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INTRODUCTION TO THE TWO KEY TECHNOLOGIES IN MACRO RRU

Tech Brief

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INTRODUCTION

A Radio Access Network (RAN) is a vital part of a mobile communication system. The major components of a RAN include base station and antenna that define the network coverage and capacity. As shown in Figure 1, Power Amplifier and Diplexer Filter are the two key elements in macro base station Remote Radio Unit (RRU), for optimizing the high-power macro layer coverage.

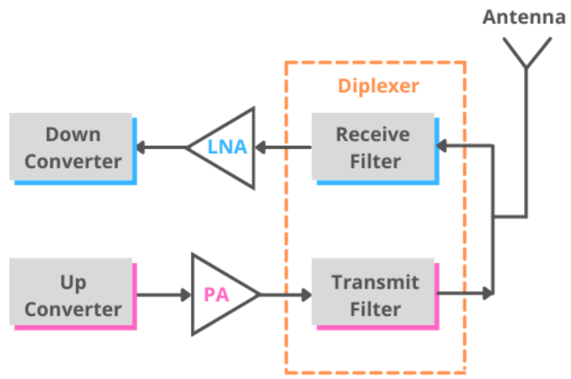

Figure 1. A simplified diagram of the front end in base stations.

This paper discusses how the two key elements of a macro base station, Power Amplifier and Diplexer, combine with different technologies in the process of high RRU system design.

1 | Power Amplifier

The Power Amplifier boosts the RF power signals for transmission to expand the network coverage. The Laterally-Diffused Metal-Oxide Semiconductor (LDMOS), Gallium Arsenide (GaAs), and Gallium Nitride (GaN) are the three mainstream technologies for RF and microwave applications.

Low-cost LDMOS devices have significant advantages in providing high power amplification, particularly in frequencies below 2GHz. The GaAs devices support higher frequency and wider range; however, the power transmission is relatively lower and the cost is higher. GaN achieves higher power gains and has quickly become the technology of choice for high-frequency, wide-band, high-power applications in smaller base stations.

Meanwhile, LTE changed the way RF could be deployed. Overlapping of coverage areas in UMTS always results in interference. With the emergency of LTE, interference is mitigated, and network performance is improved.

1.1 LDMOS

For years, base stations incorporated power amplifiers with LDMOS transistor technology. The silicon-based LDMOS transistor is a planar double-diffused metal–oxide–semiconductor field-effect transistor (MOSFET). Its source, gate, and drain are used to develop standard Doherty power amplifier chips for base stations, with an architecture housing two amplifier sections to achieve higher efficiency.

The LDMOS power amplifiers are designed for TDD and FDD LTE systems. When 2G digital mobile networks such as GSM rolled out in 850/900MHz followed by 1.8/1.9GHz, the technology became mainstream for RF base stations. LDMOS technology has been continuously improved over time, but hits the wall at frequencies above 2GHz. The introduction of UMTS and LTE networks has posed challenges to use LDMOS power amplifiers to achieve high power efficiency same as applying the previous generation of RAN technology.

1.2 GaAs and GaN

As the Very-High Frequency/Ultra-High Frequency (VHF/UHF) and Microwave (MW) bands require transistors that can easily supply tens to hundreds of watts, up to 10 GHz and beyond, the industry was looking for novel solutions, and GaAs and GaN emerged. They are both compound semiconductor materials, each composed of two elements, Category III and Category V. With higher electron mobility than silicon, they are also known as III-V semiconductors. GaAs and GaN power semiconductors have more advantages over traditional Si-based semiconductors to address the requirements for high-frequency range applications, including higher switching speed, lower electrical current loss, and higher power density.

1.2.1 GaAs

GaAs power amplifiers are available with power levels up to about 5W. Although they cannot withstand the high voltage, current, and heat of silicon or GaN, using multiple devices in push-pull, parallel or combining amplifier output in transformers or networks makes it possible to support power levels up to about 40W.

Most GaAs products are Integrated Circuits (ICs), specifically low-level gain Monolithic Microwave ICs (MMICs), which are widely used in microwave equipment designs, including radios, satellites, radar, and electronic warfare products. Small Cell is one of the major applications of GaAs amplifier to address the needs for limited area coverage or indoor solution in a cellular network.

1.2.2 GaN

GaN is a relatively new technology and higher power density is its primary advantage compared to other semiconductors. It allows signal to be transmitted with higher power and improves the base station capacity. In the Doherty power amplifier configuration, GaN achieves average efficiencies up to 60% with 100-W output power, significantly reducing the energy required and cost to run a high-power system.

The high-power density also allows GaN power amplifiers to operate at temperatures higher than 100 °C, which is unable to achieve with silicon-based solutions. The improved thermal tolerance results in cost reduction with the heat sink.

1.3 Is shifting from LDMOS to GaN for a new generation base station necessary?

In addition to satisfying the tighter coupling requirements between the transceiver, RF front-end, and antenna, RF engineers are being asked to develop base stations with better RF front-end integration: reduced size, lower power consumption, higher output power, wider bandwidth, improved linearity, and increased receiver sensitivity.

Although using Doherty topologies and envelope tracking boosts performance, equipment manufacturers and operators started turning to GaN as the next-generation semiconductor for RF power applications during the development of LTE. Also, many LDMOS major players have been shifting to GaN production as they recognize how critical GaN helps carriers and base-station OEMs accomplish Sub-6 GHz Massive MIMO.

The choice between adopting mature LDMOS and emerging GaN as high-power amplifiers in base stations remains intriguing.

1.3.1 GaN: Wideband applications is one of the keys for 5G NR

Generally, the power amplifier devices for UMTS base stations were based on mature and cost-efficient LDMOS, which also took the early lead in the LTE base station market. Since GaN power amplifiers have been making significant inroads in LTE, they are gaining steam in 5G.

With 5G NR, the need for dense, small-scale antenna arrays in network infrastructure results in critical power and thermal management challenges of RF systems. Compared to LDMOS, GaN has higher power density and operates over a much wider frequency range. Although the improvements in LDMOS amplifiers support frequencies up to 4 GHz, GaN amplifiers achieve frequencies up to 100 GHz, increased by five times. The higher efficiency and output impedance, along with lower parasitic capacitance of GaN devices offers carriers flexibility and ease to deliver mmWave high frequency transmission in future as they support transmission over multiple bands simultaneously with one wideband radio platform, particularly in Sub-6.

1.3.2 LDMOS: Competitive linearity at a lower price point

In the sub-6GHz regime in 5G, competition between LDMOS and GaN in lower-power active antenna systems is inevitable. LDMOS available at a lower price point with very competitive linearity amplify signal without distortion at specific frequencies. In contrast, GaN is relatively more expensive and its linearity is also an issue. In spite of the competition, they play their roles as some mobile operators are deploying both low- and high-frequency bands for 5G NR.

Making space for 5G NR radios, traditional macro base stations of various frequencies and power levels are integrated into a single radio unit. Low-cost LDMOS solutions with smaller size and improved performance enable equipment manufacturers to incorporate multiple stages, biasing, splitting, and even Doherty in a single unit.

GgN with higher power density, lower parasitic, and improved efficiencies enable combination of multiple bands into a single transmit chain, reducing the overall size and cost of the radio. Customization and on-demand optimization facilitate power-sharing between the two combined bands, helping operators free up space to deploy 5G NR radio in future.

1.4 GaN in its next catch-up

Each technology has its place. The first wave of 5G NR base stations has been deployed. GaN continues its race to gain market share, solving the market's technical challenges by bridging the gap with Si-based technologies. Now device makers are developing new GaN-based power amplifier chips to catch the next wave of 5G NR base station deployments.

Meanwhile, GaN and GaAs power semiconductors have more advantages over traditional Si-based semiconductors, such as higher switching speed, lower electrical current loss, and higher power density. Material suppliers are implementing new manufacturing solutions to offer lower costs and easier adoption.

In future 5G network designs of the base stations, perhaps GaN will usurp existing LDMOS devices due to their physical properties. However, LDMOS is still playing an important role and will maintain a solid market share owing to its maturity and low cost.

2 | DIPLEXER FILTER

Diplexer Filter is another key element in a base station radio unit. Figure 1 shows the Diplexer which consists of the transmit filter and the receive filter. The transmit path between the high-power amplifier and the antenna port of the radio unit enables RF signal passes through with low insertion loss and limits the out-of-band RF signals that interfere with the mobile network. The size of a diplexer filter needs to be small so that the whole radio unit is compact and lightweight for easy installation.

2.1 Air Cavity Filter

The air cavity filter has been widely used in UMTS and LTE base stations for its high-power capability and relatively simple manufacturing. It is crafted from a single metal block by a Computer Numerical Control (CNC) milling machine with a pre-designed structure.

To meet the need for lighter and smaller RF filters in base stations whilst RRU is now a common form factor in the mobile radio network, RRU normally installed at the top of an antenna tower or a rooftop of a building, has a specific loading limit. With multi-technologies (GSM, UMTS, LTE) RRUs from multi operators sharing an antenna tower, the weight of RRU is an important deployment factor. Reducing the weight and size of RRUs gives the benefits of easier installation and faster rollout.

2.2 Dielectric Resonator Filter

A typical Dielectric Resonator (DR) filter has similar structure as a cavity filter, which consists of a number of dielectric resonators mounted inside the metallic cavities. Instead of using air in the cavities, a dielectric material is placed inside each cavity. With high dielectric constant, the size of the DR filter can be reduced by about 50% compared to the corresponding air cavity filter.

2.2.1 DR with support structure and Quality (Q) factor of DR filter

DR with support and a tuning element is shown in the figure 2 below. The support structure is made of dielectric material with a low dielectric constant. The combined DR and the support structure are typically mounted inside the cavity using a screw. The support structure degrades DR filter performance if it is not properly designed.

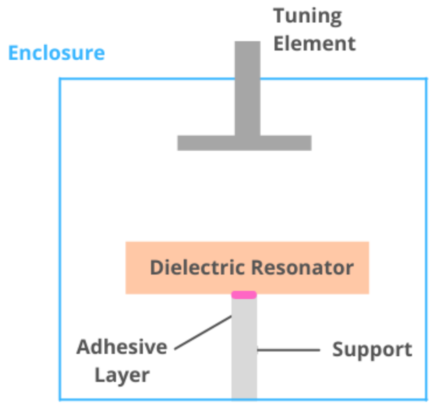

Figure 2. A typical support structure of a Dielectric Resonator.

DR filter unloaded Quality factor (Q) of 24000-50000 in Transverse Electric (TE), Transverse Magnetic (TM), Hybrid Electric (HE) modes at 1.8GHz have been reported. The achievable filter Q value is typically 70-80% of the unloaded Q value. The reduction is due to the losses in the support structure and tuning screws.

Good thermal conductivity of the support structure allows the heat generated inside the DR to be transferred to the filter housing. It is also an important factor of a DR filter design. High power DR filters have been tested for 100W with good RF performance showing DR filter is applicable to the high-power radio unit.

2.2.2 Further size reduction in DR filter

Further filter size reduction methods have also been studied by using higher order mode filters. Dual-mode DR filters save approximately 30% of the volume in comparison with single-mode DR filters. Triple mode DR filters save approximately 50% of the volume. Although higher order mode filters are more complex in design, the availability of electromagnetic field simulation software can save time and cost before making filter prototypes.

2.3 Ceramic Dielectric Filter for 5G base station

The telecom industry is looking into ceramic dielectric material for 5G base station filter applications. With massive MIMO and active antenna in 5G, using ceramic dielectric material is another approach in addition to the metal cavity solution for the base station filter.

There is no metal cavity in a Ceramic Dielectric Filter which significantly reduces the size and weight for massive MIMO applications in 16TR, 32TR, or 64TR. However, there are still some technical challenges.

The manufacturing process of Ceramic Dielectric Filter includes ceramic powder preparation, dry press forming, sintering, precision cutting, metallization, and assembly adjustment. The purities of ceramic powder, formation of the filter by dry pressing, the thickness control in the metallization process is the new know-how than in the cavity filter solution. Tuning a ceramic filter is also done by trimming, which differs from tunning a cavity filter using the tuning element.

Although there are many new areas to be explored in Ceramic Dielectric Filters for 5G, the size, weight, and RF performance advantages draw the industry's attention. Ceramic Dielectric Filters are expected to significantly share the overall wireless base station filter market in the coming years.

Conclusion

This paper discussed the two key elements in a macro base station RRU: the Power Amplifier and the Diplexer Filter. In power amplifier design, GaN is the emerging technology trend. Compared to LDMOS, its higher power density and wider bandwidth are particularly suitable for high power RRU and fulfil 5G requirements. There is substantial market demand for more compact RRU with smaller and lighter diplexer filters. Ceramic Dielectric Filter significantly reduces the size and weight, particularly suitable for 5G massive MIMO base station applications.

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Comba Group is a global leading wireless solutions provider with its own R&D facilities, manufacturing base, and sales and service teams. Leading through innovative technology, the Company offers a comprehensive suite of products and services including Antenna and subsystems, Network System Services, and Wireless Transmission to mobile operators and enterprises to enhance and extend their wireless communications networks globally. With over 50,000 system deployments around the world including turnkey in-building systems, urban/rural wireless systems, and transport wireless networks, Comba Group's end-to-end network solutions include consultation, network design, optimization and commissioning. Comba Group's product portfolio includes antennas and subsystems, passive accessories, macro cells, small cells, related extended and in-depth coverage solutions and Open RAN products as well as providing network solutions for 5G vertical industry.

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