A PRECISION T/R MODULE FOR X-BAND SAR APPLICATIONS

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ABSTRACT

T/R modules suitable for spaceborne SAR instruments have to fulfil very demanding requirements as given by the challenging environmental and electrical conditions in space.

For this application a T/R module has been designed and realized which operates in X-Band and handles the temperature range from -20° to 60°C with full amplitude and phase stability. A low loss switch enables two polarisations alternatively or multiplexed in time. The output power of the module is 7 Watts over a wide bandwidth stabilized by a power control loop. The noise figure is as low as 3.2 dB. Amplitude control will be done by a phase stable variable gain amplifier (VGA), which is also used for temperature compensation. A 7-bit phase shifter is utilized for phase setting and phase compensation over temperature.

The overall module efficiency at 10 % duty cycle is better than 18 % at ambient. This efficiency bases on radar mode operation, which means that the power consumption of the transmit path, receive path and the entire control electronic is taken into account.

The paper will discuss the chosen architecture, critical components as well as the measured data of the T/R modules with respect to SAR system requirements. The paper will also give an outlook to advanced components and technologies for cost effective high volume production necessary for complete antenna integrations in the very near future.

1 INTRODUCTION

Spaceborne SAR instruments operating in X-Band with active phased array antenna will become reality in the very near future. One key element in this kind of antenna is the T/R module. The antenna consists of thousands of such T/R modules which are connected to discrete radiators or system dependent to a group of radiators each half a wavelength apart from another.

Because every module provides individual phase and during receive mode also amplitude control, a maximum possible flexibility in beamforming is given leading to new SAR modes.

One very important constraint on a spaceborne platform is the limited prime power for running the system. Hence, the T/R modules have to operate directly in the space temperature environment without any heating.

This is critical to the electrical performance of the module especially if high precision in amplitude and phase control is required. To overcome this a calibration and temperature compensation technique has been developed which allows stable operation in a wide temperature range.

In summary, the most important requirements, which have to be met by the modules for this applications are

- full polarimetry: HH, VV, HV, VH
- high efficiency
- temperature stability
- high precision
- low mass
- high reliability
- low cost

In the following the concept, design and realization of such a T/R module is described and the superior performance is proved by measurement results in this paper.

2 T/R MODULE CONCEPT AND REALIZATION

The architecture of the presented T/R module shown in Fig. 1 is the optimum architecture for SAR requirements with demand on fully polarimetric operation (H/V agility).

The main characteristics of this architecture are high power switching and a common-path RF control structure.

By using a PIN polarisation switch with a remarkable insertion loss of only 0.55 dB an excellent performance match between both polarisations (H and V) can be achieved.

This switch enables the double use of the whole RF circuitry and therefore the mass and the size of the module can be reduced significantly. Additionally the minimized number of semiconductor devices increases the reliability and reduces the cost of the modules remarkably. By using the common-path structure the complete RF control path (phase shifter and variable gain amplifier) is available in both operation modes (Rx and Tx).

In the transmit mode the RF signal enters the T/R module via a coaxial SMA connector. The following 7-bit phase shifter provides the phase information with a very high accuracy while the VGA is used for coarse temperature compensation in transmit mode. Via transmit / receive (T/R) switches the signal reaches the activated transmit path. After passing the driver and power amplifier (PA with typicalPAE of 35 %), the circulator and the integrated microstrip coupler, necessary for calibration and test purposes, the signal is routed through the low loss polarisation switch and leaves the module via an attached SMA connector.

At the antenna ports a power level of 38.5 dBm (7 W) is available, which is stabilized by a power control loop. This leads to an excellent overall efficiency of more than 18 % for the module in full radar operation with an Tx duty cycle of 10 % at ambient temperature.

The receive signal passes the polarisation switch via the SMA connectors at the antenna ports in reverse direction, travels through coupler and circulator and reaches the activated receive path. The non-reflective limiter protects the sensitive low noise amplifier (LNA) against too high RF power levels, which may occur by non sufficient isolation from the power amplifier or from reflected power due to match variations at the antenna ports during beam steering. The 7-bit phase shifter and the following VGA provide a phase setting range of 360° with a addressable step size of 5.625° and an amplitude setting range from 30 dB to 15 dB with a step size of 0.5 dB in the temperature range from -20° to 60°C. The amplified signal leaves the module via T/R switch and the attached SMA connector. The overall noise figure of the presented module is less than 3.2 dB over bandwidth.

The digital control electronic of the module has the task to provide the RF components with power and to control the components during receive and transmit mode.

Main component here is a highly integrated silicon FPGA. The device handles the internal timing, converts the command data into the module's internal parallel format, reports module status to the external antenna controller and carries out the complex calibration pattern and the temperature compensation.

For the control electronic a design with a "3-dimensional" PCB was chosen, on which the FPGA, the E^2PROM and all other needed components including also buffer capacitors for energy delivering during RF pulse are placed. By using selected devices with a very low power consumption the design of the control electronic guarantees the lowest possible power consumption.

The complete RF electronic, which consists of several alumina substrates (Al_2O_3), highly integrated GaAs microwave monolithic integrated circuits (MMIC) and the digital control electronic is assembled on a special subcarrier. In this way best thermal match with Al_2O_3 substrates, titanium housing and GaAs, as well as good thermal conductivity and a very low weight is given. In order to fulfil the requirements for space applications the titanium housing is hermetically sealed.

After sealing every module is calibrated automatically by a computer controlled measurementsetup over the whole temperature range from -20° up to +60°C with full gain and phase stability.

In this way the module is temperature compentated because the calibration data incorporate also all temperature effects.

Due to the automatic adjustment of the modules a very high match between different modules can be achieved. The used calibration process makes expensive manual tuning of the modules superfluous and reduces the costs of module production significantly.

The compact module design with dimensions of 116.6 x 21 x 49.5 mm^3 enables a low mass of only 98 g.

3 MMICs

Key components for the T/R module are MMIC devices. They have to combine ruggedness, reliability and low power consumption in this kind of application. While suitable high power devices are off-the-shelf available, the small signal devices have been designed at Dasa-Ulm, in order to meet the demanding requirements.

The processing of the chips was done at UMS, the former Daimler-Benz GaAs Center.

To obtain maximum RF performance for the microwave control devices (VGA, T/R-´switches, phase shifter) a 0.25 µm MESFET process was selected.

This process features recessed gate MESFETs built on epitaxially grown layers and allows the design of gain blocks, medium power amps and switched circuits like phase shifters with the same process. Several symmetrical FETs with very low gate length are available for logic applications. A variety of passive components like spiral inductors, implanted resistors, via holes and MIM caps with arbitrary feeds completes the element library to allow sophisticated designs.

VGA

The variable gain amplifier (VGA) bases on a 5 stage design with two phase compensated gain control blocks. The circuit arrangement in this blocks neutralizes parasitic change of the transistor impedances caused by gain setting. This results in superior phase stability within the control range.

The amplifier provides 26 dB gain in X-Band with a bandwidth up to 20 %.

Over a gain control range of 20 dB the phase is stable within ± 2.8°.

The chip consumes only 90 mA at 3 V supply voltage.

On chip an additional transistor circuit is integrated which delivers a voltage proportional to the actual pinch off voltage on the chip. This voltage is used in the control electronic for generating the analogue control voltage. In this way an individual bias tuning of the amplifier is avoided what leads to a cost effective usage. Also the stability over temperature is improved.

Phase shifter

A highly integrated 7-bit phase shifter has been realized for the module. The design incorporates a correction bit, which is switched in an intelligent manner by the control electronic of the module in order to achieve maximum accuracy. In this way the remaining phase error for the whole module in Tx and Rx is less than ± 6° over the temperature range from - 20 to 60° C.

The phase shifting principle bases on the well known switched filter configuration. The bits have been optimised for low insertion loss difference when switching from phase state to phase state. The circuit has a mean insertion loss of 9.5 dB and a variation of only ± 0.75 dB.

The chip size is 2.5 mm x 3.5 mm.

To allow easy interfacing to the control logic the phase shifter is designed to apply a DC offset voltage. Thus this chip can be switched with ordinary levels of logic (e.g. CMOS) in contrast to other solutions which require negative switching voltages.

T/R switch

The T/R switch (chip size: 1 mm x 2.5 mm) utilizes the same switching technique as used in the phase shifter bits. As a result, also this device can be controlled by CMOS levels directly.

The switch contains a resonant structure which yields an isolation of 40 dB in off state at only 1.2 dB loss in on state over a 40 % bandwidth in X-Band.

LNA

The low noise amplifier has been relialized in 0.25 µm pseudomorphic HEMT technology. This process distinguishes itself by its high uniformity across the wafer which results in high yield.

The devices noise figure is as low as 1.1 dB with 18 dB gain. Also Remarkable is the stability with temperature which is typical for HEMT technology. The highly integrated design occupies a chip area of only 0.7 mm x 2 mm.

4 MEASURED PERFORMANCE

The hermetically sealed T/R Modules, containing all RF, logic and control elements as described above, have been successfully tested. The performed tests consisted of extensive RF (pulsed and CW) and thermal measurements, mechanical tests, i.e. vibration of the modules, as well as EMC test procedures. An in-house automatic test equipment controls the module in the temperature chamber and records the related performance data.

In Fig. 4 the receiver performance of the T/R Module is presented in the temperature range from -21°C up to +64°C for three arbitrarily chosen gain/phase setting pairs. The accuracy of Rx gain is ± 0.5 dB and the phase accuracy is in the range of ± 6° over the complete temperature range. The accuracy for transmit phase setting is as excellent as for receiver operation.

The overall noise figure for both channels is less than 3.2 dB in the frequency range from 9.3 GHz to 9.9 GHz (see Fig. 5).

The main performance characteristics of the presented module can be seen in Table 1.

5 CONCLUSION

A high precision T/R Module for spaceborne SAR instruments in X-Band has been presented. The unparalleded accuracy of ± 0.5 dB in gain and ± 6° in phase under all operating conditions including the wide temperature range from -20° to +60°C has been achieved by a novel and highly flexible calibration method. Further important design drivers were the overall module efficiency of more than 18 % at a Tx duty cycle of 10 % (at ambient) and the low noise figure of less than 3.2 dB. These remarkable figures have been achieved although a PIN-diode switch in front of the module electronic has been installed for being fully polarimetric. In this way the module provides lowest mass and size due to minimum number of components. The hermetical housing design in titanium technology reflects space qualification aspects as i. e. ruggedness and environmental conditions.

The presented module performance is the basis of today for an advanced X-Band SAR sensor with active antenna, which will become reality tomorrow.

6 ACKNOWLEDGEMENT

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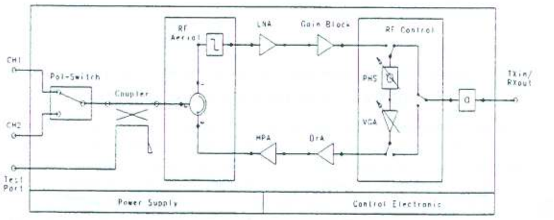

Fig. 1: Block diagram of the T/R module

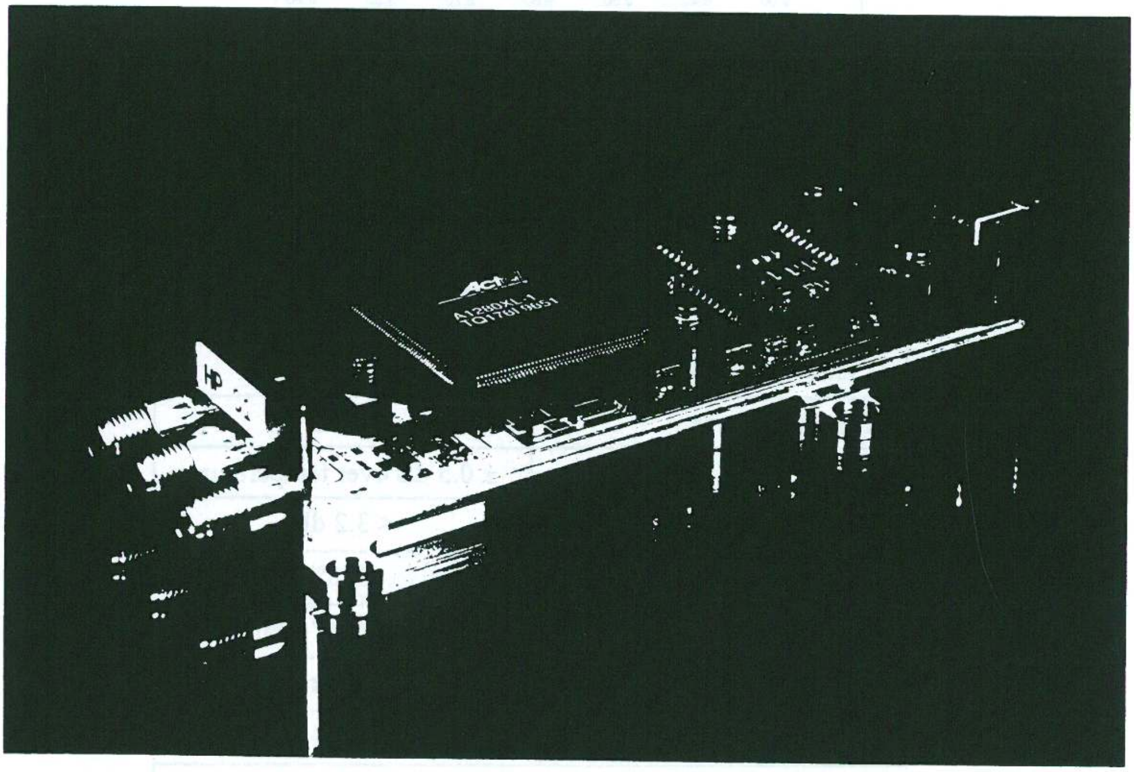

Fig. 2: High precision T/R module in test housing

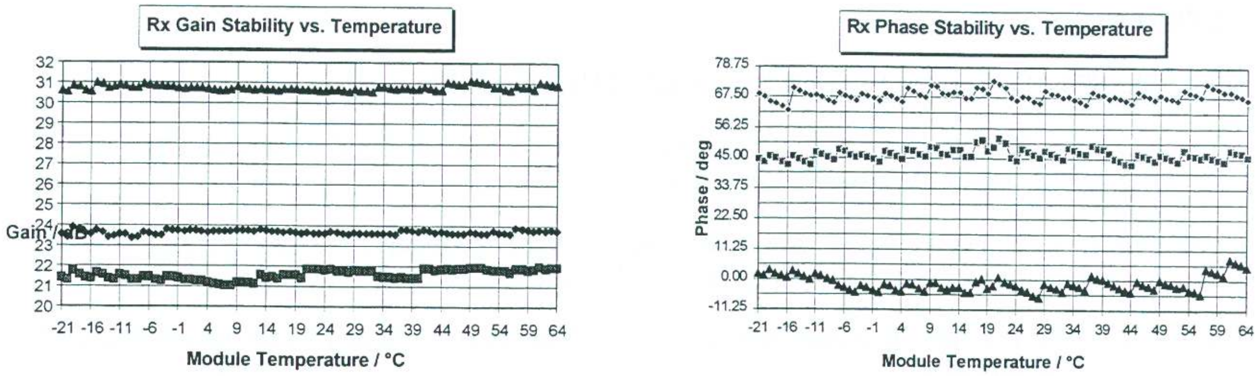

Fig. 3: Rx Temperature stability

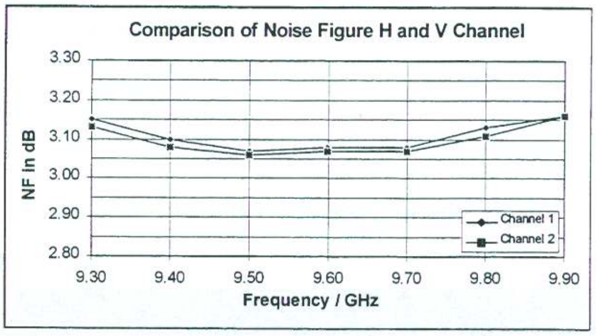

Fig. 4: Overall noise figure vs. frequency

Frequency Range 9.6 GHz ± 100 MHz	
Rx Gain	30 dB
Tx Output Power	38.5 dBm or 7.08 Watts
Rx Gain setting range	30 - 15 dB
Rx Gain step size	0.5 dB
Rx Gain accuracy	± 0.5 dB over temperature
Overall Noise Figure	< 3.2 dB
Phase Control Range	360°
Phase Quantisation	6 bit or 5.625° step size
Phase setting accuracy	± 6° over temperature range
Module envelope size	116.6 x 21 x 49.5 mm^3
Weight	98 grs
Overall module efficiency @ 10% Tx duty cycle*	> 18 %

*: calculation with full radar operation

Table 1: Electrical and mechanical characteristics