PACKAGED X-BAND T/R MODULE FOR ACTIVE PHASED ARRAY RADAR APPLICATIONS

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Abstract

In this article we describe a global design approach of an X-band T_x/R_x module which, by means of a Multi Chip Module (MCM) technique, includes in a single package the different microwave functions (4-bit phase-shifter, low-noise amplifier, power amplifier, switching control circuits), the thin film interconnections, the bias circuits, the driver circuits (Si ICs) and the switching MOS.

Introduction

The technological evolution due to GaAs MMIC's development followed steps similar to those of Silicon IC's. On Si the first step (more than twenty years ago) involved the passage from hybrid circuit using discrete components, to chip-form monolithic circuits mounted in packages.

The next step (for a term of 20 years) involved the Multi Chip Module (MCM) approach, where a whole subsystem was implemented on different chips and mounted in a single package.

The first step of GaAs technology began with a ten years delay with respect of Si, but the evolution was so fast that the passage to the MCM approach was contemporary with Si technology. In fact both Si and GaAs technology need a trade-off between yield problems (with respect of too complex chips) and technological incompatibility (i.e. between power, control and low-noise MMICs on GaAs) at one end and a reproducible control of the interactions among different circuit functions from the other.

In the fabrication of T_x/R_x modules for phased array radars, the most important objectives are: costs, weights and size reduction and the module reproducibility. Therefore the MCM technology is an ideal integration technique for such kind of units.

As is well known the successful design of active phased-array radar systems is based not only on the availability of a low cost/high yield facility for GaAs microwave monolithic integrated circuits (MMICs) production, but also on the capability of exploiting the full potential of this enabling technology during the integration of the necessary functions at the system's level. To facilitate this goal it is important that the T_x/R_x modules, with their complex assortment of microwave, digital and bias circuit functions, be integrated into self-consistent, easily testable hermetic packages that satisfy the electrical, mechanical and thermal requirements of the overall radar array.

In this article we will outline the design and fabrication of a packaged X-band T_x/R_x module optimized in order to obtain the best compromise between electrical performances and minimum size and weight.

With this purpose the microwave functions have been implemented into a reduced number of MMICs still ensuring high technological yield. Such components are assembled in an appropriately laser machined alumina substrate. On alumina the necessary r.f. and d.c interconnections together with the TTL compatible Si integrated circuits for signal control of the radar functions have been realized by means of high integration thin film deposition technology. The overall assembly is finally housed in a hermetically sealed ceramic package (approximated 20 x 25 mm) with appropriate r.f., d.c and control feed-throughs.

In reporting the overall performance of the T_x/R_x module (typically 35 dB gain and 3 dB noise figure for the receive channel and approximately 1.8 W output power for the transmit channel), the high level of integration, the reasonable assembly complexity, good yield and performance of the MMICs will be shown.

Design Approach

First of all the electrical design was based on the optimization of T_x/R_x module topology, that is on the optimization of the number of microwave subfunctions and subsequently on the reduction of assembly complexity. The block diagram of the active T_x/R_x module is shown in Fig. 1. The operating frequency is 10 GHz with 100 MHz bandwidth. The reciprocal phase shifter is common to the receiver and trasmitter front-ends; it consists of four cascaded bits in a switched-line configuration [1]. A single pole double

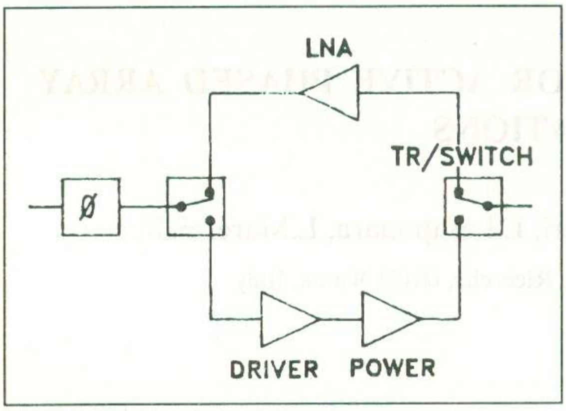

Fig. 1: Block diagram of the active T/R module.

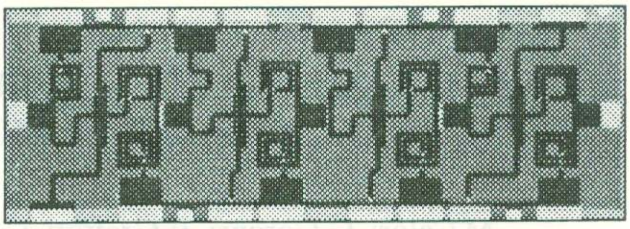

Fig. 3: Photograph of low-noise amplifier chip.

throw (SPDT) switch connects the phase-shifter with the receiving arm, or with the power amplifier in the trasmitting state. Phase shifter and SPDT switch were built on a single GaAs chip (chip size:6.5 x 3.2 mm) and are shown in Fig.2.

The receiver front-end consists of a low-noise amplifier and a small-signal gain amplifier: they were realised on a single GaAs chip (chip size:3.6 x 1.3 mm). The first stage was biased for minimum noise performances, whilst the other stages provide the gain as needed by the receiver.

The transmitter consists of a cascaded pair of chip amplifiers: a driver and a final stage power amplifier. This was a convenient, intermediate step in order to fulfil system power specifications and now is leading to a higher level of integration. In subsequent design, the two amplifiers will be integrated into one chip.

Finally the commutation between the receiving and the transmitting state of the module is provided by the power T/R switch.

With an r.f. arrangement like that it was possible to limit the number of GaAs chips and to put together the r.f. functions for technological compatibility (power, lownoise and control implantation technology).

Individual Chip Description

The phase-shifter, utilizing sixteen MESFETs, and the

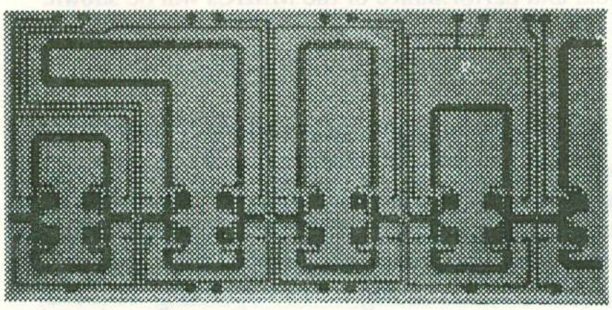

Fig. 2: Phase-shifter and SPDT switch chip.

following switch, have been realized on 120 μm thick GaAs substrate with Alenia 0.5 μm gatelength Ion Implantation MMIC technology. The switch utilizes two serial MESFETs with 600 μm gatewidth.

The total I.L. is less than 8 dB with a R.L. better than 15 dB any phase.

The 4-stage low-noise amplifier utilizes 300 μm gatewidth MESFETs on 200 μm thick GaAs substrate. We choose a serial feedback configuration in order to obtain a good compromise between minimum noise figure and matching conditions. The measured noise figure is 2.5 dB at 10 GHz and a photograph of the chip is shown in Fig. 3.

The driver amplifier on the transmitter channel consists of two stages with two 600 μm periphery MESFETs and the chip size is 1.7 mm x 1.0 mm; the "final" or power stage involves a 4 mm periphery MESFET and the chip size is 1.7 mm x 1.8 mm. The measured output power is 2 watt with a 30% of efficiency. Fig. 4 is the chip photograph.

The T_x/R_x switch is a 1.2 mm x 1.2 mm chip with 120 μm thick GaAs substrate and it consists of a serial 900 μm MESFET on the transmitting arm, and two 1500 μm serial MESFET on the receiver channel.

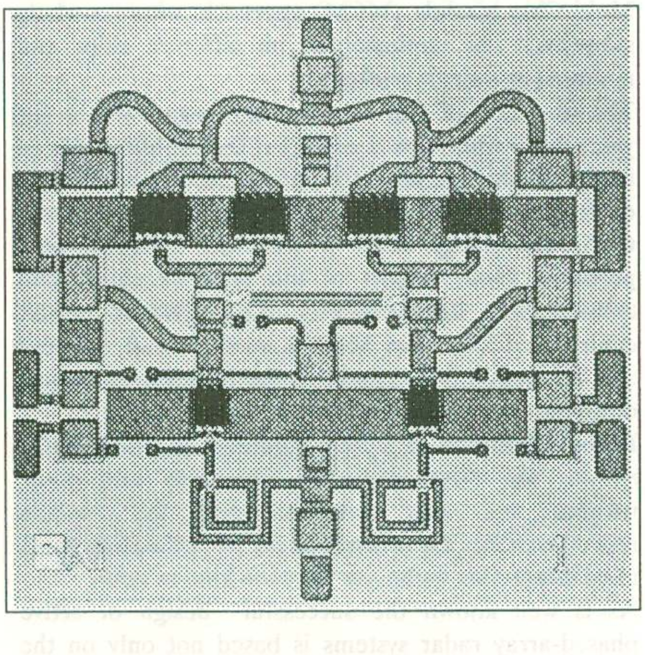

Fig. 4: 2 watt power amplifier chip.

The serial MESFET on trasmitting arm must support the power current in on state, whilst the MESFETs on receiving channel are under high voltage condition in isolation state; we choose the MESFETs peripheries in such a way that power handling specifications were easily satisfied.

Integration Technologies

The final integration of the T/R module has been accomplished in a metal-ceramic package. An hybrid thin film circuit on alumina substrate (20 x 25 mm), attached on a metallic base plate, includes the high stability resistors and the conductive pattern providing all the r.f. and d.c. interconnections of the circuit elements and the input/output of the module. The extensive use of thin film air bridges allows to avoid wire interconnections at the crossings of the hydrid circuit pattern, increasing the reproducibility and the reliability of the module performances.
The GaAs chips have been directly attached on the metallic base plate through suitable apertures in the alumina, realised by laser (Nd-YAG) cutting, allowing to obtain efficient thermal exchange. The TTL compatible Silicon ICs are mounted directly on the alumina substrate and wire interconnected to the hybrid thin film circuit, so enabling the module to be self consisting from the signal control point of view. The module is completed by attaching on the alumina a frame including the cover.

Active Module Performances

The photograph of the X-band active module is shown in Fig. 5 whilst Table 1 collects the module performances.

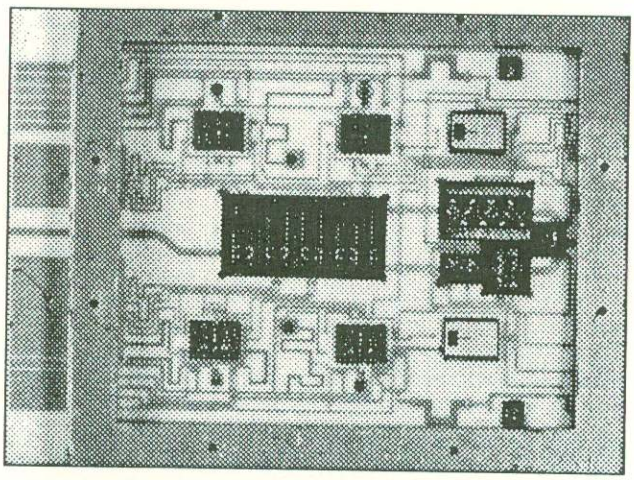

Fig. 5: X-band active module assembly.

Table 1: X-band Active Module Performances.

Receiver Gain	35 dB
Transmitter Gain	23 dB
Output Power	32.5 dBm (1.8 W)
Noise Figure	3 dB
d.c. Power Dissipation	8 W
External Connections	2 r.f., 6 TTL, 3 d.c.

Conclusions

In this article we have shown the design, realisation and performances of an X-band T_x/R_x module for phased-array applications. Such a module has been fabricated in multi-chip form and mounted in a single hermetically sealed ceramic package.

References

[1] L. Marescialli, M. Massani, S. Rapisarda, G. Geronzi, "A High-Yield Monolithic X-Band Four Bit Phase-Shifter," GAAS '92.