A 2 WATT GaAs TX/RX MODULE WITH INTEGRAL CONTROL CIRCUITRY, FOR S-BAND PHASED ARRAY RADARS

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ABSTRACT

This paper describes measured results for a TX/RX module operating in S-band over a 20% bandwidth. The module contains 8 GaAs devices, 5 of which are MMICs. The module has an integral thick film hybrid control circuit containing custom silicon ICs.

Transmit powers of 2.0 watts are reported together with receive gains of ≥20 dB and noise figures of ≤4.0 dB. The module has very accurate 4-bit phase shifting in both TX and RX modes.

INTRODUCTION

One of the most important components to be used in the next generation of phased array and multifunction radars is the transmit and receive module. To this end Tx/Rx modules operating at X-band frequencies have been reported (1). In order to ensure that the cost of a phased array radar system is not prohibitive, much emphasis has been placed upon the use, where possible, of GaAs MMICs (2,3). We report here the first measured results for an S-band Tx/Rx module that not only contains GaAs MMICs but also all the associated local control circuitry to enable its use in radar systems. Techniques for cost reduction in future generations of module are also discussed.

TRANSCEIVER MODULE DEVELOPMENT

The module block diagram is shown in Figure 1. The circuit is housed in a low weight hermetic package with an aluminium heat sink. Interconnection between the module, the antenna face and the RF beamforming network is by means of three OSP push connectors. DC power is provided by three voltage rails ± 15V and +9V. Control data is supplied via a fibre optic cable in order to reduce both the problems of data corruption from electromagnetic sources and also the weight associated with a conventional wiring loom. A complete module is shown in Figure 2, it measures 40 mm x 117.5 mm x 10 mm excluding the heat sink. The microwave circuitry occupies an area of 18.5 cm^2 at one end of the module while the remaining 28.5 cm^2 contains the custom thick film hybrid control circuit. The microwave circuits are printed on to 10 thou thick alumina substrates and have been designed for manufacture using either thick or thin film technology.

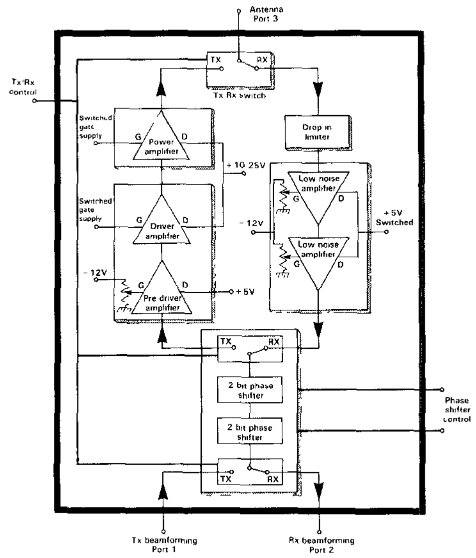

Fig. 1. Block Diagram of Phased Array Radar T/R Module

The need for a low weight module (100 gm excluding heat sink) required the development of a novel ceramic mounting technique. The use of a weighty conventional expansion matched metal carrier has been avoided for the small signal circuits by use of a gold plated ceramic carrier with through vias for improved grounding. It was decided to use 15 thou thick rolled WCu carriers under the power amplifiers in order to assist in heat removal.

MMIC FABRICATION

The MMIC circuits used in the module were fabricated on 200μm thick GaAs, the active devices having 0.7μm long recessed gates. Resistors are formed from the GaAs active layer. Capacitors are of a metal insulator metal configurations with a silicon nitride or polyimide dielectric layer. Metal crossovers and interconnects are achieved using a polyimide dielectric layer.

The power FETs are fabricated on 100μm thick GaAs in order to improve their thermal properties.

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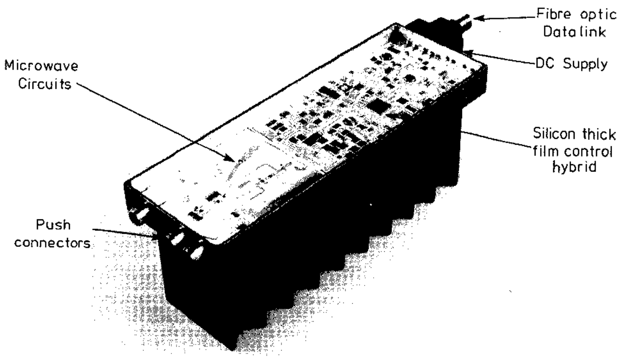

Fig. 2. Complete T/R Modules

MICROWAVE SUBASSEMBLY REALISATION

The microwave circuit can be broken down into six subassemblies, these are:

- T/R switch
- Low noise amplifier (LNA)
- Phase shifter
- Driver amplifier
- Power amplifier
- PIN diode limiter

These assemblies are shown in detail in Figure 3.

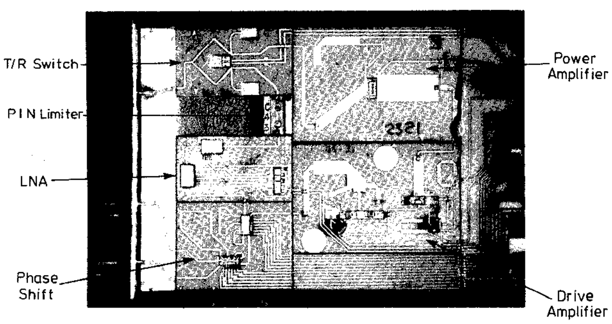

Fig. 3. Internal Detail of Module Microwave Subassemblies

The T/R switch contains a GaAs MMIC MESFET with on chip gate feed resistors and capacitors. The chip measures 1.1 x 1.57 mm. The MESFETs are used in shunt across the quarter wavelength transmission lines and a grounded stub is used to offset the stray capacitance. Insertion losses of ≤ 0.7 dB with 18 dB of isolation have been obtained.

The LNA subassembly is made up from two cascaded GaAs MMIC LNAs. These MMIC LNAs have an individual chip area of 5.0 mm^2. The MMIC circuit is a two stage design with feedback on the first stage in order to improve the input VSWR. Gains of 18 $\pm$ 1.5 dB from 2.5 GHz to 3.5 GHz with a noise figure of 2.1 dBmax have been reported for the chip (4).

Very good overall yields of better than 57% are seen for this MMIC, which has been tested using our in house automatic RF on wafer facility (5).

The 4-bit phase shifter is a switched line design with the delay lines being realised on alumina as reported in ref. (6). The phase shifting is accomplished by use of two GaAs MMIC switching chips measuring 1.12 mm x 2.54 mm each. Each chip contains 2 bit phase switching by means of series FETs and a T/R routing switch. The insertion losses through the phase line and the bypass switch have been equalised by tailoring the gate widths of the FETs. This gives an amplitude imbalance between all 16 phase states of ≤ 1 dB. Phase shifting accuracy at the 2.7 GHz design frequency was 4 deg rms over all 16 phase states.

The driver amplifier is a conventional two stage hybrid design using 2 GaAs power FETs. The amplifier has an overall gain of ≥ 22 dB from 2.5 GHz to 3.5 GHz with a 1 dB gain compressed output power of 28 dBm. The power amplifier is also a hybrid design using an 8000μm gate width power FET. The circuit has a gain of ≥ 8 dB and a 1 dB compressed output power of +34 dBm (2.5W). The power FETs were characterised by a load pull technique and novel two port extraction routine (7).

The PIN diode limiter subassembly is capable of limiting pulsed signals of up to 10W at peak power.

The thick film control hybrid is shown in Figure 4. It contains the DC voltage regulation for each of the microwave subassemblies together with a custom gate array and E^2PROM. The gate array interprets the data sent to the module via the external fibre optic control link. Each module has a unique address held within the E^2PROM which defines its position within a radar array face. The gate array performs all the necessary Tx/Rx switch sequencing together with computation of the optimum phase shifter setting for a given beam direction and module location.

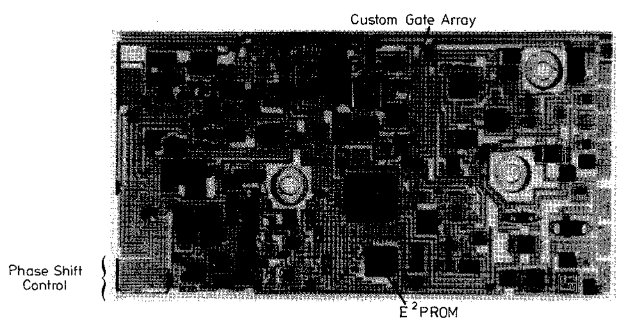

Fig. 4. Thick Film Control Hybrid Circuit

MEASURED RESULTS FOR TX/RX MODULE

During the development modules have been assembled to various build states. The results measured on 2 modules are reported here. The modules have been tested over temperatures up to +55°C.

The receive mode phase shift performance at 25°C is shown in Figure 5. This can be seen to be very good being well within 6° of the design value for all the 16 states. An average gain of 26.5 dB was seen over 2.7 GHz to 3.3 GHz with an associated noise figure of 3.8 dB ± 0.2 dB as shown in Figure 6. The 1 dB receive gain compression was +12 dBm.

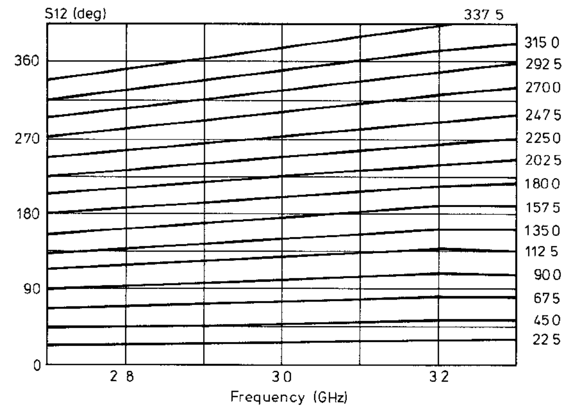

Fig. 5. T/R Module Receive Phase Shift

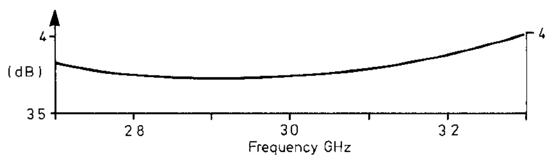

Fig. 6. T/R Module Max Noise Figure for all Phase States at 20°C

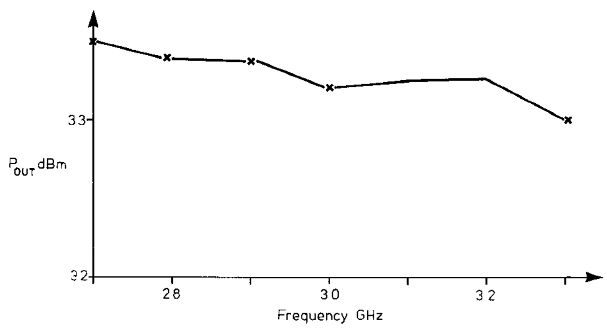

Fig. 7. Transmit Output Power from T/R Module (P_{IN} = +10 dBm)

The transmit mode characteristic is seen in Figure 7 which illustrates the output power over the operating band with an input signal of +10 dBm. The maximum phase deviation seen between Tx and Rx modes in all 16 states was only 4.6 degrees worst case. Spurious signal output was below 30 dBc for all modules. The overall power added efficiency for the module transmitter chain is 22%.

MODULE COST REDUCTION

The active phased array radar system of the future will contain several thousand Tx/Rx modules and thus the cost per module is of vital consequence.

Many factors affect the cost of a module, such as the degree of complexity and power output capability. The use of shared control circuits for several RF modules should give significant cost reductions over the present design. The S-band module described here contains 5 GaAs MMICs and 3 discrete GaAs FETs, all housed in an aluminium package.

We have carried out design studies that show that the RF circuits in this module can now be implemented using our current selective ion implanted 0.5µm via'd process with just 3 high packing density MMICs. Having all Tx/Rx functions within 3 MMICs allows the packaging to become surface mountable thus reducing assembly and testing time.

This type of approach should enable significant module cost reductions. Future yield improvement developments will eventually enable all Tx/Rx functions to be integrated on to one IC.

CONCLUSIONS

We have demonstrated that an S-band 2.0W transmit-receive module with integral control circuitry for use in phased array antennas is technically achievable using a combination of GaAs MMIC and discrete FET components.

A major feature of this S-band design is the combination of small GaAs MMICs and alumina microstrip circuits in order to minimise the module cost together with the use of advanced integral control circuitry.

Future lower cost modules will probably only contain 3 MMICs housed in a surface mounted package with shared control electronics.

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REFERENCES

(1) R.A. Pucel, Y. Ayasli et al, A multichip GaAs monolithic transmit/receive module for X-band, IEEE MTT-S Digest 1982, pp.489-492.

(2) E.R. Billam, Phased array radar and the Royal Navy, J.N.S. Vol. 12, No. 2, pp.93-103.

(3) E.H. Gregory, Applicability, availability and affordability of GaAs MMICs to military systems, 1986 IEEE GaAs IC Symposium Digest, pp.183-186.

(4) P.D. Cooper, et al, A family of low noise feedback amplifiers for radar and communication applications, IEE Colloquium on 'Design and fabrication of GaAs ICs' (Digest No. 107, London, p.13/1-1-5 1984).

(5) B.J. Buck, I.G. Eddison, 'The development and use of an ATE system for on-wafer microwave characterisation of GaAs MMICs' Proc. 15th European Microwave Conference, Paris, p.1031-1036, 1985.

(6) T. Bambridge et al, Active and passive phase shifters employing GaAs MMICs, IEE Colloquium on 'Manipulation microwave signals' (Digest No. 108, London, p.6/1-4, Dec. 1984).

(7) J. King et al, 'The design and performance of a pre-matched 2.5 watt X-band GaAs power FET', IEE Colloquium on Solid State Microwave Power Generation, (Digest No. 88, London, p3/1-4, May 1986.)