MODULAR MILLIMETRE-WAVE TRANSCEIVER DESIGN FOR TODAY DIGITAL RADIO-LINKS

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ABSTRACT

The development of a highly integrated Ka-band (24-26GHz) transceiver module for a high volume point to multipoint telecommunication application is presented. In order to reduce the costs, a full GaAs MMIC solution has been chosen. The module architecture and assembly technology are described. 8 different Ka-band MMICs have been or are being designed and fabricated for this application. The measured performances of the developed MMICs and of the module prototypes are given.

INTRODUCTION

The market for Wireless Local Loop systems at millimetre-wave is rapidly developing, covering several applications such as point to point digital radio links for mobile phone networks and point to multipoint links (MMDS, LMDS, MVDS) for interactive multimedia (telephony, video conferencing, video on demand, internet) distribution for business or residential services. With respect to conventional wired systems (including optical fibres), the wireless solutions offer the advantages (i) of being more cost effective, especially for the coverage of rural or suburban areas ; (ii) of a much faster deployment, with potential rapid returns on investments (iii) and of being more easily scaleable to fit with the subscriber demand.

We present here the development of a full duplex 24-26GHz Transmit/Receive module (transceiver) for a point to multipoint distribution system. The point to multipoint system is developed by P.COM and the modules are designed and manufactured by TCM ; all the millimetre-wave active components are GaAs MMICs for a drastic reduction of the assembly complexity and of the module cost. All the MMICs are designed and manufactured by UMS.

TRANSCEIVER MODULE DESIGN AND TECHNOLOGY

The module is composed of one single microwave Duroïd board on which are integrated the millimetrewave receive and transmit microstrip circuits and of one DC Teflon board for the control and active biasing of the MMICs. The boards are assembled in a low cost aluminium package. Walls partly separate the LO harmonic mixer and the input and output channels for decoupling. The receive channel input and transmit channel output ports are microstrip to waveguide (WR42) transitions which have 15 dB return loss and 0.5 dB insertion loss. The block diagram of the microwave transceiver circuit is given in Fig. 1.

The frequency of the X-band LO signal from a synthesised source (the synthesiser is not integrated in the transceiver module) is first doubled by a frequency multiplier circuit (MULT). It is then splitted by a Wilkinson coupler and fed through two buffer amplifiers (BUF) to the two balanced mixers (MIX) for the up- and down-conversions. The Transmit amplifier chain is composed of a variable gain driver amplifier (VGA) followed by a HPA. A very low noise amplifier (LNA) equips the receive channel in order to achieve the requested noise figure specification of the module (NF < 3.5dB).

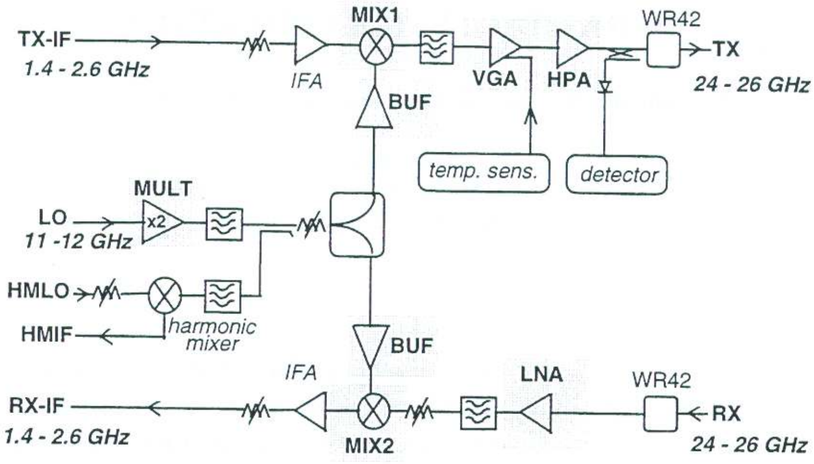

Fig. 1 : Point to multipoint transceiver module block diagram, stressing the integration of 8 Ka-band MMICs from UMS.

The transmission lines, couplers and filters are directly integrated on the Duroïd substrate by thin film lithography. The 8 MMICs (HPA, VGA, LNA, MIX1, MIX2, BUF (x2), MULT) are positioned and glued on the substrate by an automatic pick and place machine ; the HPA is preliminary brazed on a metallic carrier for better thermal dissipation. The other active components are two commercial IF amplifiers and one hybrid harmonic mixer which is used in the PLL loop of the source. This harmonic mixer, which has been developed by P.COM, is integrated on the RF board using discrete SMD components.

A great care has been taken to warrant the module performances in a large temperature scale. The LNA of the receiver channel is biased at a fixed drain current in order to compensate for thermal drifts. A thermocouple is integrated close to the HPA which allows to control the gain of the transmit channel as a function of temperature via the variable gain driver amplifier (VGA).

MILLIMETRE-WAVE MMICs

The 8 Ka-band MMICs have been, or are being designed and fabricated using three different UMS processes :

- PH25, a pseudomorphic HEMT (P-HEMT) process with 0.25µm Al gates, dedicated to very low-noise and small/medium signal circuits up to 40GHz. The typical noise figure of PH25 transistors is 1.5 dB with 8 dB of associated gain at 40GHz.
- PPH25, a power variant of PH25, also with 0.25µm Al gates , with a double heterojunction / delta doping epitaxial sequence and a double gate recess for increased linear power amplification capability up to Ka-band. The PPH25 transistors exhibit a typical breakdown voltage Vbds > 10V, and about 600mW/mm of power density at the 1dB gain compression point.
- BES, a 1µm Schottky diode MMIC process dedicated to millimetre-wave low conversion loss mixer circuits.

All these three processes are fully documented with design rules and small and large signal electrical models for MMIC design and simulation.

Frequency multiplier (MULT) :

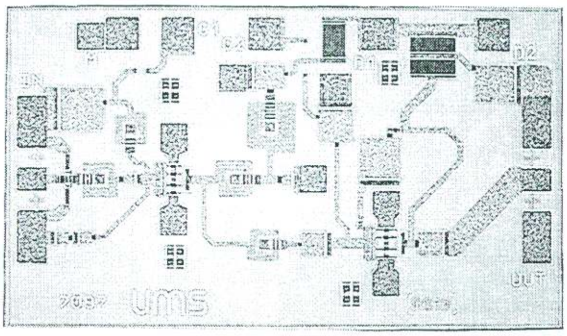

Fig. 2 : Photograph of the PH25 frequency multiplier CHX2090 (1.7x1 mm^2)

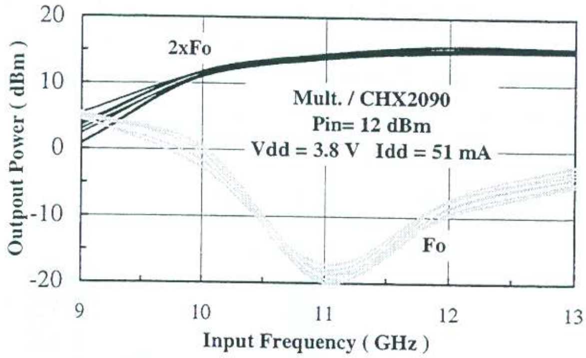

Fig. 3 : On-wafer measurement of the output power at the fundamental (F0) and doubled (2xF0) frequencies as a function of the input signal frequency (F0).

The frequency multiplier (MULT) in the LO branch of the transceiver is a PH25 MMIC, labelled CHX2090. Fig. 2 is a photograph of this chip. This MMIC multiplies by 2 the frequency of the X-band LO source. It has an attenuator circuit at the input and a one-stage buffer amplifier at the output for good matching purposes. The measured output power at the doubled frequency is given in Fig. 3 as a function of the input signal frequency ; it is higher than 13dBm for an input signal of 12dBm in the 11-12GHz LO frequency range. The leakage at the fundamental frequency is also given and is lower than -10dBm in the same input frequency range.

Buffer amplifiers (BUF) :

After frequency doubling, the LO signal is splitted by a Wilkinson coupler towards the two up- and down-converter mixers. The LO signals are amplified before attacking the mixers by two identical buffer amplifiers, labelled CHA2092. This PH25 chip is a compact, high gain broadband 3-stage LNA. Its typical noise figure and associated gain are respectively 3 dB and 22 dB in the 20 - 30GHz frequency band. This chip is a standard catalogue product of UMS.

Mixers (MIX1 and MIX2) :

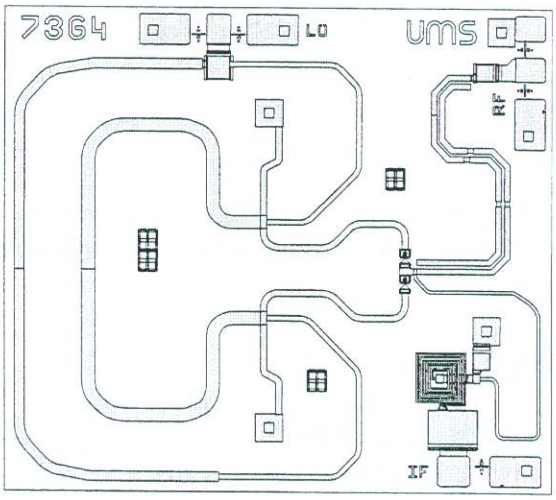

Fig. 4 : Lay-out of the up-converter balanced mixer (MIX1) designed using the BES Schottky diode MMIC process.

The prototype versions of the transceiver module use two hybrid Schottky diode mixers for the up- and down-converters. The final version will use two Schottky diode balanced mixers in a MMIC format, using the BES process. These two MMIC mixers have been designed and manufactured. The measured performances will be presented at the conference. The lay-out of the up-converter mixer is given in Fig. 4. The down-converter mixer has a very similar design.

Low Noise Amplifier (LNA) :

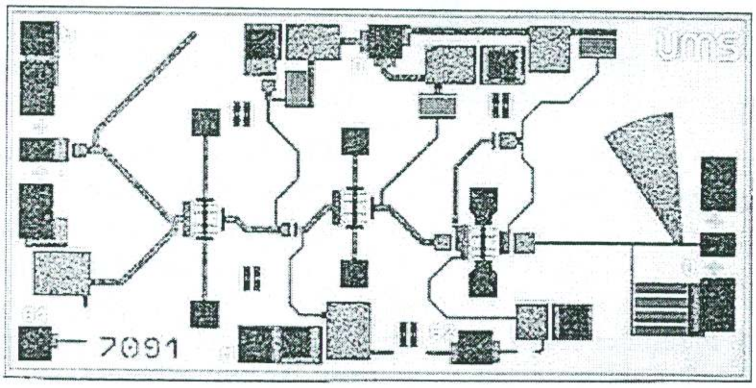

Fig. 5 : Photograph of the PH25 CHA2193 LNA (1.7x1.0 mm^2)

The LNA of the receive circuit is a very compact 3-stage PH25 amplifier which has been specially optimised for this application. It incorporate a resistive attenuator at the output in order to optimise the trade-off between linearity and noise figure of the receive channel and to improve the output VSWR. The photograph of this chip, labelled CHA2193, is given in Fig.5. This amplifier exhibits excellent noise figure and impedance matching performances, as shown in Figs 6 & 7. The typical noise figure is below 1.9dB with an associated gain above 18dB in the module frequency range (24-26GHz). The output and input return losses are below -15dB in the same frequency range.

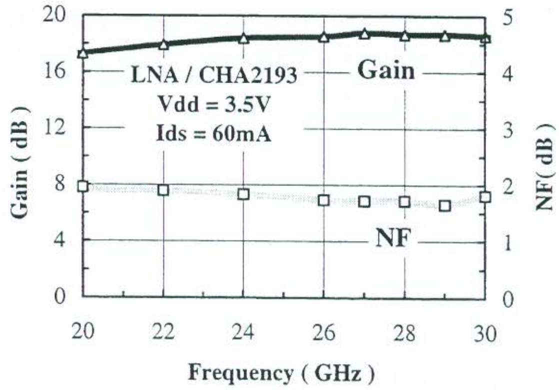

Fig. 6 : On-wafer measurements of the noise figure and associated gain as a function of frequency

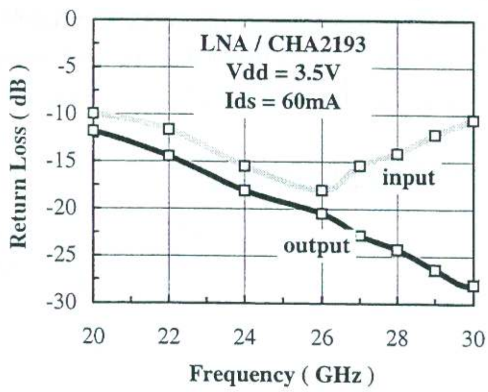

Fig. 7 : On-wafer measurement of the input and output return losses as a function of frequency.

Variable gain amplifier (VGA) :

The driver amplifier of the transmit channel is a variable gain amplifier, allowing a precise control of the module output power, accommodating for thermal drifts. The control signal is obtained from an hybrid control circuit and a temperature sensor integrated on the microwave board close to the VGA. The VGA is a PH25 MMIC, labelled CHA2097, whose photograph is shown in Fig. 8.

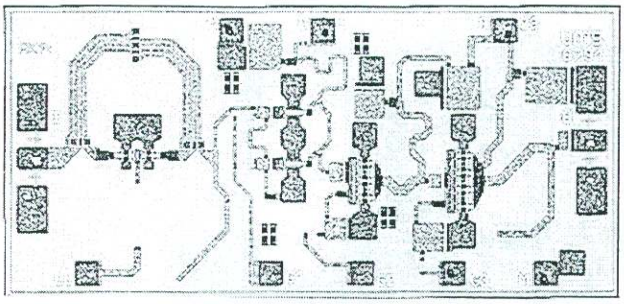

Fig. 8 : Photograph of the variable gain amplifier CHA2097 (2.1x1.1 mm^2)

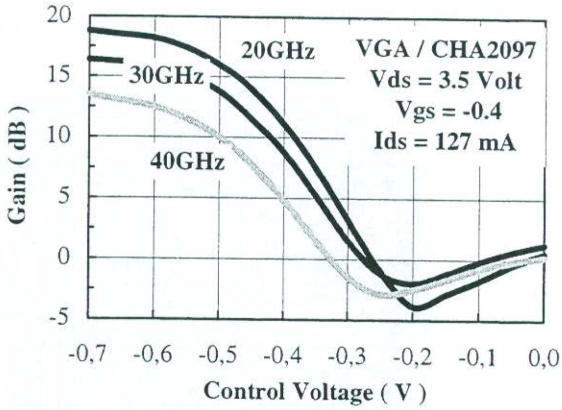

Fig. 9 : Performances of the VGA CHA2097 : Gain control at three different frequencies.

The principle of the gain control is based on a double cold FET reflective attenuator using a Lange coupler. This attenuator stage is followed by a 3-stage gain block. The gain control capability is shown in Fig. 9. Its gain is set to 15dB at 45°C ambient temperature.

High Power Amplifier (HPA) :

The HPA has been designed using the PPH25 power HEMT process which has been recently developed by UMS. This MMIC, labelled CHA5093 is a 3-stage power amplifier having a total of 3.7 mm gate periphery. The small signal gain, of 22 dB in the 24 to 26GHz frequency range, and the input and output return losses are given in Fig. 11. At the time of writing this paper, the power and linearity performances of the HPA and of the complete module cannot be disclosed for commercial confidentiality reasons.

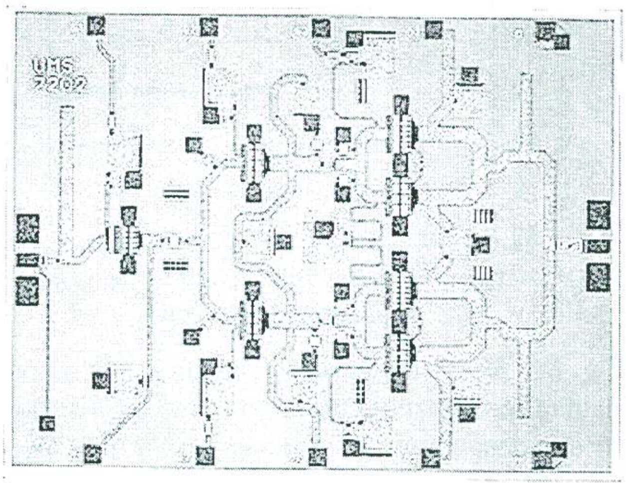

Fig. 10 : photograph of the HPA CHA5093 (3.2x2.4 mm^2)

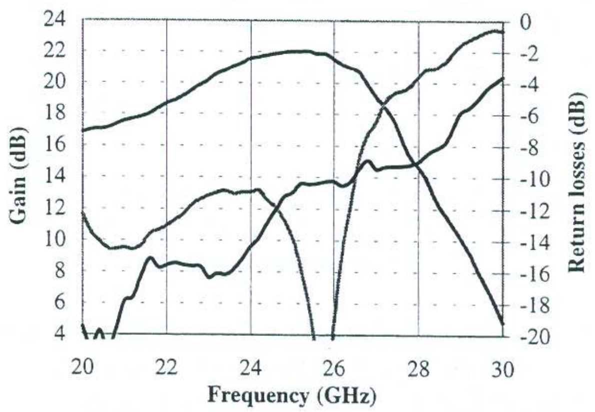

Fig. 11 : Measurement of the small signal gain and return losses of the CHA5093 HPA in a test-jig.

TRANSCEIVER MODULE PERFORMANCES

The photograph of an assembled module is given in Fig. 12. The transmit channel is on the bottom of the RF board, the receive channel at the top. The LO part (the hybrid harmonic mixer) of the circuit is on the left hand-side of the RF board. The two microstrip to waveguide transitions are visible on the right hand side of the module. Also visible are the internal walls for decoupling and two microwave absorbers covering partly the transmit channel.

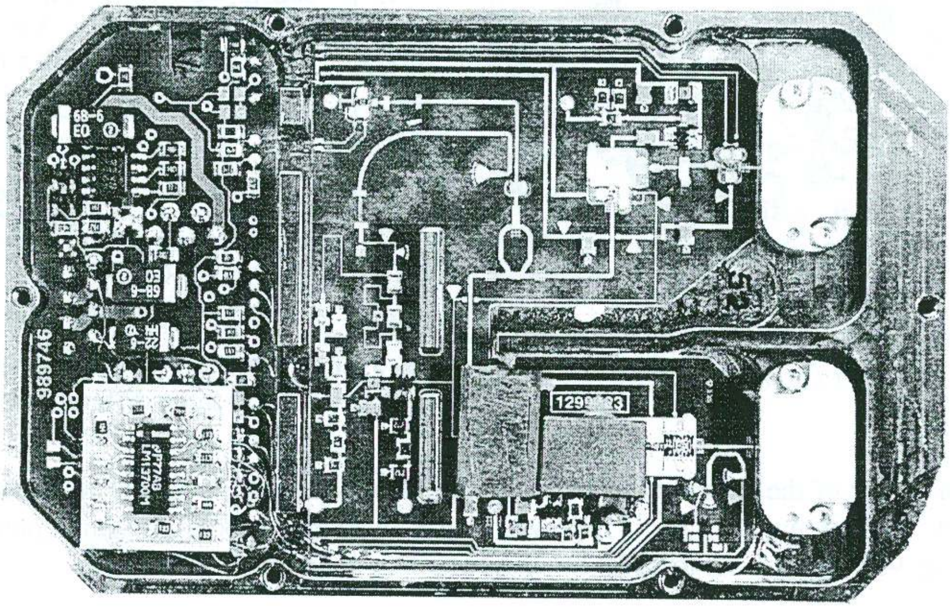

Fig.12 : Photograph of a fully assembled 24-26GHz point to multipoint transceiver module.

The receive channel gain and noise performances at room temperature are given in Fig.13, as a function of the input RF frequency ; the average measured conversion gain is 21dB, with a ripple of about ± 0.5dB. The noise figure is below 3.0 dB in the module bandwidth. The measured transmit channel gain is given in Fig.14, as a function of the input intermediate frequency. The conversion gain is 40.5 ± 0.7dB.

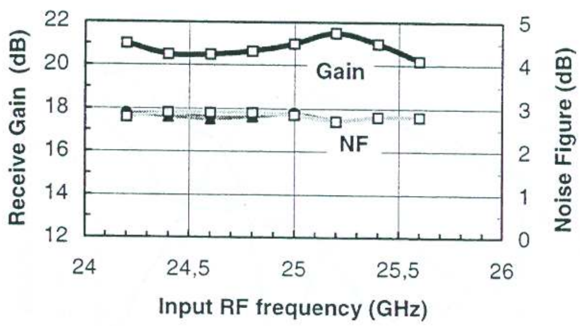

Fig. 13 : Room temperature measurement of gain and noise figure of the receive channel.
The noise figure has been measured for three LO frequencies : 11.2, 11.3 and 11.45GHz.

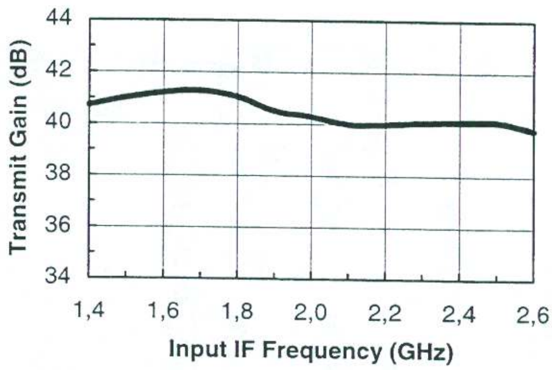

Fig. 14 : Room temperature measurement of the gain of the transmit channel as a function of the IF frequency, for a LO frequency of 11.45GHz

CONCLUSION

We have demonstrated the successful development of a full duplex transceiver module for a high volume 24-26GHz point to multipoint telecommunication application. This module is using a full MMIC solution for the Ka-band part of the module. The chipset is a family of 8 MMIC, including LNA, HPA, driver / buffer amplifiers, mixers and frequency multiplier. The noise figure of the module has a record value of 3 dB in the whole bandwidth of the module. This work demonstrates the high potential of GaAs MMICs for volume production of commercial millimetre-wave communication systems.