Design and Research of Highly Integrated Multi-channel Tile-type T/R Module

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Abstract. This paper introduces a design scheme and key technology of a multi-channel tile-type T/R module. In order to meet the requirements of high reliability, miniaturization, lightweight and multi-functional integration, a vertical interconnection design method of high integrated multi-channel tile-type T/R module is proposed. LTCC technology is used to achieve high-density stacking of radio frequency devices, while bare chips are used to improve system integration and reliability. The module integrates 4 isolated transceiver channels with a size of 40mm×40mm×10mm, which significantly reduces the volume and weight compared to the traditional T/R module structure. The module simulation results prove that the design scheme is easy to implement and fault location maintenance, and the test results meet the design indicators.

1. Introduction
Active phased array antenna has been widely used in military and civilian fields such as radar and communications[1]. The T/R module is the most important component in this type of antenna. The RF signal direction of the traditional brick-type T/R module is parallel to the module installation direction, which has the advantages of simple circuit, mature technology and low cost[2,3]. However, with the increase of the working frequency, the element spacing of the active phased array antenna becomes very small, resulting in a very thin thickness of the brick assembly, which is even difficult to realize in engineering. Moreover, the module is far away from the cold plate, with long heat dissipation path, large thermal resistance and complex heat dissipation structure[4]. At the same time, the installation method determines its large longitudinal size, which makes it difficult to reduce the profile of the entire active antenna. It cannot be used for active phased array antenna applications with low profile requirements such as limited space size, special loading platforms or conformal array[5,6].

Tile-type T/R module was developed earlier in foreign countries, and some progress has been made. Mark S. Hauhe et al. adopted a new high-density package design. The package used multilayer aluminum nitride (AlN) substrates, flipped monolithic microwave integrated circuit (MMIC) chips, coplanar waveguide transmission lines, and solderless fuzz button interconnects[7].

The domestic research on the technical problems and implementation technology of tile-type T/R module started relatively late. Zhiguang Zhang et al. proposed a method to achieve effective vertical interconnection. Microstrip in the cavity is connected to radiating unit through offset strip line, coaxia[8]. Jinzhong Hao et al. proposed a new 3D cubic packaging technology in the highly integrated packaging T/R module. The module has 4 receiver and transmitter channels, and the multifunctional monolithic microwave integrated circuit( MMIC) chip technique and multi- chip module( MCM) technique are also adopted to increase the integration level[9].
The working frequency of the tiled T/R module in this paper is the X-band, which has strict requirements for high reliability, miniaturization, light weight, and multi-function integration. However, the above models have technical problems in heat dissipation structure, engineering application and other aspects, which can’t meet the design requirements or engineering batch application.

Based on the above analysis, this paper provides a highly integrated multi-channel tile-type T/R module for the shortcomings of the existing technology. The module integrates multiple RF channels to achieve miniaturization, which can effectively reduce the profile height of the active phased array antenna, and the internal heating device of the T/R module is close to the heat sink to achieve the purpose of rapid heat conduction.

2. The working principle and design scheme of the component

The highly integrated multi-channel tile-type T/R module proposed in this paper adopts bare chip to improve the system integration and reliability, makes full use of the space volume, realizes the interconnection of RF signal and low-frequency power supply control signal by vertical interconnection technology, and realizes high-density stacking of RF devices by LTCC technology. The block diagram of the module is shown in Figure 1.

The T/R module integrates 4 transceiver channels, each of which is composed of transceiver branches. The received 4 channel signals are transferred to micro-strip line through SSMP1 connector, and then into limiter and LNA, then to multi-function module through conversion module 1, and then to power divider module through conversion module 2. After 4 channel synthesis, the signal is vertically transited to SSMP2 output.

The transmitted signal is transited from SSMP2 input to power divider module, divided into 4 channels, and then to multi-function module through conversion module 2, then to power amplifier module through conversion module 1, and finally transited to SSMP1 output to 4 transmission channels.

![Figure 1. Module principle block diagram](image_url)
The first layer is power amplifier and LNA layer, which mainly includes power amplifier module, limiting and LNA circuit, SSMP connector 1, etc. It is installed on the aluminum alloy cavity to realize the functions of limiting amplitude and low noise amplifier of receiving channel and power amplification of transmitting channel. Among them, ong them, the mounting surface of the power amplifier module is in close contact with the heat sink, so that the heat generated by the power amplifier can be quickly everywhere, and the temperature of the power amplifier chip and the whole active antenna array can be reduced.

The second layer is the multi-functional module layer. The multi-functional module includes 4 channels, multi-functional chip and control chip, which are all bonded to the LTCC substrate with conductive adhesive. The gold wires are cascaded between the chip and the chip and between the chip and the substrate. The contacts on the front and back of the substrate are flexibly connected with conversion module 1 and conversion module 2, so as to realize the miniaturization and integration of the components.

The third layer is the power divider module layer. The power divider module consists of 4 channel driver chips, control chips and power supply chips. The front contact of the substrate is connected with the conversion module 2 flexibly, and the back contact is connected with SSMP2 and external connector. It mainly realizes the shunt synthesis of RF signal and power control signal.

Considering that the transmission path should be shielded and isolated to avoid signal interference, the space volume should be fully utilized in the structure, and the multi-layer circuit and ground circuit should be reasonably divided to solve the mutual interference problem of RF, power supply, digital signal wiring.

In addition, the conversion module, multi-function module and power divider module are placed in the aluminum alloy cavity, and the internal space of the cavity is divided into several closed small spaces, and the 4 transceiver channels are isolated from each other, which effectively solves the EMC problem between channels.

3. Simulation of key circuit design

Based on the above design scheme, a highly integrated multi-channel tile-type T/R module of X-band was designed with a size of 40mm×40mm×10mm.

3.1 Design of vertical interconnection based on LTCC

The T/R module is realized based on 3D stacked mode. The module is connected vertically and horizontally by customized connector to solve the problems of power supply, standing wave and power on the module.

The advantage of tile-type module is that the module is compressed in the longitudinal direction without increasing the area in the horizontal direction, which greatly reduces the volume and weight of the module, and solves the interconnection problem between the vertical and horizontal directions.
The carrier material of wool button (elastic button) is PTFE, and the material of wool button is cylinder beryllium copper wire. After the wool button carrier is installed into the wool button carrier, it is integrated into the metal partition wall.

The vertical interconnection design of the T/R module based on LTCC is mainly divided into 3 core parts.

In the first part, SSMP connector realizes 4 channel signal vertical transition. The SSMP connector is connected with the circulator externally, and connected with the microwave printed circuit board of the first layer in the vertical direction. The microwave printed circuit board is connected with the power amplifier module, limiting and LNA circuit with gold tape or gold wire, and then connected to the second layer multi-functional module through the conversion module 1.

Through the optimization design and Simulation of the SSMP connector to the multi-function module, as shown in the figure, the S11 of the vertical transmission structure is better than -15dB in the frequency band of 5~25GHz, which can be well applied to the 3D vertical transmission of the RF signal of the module.

In the second part, the front contact of the multi-functional module is connected to the front contact of the third layer power divider module through the conversion module 2. Through the optimization design and simulation of the multi-functional module to the power divider module, as shown in the figure, the S11 of the vertical transmission structure is better than -10dB.

In the third part, the power divider module and carrier plate are sintered to the aluminum alloy cover plate with alloy solder, and the bottom contact of power divider module is elastically connected with the inner conductor of SSMP2 connector to output to the port. Through the optimization design and simulation of the power divider module to SSMP2 connector, as shown in the figure, the S11 of the vertical transmission structure is better than -20dB.
3.2 One-to-four power divider

The tile-type T/R module consists of 4 independent channels, which are isolated from each other. The RF signal and power control signal are synthesized by the third layer power divider module. Through the optimization design and simulation of one-to-four power divider, as shown in the figure, all ports of the structure are better than -12dB, which meets the application requirements of components.

3.3 Transmission from LCTT flat layer microstrip line to stripline

The coaxial-like structure is used between the flat layers of LTCC. The signal flows through the quasi coaxial-like in the micro-strip line and outputs to the stripline to realize the transition transmission in the flat layer, which fully guarantees the isolation of the transmission path. As shown in the figure, the transmission structure from micro-strip to stripline is optimized and simulated, and the ports of the structure are better than -22dB.
4. Concluding remarks
This paper presents a design method of vertical interconnection for highly integrated multi-channel tile-type T/R module. The module integrates 4 isolated transmission and reception channels with a size of 40mm×40mm×10mm. Compared with the traditional T/R module structure, it has the advantages of high reliability, miniaturization, lightweight and multi-functional integration. It can meet the application of active phased array antenna with limited space size, special loading platform or conformal array with low profile requirements.

5. References
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