Design and Discussion of High Power t/r Module Based on Gan

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Keywords: Aesa Jammer, t/r Module, the 3rd Generation Semi-Conductor, Gan Mmic, Diamond-Cu Composite Material

Abstract: Nowadays,the Tr-Based Active Electronically Scanned Array (Aesa) Jammer is Growing Rapidly and Will Dominate the Future Applications of Ew System.the High Power Circuit is the Key Circuit of t/r Modules,Will Influence Development of System. Firstly the Design of High Power Circuit Based Gan Mmic Technology is Presented. Secondly the Technological Development of Heat Radiation Based New Packaging Material and High Performance Emc is Analysed. Finally Design Result Has Been Applied to the New Generation of t/r Product. This Will Promote Rapid Growth of Our country’s Chinese Aesa Jammer.

1. Introduction

In recent years, the active phased array jammer with solid state T /R module as its core has been widely used in the field of electronic warfare.The active phased array jammer is connected with a T /R module based on a solid-state power amplifier after each unit or a number of radiating units. An AESA jammer at least needs a few hundreds, more needs tens of thousands of T/R modules,The development cost of T/R modules is about 60% of the cost of the whole AESA Jammer system,The performance of the module directly determines the functional characteristics of the AESA Jammer.Therefore, the T /R module is the core component of the AESA Jammer.

At present, microwave monolithic integrated circuit (MMIC) technology has become one of the key technologies of AESA Jammer T/R module.With the development and application of third-generation semiconductor devices represented by GaN [1], T/R components are developing rapidly towards high power, miniaturization and multi-function.The transmitting output power of T/R module has developed from several watts, tens of watts to hundreds of watts. The high-power amplifier circuit has become the core functional circuit of T/R module. The success or failure of its development will directly affect the development progress of the whole set of active phased array jammer.This paper summarizes the key technologies of GaN based high-power microwave circuit, at the same time,it analyzes and discusses the characteristics of T/R module's high-density heat dissipation and electromagnetic compatibility.

2. Design on Gan High-Power Microwave Circuit

The development of microwave power components has gone through three stages:The first generation of microwave power devices is mainly represented by Si. The output power of Si tube power devices can reach more than 100 watts, but they cannot work in continuous waves, and their working frequency is low, so the highest working frequency can only reach S band.The second generation of microwave power devices is mainly represented by GaAs. The low thermal conductivity and low breakdown field strength of GaAs materials restrict its further development in solid-state high power. At present, the output power of a single tube can only reach more than 10 watts, which is difficult to meet the requirements of miniaturization of T/R module and the use of high-power microwave circuits.The third generation is a wide band gap microwave power device represented by GaN, which has the advantages of high thermal conductivity, high breakdown electric field, wide band gap, high electron saturation rate, high electron mobility, strong anti-radiation ability and good chemical stability. Its output power per millimeter gate width can reach tens of watts, which is much more than that of GaAs microwave power device. The third

  DOI: 10.25236/ISMHI.2019.124

generation semiconductor technology has become a hot spot of the development of microwave chip industry.From the comparative analysis of the above-mentioned three generations of microwave power devices, we can see that with the gradual improvement of the development maturity of GaN microwave power devices and the significant reduction of the development cost,the GaN high-power microwave devices have now become the preferred device for the amplifier circuit of T/R module[2].

The T/R module is mainly used to transmit high-power RF excitation signals and receive weak echo signals.Figure 1 is the functional block diagram of typical T/R modules,It usually consists of transmitting circuit, receiving circuit, receiving and transmitting common circuit, power supply and control circuit, etc.At present, the new generation of AESA Jammer usually has higher requirements on the output power of T/R module, and its peak pulse power is as high as kilowatt. Such a high peak pulse power can only be realized through multi-tube power synthesis. Generally, multi-tube power synthesis transmission channel includes front stage amplification, excitation stage amplification and final stage amplification.The amplifier circuit design of transmission channel needs to consider inter-stage matching, amplitude balance, temperature compensation and moderate gain compression,Meanwhile, the amplitude and phase inconsistency design between multiple transmission channels also needs to be considered [3].Therefore, the high-power transmitting circuit is the core function circuit of T/R module, and it has become the main restriction factor of structure size and development cost of T/R module.

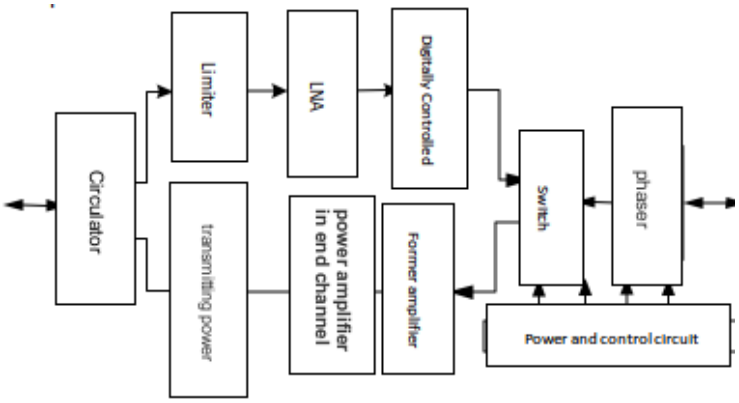

Fig.1 Functional Block Diagram of Typical t/r Modules

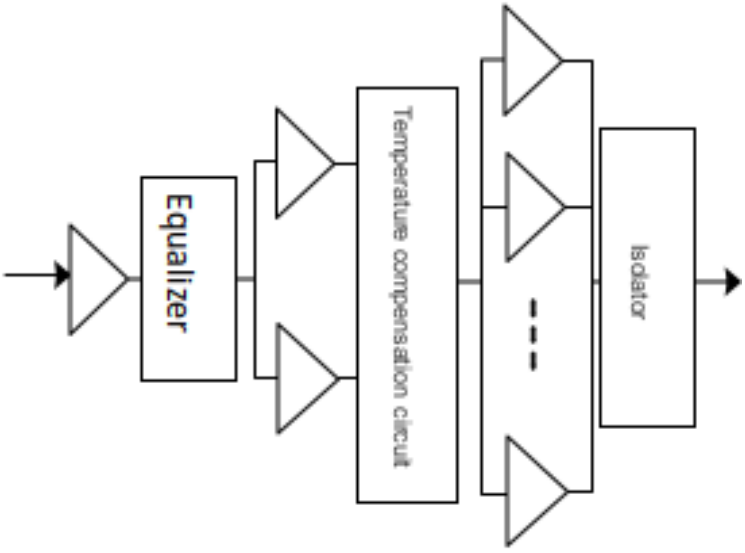

Fig.2 Functional Block Diagram of Typical High Power Transmission Channel

The schematic diagram of high-power transmission channel based on traditional power devices is shown in figure 2.If the high-power output of 1200W is realized and the transmission channel of power gain is greater than 70dB, the multi-stage power tube power synthesis circuit and the corresponding power synthesis/distribution network should be adopted.Considering that the output

power of a single Si power tube is no more than 120W, power synthesis of at least 10 power tubes is needed to realize the amplification circuit of this index [4].If GaN power tube technology is adopted, the output power of GaN power tube is more than 10 times higher than Si or GaAs power tube at the same level of chip manufacturing technology, which can reduce the series of transmitting channel chip to 1/2.

Therefore, as GaN microwave power devices inside of the T/R modules are widely used, which can not only effectively reduce the volume and weight of the T/R modules, reduce cost, but also greatly improve the efficiency of assembly components, reduce the wire interconnection between chips and improve the electrical property and the reliability, especially to improve component consistency of amplitude and phase consistency in order to satisfy the special needs of active phased array radar system .

3. Thermal Design and Concerns

The installation structure of active phased array jammer is closely related to the type of installed platform. Generally, the space of airborne platform or shipborne platform is limited, which results in the reduction of the structural size of T/R module and the compact layout of power amplifier circuit in the module, so the heat flux density of the component is very high.If the power inside the power transistor is not dissipated in time, the temperature of the pn junction in the tube will rise sharply, even exceeding the maximum allowable temperature, resulting in the failure of the transistor.In addition, the direct effect of the transistor junction temperature is that the output power, efficiency and other performances of the tube drop sharply, and the reliability of the tube is reduced.Normally, the junction temperature of power transistors increases by 10℃, and its reliability will decrease by 60%. Therefore, thermal design is an important part of T/R component design. Only through reasonable heat dissipation design of power amplifier circuit can the long life and high reliability of components be guaranteed.

Table 1 Main Performance Parameter of Common Packaging Material

Materials	Coefficient of thermal expansion /10^{-6}.K^{-1}	Thermal conductivity /W.(m.K)$^{-1}$	Density /g.cm^{-3}
Al_2O_3	6.5	20	3.9
BeO	6.8	250	2.9
Si	4.1	150	2.3
GaAs	5.8	39	5.3
GaN	5.6	-	-
AI	23	230	2.7
Cu	17	400	8.9
Mo	5	140	10.2
W	4.45	168	19.3
Kovar	5.9	17	8.3
Invar	1.6	10	8.1
Cu-85%Mo	6.3	160	10
CE7(AI-70%Si)	11	150	25
CE11(AI-50%Si)	7	120	24

With the obvious increase of power density of GaN microwave power device, the local thermal management pressure of power chip becomes more and more serious, which puts forward higher requirements for the structural thermal design of T/R components.Traditional electronic power device packaging materials include plastic packaging materials, ceramic packaging materials, metal or alloy encapsulation material, table 1 shows the main performance parameters of common electronic power device packaging materials,and from the table we can see that the thermal conductivity and thermal expansion coefficient are unable to meet the demand of development of high power T/R modules at the same time [5]. Therefore, the research of new electronic packaging

materials is one of the key technology of high power T/R modules.

Diamond/copper composite material is a composite material made of high thermal conductivity, low-thermal expansion diamond and copper with good thermal conductivity, which is non-solid soluble and can give full play to the characteristics of each component. It has the following advantages :(1) high thermal conductivity;(2) the thermal expansion coefficient (CTE) can be controlled by changing the mass fraction of diamond and Cu;(3) small density;(4) good plating and processability.Table 2 shows the main performance parameters of diamond/copper composites developed by Somitomo Electric Industries(SEI).The industry has proved that the new electronic packaging material is the preferred material for solving the heat dissipation of current GaN high-power devices. It can solve the urgent need of high-density heat dissipation of high-power power chip and improve the electrical performance of the product, and improve the heat dissipation performance and reliability of the product.

Table 2 Main Performance Parameter of Sei Diamond-Cu Composite Material

Materials	Coefficient of thermal expansion /10^{-6}. K^{-1}	Thermal conductivity /W. (m. K)$^{-1}$	Density /g. cm^{-3}
Diamond-Cu DC40	4	600	4. 6
Diamond-Cu DC60	6	550	5. 1

4. Considerations on the Emc Design

The new generation of AESA Jammer has a high front power density, which makes it difficult to design electromagnetic compatibility between T/R modele' sending and receiving channels.In T/R module, the signal of transmitting channel is much higher than that of receiving channel. It is necessary to consider the EMC characteristics of components and pay attention to the shielding between receiving and sending channels. Generally, receiving and sending channels are installed in different shielding cavities, which is especially important for receiving channels with high sensitivity, because they are highly sensitive and easy to self-excitation [6].For signal line and power line should also be reasonable layout, so as not to affect each other.The grounding problem of T/R module is also very important. Poor grounding will increase signal crosstalk and make the circuit unstable.With the wide application of GaN microwave power device, the structure size of T/R module amplifier is greatly reduced, which is more conducive to the independent shielding design of amplifier circuit.

In practical engineering applications, GaN wide bandgap high-power devices also have the characteristics of high working voltage (generally 28V or 50V) and small working current.This kind of power supply advantage can reduce the circuit loss of the AESA Jammer and reduce the heat loss of the antenna array, and can improve the transmitting efficiency of the AESA Jammer .At the same time, it greatly simplifies the design of the system feed network, which is more attractive to the design of the new generation, multi-function and miniaturized AESA Jammer.In addition, small working current can reduce the crosstalk among various signals in the antenna array and improve the electromagnetic compatibility of the system.

5. Conclusion

Several technological developments of high-power microwave devices are closely related to the corresponding semiconductor materials. GaN materials in the third-generation semiconductor materials have the characteristics of large bandgap width, high breakdown strength, high peak electron drift velocity and high thermal conductivity. The high power microwave device made of GaN material will improve the performance of the power amplifier and have a profound influence on the development of the active phased array jammer system.

This paper discusses the design of the key technology of the high-power T/R module, expounds the design of the high-power microwave circuit based on GaN MMIC technology, and analyzes the

technical development of the new packaging material heat dissipation and high-performance electromagnetic compatibility of T/R module. The design results are applied to the practical products of the new generation of T/R module, which provides reference for the further development of the new active phased array jammer in China and promotes the rapid development of the active phased array jammer in China.

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