Fully MMIC-Based Front End for FMCW Automotive Radar at 77GHz

M. Camiade, D. Domnesque, Z. Ouarch, A. Sion

United Monolithic Semiconductors, RD128, BP46, 91401 ORSAY, Cedex, France
camiade@ums-gaas.com domnesque@ums-gaas.com ouarch@ums-gaas.com sion@ums-gaas.com

Abstract - This paper gives the last UMS developments in the field of automotive radar at 77GHz. A complete front-end based on four MMICs is described, it is dedicated to FMCW radar for Collision Warning/Avoidance systems. A detailed characterization results are given for a single channel front-end. These designs already demonstrate high level of performance on industrial MMIC technologies.

INTRODUCTION

Due to tremendous efforts done to improve safety of the cars, a lot of work is done in the field of automotive sensors. At 77GHz, 1998 saw the first commercial introduction of millimeter-wave car radar ; the millimeter-wave front-ends of these radars are manufactured using hybrid assemblies of Gunn, Schottky and PIN diode circuits. However, for a very large availability of this kind of car equipment, very low prices are required. For more and more people now, this will be only possible by using a full MMIC solution, which will bring the following advantages :

- a drastic reduction of the need for circuit tuning
- a unique micro-strip or coplanar assembly technology
- an overall reduction of the size of the front-end module
- an improved thermal stability
- an improved reliability

In 1996 UMS was the first company proposing standard products at 77GHz. A development of a chip-set for narrow band FSK radar has already been done, described in [2] and is now in production. Some MMIC-based solutions are proposed for FMCW modulation [1], [4] but the level of characterization and performance is still limited. The first UMS specific components for FMCW-oriented source was presented in [3].

In this paper we give a detailed description and characterization of a complete and fully MMIC-based front-end dedicated to FMCW automotive radar at 77GHz.

FRONT-END ARCHITECTURE

The main difference compared to FSK concept concerns the source. For this development the objectives were:

- 300MHz frequency tuning range at 77GHz
- phase noise of the free running VCO in the range of -65 to -70 dBc/Hz at 100kHz from carrier at 77GHz
- to provide means for VCO control (linearity, phase noise, stability …), this mainly consists of the generation of an IF frequency (IF2) necessary to drive a control loop.

After global front-end analysis, an optimised MMIC partitioning has been defined and led to the architecture given in Fig. 1. This chip-set is composed of four MMICs: a 38GHz VCO multifunction (CHV2242), a reference oscillator/harmonic mixer multifunction (CHV2241), a 76.5GHz power transmitter multifunction (CHU2277) and a down-converter circuit (CHM2179). Compared to FSK approach this architecture choice allows to use the same concept (even the same chips in some applications) for transmitter and receiver, only the source at 38GHz is different.

In order to reach the optimum cost / performance trade-off, three different MMIC processes are used: the VCO and reference/harmonic mixer chips for the source use a 0.25µm P-HEMT process (PH25); the 76.5GHz transmitter circuit uses a 0.135µm P-HEMT process (PH15); the down-converter receiver circuit uses a GaAs MMIC Schottky diode-based process (BES).

This MMIC partitioning minimizes the number of bonding wires at 76.5GHz.

MMIC DESIGN AND MANUFACTURING

Each MMIC has been designed taking into account the constraints imposed by the use of automatic equipment for pick and place and wire bonding. On chip self biasing of all the active devices is also included.

A. VCO multifunction chip

The oscillator circuit is composed of a VCO at 12.75GHz followed by a frequency tripler. Buffer amplifiers at VCO frequency and at 38GHz reduce circuit sensitivity to temperature and spreads. The on-chip varactor is based on a HEMT Schottky diode. An external medium Q passive resonator gives the centre frequency, temperature stability and optimum phase noise performance for a given frequency tuning range. This off-chip resonator is based on a micro-strip filter used as transmittive mode. The obtained typical results are a frequency tuning range higher than 300MHz, a phase noise at 38GHz around –75dBc/Hz @ 100kHz from carrier and an output power higher than 5dBm. The operating temperature range is from –40 to +100°C. These results are today among the best ones obtained on P-HEMT process. As the VCO is the most critical part these obtained performances allow to propose a complete MMIC solution for the millimetre-wave front-end.

B. Reference multifunction chip

This multifunction is composed of a high quality fixed frequency oscillator and a second order harmonic mixer. Buffer amplifiers are also used for performance improvement in all the environmental and spread conditions. The oscillator has to be coupled to an external high Q resonator (i.e. dielectric resonator) in order to achieve stability and phase noise performances. In a specific test fixture and coupled to a dielectric resonator at 19GHz the oscillator has shown a stability of 3ppm/°C and a phase noise better than –106dBc/Hz @ 100kHz from carrier. The conversion loss is from 4 to 8dB whatever the IF (from 0.1 to 1GHz) and the temperature range (from -40°C to +100°C). Without any off-chip filtering, the second LO harmonic leakage at RF port is lower than -40dBm. The LO leakage at IF port is lower than -25dBm.

C. Power transmitter circuit :

The power transmitter circuit is composed of a frequency multiplier (converting the input 38GHz signal of the local oscillator circuit to 76GHz) followed by a medium power amplifier. This circuit has a main output and an auxiliary output ; the main output is used to feed the radar antenna ; the auxiliary output is used as the local oscillator input to the down-converter receiver circuit. The main and auxiliary saturated output power levels are respectively above 13 and 9dBm between 75 and 79GHz. As the AM noise is a limiting factor for radar sensitivity and as the transmitter contributes a lot to this characteristic an important work is done for improving this performance. The current value, measured in a test-fixture is below -153dBc/Hz at 100kHz from carrier.

D. Down-converter receiver circuit :

Compared to the standard product available since more than 3 years, the MMIC was deeply modified and transferred from P-HEMT to Schottky diode technology. This BES process allows to integrate in a MMIC format Schottky diodes with very low series resistance, resulting in high performance mixer circuits with very low conversion loss. However, the key advantage of this technology is a very low level of low frequency noise, this allows to reach excellent noise figure for a very low IF frequency. Based on a balanced structure, a conversion loss lower than 7.5dB has been obtained. Under certain conditions, the noise figure at 1MHz frequency can be around 13dB.

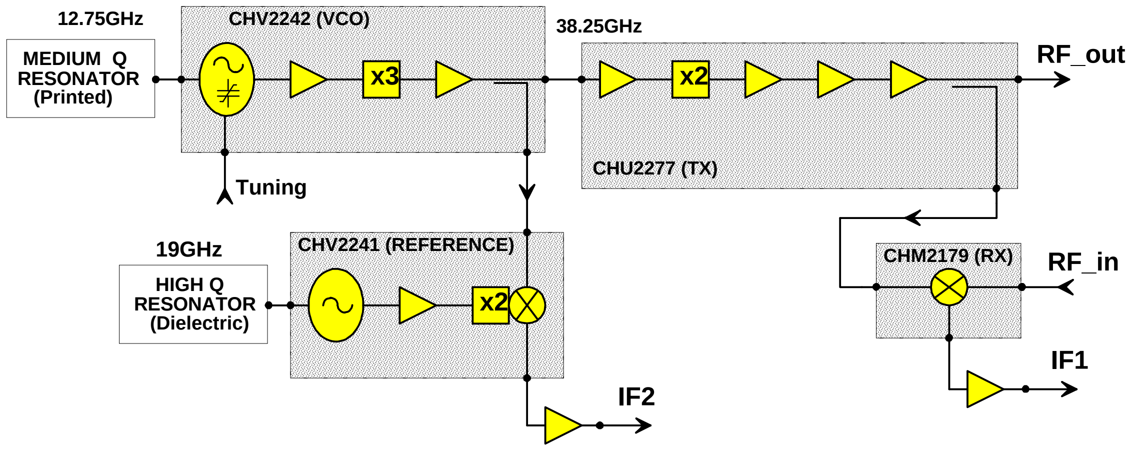

Fig. 1 : Block diagram of the 77GHz front-end for a FMCW radar, showing the MMIC partitioning in four chips: the VCO (chip 1), the reference (chip 2), the power transmitter (Chip 3) and an example with a single channel receiver (Chip 4).

FRONT-END DEMONSTRATOR

In parallel to MMIC development phases, an important validation work is done and consists of assembling several MMICs in order to built a complete front end. This assembly is done according to the rules and the constraints of industrial production, this mainly concerns the choice of inter-connection substrates and wire bonding lengths. A complete module based on the architecture given in fig. 1 has been realized and fully characterized.

The frequency and output power characteristics versus the tuning voltage are shown in Fig. 2. More than 800MHz tuning range has been obtained with an output power (at wave guide output port) higher than 13dBm.

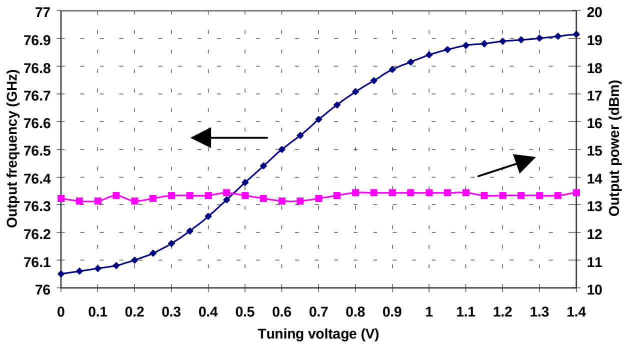

Fig. 2 : Output frequency and power (on RF_out port) versus the tuning voltage

The frequency characteristic after transposition (IF2 output port) is given in Fig. 3. The oscillation frequency of the reference which drives the harmonic mixer is 19GHz, its phase noise obtained in a non optimized cavity environment is better than –102dBc/Hz at 100kHz from carrier.

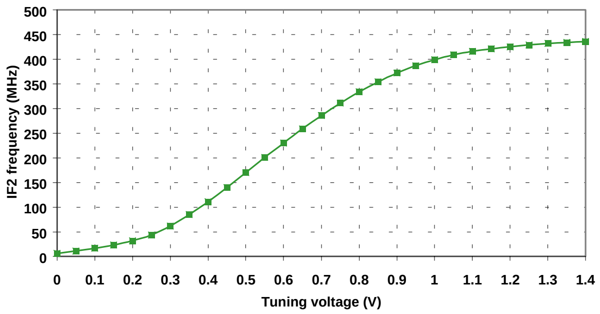

Fig. 3 : IF2 characteristic versus tuning voltage

The free running VCO phase noise has been measured using the IF2 output for a tuning voltage of 1.25V (Fig. 4), the obtained result is better than -76dBc/Hz @ 100kHz from carrier at 38GHz (the phase noise of the reference oscillator doesn't affect the result). This result is equivalent to a phase noise of -70dBc/Hz at 100kHz from carrier at 77GHz.

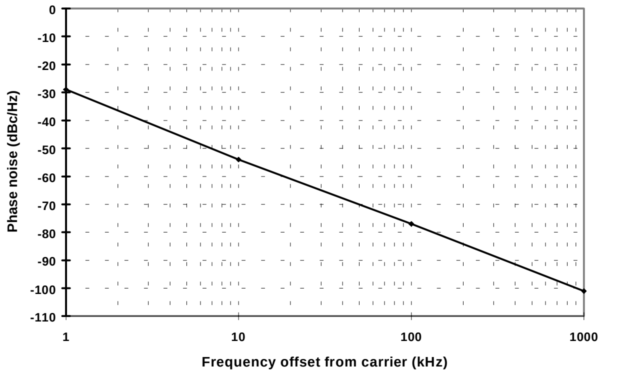

Fig. 4 : VCO phase noise. This measurement is done on IF2 port for Vt=1.25V.

The conversion gain (shown in Fig. 5) is between 12 and 13dB, a 23dB IF amplifier gain is included.

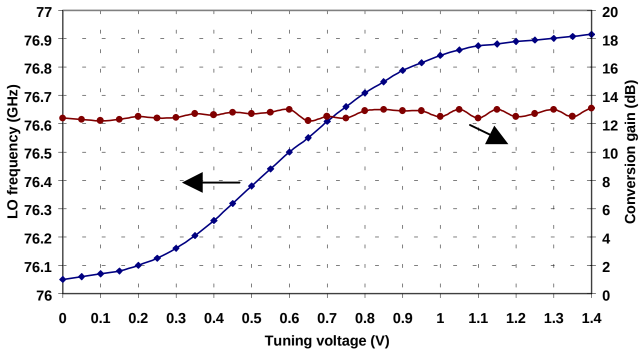

Fig. 5 : Receiver conversion gain versus tuning voltage

The noise figure has been measured according to two different methods:

1. For very low IF frequency, when the low frequency noise is high, the IF noise power is measured on IF1 port. The noise figure is then the ratio between the measured noise power on IF1 port and the theoretical noise power due to only a 50Ω resistance at RF input.
2. When the noise power on IF1 port is in the range of thermal noise, the well known method based on the Y factor is used. The ENR of the noise diode source is 15dB.

Fig. 6 gives the noise figure of the receiver versus the IF frequency. This result includes the IF amplifier with around 23dB gain and 3.5dB noise figure. These results are the best one obtained for a fully MMIC-based front-end.

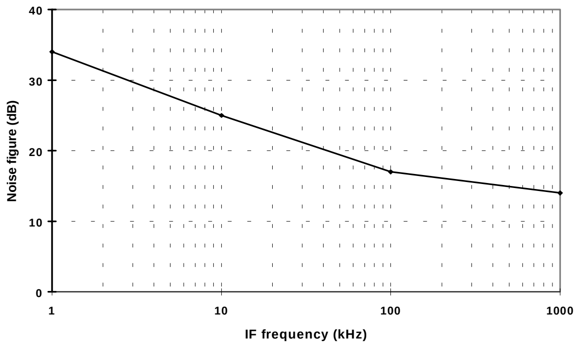

Fig. 6 : Receiver noise figure measured at low IF frequency

The LO leakage at RF port is also an important characteristic: it gives the quality of the mixer according to the AM noise rejection. A power leakage lower than –17dBm is measured (Fig. 7) within all the frequency range. This is equivalent to more than 23dB LO/RF isolation of the mixer.

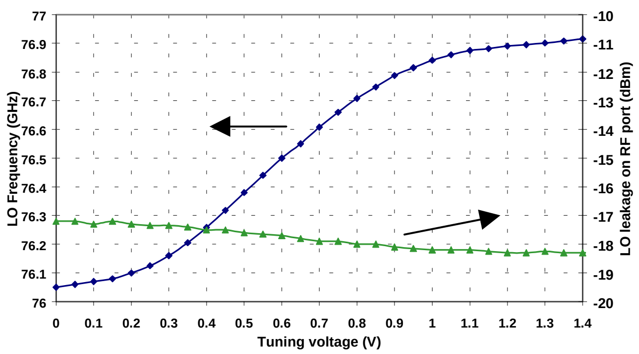

Fig. 7 : LO leakage on RF port versus Tuning voltage

CONCLUSION

Based on a four MMIC chip-set a complete front-end has been done and demonstrates that a high level of performance can be achieved for a 76.5GHz FMCW-based car radar. Each chip has been designed taking into account self biasing and automatic equipment for assembly. This allows to built a low cost and low size module based on micro-strip approach. The total chip-set area is 13.7mm² for a single channel receiver.

ACKNOWLEDGMENTS

These developments are partially funded by the DG13 of the European Commission within the framework of the project 28311 LOCOMOTIVE.

REFERENCES

[1] : T. Shimura, Y. Kawasaki, Y. Ohashi, K. Shirakawa, S. Aoki, H. Someta et al., '76GHz flip chip MMIC for automotive radars', RFIC Symposium, Baltimore, June 98

[2] : M. Camiade, D. Domnesque, P.F. Alleaume, A. Mallet, D. Pons and H. Dämbkes, 'Full MMIC millimetre-wave front-end for a 76.5GHz Adaptative Cruise Control Car Radar' , IEEE MTT-S, Anaheim, 1999. vol. 4.

[3] : M. Camiade, J.P. Brandeau, D. Domnesque, 'Mm-wave front-end developed within the on-going WARE/LOCOMOTIVE projects for automotive applications at 77GHz', European Microwave week, Oct. 99.

[4] : H. J. Siweris, A. Werthof, H. Tischer, T. Grave, H. Werthman, R. H. Rasshofer et al., 'A mixed SI and GaAs chip-set for millimeter-wave automotive radar front-ends', IEEE MTT-S, Boston, June 2000