

A European Low Cost MMIC based Millimetre-Wave Radar Module for Automotive Applications

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Abstract — The development of a low cost MMIC based millimetre-wave radar module is presented. The paper concentrates on the design of the front end module which forms the heart of a synchronised multistatic radar network designed by Roke Manor Research Ltd. for short range automotive applications. The concept, design methodology, simulation data, and monostatic test results are presented.

I. INTRODUCTION

This paper describes the development of a low cost, MMIC based millimetre-wave front end module for short range automotive radar applications. The mm-wave front end module forms part of a synchronised multistatic radar network developed as part of the European RadarNet project. The partners in the RadarNet consortium include a number of car manufacturers who are investigating new applications including: collision warning, urban collision avoidance, stop and go functionality, airbag pre-crash sensing and parking aids. These applications require accuracy over a short range.

Several car manufacturers now offer vehicles fitted with long range 76-77GHz autonomous cruise control radars. These are often combined with lower frequency or ultrasonic short range sensors for parking, reversing etc. The synchronised multistatic radar network developed by Roke Manor Research Ltd. operates within the same band as the long range cruise control radars. This means that there is the potential for substantial cost savings by using the same chipset for both the long and short range sensors. Further cost savings can be achieved by using low cost substrates and integration techniques.

The development of the synchronised multistatic radar network is covered in detail elsewhere [1]. A multistatic radar network consists of several spatially separated modules, one of which acts as the transmitter and the rest act as receivers. For the system developed at Roke Manor Research Ltd. each module can act as either a transmitter or a receiver. This allows several measurements to be gathered together, which results in precise obstacle location across a broad area. This is known as multilateration [2]. Fig.1 illustrates the multilateration technique.

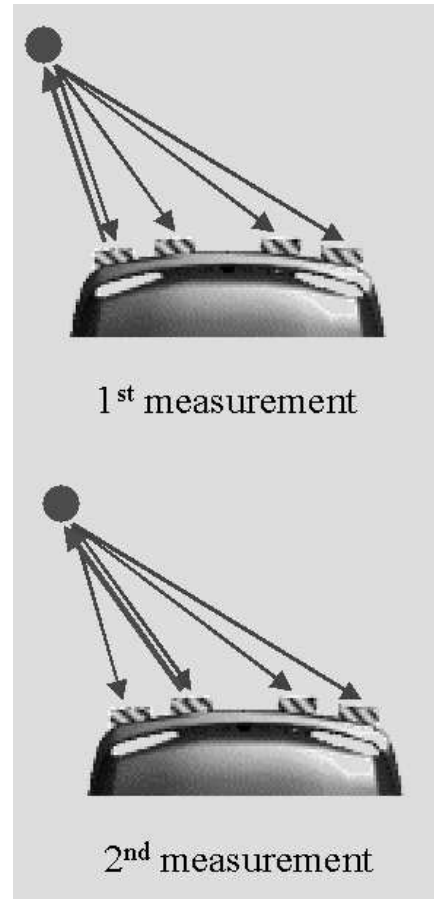


Fig. 1. Multilateration technique.

II. DEVELOPMENT OF THE MILLIMETRE-WAVE FRONT END MODULE

In this paper we shall concern ourselves with the development of the mm-wave front end module which forms the heart of the system.

The aim of this work was to design a mm-wave front end module that had the potential to be manufactured for a low enough cost to make it attractive to the automotive manufacturers. In order to design a low cost front end module the following conditions needed to be met.

- 1) The design should be based on COTS MMICs.
- 2) The module should be made from a single substrate to simplify the assembly of the module.
- 3) No special integration techniques should be required.
- 4) The substrate material should be low cost, yet provide good performance.

The front end module can be considered as a frequency generation block and a receiver block. The frequency



generation block provides both the drive power for the transmit antenna and the LO for the mixer in the receiver block. Fig.2 shows the main functional blocks of the mm-wave module.

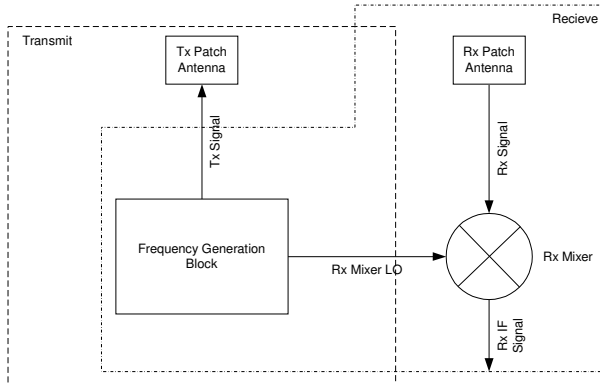


Fig. 2. Functional Block Diagram of the mm-wave module.

III. FREQUENCY GENERATION BLOCK

There are essentially two approaches for realising the 76-77GHz frequency generation block with MMIC technology. The first method is to use a fundamental oscillator (i.e. one that oscillates in the 76-77GHz band). This has several disadvantages. In order to control the fundamental oscillator, a down-converter is required to give a frequency that is low enough for modern frequency control components. This can be realised by a 5th order harmonic mixer, but these exhibit a high conversion loss. Also a relatively high frequency, stable LO is required, which is a challenging component. The advantage of this approach is that the GaAs area required to achieve the frequency generation block should be lower, and hence the unit cost should be lower.

The second method is to generate the signal at a fraction of the required frequency, and use frequency multipliers to achieve the desired 76-77GHz signal. This has the advantage that the frequency control loop is simpler (no harmonic mixers or high frequency LOs are required). The GaAs area using this approach was not significantly greater than for the fundamental oscillator approach. The second approach was adopted in this instance.

IV. RECEIVER BLOCK

The receiver block consists of the receive antenna and W-band mixer. The mixer mixes the received signal with the LO signal supplied by the frequency generation block, to provide an IF of a few hundred kHz. Several mixer topologies are suggested for the realisation of a W-band mixer, but for the required bandwidth a simple ring mixer is sufficient. The ring mixer can be realised by using discrete diodes and a microstrip ring structure on the substrate or by using an integrated Schottky diode MMIC process.

V. SUBSTRATE MATERIAL CHOICE

Traditionally high dielectric ceramic materials have been the substrate of choice for high frequency

applications. Ceramics such as alumina and aluminium nitrate processed using thin film methods offer high stability and accurate circuit features. However the raw materials are expensive and can be difficult to integrate into modules where there is a combination of chip and wire and SMD components.

Modern PTFE based materials offer potential cost benefits over ceramic materials, and with universal finishes, both SMD and chip and wire components are easily accommodated leading to a higher level of integration than is possible with ceramics. Rogers RT/Duroid 5880 material was chosen as the substrate material for the mm-wave module. This offers an acceptable trade off between performance and cost. For ease of integration, the material is available pre-bonded to a metal backing. The thickness of the substrate was chosen to be 0.127mm. This is comparable with the height of the MMICs, leading to short bond wire lengths.

VI. ANTENNA DESIGN

The antenna requirement for the short range sensor is highly specialised. In order to achieve the required coverage, a broad beam in azimuth is required. However a narrow beam pattern is required in elevation, in order to reduce the detection of low level objects such as drain covers.

Two antenna concepts were investigated. The first, a single patch antenna, and the second a series fed array consisting of four patches. The anticipated benefit of an array was a narrower beamwidth in elevation, without the need for lenses. A series fed array was chosen in preference to a traditional corporate fed array, due to the more compact nature of the design, and the improvement in feed losses over the more traditional array. Several patch antenna designs were simulated using a 2.5D EM simulator, and the most promising designs were then verified with a full wave 3D simulator.

Test antennae were fabricated on 0.127mm thick Rogers RT/Duroid 5880 material. The test pieces consisted of the test antenna and a modified form of the waveguide to microstrip transition reported by Iiuzuka et al [3], allowing the antennae to be tested using standard laboratory equipment. The test pieces are shown in Fig. 3.

The radiation patterns of the test antenna were measured in an anechoic chamber using standard test methods. The test signal was provided by a mechanically tuned Gunn Diode oscillator. The radiation patterns were measured for a single patch antenna and a series fed array of four patches. A series fed array was chosen in favour of a traditional distributed feed array, due to the compact nature of the design. The measured radiation patterns were broadly in line with the simulated results, however the side lobe level was found to be slightly higher than predicted and there was some perturbation of the main lobe. It was assumed that the degradation of the performance of the antennae was due to unwanted radiation from the waveguide to microstrip transition. It was shown experimentally that the performance of the antennae could be improved with the addition of a shielding plate to remove this unwanted radiation. Fig. 4

shows the predicted and measured performance for the series fed array patch antenna.

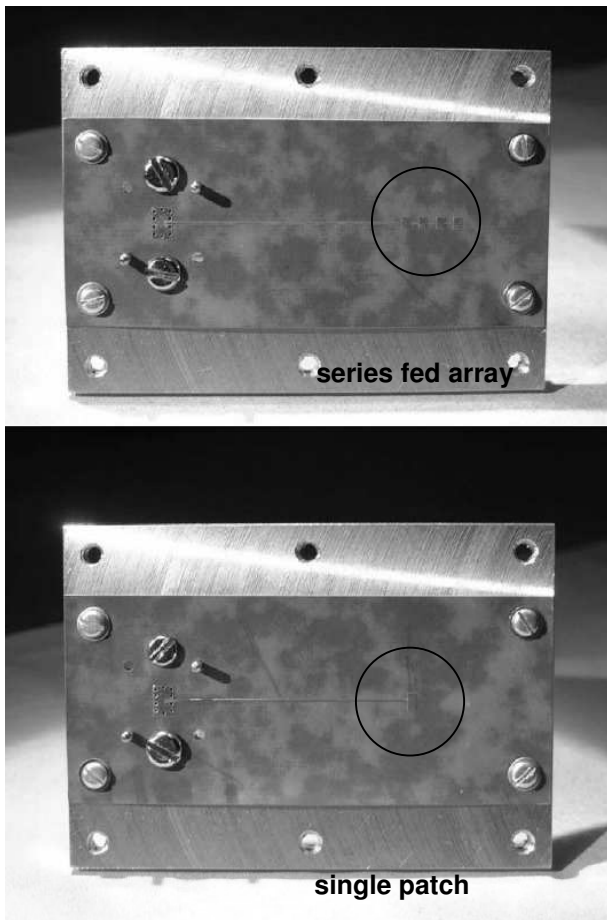


Fig. 3. Antennae test pieces.

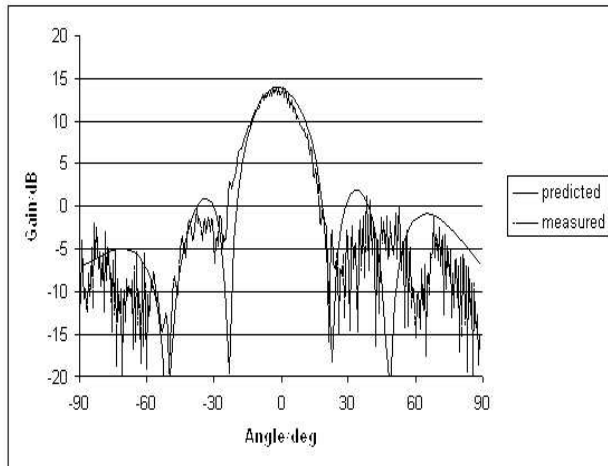


Fig. 4. Predicted vs. measured performance of the Series Fed Array Patch Antenna

VII. COMPLETE MM-WAVE FRONT END MODULE

The mm-wave MMICs used in the front end module are supplied by UMS. The prescaler is supplied by Agilent, and the IF amplifier by Maxim. Fig. 5 shows the front end block diagram.

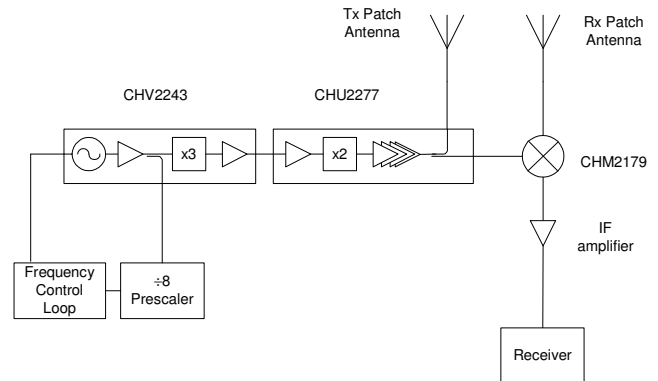


Fig. 5. Functional Block Diagram of the mm-wave module.

The CHV2243 oscillator MMIC is a 0.25um PHEMT device, the CHU2277 multiplier MMIC is a 0.15 PHEMT device, and the CHM2179 mixer is a BES-MMIC device with 1um Schottky diode technology. The MMICs can all be fully tested using RFOV methods. This allows the MMICs to be tested in the front end module before the RF bonds are made. In the development phase, this is highly desirable, as it allows one to integrate only known good front ends into the complete mm-wave radar module. The CHV2243 oscillator is controlled using a double PLL loop with a DDS providing the frequency control.

VIII. INTEGRATION

The MMICs were located in cavities milled out of the substrate material. The MMICs were mounted with conductive epoxy, directly onto the exposed metal backing (0.5mm thick brass). The MMICs were bonded using 25µm diameter gold bond wire which for the short lengths employed, had an equivalent inductance of around 0.3nH.

The mm-wave module also includes several SMD components (a divide-by-8 prescaler, IF amplifier, and associated bias components). These were soldered directly to the module using standard assembly techniques. Solder dams were employed to ensure that solder could not flow onto the pads that were to be bonded to. This allows the entire mm-wave module to be integrated in one facility, leading to time and cost savings. The mm-wave front end module is then integrated into the low frequency board using simple solder links. A fully integrated PTFE module is shown in Fig. 6.

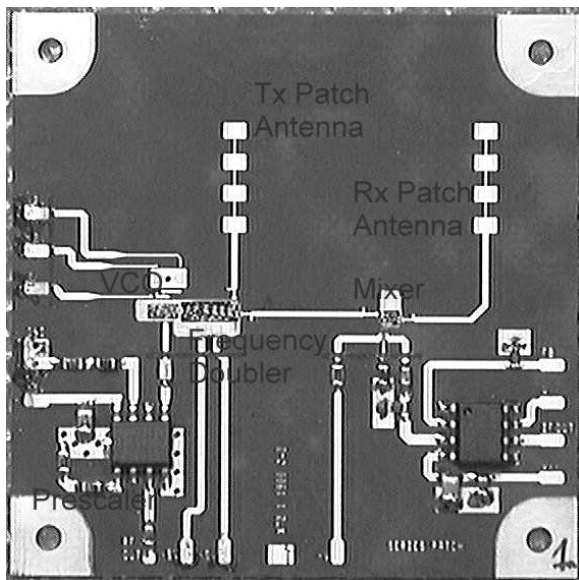


Fig. 6. Integrated PTFE mm-wave module.

IX. MEASURED RESULTS

The mm-wave front end was integrated into the complete radar module, and its performance measured for monostatic operation. The measured performance is shown in Fig. 7.

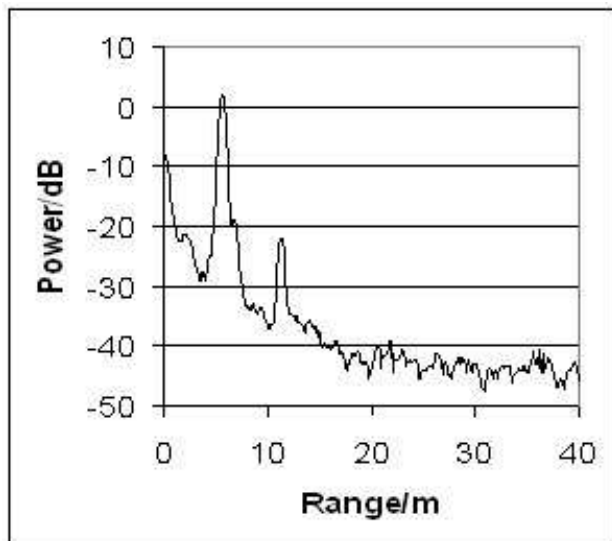


Fig. 7. Measured performance of monostatic operation.

The results show the measurement of a test corner reflector with a RCS of 30m^2 placed 5.6m from the sensor. The impressive performance of the sensor is demonstrated by the high signal to noise ratio.

Following the success of a single sensor operating in monostatic mode, two sensors were measured with a 100kHz frequency offset, and bistatic operation was successfully demonstrated [1]. This shows that a multistatic network is readily achievable.

X. CONCLUSION

The paper has demonstrated the design of Low Cost MMIC based radar modules for automotive applications. The module makes use of COTS MMICs which are readily available through normal distribution channels and low cost PTFE material. The module is relatively simple to assemble requiring no specialised assembly or bonding techniques.

The development of the module demonstrates that an affordable synchronised multistatic radar network is readily realisable.

ACKNOWLEDGEMENTS

Roke Manor Research Ltd would like to acknowledge the support of the partners of European Union Fifth Framework RadarNet project for the work described in this paper. The project is a challenging and highly innovative joint endeavour, coordinated by Siemens VDO Automotive Technology, between major European car manufacturers (BMW, DaimlerChrysler, Volvo, Jaguar and Fiat Research Centre), electronic industry partners (Siemens VDO Automotive Technology) and research institutes and universities (University of Birmingham, Institut National Polytechnique de Toulouse and Technische Universität Hamburg-Harburg). Roke Manor Research Ltd has provided radar design expertise to the consortium as a subcontractor. Further details are available on the project website www.radarnet.org.

REFERENCES

- [1] A. Garrod, "A Synchronised Multistatic Automotive Radar Network," VehCom 2003, Birmingham, England, June 2003.
- [2] H. Rohling, A. Hoess, U. Luebbert, M. Schiemetz, "Multistatic Radar Principles for Automotive RadarNet Applications," 2002 German Radar Symposium, Bonn, Germany, September 2002
- [3] H. Iizuka, T. Watanabe, K. Sato, K. Nishikawa, *Millimeter-wave Microstrip Line to Waveguide Transition Fabricated on a Single Layer Dielectric Substrate*, "R and D review of Toyota CRDL Vol.37 No.2 pp13-18.

BIOGRAPHY

Mark Walden was born in Corby, England in 1971. He graduated from Manchester University in 1993 with BSc. (Hons) Physics. After gaining an MSc. in Microwave Solid State Physics from Portsmouth University in 1995, he joined Roke Manor Research Ltd. He has worked in the RFIC group for the last eight years designing MMICs for radar, satellite communication and mobile communication applications. His recent areas of interest include Wide Bandgap materials and millimetre-wave design.

Adrian Garrod was born in Ipswich, England in 1964. He received a BSc. degree in electronic engineering from the University of Southampton in 1987. After graduating he joined the Radar Applications Group at Roke Manor Research Ltd. While working at Roke Manor he has been involved in a wide range of radar system design and analysis projects.