, new businesses and new services continue to emerge, and the demand for traffic is increasing. However, the 4G mobile communication system cannot meet people’s expectations for the future. With the ever-increasing communication demand, the fifth-generation mobile communication system characterized by high speed, large capacity, high reliability, and low latency has begun to rise. The base station antenna is a converter for information exchange between the base station and the user, which transmits and receives electromagnetic waves to achieve signal transmission. The base station antenna directly affects the quality of information transmission. 5G directly promotes the development of base station antennas.

IV.2. The support of the technology

IV.2.1. The Massive MIMO technology

Multiple-input multiple-output (MIMO) uses multiple antennas at both the transmitting end and the receiving end to form multiple channels between the transmitting and receiving ends to increase the channel capacity. However, in the traditional 4G system, the antennas are mainly 2T2R (2 transmitting antennas, 2 receiving antennas) or 8T8R, and the MIMO performance gain is greatly limited. Due to the shortcomings of traditional MIMO technology, Massive MIMO technology was developed. There is an example of channel state information used to characterize a Massive MIMO system as showing in Figure 10. Using Massive MIMO technology, the antenna can be changed to 64T64R, which greatly increases the number of base station antennas. By increasing the number of antennas to increase the channel capacity and to improve the spectrum utilization. There is an example of upgrade from 2x2 MIMO to Massive MIMO as showing in Figure 11. Since a large number of antennas have to be placed in a limited device, it brings higher requirements on the antennas. The antenna must have the characteristics of small size, light weight, and high isolation. Massive MIMO technology promotes the development of base station antennas.

At the same time, Massive MIMO technology has also changed the structure of the base station antenna. The structure of the 4G macro base station is that the antenna-cable-RRU-BBU are separated independently. There is an example of the Ericsson W-cdma BBU/RRU System, as shown in Figure 12. However, with the increase in the number of antennas, a large number of cables will be required if the structure of the 4G macro base station continues to be used. A large number of cables will generate more power consumption, and the workload of cable installation and subsequent equipment maintenance will also increase. Therefore, in the deployment of 5G antennas, the antenna using Massive MIMO technology replaces the connection and power distribution of the original cables with a PCB board. The active antenna integrates the functions of the antenna and RRU, which greatly reduces the loss of cables. There is a comparison between the traditional solution and AAU solution, as shown in Figure 13.

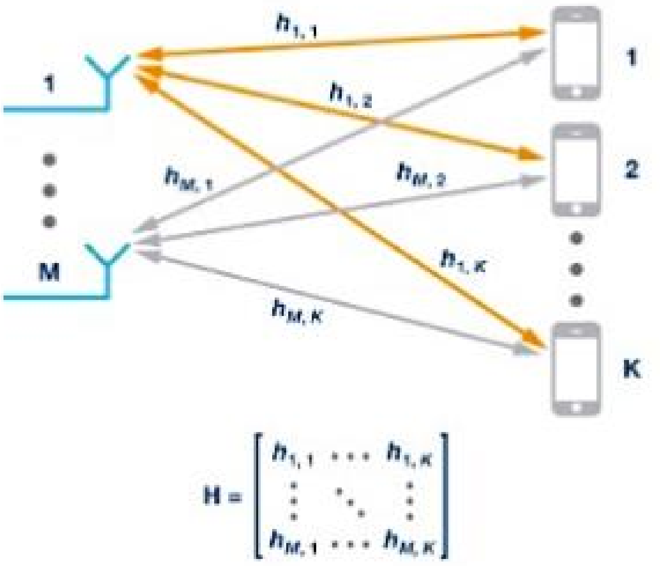


Figure 10: Channel state information used to characterize a massive MIMO system [13].

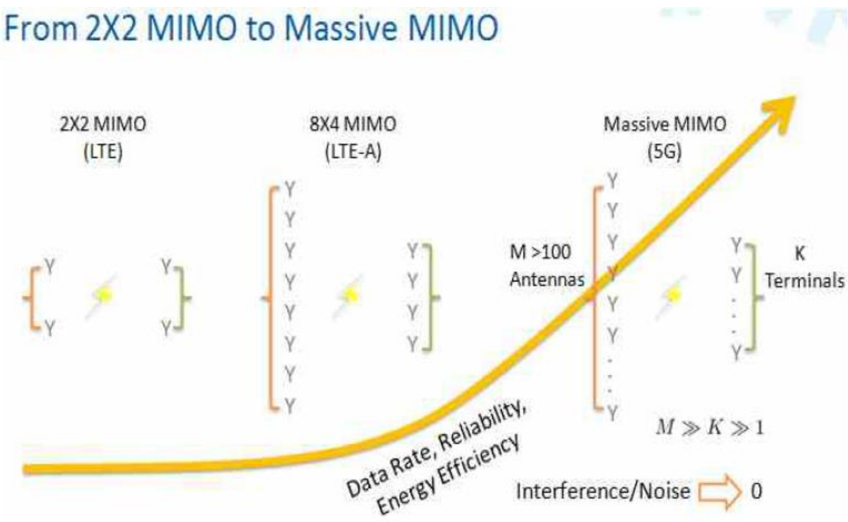


Figure 11: Example of upgrade from 2x2 MIMO to Massive MIMO [14].

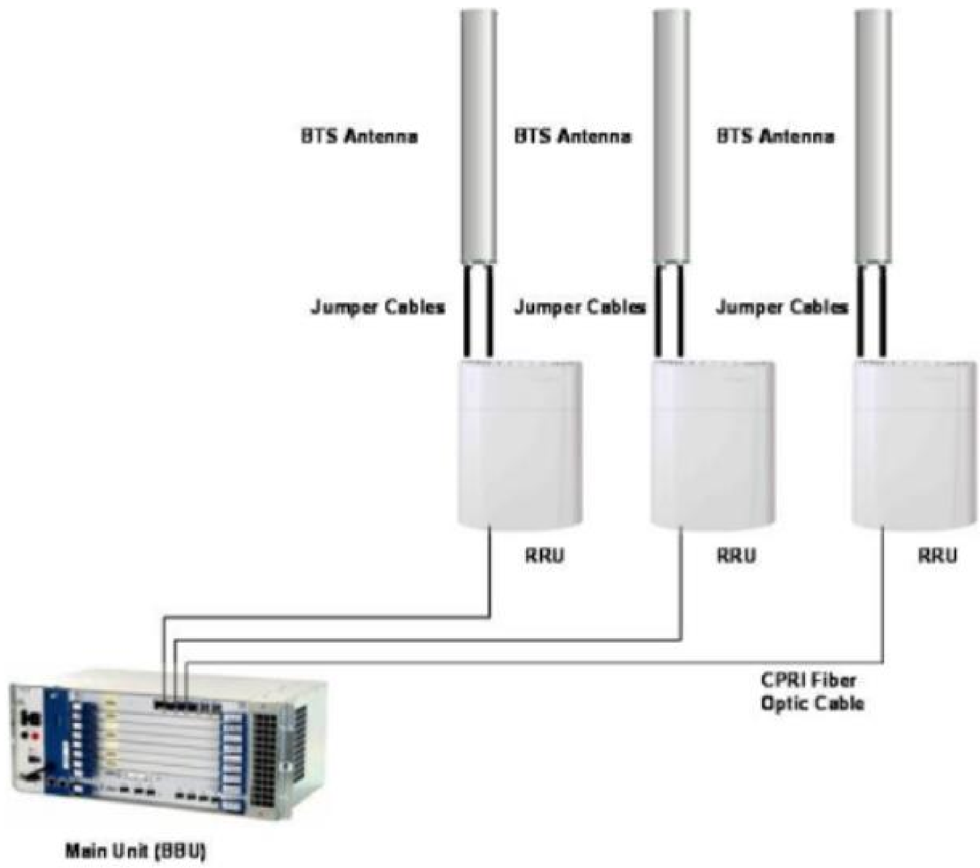


Figure 12: Example of the Ericsson W-cdma BBU/RRU System [15].

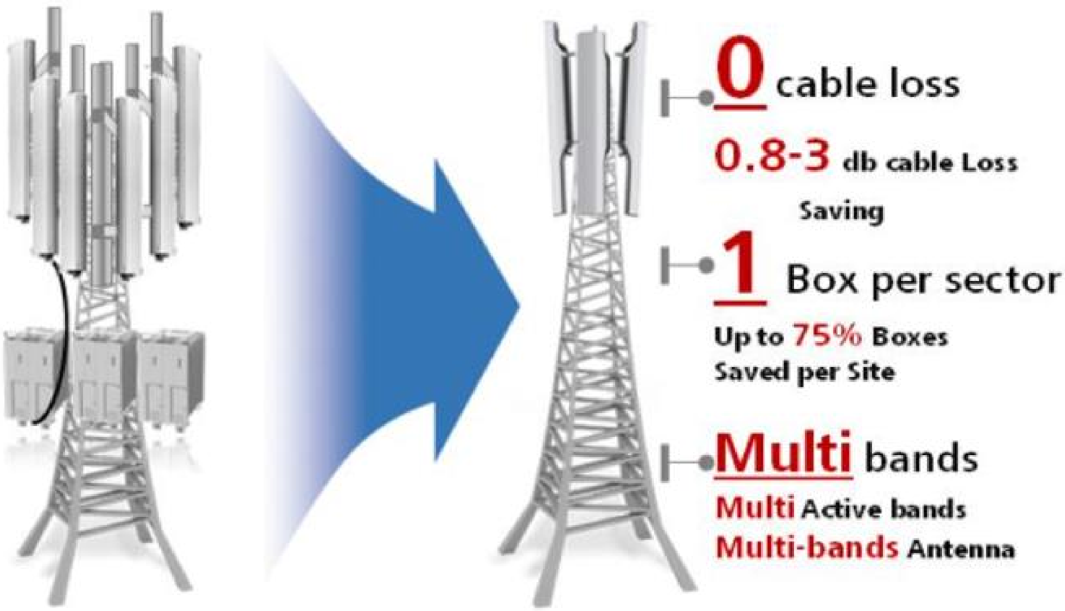


Figure 13: Traditional base station solution VS. AAU base station solution [16].

IV.2.2. The UDN (Ultra-Dense Network)

According to different literatures, UDN has different definitions. In [17] , UDN is defined as a network where the base station density is greater than the user density. In [19], UDN is defined as a network where base station density is greater than 10^3 cells/Km^2. There is a comparison between the traditional cellular network and UDN, as shown in the Table 4. We can clearly see that the traditional cellular networks cannot meet the high-speed requirements of users in hotspots, and ultra-dense network（UDN） can effectively solve this problem. Ultra-dense network is one of the core technologies that supports 1000 times the traffic growth of 5G networks and meets the needs of 10-100 times the user experience rate [21]. It increases the frequency reuse and system capacity through more dense deployment of base stations. In the macro base station, the number of low-power base stations in its coverage area has increased greatly, forming an ultra-dense heterogeneous network, as shown in the Figure 14. According to predictions, the distance between the base stations in the coverage area of the macro base station will eventually be controlled within 10m, and each 1 Km^2 area can serve 25,000 users [23].

Due to the deployment of UDN, the demand for base stations has greatly increased, and of course, it has also promoted the demand for base station antennas.

	UDN	Traditional cellular network
Deployment scenarios	Indoor, hotspot	Wide coverage
Access point density	Comparable to the user density	Much lower than user density
Access point types	Small cell, pico femto, UE relay, relay	Macro/micro base station (BS)
Typical coverage	Around 10 m	Several hundred meters and more
Coverage characteristics	Heterogeneous, irregular	Single layer, regular cell
User density	High	Low/medium
Backhaul	Ideal/non-ideal, wired/ wireless	Ideal, wired
User mobility	Low mobility	High mobility
Data rate requirement	High	Low/medium
Spectrum bands	Higher, wider	Lower, limited

Table 4 : Comparison between UDN and the traditional cellular network [20].

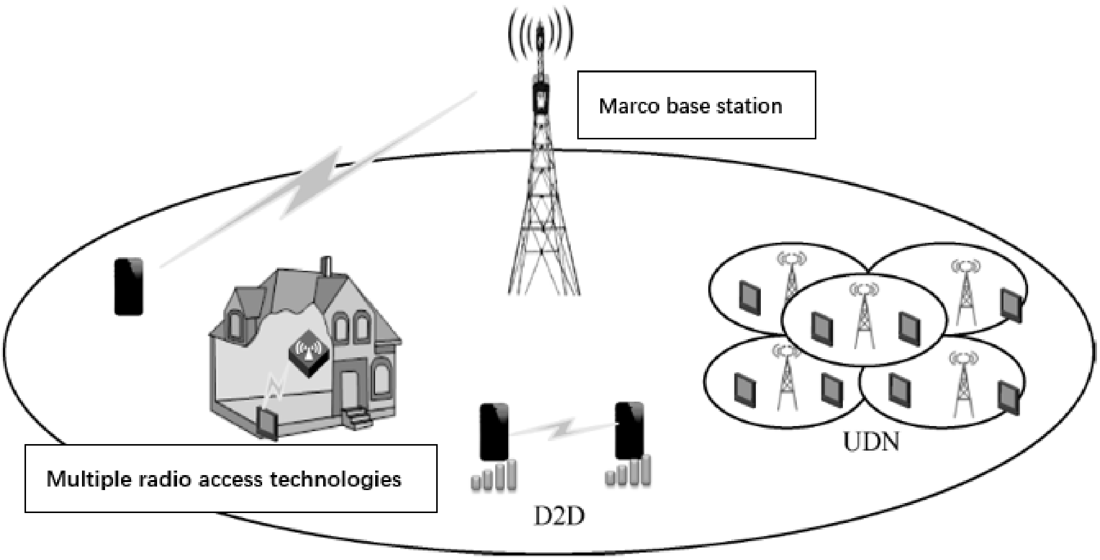


Figure 14 : Schematic diagram of ultra-dense heterogeneous networking [22].

IV.2.3. The mmWave technology

Millimeter waves are electromagnetic waves with millimeter-level wavelengths, usually referring to the 30-300 GHz frequency band [24]. 5G communication mainly uses two frequency bands: Sub-6GHz and 24-100GHZ millimeter wave, as shown in the Figure 15. Compared with the Sub-6GHz frequency band, millimeter wave has a huge bandwidth, which can effectively increase network speed and is one of the core technologies of 5G. At the same time, millimeter wave spectrum resources are more abundant, and more frequency bands can be allocated, effectively solving the problem of shortage of spectrum resources. Millimeter wave technology also has the advantages of extremely low latency, high precision positioning and so on [24], which has promoted the development of 5G. At the same time, millimeter wave technology has also promoted the upgrade of base station antennas. Due to the short propagation distance of millimeter waves and severe attenuation, the use of dense base station layout and large-scale antenna array technology can ensure transmission quality. Therefore, the number of base station antennas has greatly increased. Traditional passive antennas are gradually converted to active antennas due to excessive signal transmission loss and unable to transmit signals smoothly. The increase in the number of antenna channels and the transition to active antennas have put forward higher requirements on the design and production of antennas, and promoted the upgrade and large-scale application of antennas.

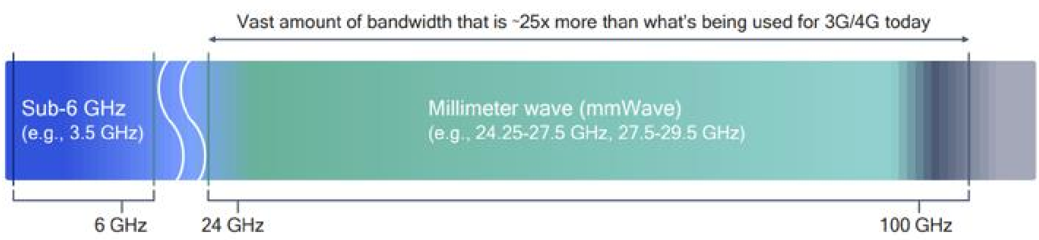


Figure 15 : 5G communication spectrum [25].

There is an example of combined deployment of 5G millimeter wave network, Sub-6 GHz and 4G LTE, as shown in Figure 16. There is an example of Massive MIMO antennas used in 5G mmWave, as shown in Figure 17. At the 2022 Winter Olympics, China will use 5G millimeter wave and other technologies to create smart wireless venues.

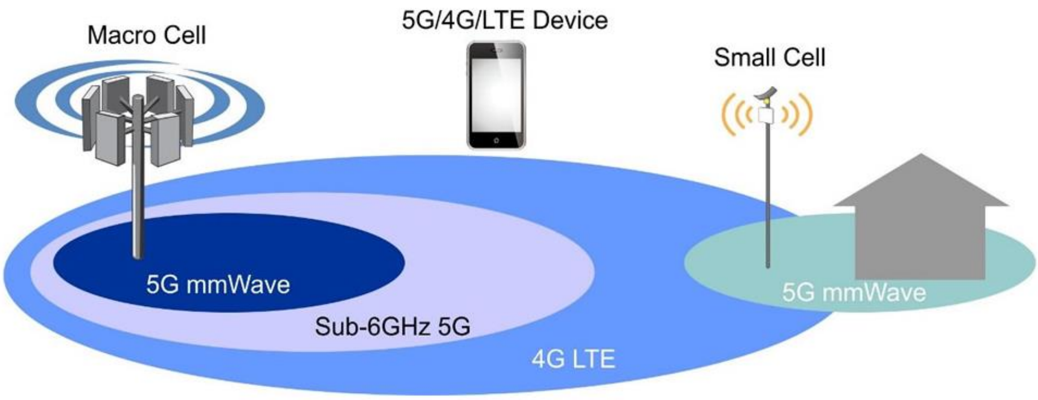


Figure 16 : Combined deployment of 5G millimeter wave network, Sub-6 GHz and 4G LTE [26].

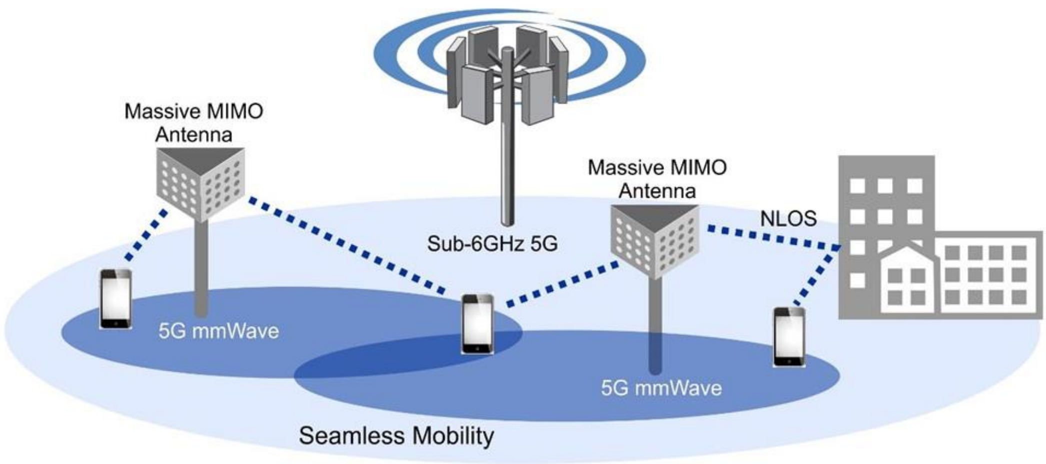


Figure 17 : Massive MIMO antennas used in 5G mmWave [26].

IV.3. The NB-IoT

Nowadays, mobile communication is not just a connection between people, but a connection between people and things, things and things. Narrowband Internet of Things (NB-IoT) is an important branch of the Internet of Everything based on cellular networks. It has the advantages of wide coverage, low power consumption, and low cost, and is applied in smart parking, smart home, smart medical and other fields. Currently, China's three major operators have all deployed NB-IoT construction, which has greatly promoted antenna demand. According to statistics from the Ministry of Industry and Information Technology, as of 2019, more than 700,000 NB-IoT base stations have been built. In addition, as of January 2020, the number of NB-IoT connections has exceeded 100 million, and the number of connections for typical applications such as smart water meters, smart gas meters, smoke detectors, and electric vehicle monitoring has reached millions. The Internet of Things has also played an important role in the management and control of the COVID-19, reducing people's contact. Products such as non-contact remote temperature measurement and epidemic prevention robots have been widely used.

IV.4. The support of the government

In recent years, China has promulgated various policies to actively promote the development of 5G. China's 5G trial is the world's first government-led and planned 5G trial, and it is also the world's largest regional 5G trial. It is conducted in two phases: the first phase of technology research and development (2016-2018) and the second phase of product research and development (2018-2020). The issuance of 5G commercial licenses in 2019 heralds the official opening of the 5G era. In March 2020, the Ministry of Industry and Information Technology issued a notice on accelerating the development of 5G, making every effort to promote 5G network construction, application promotion, technology development and security assurance, and give full play to the scale effect and leading role of 5G new infrastructure to support high-quality economic development. Because of the full support of the government, the infrastructure construction of base stations has been accelerated, and the rapid development of base station antennas has also been promoted.

CHAPTER V

V. Restrictive Factors of China's Base Station Antenna Industry

V.1. Lack of upstream supply

As a result of the China–United States trade war, some developed countries imposed technical blockades on China and prohibited the supply of raw materials to Chinese companies, which affected the development of the antenna industry. Developed countries have a monopoly on some high-end electronic components and PCB boards in the antenna industry. The lack of core electronic components and high-end PCB boards of base station antennas directly reduces the development of base station antennas in China.

At present, Chinese companies (Huawei, ZTE, etc.) have increased their R&D investment in 5G high-end technology, and the Chinese government has also issued a number of policies to support it. But the lack of raw materials is still a main problem.

V.2. The slow construction of 5G base stations

The Ministry of Industry and Information Technology once put forward the goal of building more than 600,000 5G base stations this year at the National Industry and Information Work Conference in 2021. However, according to data from the Ministry of Industry and Information Technology, China built 190,000 5G base stations from January to June this year, and the number of newly built 5G base stations in the first half of this year decreased by 97,000 compared with the same period last year, a year-on-year decrease of 33.7%. Mainly due to factors such as trade frictions, lack of raw materials, and epidemics. The slow construction of 5G base stations has also affected the development of the antenna industry.

CHAPTER VI

VI. The challenges

While the base station antenna industry is developing rapidly, it is also facing corresponding cost and technical challenges. Whether manufacturers can solve these challenges is the key to victory in the base station antenna industry.

VI.1. The Cost

Due to the reduced coverage of 5G base stations, the number of required base stations has increased significantly, and the cost of infrastructure construction has increased significantly. The demand for 5G Massive MIMO antennas has also increased significantly, and the demand for raw materials such as vibrators and PCBs has increased significantly. At the same time, due to the high requirements of 5G antennas, the manufacturing cost of antennas is also more expensive than that of 4G base station antennas. The cost of 4G base station antenna is about 800-1000 RMB/pair, and the cost of 5G base station antenna is about 3000-4000 RMB/pair [27]. Therefore, whether antenna manufacturers can meet the high requirements of 5G for base station antennas while reducing antenna costs is the key to the success of the antenna industry.

VI.2. Mass production and rapid testing capabilities

As the number of base stations increases by millions, the required base station antennas will increase by tens of millions. Antenna manufacturers must have the capability of mass production and rapid testing. Automation, digitization and intelligent production and testing are necessary capabilities of antenna manufacturers in the antenna industry.

VI.3. The Heat dissipation

The power consumption of a 5G base station is about three times that of a 4G base station. How to reduce the power consumption of base stations through new technologies and new materials is a major challenge. The main source of base station energy consumption is the radio frequency unit. For example, in 4G, the antenna system is separated from the RRU, and the power amplifier is included in the RRU, as shown in the Figure 18. Each radiating element in the Massive MIMO antenna is connected to a power amplifier, as shown in the Figure 19. Massive MIMO antennas have more power amplifiers and generate greater power consumption, so they face greater heat dissipation problems. At the same time, the size of 4G to 5G antennas has shrunk, which requires reducing heat transfer resistance and improving heat transfer efficiency in a limited space. Therefore, the research and development of new heat dissipation methods, new heat dissipation materials, and new structures that are conducive to heat dissipation are necessary capabilities for major manufacturers to succeed in base station heat dissipation.

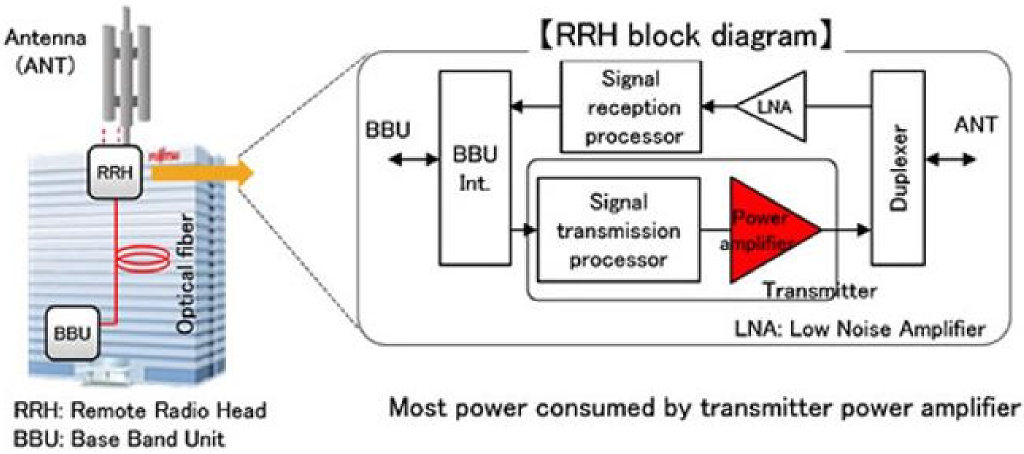


Figure 18： Base station diagram [28].

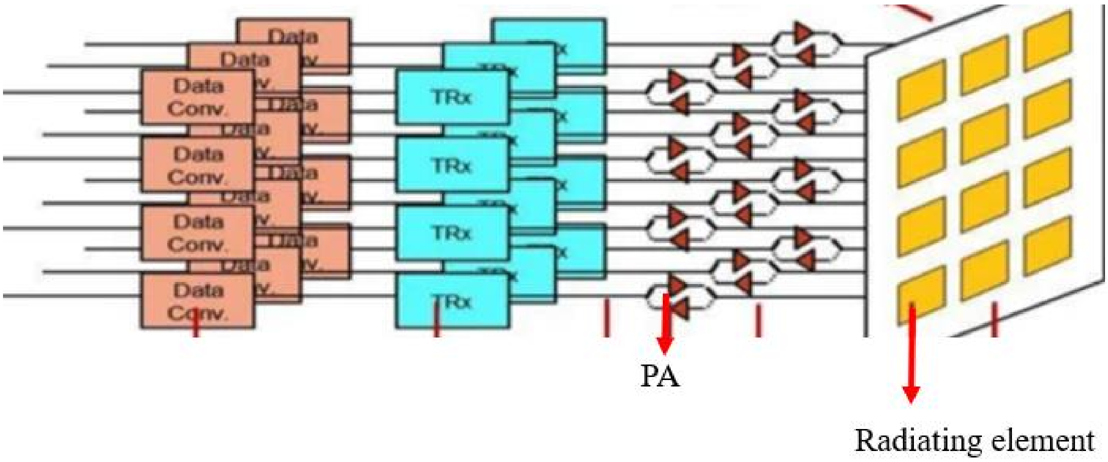


Figure 19: 5G massive MIMO antenna channel chain [29].

Regarding the new heat dissipation method, the literature [30] believes that the heat dissipation method of semi-solid die casting + inflatable plate is a good solution. Semi-solid die castings are light in weight and have good heat dissipation performance. The inflatable plate has high heat conduction efficiency and fast cooling speed. There are several inflatable plate heat exchangers, as shown in the Figure 20.

Figure 20: Inflatable plate heat exchangers [30].

The main thermal interface materials include thermally conductive silica gel and thermally conductive gel. SUZHOU HEMI Electronics developed several thermal interface materials, as shown in Figure 21.

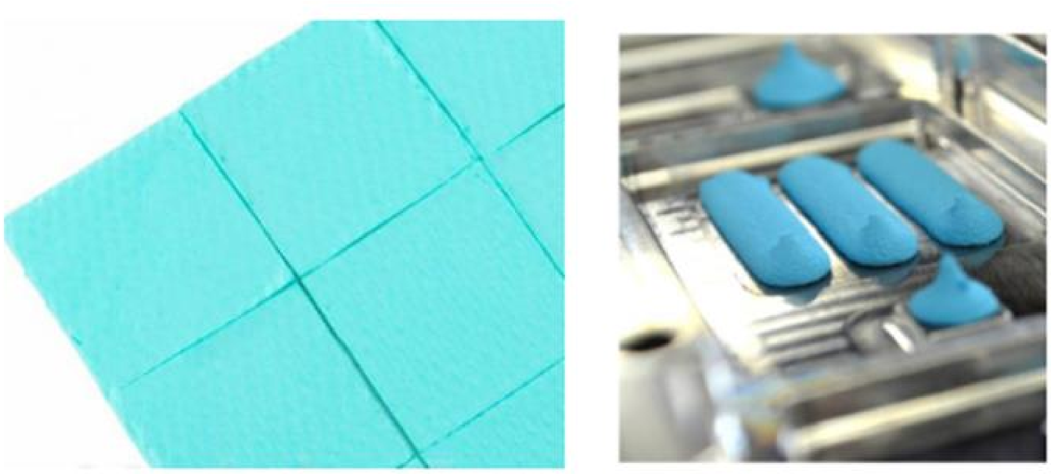


Figure 21: Tflex HD 80000 & Tputty 607 [31].

Graphite film is one of the main materials for heat dissipation and has been widely used in the heat dissipation of smart phones. Its thermal conductivity is much higher than copper and aluminum. In addition, its low density meets the requirements of lightweight. There is a performance comparison between graphite and copper and aluminum, as shown in the Table 5. Natural graphite film is also used for base station heat dissipation.

Material	Thermal Conductivity W/(m.K)	Specific heat capacity J/kg.K	Density g/cm^3
Aluminum	200	880	2.7
Copper	380	385	8.96
Graphite	Horizontal direction:300-1900; Vertical direction: 5-20	710	0.7-2.1

Table 5 : Performance comparison between graphite and copper and aluminum [30].

Regarding the design of the heat sink structure, ZTE Corporation adopts a unique V-tooth structure design (as shown in Figure 22), which increases heat dissipation by 20% [32].

Figure 22: V-tooth structure design of the heat sink structure developed by ZTE Corporation [33].

VI.4. The Base station antenna design

Literature [34] describes the base station antenna challenges based on design, as shown in Figure 23, and shows some solutions/techniques, as shown in Table 6.

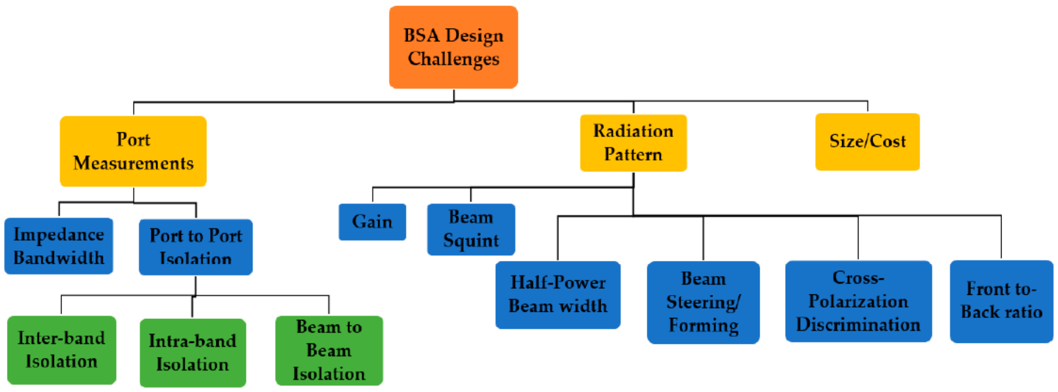


Figure 23: Base station antenna challenges based on design [34].

Design Challenge	Solutions/Techniques
Achieving wide impedance bandwidth	Wideband balun design Modification to radiator shape Use of parasitic element/s to widen bandwidth
Achieving high isolation levels	Use of differential feed structure Use of decoupling network
Stable HPBW in bandwidth of operation	Cavity shape reflector Convex shaped reflector
Achieving high front-to-back ratio	Modifications to the radiator-Downward sloping dipoles
Minimizing Beam Squint	Enforce symmetric current distribution on the radiating element
Achieving high Cross polarization discrimination	Modifications to the radiator shape
Improving the gain	Modifications to the radiator-addition of notch metal wall
Achieving beam steering	Butler matrix Luneburg lens Digital beamforming-integrated RF transceiver
Achieving compact size designs/cost	Multiband compact radiating element design

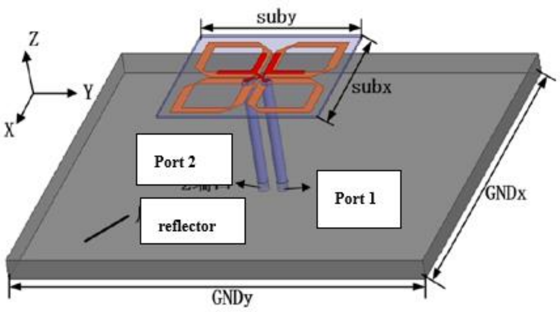
Table 6: A summary of available solutions for design challenges in Base station antenna design [34].

Updated to 5G base station antennas, there are additional challenges in design. Because 5G's Massive MIMO, millimeter wave, beamforming, high-frequency communication, and other technologies are all based on the integrated active antenna design. The trend of antenna activation is one of the challenges when designing antennas. At the same time, the coverage of 5G communication technology is low, base stations carry more antennas, and reducing antenna size is also one of the main challenges in antenna design. In addition, the integration of the antenna and the radio frequency module increases the overall integration of the antenna.

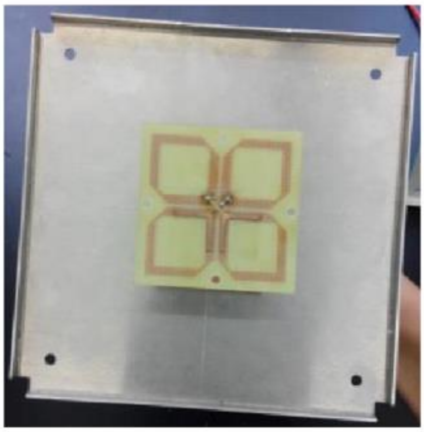
CHAPTER VII

VII. Examples of base station antennas

In literature [35] shows the design of a dual-polarized ring dipole antenna with a radiating element size of 48 mm*48 mm, covering all frequency bands of 2G/3G/LTE, as shown in the Figure 24. The simulated and measured VSWR and isolation paramter of the antenna are shown in Figure 25. The simulated and measured gains and the half-power lobe width in the H-plane are shown in Figure 26. The simulated and measured main polarization and cross polarization patterns of the two ports of the antenna are shown in Figures 27 and 28. The impedance bandwidth of this antenna reaches 48% (1.7-2.8 GHz, VSWR<1.5), and the in-band isolation is greater than 29 dB. The antenna also shows a very stable pattern at different frequencies.



(a)



(b)

Figure 24: The radiating element of the dual-polarized ring dipole antenna. (a) The geometry (b) The prototype [35].

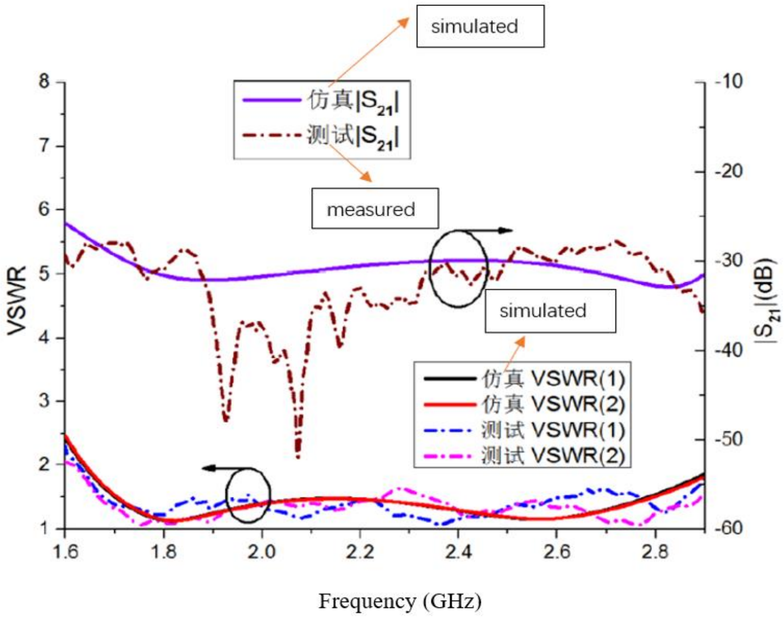


Figure 25: The simulated and measured VSWR and S_{21} paramter of the dual-polarized ring dipole antenna [35].

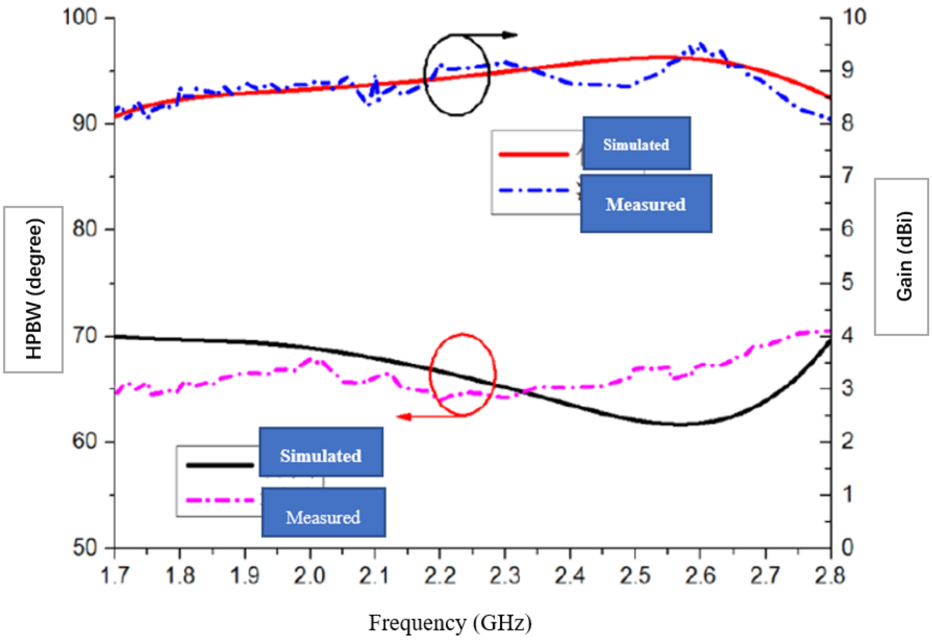


Figure 26: The simulated and measured gains and the half-power lobe width in the H-plane of the dual-polarized ring dipole antenna [35].

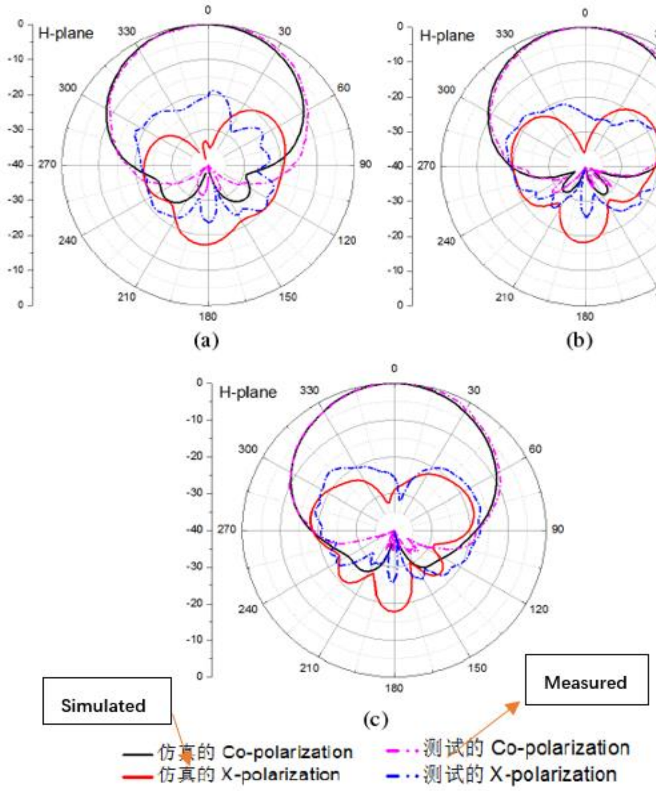


Figure 27 : The radiation pattern of port 1 of the dual-polarized ring dipole antenna. (a)1.7GHz; (b)2.2GHz; (c) 2.7GHz [35].

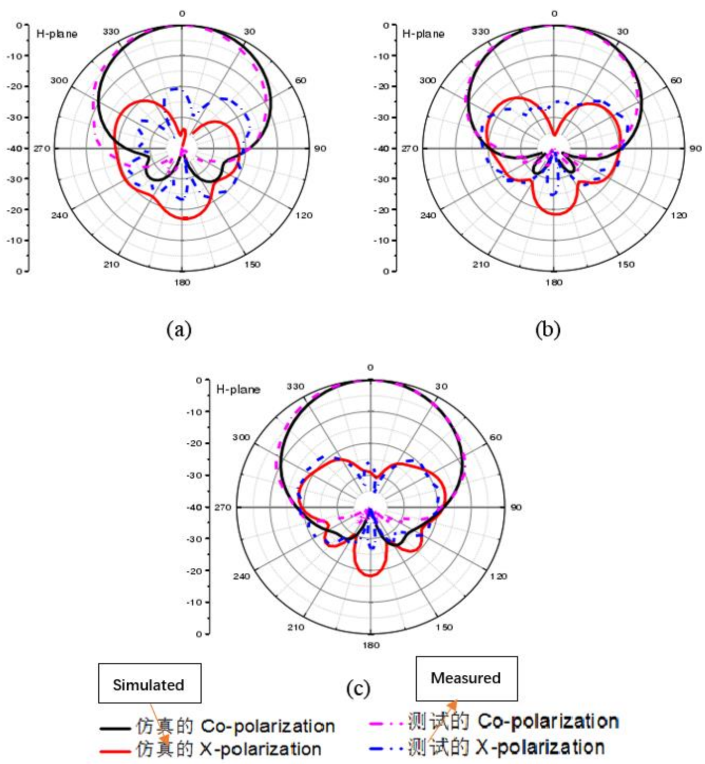
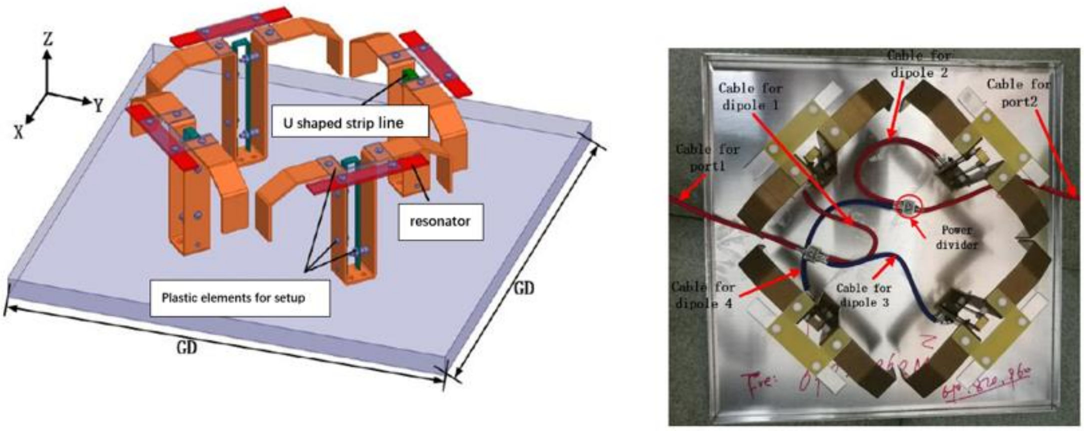


Figure 28: The radiation pattern of port 2 of the dual-polarized ring dipole antenna. (a)1.7GHz; (b)2.2GHz; (c) 2.7GHz [35].

Literature [35] shows the design of dual-polarization broadband base station antenna based on resonator coupling, as shown in Figure 29. The Simulated and measured S parameters are shown in Figure 30. The simulated and measured Gians are shown in Figure 31. The radiation patterns are shown in Figure 32. The antenna is in the range of 0.67 GHz to 0.98 GHz, |S11|<-15 dB. The in-band isolation is greater than 40 dB, and the measured gain is 9.25±0.25 dBi. The antenna also shows a very stable pattern.



(a) (b)

Figure 29: The antenna. (a) Geometry; (b) Prototype [35].

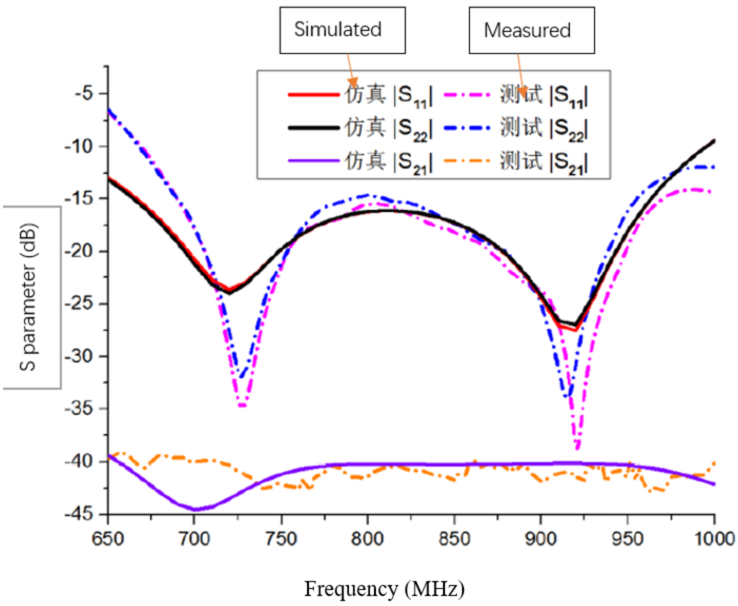


Figure 30: The Simulated and measured S parameters [35].

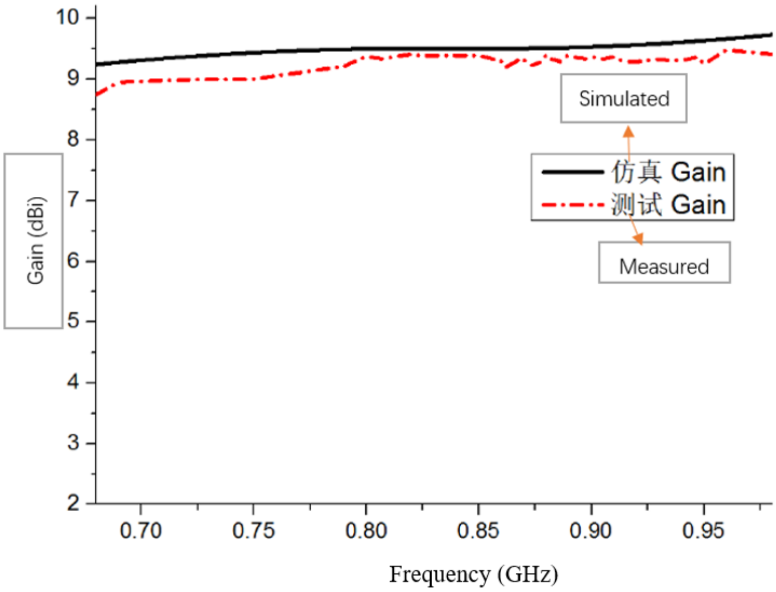


Figure 31: The Simulated and measured Gains [35].

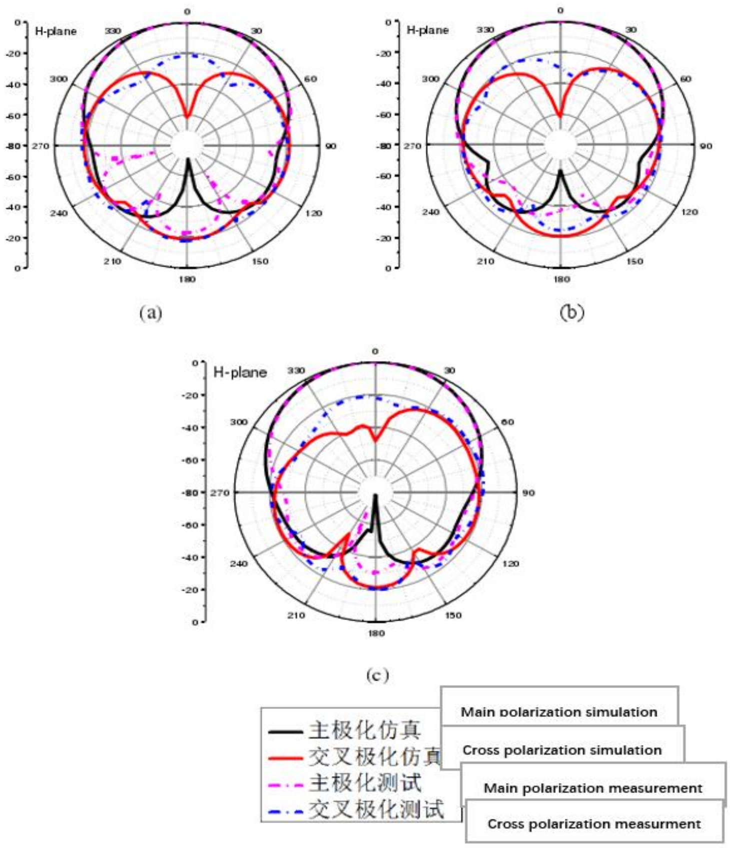


Figure 32: The radiation pattern. (a) 0.69GHz; (b) 0.82GHz; (c) 0.96GHz [35].

I would like to introduce the new 5G products that produced by HUAWEI, as shown in Figure 33.

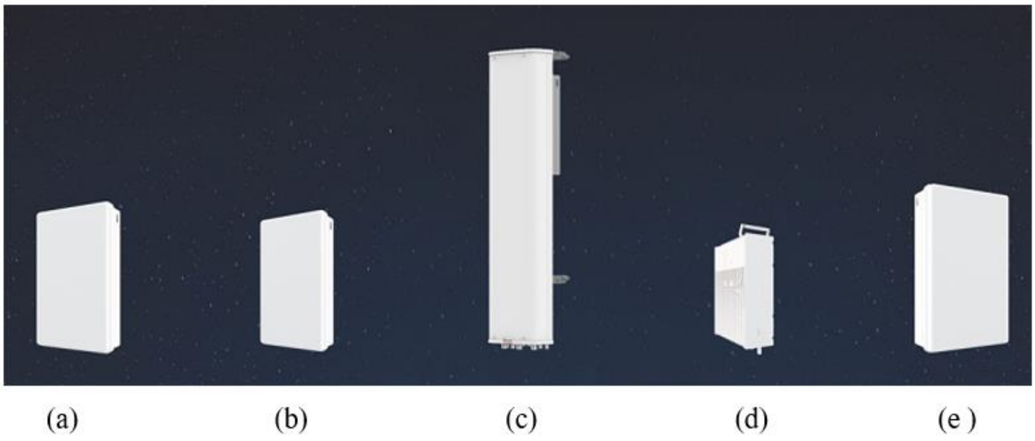


Figure 33: The 5G products produced by HUAWEI [36].

Product (a) is the industry's only Massive MIMO antenna that supports both 400MHz UWB and 64T64R. It solves the problem of insufficient spectrum bandwidth.

Product (b) is the industry's lightest 64T64R Massive MIMO antenna, a single module weighs only 19kg.

Product (c) is BladeAAU Pro. Through the integrated design of active antenna + passive antenna, the number of channels of the active antenna part has been upgraded from 32 to 64 channels, and the frequency band interface of the passive antenna part has been further upgraded.

Product (d) is BladeRRU Pro. It is the first time to realize the integration of low three-frequency and medium-frequency three-frequency, reducing the number of RRUs required for FDD full-band deployment by 2/3.

Product (e) is FDD Massive MIMO. Huawei uses Meta metamaterial array design and ultra-small PIM-Free filter technology to break through FDD Massive MIMO has been facing challenges such as equipment size, weight, and system performance.

CHAPTER VIII

VIII. Conclusion

The fifth-generation mobile communication (5G) technology is the latest generation of cellular mobile communication technology. Its transmission speed, time delay and capacity have all been improved by leaps and bounds, whether in the time domain, space domain or frequency domain. While the 5G communication performance has improved, new requirements have also been placed on base station antennas. The materials for base station antennas have also undergone new developments.

The traditional MIMO technology is upgraded to Massive MIMO technology. The number of antennas increases geometrically, and a large number of antennas are placed in a limited space. Therefore, the antennas are required to be light in weight and small in size. Radiation elements began to develop towards lightweight, high-precision, highly integrated plastic vibrators and low-cost plastic vibrators.

5G requires base station radome materials with high light transmittance, low absorption and high dielectric properties. At the same time, in order to meet the design requirements of 5G antennas for lightweight, miniaturization, and integration, radome materials will also develop in the direction of lightweight and environmental protection.

Due to the larger data volume and transmission frequency of 5G, higher working frequency, and the structure tends to be multi-layered and highly integrated design, PCB substrate materials need to meet the requirements of high heat resistance, high heat dissipation, miniaturization, and light weight.

The energy consumption of 5G base stations increases, and the heat dissipation problem increases. How to reduce the energy consumption of base stations and effectively solve the heat dissipation problem is one of the challenges faced by manufacturers. Due to the rapid increase in the number of antennas, how to reduce costs and mass-produce antennas is also an indispensable ability for antenna manufacturers to win in the antenna industry.

The arrival of 5G has brought new opportunities and challenges to China's base station antenna industry. If antenna manufacturers can seize opportunities and break through challenges, they will win a place in the antenna industry.

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