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HIGH PERFORMANCE MMICs FOR AUTOMOTIVE RADAR APPLICATION AT 77 GHz

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Abstract - A set of functions and multifunctions has been developed using 0.25 µm HEMT and 0.15 µm pseudomorphic HEMT processes for automotive radar application at 77 GHz. The main objective of this work was to appreciate which performances can be reached on these processes for high volume applications. A large number of functions were considered in order to be able to fulfil several radar block diagram requirements (FMCW, pulsed, homodyne, heterodyne...). A set of high performance functions has been realised for frequency generation, transmission and reception circuits.

INTRODUCTION

The market for collision avoidance radar or Autonomous Intelligent Cruise Control system sensors (AICC) will increase rapidly in the near future due to high traffic density growing. A lot of companies are involved in these applications (U.S., Europe, Japan...). Low cost and high volume of production have to be considered at RF module level. The key components for these modules are the semiconductor devices. Discrete components are mainly being used in hybrid structure for radar architecture evaluation and even for prototype phases but these techniques are not suited for mass production because inter-connections are critical and fabrication requires some tunings.

GaAs MMIC components are today the best candidate to reach good performance and relatively low module integration complexity thanks to the availability of millimetre-wave processes and the possibility of designing highly integrated multifunctions.

The purpose of this paper is to give an overview, resting on a set of realisations, about the performances which can be reached on the 0.25 µm HEMT (VLN02) and 0.15 µm P-HEMT (MM015) TCS processes. The MM015 process has been developed in the frame of European projects in collaboration with Daimler-Benz.

GENERAL DESIGN CONSIDERATIONS

The optimisation of the millimetre wave front-end has to be considered at RF-module level. Then the cost compromise takes into account the components but also the mounting process, the inter-connection substrate, the coupling technique to the antenna and the complete housing.

Important work is being done in the field of low cost MMIC assembly at millimetre-wave frequencies. Several approaches like wire bonding, flip-chip, contact-less techniques are evaluated by trying to find a reproducible process compatible with high volume applications. This work has an important consequence on the MMIC design. At the component level a simplified and reproducible process is required but it can not be totally defined before the choice of the inter-connection technique. So, in order to evaluate the specifications which can be reached on TCS millimetre-wave technologies the microstrip approach has been chosen because of the best availability of active and passive component models and the possibility of designing highly integrated multifunctions up to W-band.

FUNCTIONS FOR FREQUENCY GENERATION

Source architecture

The source architecture will depend on the main specifications (stability, phase noise and electronic tuning) but the cost will remain an important objective.

A set of functions has been developed in order to realise each structure described in TABLE 1.

Up to now, the best trade off for low cost radar application seems to be the use of an external resonator. Fig. 1 shows the block diagram of such kind of oscillator. It consists of the following functions:

- K-band oscillator (19 GHz)
- Q-band frequency multiplier (19 → 38 GHz)
- W-band frequency multiplier (38 → 76 GHz)

TABLE 1 : Main source characteristics

Architecture	Phase noise near carrier Stability	Phase noise far from carrier	Cost
Fully integrated	bad	bad	low
Use of external resonator	good	good	medium/low
Phase locked loop	excellent	same as free running oscillator	high/medium

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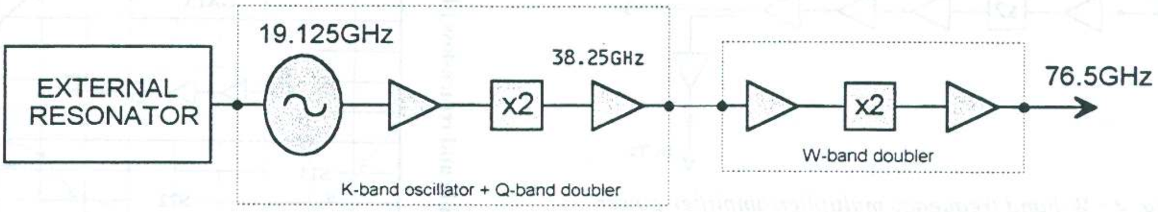

Fig. 1 : Source based on K-band oscillator, Q and W-band doubler

A direct generation oscillator at 77 GHz has not been considered because of poor phase noise and stability performances. The harmonic generation approach allows the use of high quality coefficient resonator which can be easily coupled to the chip. A K-band oscillator followed by a multiplication row of 4 remains a reasonable solution in terms of complexity and spurious rejection. A high integration is yet obtained thanks to the development of a multifunction including the K-band oscillator, the Q-band frequency doubler and all the necessary buffer amplifiers.

MMIC designs for frequency generation

The **K-band oscillator** is based on structures using lumped elements with a feed-back on the source of the transistor. The output is also on the source. The external resonator is coupled to the gate thanks to a specific port. The oscillator frequency can be tuned by using the gate-source capacitance variation as a function of gate to source voltage of the oscillating transistor. This technique is very attractive for low frequency bandwidths.

Several different topologies have been evaluated for each **frequency doubler**. Single ended structures have been chosen because of an interesting trade-off between specifications, power consumption and size. For technology capability optimisation they are based on active transistors biased near pinch-off. The drain current at the output frequency and the rejection of the fundamental frequency are optimised by the use of an output short circuit at the input frequency. Input and output amplifiers are used for buffering purposes and conversion efficiency improvement.

FUNCTIONS FOR TRANSMISSION AND RECEPTION

Amplifier at 77 GHz

The developed function is a 3-stage amplifier with a typical output power of 13 dBm. Compactness and low power consumption were obtained by choosing a single ended structure. Only distributed elements are used for in-band matching networks. Additional resistors and lumped capacitors provide out-off band stability conditions.

Mixers at 77 GHz

They are based on unbiased (cold) transistors. This technique seems to fit well narrow but even wide band applications, optimising the performances on standard HEMT/P-HEMT technologies. The LO signal is applied to the gate. The RF signal is applied to the drain. The IF signal is the mixing product between the drain to source varying conductance and the RF signal. The IF output is provided thanks to a double quarter wave structure.

Two types of mixers have been realised : a "double mixer" (fig. 2) and an Image Rejection Mixer (fig. 3). Both use a Lange coupler for splitting the LO power. The power splitter for the RF signal of the IRM is based on a Wilkinson structure.

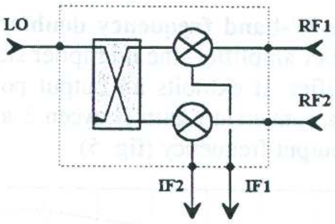

Fig. 2 : Double mixer block diagram

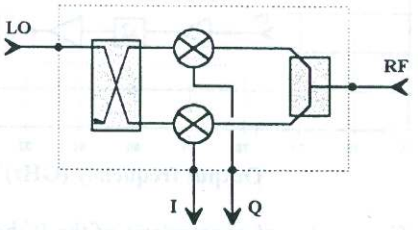

Fig. 3 : Image rejection mixer block diagram

Multifunction

Two multifunctions have been considered during this development:

- a 3-stage amplifier/power divider. This function allows the use of only one chip to deliver the necessary transmitted power (~13 dBm) and the required power to drive the receiving mixers (~7 dBm). This design is based on the 3-stage amplifier circuit.
- a multifunction including the W-band frequency multiplier and the 3-stage amplifier/power divider (fig. 4). This chip has the same output power characteristics as the previous one and is directly compatible with a Q-band oscillator. The required input power is around 3 dBm.

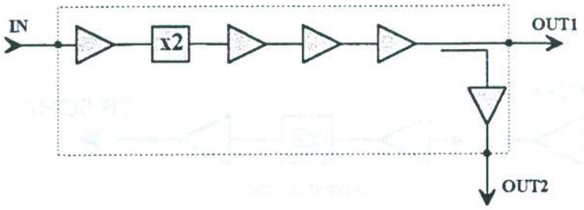

Fig. 4 : W-band frequency multiplier/amplifier/power divider multifunction

EXPERIMENTAL RESULTS

The following results have been done on wafer or in test fixture. They concern all the components estimated to be the most interesting for the considered application.

On wafer measurements

All the functions have been designed by taking into account the wire bondings for inter-connections. At W-band frequencies even a low inductor (~ 0.12 nH) has an important effect so the presented results are deduced from on-wafer measurements and a correction due to these inductors.

The **W-band frequency doubler** chip consists of an input buffer amplifier, the multiplier stage and an output buffer amplifier. It exhibits an output power greater than 6 Bm with a conversion gain between 3 and 5 dB from 75 to 84 GHz output frequency (fig. 5).

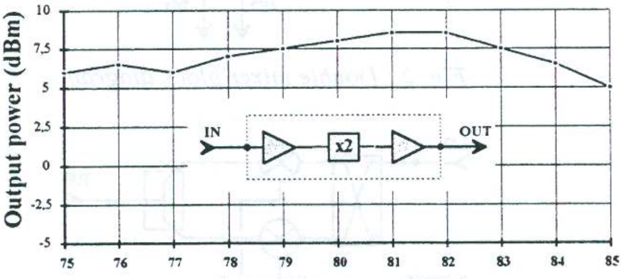

Fig. 5 : Conversion characteristic of the W-band frequency doubler (Pin = 3 dBm)

The **3-stage amplifier** gain and input/output return-loss characteristics are given in fig. 6. A typical gain of 12 dB is obtained with good input/output matching in a frequency range from 75 to 86 GHz.

The mixers have been measured at a fixed IF frequency (100 MHz), both LO and RF vary at the same time. Fig. 7 shows the conversion loss (~9 dB) of the **double mixer** structure. This result demonstrates once again the interest of a "cold transistor"-based mixer for wide band and high performance. The amplitude unbalance between both branches is lower than 0.6 dB. The characteristic of the **image rejection mixer** is in fig. 8. The conversion loss is very close to the one obtained with the double structure when the input RF power divider is taken into account. The amplitude unbalance is lower than 1 dB at 77 GHz.

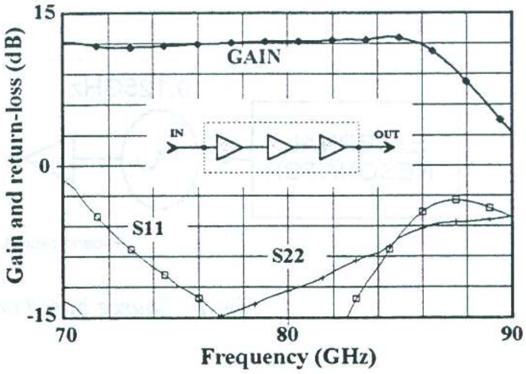

Fig. 6 : Characteristics of the W-band amplifier

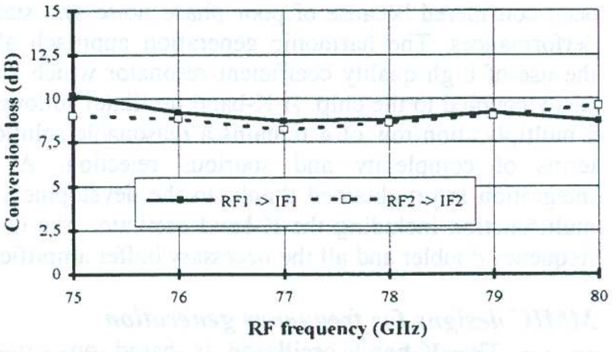

Fig. 7 : Conversion characteristic of the W-band double mixer

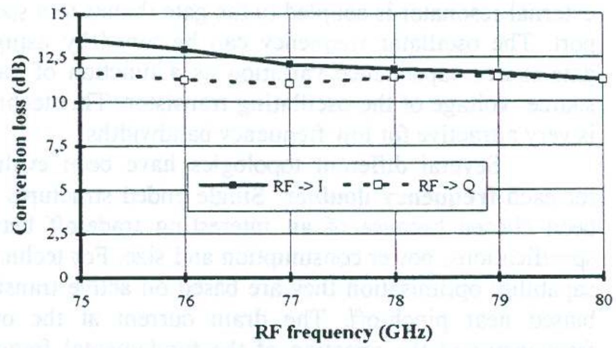

Fig. 8 : Conversion characteristic of the W-band Image Rejection Mixer

Measurements in test fixture

A **W-band source** has been evaluated in a specific housing. It consists of the association of three chips:

- The K-band oscillator/Q-band multiplier multifunction coupled to a dielectric resonator (as shown in fig. 1).
- The W-band multiplier (as shown in fig. 1)
- The W-band 3-stage amplifier.

The obtained results are the following:

- The tuning characteristic (fig. 9) shows a bandwidth of more than 10 MHz. A stability better than 1 ppm/°C is obtained within the temperature range from -20°C to +50°C.
- The output power does not depend on tuning voltage and varies from 13.5 to 14.5 dBm within the temperature range (fig. 10).

- The phase noise is around -82 dBc/Hz at 100 kHz from carrier at 76.9 GHz (fig. 11).

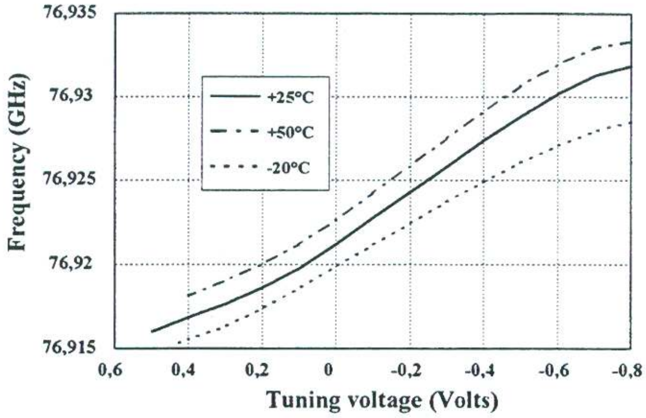

Fig. 9 *: Frequency -tuning characteristic of the W-band source*

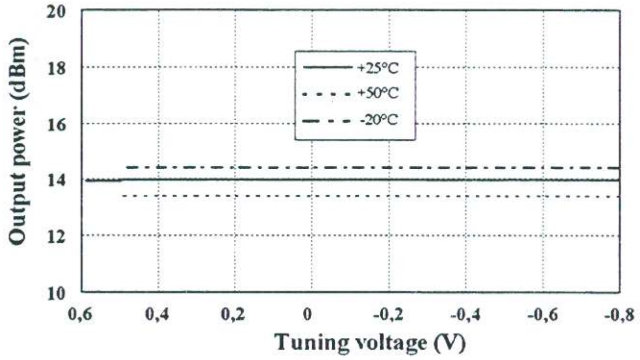

Fig. 10 *Output power tuning characteristic of the W-band source*

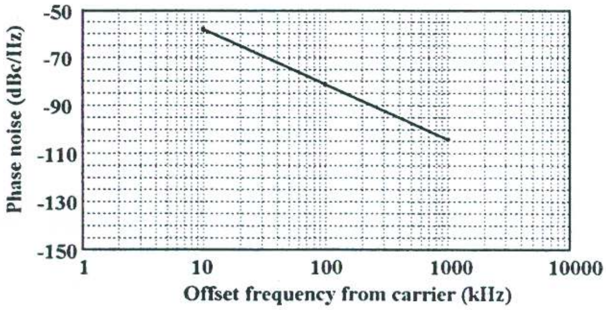

Fig. 11 *: Typical phase noise of the W-band source*

The obtained performances of this source are very attractive and show that the diode-based oscillator can be favourably replaced by MMICs.

The **multifunction** and the **double mixer**, respectively described in fig. 4 and fig. 2, have been evaluated together in a test fixture. In this configuration the auxiliary output of the multifunction (OUT2) drives the LO of the mixers. The main output (OUT1) is coupled to a microstrip to wave-guide transition. Two additional transitions are used for the RF inputs of the mixers. The characteristic given in fig. 12 shows the output power (transmission path) versus the output frequency for several input powers. A value close to 13 dBm is obtained at 77 GHz. Each mixer has also been characterised in this environment, the results are well correlated with on wafer measurements since the conversion loss is around 9 dB. The LO leakage at RF port is lower than -10 dBm. The RF input return loss is better than 12 dB at 77 GHz.

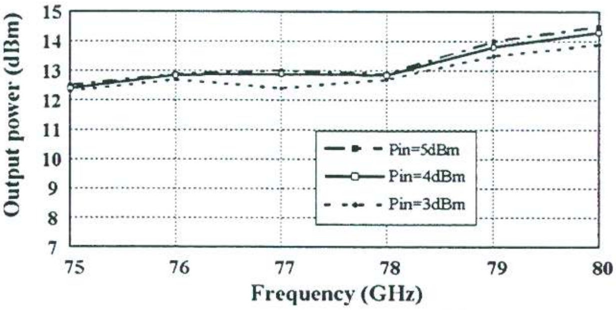

Fig. 12 *: Output power (OUT1) of the W-band multifunction*

CONCLUSION

An important work has been focused on the evaluation of millimetre-wave technology capabilities for automotive radar applications. The main basic functions have been realised for frequency generation, transmission and reception. A set of high performances has been demonstrated and allows the optimisation of the RF part of the radar by choosing the best trade-off between performances and cost.

This chip set is now used for block diagram evaluation and prototyping phases.