

Application of GaN High Power Chips in T/R Modules

CAN LIN^[1], HAN LIU^[1], YIYUAN ZHENG^[2]

(1. Nanjing Research Institute of Electronics Technology, Nanjing 210039, China; 2. Nanjing University of Science and Technology, Nanjing 210094, China)

Abstract-Digital transmit/receive modules (digital T/R modules) play a vital role in active phased array antennas for electronic warfare applications. High power amplifier (HPA) chain is the key component in the next generation of T/R modules for the future S band phased array antenna. Today GaAs MMIC HPA is widely used in most of T/R modules. However, the drawbacks of GaAs MMIC HPA such as low efficiency and limited output power level (usually in the range of 5W to 15W) have made it not to be a competent candidate of power chips. In this paper, the GaN power chip with better characteristics is introduced and analyzed. Compared with GaAs MMIC HPA, it has remarkable advantages such as high power, high-gain, high efficiency, wide operating bandwidth, and etc. An S band 85W GaN power chips amplifier is developed and investigated. The performance tests of the amplifier have verified that the performance of T/R modules can be improved by using the GaN power chips. The improvements of the T/R modules system in output power, efficiency, reliability, size and weight have illustrated that the GaN power chips is a prime candidate for warfare systems and electronic warfare application.

I. INTRODUCTION

Microwave power chips which used in T/R modules are one of the most important components of active phased array antenna. It determines whether the T/R modules can meet the performance of warfare systems. Thus the development level of T/R modules technology to some extent depends on the development level of power devices. The main power device which commonly used in S-band solid-state T/R modules is mainly GaAs MMIC. Its typical output power level is in range of 5W to 15W [1-3]. Modern warfare systems for military applications place new requirements on RF power amplifiers due to the desire to reduce system size, weight, and improve system reliability. High output power, high power density, wide broadband and high efficiency microwave power devices are needed [4-6]. Power device requirements for T/R modules of power electronics are at a point that the present GaAs MMIC cannot handle. In order to meet the requirement of warfare systems, new semiconductor materials for power device applications are needed. Wide band gap semiconductor technologies like gallium nitride (GaN) are used to create new type T/R module systems to support the next generation active phased array antenna. The improved RF power device is made possible due to the much improved material properties: wide band gap, high electric breakdown field and high saturated electron drift velocity. With the GaN RF power chips offering particularly high performance, it showed that this will ultimately result in reduced circuit complexity, improved power density, gain, efficiency, and higher reliability. In particular, the abilities of warfare systems detection will benefit from the development of this technology.

Compared with GaAs MMIC, GaN power chips offer high power capabilities in S band, high power density, high gain, and high efficiency and thus, they would be used more and more widely in modern warfare systems. In order to fully investigate the application analysis of GaN power chips in T/R module systems, it is crucial to design RF power amplifiers intended for T/R modules applications with GaN power chips. In this paper, An S band 85W GaN power chips amplifier for warfare applications was developed. The performance test of the GaN power chips amplifier was carried out. Additional comparisons of the test results were made to investigate the application analysis of GaN wide bandgap power chips in T/R module systems.

II. ADVANTAGE OF GAN WIDE BANDGAP SEMICONDUCTOR

TABLE I
PHYSICAL CHARACTERISTICS OF GAAS AND GAN WIDE BANDGAP SEMICONDUCTOR

material	Bandgap E _g (eV)	Electric Breakdown Field, E _c (kV/cm)	Thermal Conductivity (W/cmK)	Saturated Electron Drift Velocity ($\times 10^7$ cm/s)
GaN	3.45	2000	1.3	2.2
GaAs	1.13	400	0.46	1

GaN wide band gap semiconductor materials have superior electrical characteristics compared with GaAs semiconductor materials. GaN wide bandgap semiconductor has many properties ideal for electronic devices for high temperature, and high power and radiation hard applications. GaN have bandgap and electric field values which are significantly higher than GaAs. Generally, wide bandgap and high electric breakdown field values is desirable. Semiconductors with wider bandgaps can operate at higher temperatures. Higher electric breakdown field results in power devices with higher breakdown voltages. As shown in Table I [7-8], the theoretical breakdown voltage of a GaN semiconductor material is 5 times more than that of GaAs semiconductor materials. The bandgap in the GaN semiconductor is significantly higher than GaAs semiconductor. This permits high breakdown voltages and high operating temperatures to be developed. With the advantages of the material, the width of the drift region can be reduced, which can reduced power device size and improve power density of power device. GaN wideband semiconductor offers an unmatched combination of electronic and physical properties which enable the fabrication of new classes of power devices for applications ranging from L-band, S-band and X-band to radiation-hard and nuclear environment. In comparison with GaAs, GaN is

also physically rugged and chemically inert which is an advantage is for semiconductor power devices required to operate in harsh environments.

III. 85W GaN HIGH POWER CHIPS AMPLIFIER DESIGN

A. The principle of GaN power amplifier

In this paper, the design and realization of GaN high power chips amplifier are researched and analyzed, which covers from f_0 to $1.6f_0$ GHz frequency range in S band. The output power of power chips amplifier is 85W. The amplifier uses 4 GaN power chips with 8mm gate width. The basic specification for the GaN power amplifier is shown in Table II.

TABLE II
SPECIFICATIONS FOR THE GaN POWER CHIPS AMPLIFIER

Frequency Band	Frequency Range	Power Gain	Output Power	Drain Efficiency	Duty Cycles
S	f_0 to $1.6f_0$ GHz	> 11 dB	> 85W	>45%	10%

The power amplifier was consisted of wideband divide/combine circuit and match network. The block schematic diagram of the GaN power chips amplifier is shown in Fig.1.

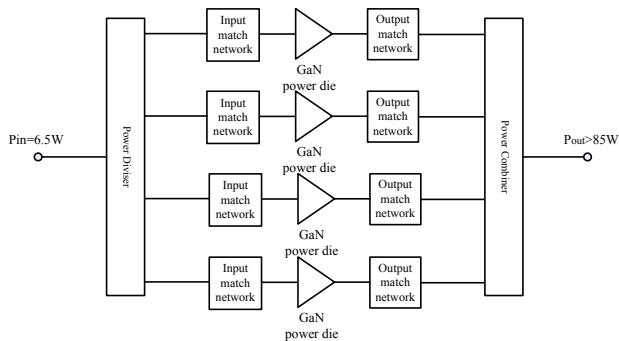


Fig 1. Block schematic diagram of the GaN power chips amplifier

B. Design of match network

The output impedance match was designed to achieve the optimum load impedances for the dies. These impedances were obtained from load-pull simulations taking the bond wires into consideration. The input impedance match was designed to conjugate match. The hybrid circuit incorporating microstrip technology is based on ceramic substrates with 10 mil thickness. The necessary bonds interconnect between the transistors and the microstrip circuit is analyzed with a 3D electromagnetic field simulator. Fig 2 show the block schematic diagram of the match circuit

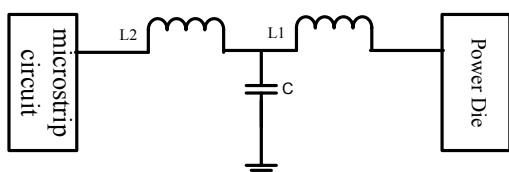


Fig 2. Block schematic diagram of the match network

C. Design of wideband division and combination

In the chip, a two branches divider and combiner is designed with the chebyshev broadband match method [9], the schematic diagram was shown as Fig. 3. The computer-aided design of the matching network using Agilent ADS tools was accomplished by an optimization. If isolation is reduced, the power chips are unstable. So the divider and combiner is designed that all port is isolated with the isolating resistor.

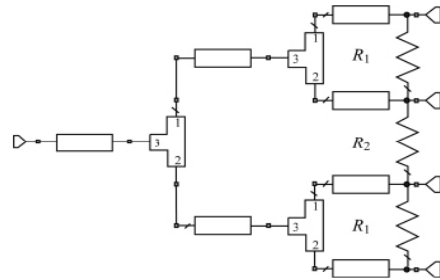


Fig 3. Block schematic diagram of the divider/combiner

IV. PERFORMANCE TEST OF THE GaN POWER HIGH CHIPS AMPLIFIER

Fig4 shows the view of the GaN high power chips amplifier. The size of the amplifier is $16\text{mm} \times 16\text{mm}$.

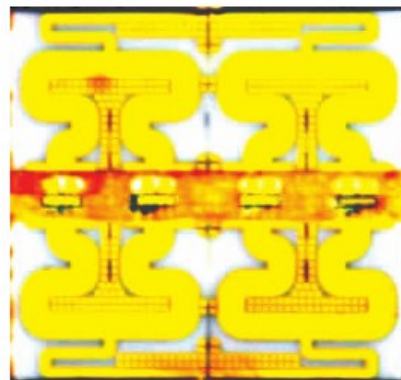


Fig 4. The photograph of the GaN high power chips amplifier

The GaN high power chips amplifier was measured under various pulsed conditions intended to replicate typical Warfare operating conditions. For all measurement both the RF and the drain supply were pulsed. The amplifier were measured with 38dBm (pulsed) input power with a duty cycles of 10%. Additional measurements were also made to investigate the application analysis of GaN wide bandgap power chips in T/R modules. Output Power & efficiency vs. Frequency for GaN high power chips amplifier is shown in Fig 5. Power gain & spurious vs. Frequency for GaN high power chips amplifier is shown in Fig 6.

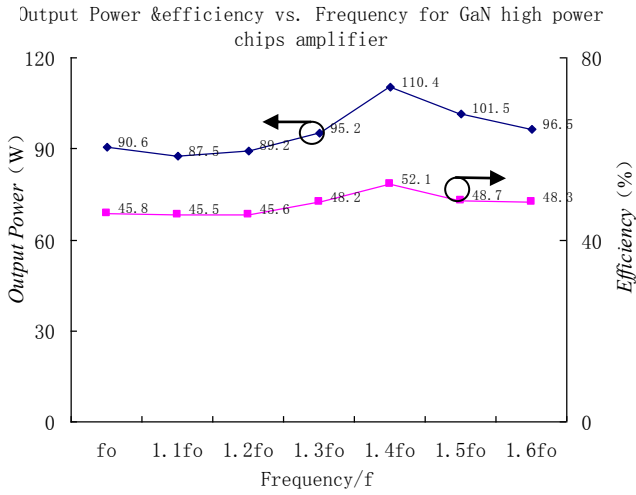


Fig 5. Output power & Efficiency vs. Frequency for GaN high power chips amplifier

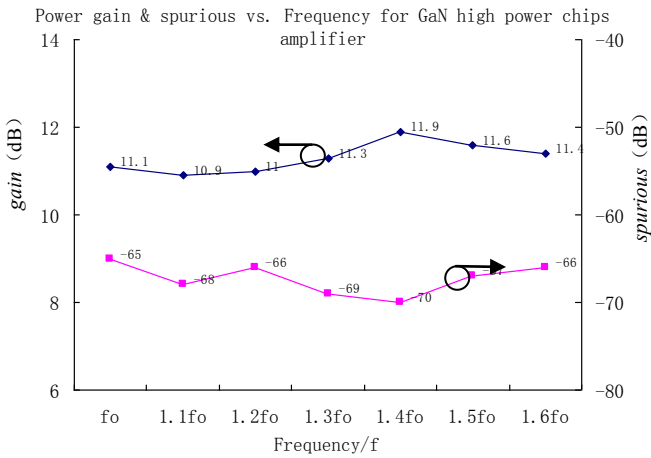


Fig 6. Power gain & Spurious vs. Frequency for GaN high power chips amplifier

V. DATA ANALYSIS

A. Output power

GaN chips offer important advantages for high power applications due to the GaN wide band-gap. GaN-based dies offer power densities in the few W/mm range. Typically GaAs MMIC has demonstrated high out-power of 5-15 W. A principal reason for this was the lack of band-gap. Compared with GaAs MMIC GaN chips supplies higher out-power for T/R modules. Besides this, The GaN power chips support long plus length with high duty cycle waveform which GaAs power amplifier can not handle. This results in an improvement of the warfare systems detection range.

This would make it possible in the future to upgrade existing phased arrays antenna by replacing the GaAs power device with GaN power device having high power in a limited space. This reduces the volume of the T/R modules and provides either an improvement in search volume or an increase in track range.

B. Gain and efficiency

Modern warfare systems for military applications place

new requirements on T/R modules due to the desire to reduce system size, weight, and cost. A major shift in T/R module specifications focuses more on efficiency to reduce DC power requirements. Lower component power dissipation can also improve phased arrays warfare systems reliability. GaAs MMIC typical gain is 6-8 dB in one stage and efficiency is 30%. As Fig5 shows, the GaN chips amplifier has higher efficiency and gain compared with GaAs power amplifier. The total Efficiency of warfare T/R module is expressed in (1) as follows [10]:

$$\eta_M = \eta_c L_c \left(1 - \frac{1}{G}\right) \quad (1)$$

Where

η_c is the efficiency of the amplifier

L_c is the efficiency of the combine network

G is the Gain of the amplifier

Compared with the GaAs power amplifier, for the same L_c , the total efficiency of T/R module can be improved with the GaN power chips due to its high efficiency and gain. The higher efficiency and gain reduces DC power requirements and simplifies cooling. This is an important advantage, since cost and weight of cooling systems is a significant fraction of the weight and cost of a T/R module.

C. Reliability

GaN technology offers much higher impedance of the chips. This enables lower complexity and lower cost impedance matching in T/R modules. With the application of GaN power devices with simple matching due to high impedance, reliability of T/R modules can be improved. GaN devices can easily operate at 32 V and potentially up to 42 Volts. The high voltage feature eliminates or at least reduces the need for voltage conversion. Furthermore, the wide bandgap offers a rugged and reliable technology capable of high drain-source breakdown voltage. In this paper, the drain-source breakdown voltage of the GaN power chips is 100V. However, the operate voltage of the GaAs power device is just only 8V. The higher drain-source breakdown voltage results in higher reliability, which T/R modules system applications can benefit from this advantage.

VI. CONCLUSION

In this paper, An S band 85W high power amplifier for T/R modules applications was developed with the GaN power chips. The performance test of the GaN power amplifier was carried out. Compared with GaAs MMIC, it showed that the output power, efficiency, and reliability of the phased arrays warfare systems can be improved with the application of GaN wide bandgap semiconductor power chips. The size and weight of the T/R Modules system can be reduced with the application of GaN power Chips.

REFERENCES

- [1] ZHENG Xin. "Research on the application of novel semiconductor power device in modern radar". *Semiconductor Technology*. vol 34, pp. 828-832. 2009
- [2] Adolph M, Hackenberg U, Reber R, et al. "High-precision temperature drift compensated T/R-Module for satellite based SAR applications". *European Microwave Conference*. Paris: IEEE Press, 2005.
- [3] YU Zhenkun, LIU Dengbao. "Application research on broadband amplifier with GaN power chips in S band". *Journal of Microwaves*. vol 27, pp.68-71, Apr.2011
- [4] Milligan J W, Sheppard S, Pribble W, et al. SiC and GaN wide bandgap device technology overview. *IEEE Radar Conference*. Boston MA, 2007. 960-964
- [5] Millan, J. Wide band-gap power semiconductor devices. *Circuits, Devices & Systems, IET*. 2007: 372~379
- [6] Chow T P. High-voltage SiC and GaN power devices [J]. *Microelectronic Engineering*, 2006, 83(1):112-122
- [7] LIU Han, ZHENG Xin, YU Zhen-kun. "The Application Analysis of GaN Power Devices in Radar Transmitter". *IET International Radar Conference 2009*.
- [8] ZHANG guangyi Wang bingru. "Some requirements for active phased radar and application of wide bandgap semiconductor devices", *Modern Radar* vol.27, pp.1-5 2005
- [9] Inder Bahl Prakash Bhartia "Microwave Solid State Circuit Design (Second Edition)" ZHENG Xin translate Publishing House of Electronics Industry, 2006
- [10] YU Zhenkun, ZHENG Xin. "The application analysis of SiC power device in radar transmitter", *Journal of Microwaves*. vol.23, pp.61-65, June 2007