A HIGHLY INTEGRATED T/R MODULE FOR ACTIVE PHASED ARRAY ANTENNAS

Kohei Fujii, Yasuhiko Hara, Yuzo Shibuya, Taturo Sakai, and Yuji Takano

Japan Radio Co., Ltd.
Mitaka-Shi Tokyo, 181-8510 Japan

ABSTRACT

A highly integrated transmit/receive (T/R) module that has achieved integration levels superior to any MMIC module will be described. Highly integrated T/R module is achieved by using LTCC(Low Temperature Co-fired Ceramic) multiple layer substrate, highly integrated MMIC chip-set, large-signal simulation for switching MESFET circuits, high power and high efficiency amplifiers using a PHEMT process, multiple-cavity package, advanced thin-film substrate which enables to realize air bridge structures, and self align like void free MMIC die-bonding technique.

INTRODUCTION

Many papers for state-of-the-art performance and multiple function MMICs have been published; however, a few papers have been published for high integration of the microwave circuit utilizing MMIC chips for T/R module applications [1]. In order to realize the highly integrated T/R module for active phased array antennas, this paper clearly describes a design strategy that a T/R module designer should apply a combination technique between an advanced MMIC design technique and an advanced packaging technique. In addition, since the active phased array antenna requires mass production capability [2], this paper also proposes the efficient production technique utilizing a self alignment like void-free die-bonding technique.

The successfully designed T/R module for an X-Band phased array radar system will be shown with an excellent performance.

T/R MODULE CONFIGURATION

A block-diagram for the developed T/R module is shown in Figure 1. The T/R module is designed for a pulse radar application required a high speed T/R switching function and a dc power switching function. MMIC amplifiers for the transmit function are consisted from two high power amplifiers and three power amplifiers fabricated by the PHEMT process to maximize the power added efficiency and the output power. Receiving circuit contains a SPDT switch in front of an LNA to protect the LNA from the transmit signal leakage. There is one more LNA in receiving circuit to increase the receiving gain. A five bit phase shifter and the SPDT switch are placed to a common circuit for the T/R function since the phase shifter and the SPDT switch have bi-directional characteristic. The T/R module has two dc switches to maximize dc power consumption of amplifiers. A custom LSI controls T/R rf. switching signal, phase shifter control signals, and dc power switchings.

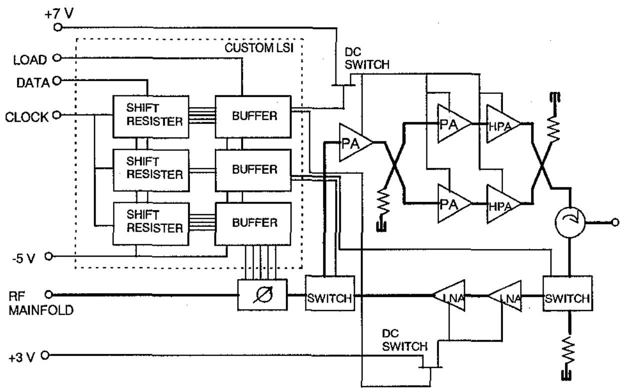

Figure 1. Block diagram for the developed T/R module.

INTEGRATION TECHNIQUE OF THE T/R MODULE

In order to realize high integration, the developed T/R module is applied seven different techniques.

1) Three different functions such as rf. distribution, control logic, and dc. power distribution are integrated by the seven layer LTCC substrate. Vertical rf. interconnection technique is applied. The structure of the vertical rf. interconnection was optimized by a three dimensional EM simulator.
2) MMIC phase shifter and SPDT switch are designed to meet the requirement of system integration such as minimizing control signals into half numbers. In order to realize this requirement, CMOS compatible digital interface circuits are integrated on the same chip of the phase shifter and the SPDT switch[3].
3) The specially designed large signal model[4] which enables accurate large-signal simulation for switching MESFETs is applied to analyze both small signal and large signal performances for the phase shifter and the SPDT switch. This effort optimizes the phase shifter topology not only for rf. performance, but also for process insensitivity and high yield.
4) The high power amplifier shown in Figure 2 is the key contributor to establish the power added efficiency of the T/R module. Highly accurate large signal models [5],[6] are applied to the HPA design. The new large signal model realizes the accurate large signal simulation; therefore, the HPA performance is maximized to achieve the highest power added efficiency and output power at the highest technical level ever announced [7]. Figure 3 shows the comparison result between measured and simulated of output power, power added efficiency, and drain current at 8GHz. Low power consumption characteristic reduces the power control switch size and the power distribution circuit size too.

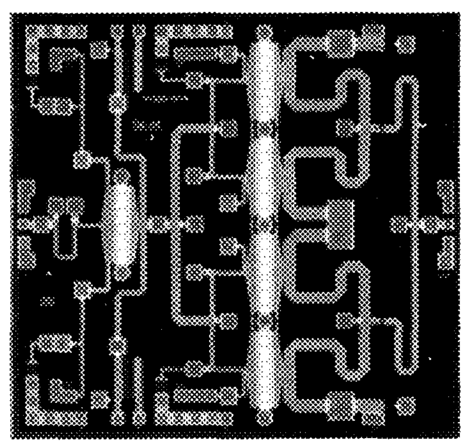

Figure 2. A Photograph of the MMIC high power amplifier.

5) HPA, PA, and LNA integrate the gate biasing networks into the MMIC structure to reduce the off-chip thin film circuit requirement.

6) The package with the multiple cavity configuration eliminates the possibility of moding and enhance module stability. This technique enables the highly integrated rf. circuit without sacrificing the unstable condition, since multiple cavity configuration reduces the mutual coupling between high gain MMICs. The layout of the T/R module is shown in Figure 4. The developed T/R module size is 97 x 38 x 4.5 mm.

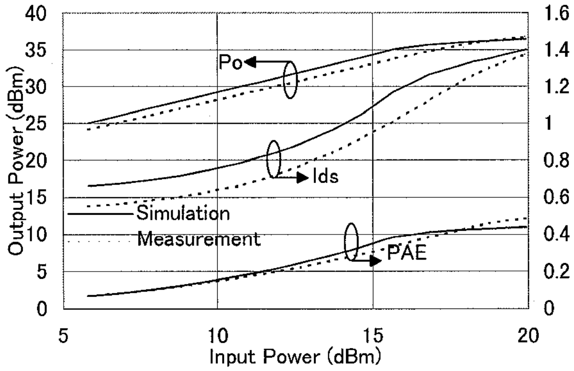

Figure 3. MMIC high power amplifier performance at 8GHz.

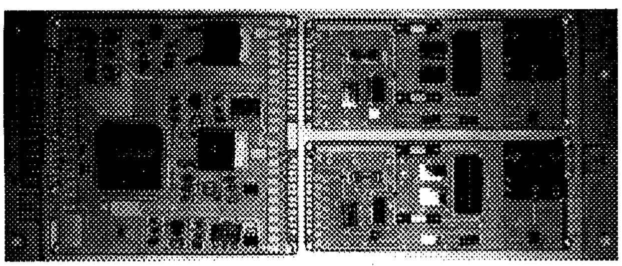

Figure 4. A photograph of the T/R module.

7) Mother substrates are consisted from advanced thin film technology which integrates both Ta2N resistors for 50 Ω terminations and air-bridge configurations to realize the crossovers between rf. microstriplines and dc. Power distributions. Since thin-film crossover between rf. and dc. line realizes perpendicular structure which has the minimum mutual coupling, the crossover technique enables circuit integration with the minimum degradation of rf. performances.

The combination techniques mentioned above realized the highly integrated T/R module, and Table 1 shows the measurement result of the T/R module. The T/R module achieved the 38% maximum power added efficiency.

Table 1. Measured performance of the T/R module. (Frequency is 8.5 to 10.5 GHz)

Parameter	Min	Max
Receive gain(dB)	17	23
RMS gain vs. Phase(dB)@Rx	-	1.3
RMS phase error(°)@Rx	-	5.5
Noise figure(dB)	6	8
Transmit gain(dB)	37	39
Output power (dBm)	37	39
Power added efficiency(%)	33	38
RMS gain vs. Phase(dB)@Tx	-	1.2
RMS phase error(°)@Tx	-	5.0

LOW COST ASSEMBLE TECHNIQUE

Voids between GaAs MMICs and a Cu-W package drastically increase the thermal resistance; consequently, voids degrade the reliability of high power amplifiers. Self alignment like void-free die-bonding technique was introduced. Mother substrates incorporate all MMICs in inside holes which realizes the accurate placement without a delicate worker's skill. Mother boards and all MMICs are eutectically bonded coincidentally into the package. A five-minute vacuum bake at 240℃, followed by a two-minute gold-tin eutectic soldering at

325℃ in an atmosphere of dry nitrogen at 3 psig was applied. Vacuum baking is instrumental for removing moisture and other contaminants. This die-bonding technique reduces chance of the existence of voids dramatically between the GaAs MMICs and the Cu-W package.

CONCLUSION

This paper has been described that the combination technique of LTCC substrate, highly integrated MMICs, large-signal analysis for switching MMICs, PHEMT high power and high efficiency MMICs, multiple cavity rf. package, advanced thin-film substrate, and self alignment like die bonding technique realizes the highly integrated T/R module.

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