A Wide Band Receiver Module

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Abstract — **This paper presents the design and measured results of a highly integrated Multi-Chip-Module (MCM) developed for a wide band Electronic Support Measure (ESM) application. The MCM is based on Low Temperature Co-fired Ceramic (LTCC) technology and the main functionality is implemented in several wide band multifunction MMICs. By using an all-level design approach, the MMICs and the MCM showed full performance after the first design iteration. Simulations and measured results show excellent agreement.**

I. INTRODUCTION

A multifunction ESM system requires several wide band receiver front-ends, which in turn require small high-density packages.

By integrating many of the microwave functions into custom developed MMICs, and using multilayer ceramic substrates, a compact MCM has been achieved.

This report describes the requirements, design and measured results of a Wide band Receiver Module (WRM) covering the frequency band 6.6 to 18.0 GHz for an airborne ESM-demonstrator.

II. SYSTEM ARCHITECTURE AND REQUIREMENTS

To be able to detect emitter signals from all directions, several antennas located around the aircraft are used. Following each antenna is a wide band front-end MCM that will amplify and distribute the signals to the receivers. By measuring the relative phase and/or amplitude of the emitter signal at several antenna positions, the bearing to the emitter can be calculated.

In this paper a wide band receiver front-end with the principal block diagram of Fig. 1 is presented.

A. Front-End Functionality

The WRM has several antenna and receiver channels. Every receiver (output) channel can be connected to several antenna (input) channels independent of how the other receiver channels are connected.

Each antenna channel contains a reflective limiter chip, a band pass filter and a front-end chip (XIBIT). The receiver channels each consists of a single back-end MMIC (XOTIC).

The front-end chip has two input ports, one for the antenna input and one for the auxiliary channel. The chip has several output ports, each connected to a receiver channel. Dynamic range control is obtained by a 30 dB attenuator with 10 dB steps.

The back-end chip (XOTIC) compensates for different transmission line lengths between the MMICs by using a 6-bit attenuator with a 0.25 dB resolution. The attenuator is also used for compensating gain variations due to temperature variations in the MCM.

The auxiliary channel is mainly used for calibration and Built In Test (BIT).

B. Requirements

In Table I some of the WRM main requirements are listed.

TABLE I
MAIN REQUIREMENTS

Frequency band	6.6 – 18.0 GHz
Nominal gain	25 dB
Gain control	±7.5 dB in 0.25 dB steps
Gain flatness	±3.0 dB
Dynamic Range Control	30 dB in 10 dB steps
IP3 (input)	-19 dBm

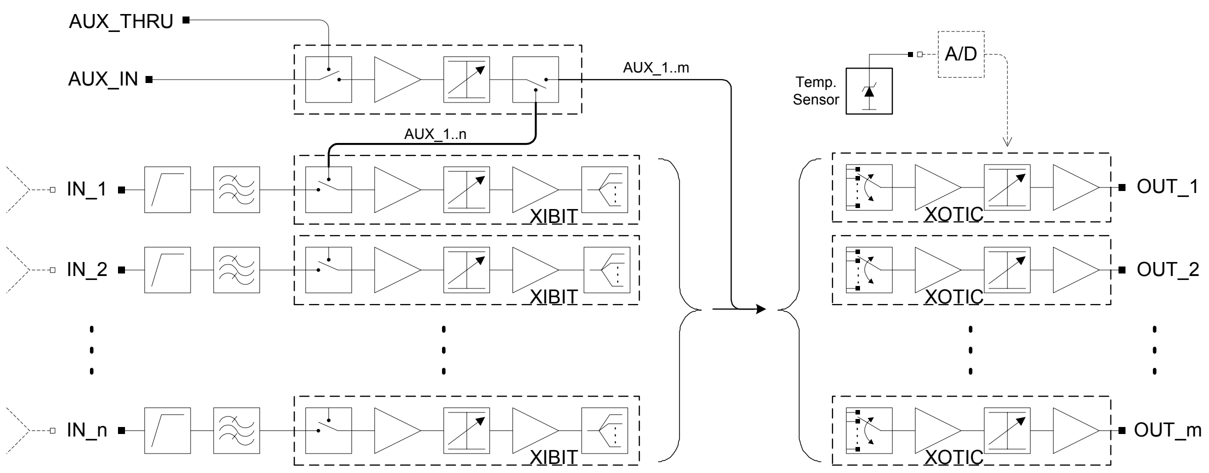

Fig. 1. Principal block diagram of an ESM Receiver Module. Dashed boxes represent MMICs.

III. Module Design

A suitable substrate for this kind of module is Low Temperature Co-fired Ceramic (LTCC). It exhibits properties suitable for chip cavities, couplers, filter structures and shielded transmission lines in several layers [1]. The WRM is built up by eleven Dupont 951-AX tapes with an all gold system. The eight top layers are used for RF circuitry and the remaining layers are used for power and signal wiring.

The functionality given in Fig. 1 implies a need for many RF transmission lines and RF crossings with high isolation. The RF crossings are obtained by using asymmetrical strip line transmission lines shielded by via fences and a separating ground plane at the crossing, see Fig. 2. Measured leakage between the crossing transmission lines is less than -45 dB up to 24 GHz.

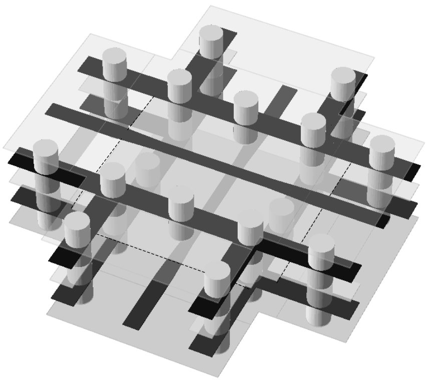

Fig. 2. Layout of RF crossing using asymmetric strip lines, 2.4 x 2.4 mm^2.

To achieve 20 dB gain suppression at 5.4 GHz, a seven-pole strip line stub filter integrated in the LTCC substrate was designed using the substrate parameters in Table II.

TABLE II
SUBSTRATE DEFINITION DATA

Relative Dielectric Constant	7.8
Loss Tangent	0.0063
Height (four tapes)	864 um
Transmission line conductivity	$2.1 \cdot 10^7$ S/m

The filter impedances were calculated using filter parameters obtained from [2]. Iterative simulations in Agilent's ADS Momentum further improved the filter design. To increase the module density, the filters have been located under the RF connectors pictured in Fig. 3.

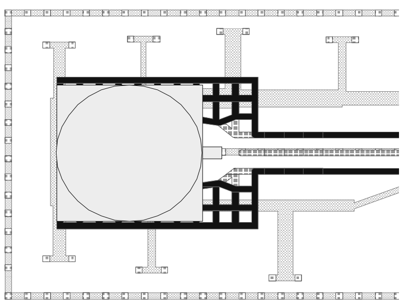

Fig. 3. Strip line stub filters are placed under the RF connectors. Filter size: 12 x 9.5 mm^2.

To suppress cross talk between the receiver channels, all MMICs are placed in shielded cavities, see Fig. 4. Channel isolation better than 45 dB is obtained below 14 GHz. At higher frequencies the crosstalk between the RF connectors has impact on the performance, resulting in a minimum of 25 dB isolation at 17 GHz. The SMP connectors have a RF pin emerging from the connector house base. Shielding of the RF pin – LTCC interface increases the channel isolation.

The WRM is designed to be manufactured in a fully automated hybrid production line. The substrate is soldered onto a molybdenum heat sink. To achieve a good environmental protection, a Kovar frame is brazed onto the substrate and after initial testing the MCM is sealed by welding a lid onto the frame.

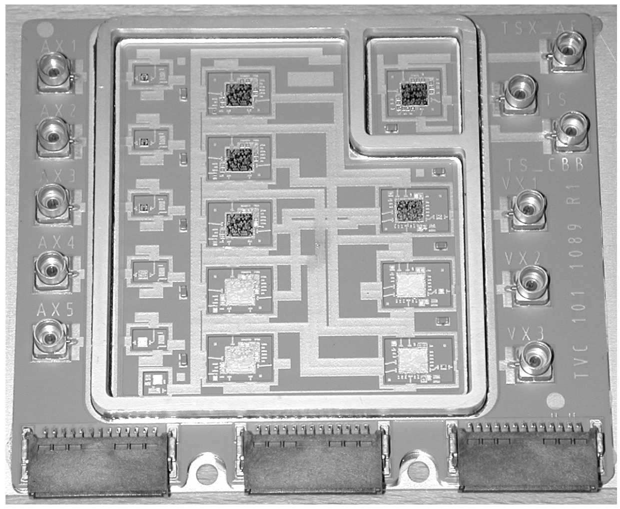

Fig. 4. Wide band receiver module, 84 x 71 mm^2.

IV. Chip Design

Commercial foundry services have made it possible to develop tailor made MMIC for special applications. In the WRM, all functionality except couplers, filters and limiters, is implemented in a wide band chip-set covering the frequency range 6.6 to 18 GHz. The chip-set consists of three GaAs MMICs, designed by Ericsson and manufactured by UMS using their PH25 PHEMT process.

The following functions are implemented in the MMICs:

- Amplifiers
- Level shifters
- Attenuators
- Switches

The amplifiers are based on a feedback topology, similar to the one presented in [3]. The level shifters convert incoming TTL signals into two complementary gate voltages to control the switches and the attenuators. The use of level shifters also reduces the number of control signals and thus simplifies both the MMIC and MCM layout.

In Fig. 5 and Fig. 6 the block diagram and layout of one of the MMICs, named XOTIC, are displayed.

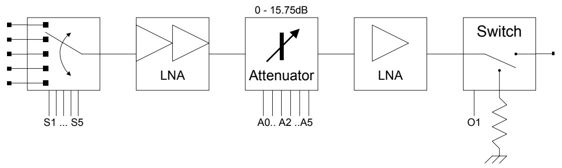

Fig. 5. Block diagram of XOTIC.

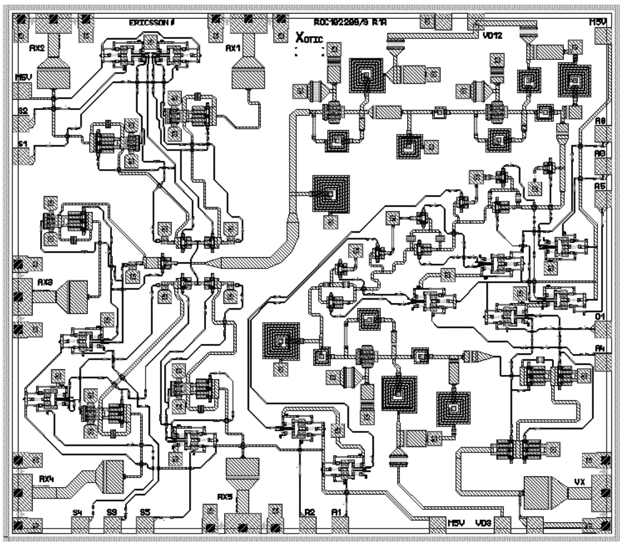

Fig. 6. XOTIC layout, 3.8 x 3.5 mm^2.

A great effort has been made to achieve good isolation in switches and between RF ports. Extensive work has also been made in analyzing and making useful models of the RF leakage between components in the MMIC. In Fig. 7 measured gain and isolation of the five branches in XOTIC are displayed.

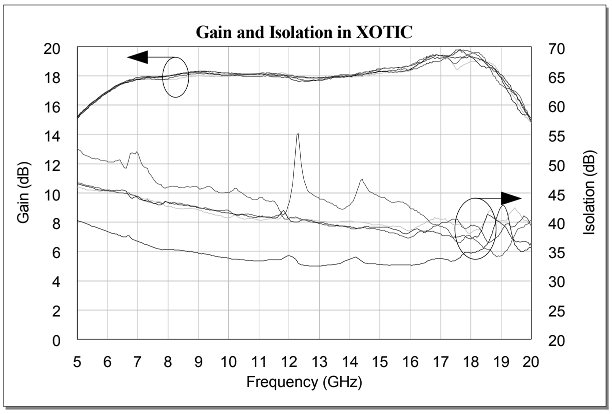

Fig. 7. Measured gain and isolation in the five branches of XOTIC.

V. Design Methodology

The foundation of developing multifunction MMICs and MCMs is to have accurate models and understanding their limitations.

The three multifunction MMICs and the MCM were developed using the following design approach:

i. A few components common to all MMICs were identified and designed, e.g. amplifiers, switches and attenuators.

ii. With these key components the complete receiver chain (i.e. MCM) was modeled and simulated. No explicit MMIC specifications were used.

iii. Corrective actions to fulfill the MCM specification were made at the points easiest to implement in the MMIC designs, trying to maintain an equal complexity in the different MMICs.

With this approach, substrate losses and other MCM imperfections affecting the receiver gain are automatically compensated for.

Using this design method, a total of seven different multifunction MMICs for two different MCMs were designed in parallel and manufactured. All MMICs and MCMs showed full performance after the first design iteration.

VI. Results

Measured and simulated gain of the WRM show excellent agreement, see Fig 8. The small discrepancy between simulation and measurements above 15 GHz is believed to result from a sensitive source network in the amplifier design. The maximum difference in gain for all channels, at each frequency, is less than 1.5 dB. For frequencies below 15 GHz the maximum difference is less than 0.75 dB. The gain suppression at 5.4 GHz is 20 dB.

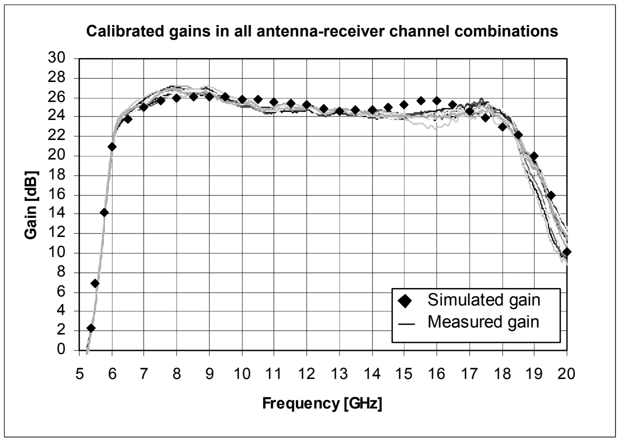

Fig. 8. Measured gains in all antenna-receiver channel combinations vs. simulated gain in one of the channels.

The main results from the measurements made on the MCM are summarized in Table III.

TABLE III
MEASURED RESULTS

Frequency band	6.6 – 18.0 GHz
Nominal gain	25 dB
Gain control	±7.5 dB in 0.25 dB steps
Gain flatness	±2.0 dB
Dynamic Range Control	30 dB in 10 dB steps
IP3 (input)	-10 dBm

VII. CONCLUSIONS

A compact wide band receiver module for a future ESM application has been designed and manufactured using a few multifunction MMICs and a multilayer LTCC substrate. Excellent channel similarity and agreement between simulations and measured results over the frequency band 5 to 20 GHz have been demonstrated. Up to 14 GHz, a channel isolation better than 45 dB has been obtain.

By using an all-level design approach, full advantage has been taken of both the MMIC and the MCM designs in a cooperative manner. A MCM with three different types of multifunction MMICs have been manufactured showing full performance after the first design iteration.

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