InP Technology for 60 GHz Telecommunication Applications

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ABSTRACT

Low Noise, Medium Power and Transimpedance MMIC Coplanar Waveguide Amplifiers have been successfully designed in one pilot line run using HRL InP based 0.15 μm HEMT technology to evaluate the feasibility of 60 GHz advanced Optoelectronic module. The Low Noise Amplifier exhibits 3.5 dB Noise Figure with an associated gain of 11 dB from 55 to 65 GHz. The Medium Power Amplifier exhibits 11 dBm output Power with a gain of 15 dB from 55 to 65 GHz. The Transimpedance Amplifier exhibits 44 dBohms gain from 55 to 65 GHz.

INTRODUCTION

60 GHz frequency represents a real interest for future Telecommunication applications such as WLAN, WLL or Fiber to the Home where High Bit Rate and Short Range links are required. For these applications, technology aspects are a real challenge for achieving cost and performance objectives. This paper describes a collaboration work between Dassault Electronique, France Telecom and HRL Laboratories for developing an advanced Optoelectronic module for Fiber to the home application at 60 GHz. This modules includes InP Photodiode, InP MMIC Low Noise, Medium Power and Transimpedance Amplifiers .
These technological developments are based on the use of HRL InP based 0.15 μm HEMT technology allowing to reach MMIC Noise Figure and Gain specifications. Dassault Electronique and France Telecom are involved in system definition, device design and module integration.

InP HEMT STRUCTURE

Lattice-matched to a 3 inch InP semi-insulating substrate, the InP HEMT structure consists of a 250 nm undoped superlattice AlInAs buffer with a 40 nm GaInAs channel, an undoped spacer, an AlInAs donor layer, a 20 nm undoped AlInAs barrier layer and a 7nm GaInAs n+ doped cap. The electron sheet density is nominally 2.7 10^{12} cm^{-2} and the room temperature electron mobility > 10,000. A double exposure e-beam lithography process is used to create a highly repeatable 0.15 μm gate definition through the resist. To shield the active device from moisture and contamination, a 100 nm thick silicon nitride passivation layer is used [1,2,3].

OPTOELECTRONIC MODULE
(Optical Receiver)

The receiver module is studied only. The block diagram of this Optoelectronic module is shown in figure 1. It consists of an InP chipset : a Photodiode followed by a Transimpedance Amplifier, a Low Noise Amplifier, a Medium Power Amplifier and an antenna patch.
All the MMIC functions were designed using the coplanar waveguide structure mainly for cost aspects.

The next generation can be imagined easily having a compact millimeter wave system with the photodiode and amplifiers on the same InP chip. It will avoid RF connecting problems and will reduce the effective cost of millimeter wave systems.

PHOTODIODE

In order to achieve both high-speed and high sensitivity, a side illuminated PIN photodiode was developed by CNET. The structure is grown by MBE on semi-insulated InP substrate and includes an undoped GaInAs absorption sandwiched between AlGaInAs optical confinement layers, n and p type doped layers provided to improve the coupling efficiency with the fiber. Contact layers are also designed to get a low serie resistor. The fabrication process uses contact lithography and lift-off techniques. Air bridges are used to reduce parasitics. This kind of photodiode exhibits a DC responsivity as high as 0.8 A/W over more 40GHz bandwidth [4] and may keep 0.25 A/W at 60GHz. New designs are under investigation to get more responsivity at 60GHz.

MMIC DESIGNS and TEST RESULTS

- **Design software and modeling**

All circuit-level simulations were done using HP-EESOF's Software. Coplanar discontinuities such as tee-junctions and stubs were analyzed using Sonnet em^{TM} for validation and comparison with LIBRA.
A 17-element HEMT linear model developed by HRL from measured data was used to generate the S-parameters at V-Band.
The HRL noise model was generated from discrete devices that were characterized for noise figure.
Dassault Electronique test bench and software were used to generate the Angelov's HEMT large-signal model.

- **Two-stage V-band LNA and Transimpedance Amplifiers**

Two V-band MMIC LNA Amplifiers were designed, respectively a 50 ohms low noise amplifier and a Transimpedance low noise amplifier.
- The V-band LNA design uses two 150 μm PHEMT devices, 6 x 25 μm, biased for low noise (Vds = 1.0 V at 15 mA) in the first and the second stage. The 150 μm device was chosen to minimize the matching network required for the best noise match and return loss at V-band. Coplanar structures, MIM capacitors and epi-resistors were used for the input, interstage and output matching circuits and to stabilize the devices. Chip size is 2 x 2 mm^2 and consumes 30 mW of DC power (see figure. 2). This LNA provides better than 11dB of gain from 55 to 65 GHz with a flatness of 0.7dB (see figure 3).A Noise Figure of 3.5dB with a saturated Output Power of 4 dBm has been measured at 60GHz
A very good agreement between on wafer S-parameter measurement results and simulated results using LIBRA CPW library has been found (see figure 4). The use of electromagnetic simulator like SONNET software has been done without any significant improvement.

- The Transimpedance amplifier is very similar to the LNA. The transimpedance design uses the same 150 µm PHEMT devices. The main difference between the Transimpedance and the LNA is the matching network between the photodiode and the first transistor. Chip size is 2.5 x 2 mm² (see figure 5). The Transimpedance of the optical receiver provides a 44 dBOhms gain in a bandwidth of 55 to 65 GHz (see figure 6).

- **Two-stage Medium Power Amplifier**

A V-band MMIC medium power amplifier has been designed using one 150 µm PHEMT device (6 x 25 µm) for the first stage and one 300 µm PHEMT (6 x 50 µm) for the last stage.
The two stage medium power amplifier is biased in class A operation to get the maximum power (V_{DS} = 1.5V at 30 mA and 60 mA respectively).
Coplanar structures, MIM-capacitors and epi-resistors were used for the input, interstage and output matching circuits and to stabilize the devices. Chip size is 2 x 2 mm² and consume 135 mV of power (see figure. 7).
This MPA provides better than 15 dB of gain from 55 to 65 GHz with a flatness of 1dB (see figure 8). A Output Power of 11 dBm has been measured from 58 to 62 GHz (see figure 9 and 10).

CONCLUSION

Low Noise, Transimpedance and Medium Power Amplifiers were developed in one pilot line run using 0.15 µm InP based HEMT MMIC technology, for a feasibility study of a 60 GHz advanced Optoelectronic module for Fiber to the Home applications. These MMIC amplifiers using Coplanar Waveguide structures demonstrated very good performances (3.5dB Noise Figure with 11dB associated Gain for the LNA , 11dBm output Power with 15dB associated Gain for the MPA).
The modules for these 60 GHz telecommunication applications require small size, high performances, light weight and low cost devices. In this aim, InP technology seems very suitable for these kind of applications.

REFERENCES

[1] L. NGUYEN, et al ; 1993 IEEE MTT-S Digest pp. 345-7

[2] R. ISOBE, et al ; 1995 IEEE MTT-S Digest pp. 1133-6

[3] L.TRAN, et al ; 1996 IEEE MTT-S Digest

[4] G.WANLIN, L. GIRAUDET et al ; 1997 ECOC Digest

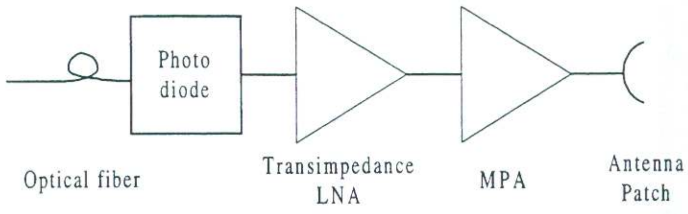

Figure 1 Block diagram of receiver module

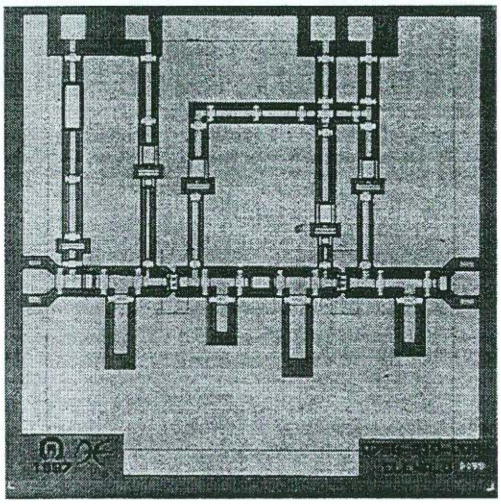

Figure 2 - Layout of the V-band MMIC LNA

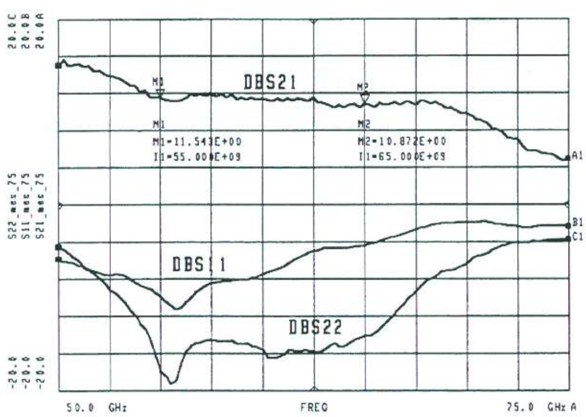

Figure 3 –S parameters Measurement results for the MMIC LNA

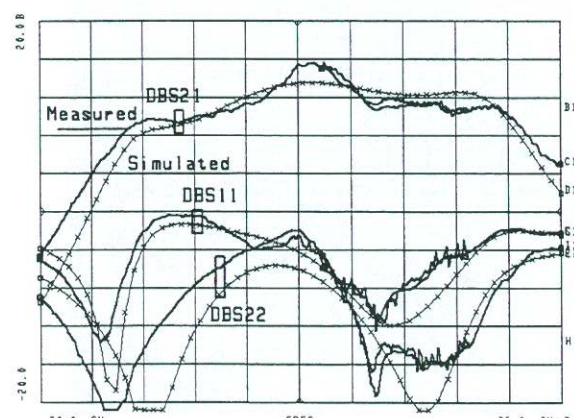

Figure 4 – comparison of S parameters Measurement and simulated results

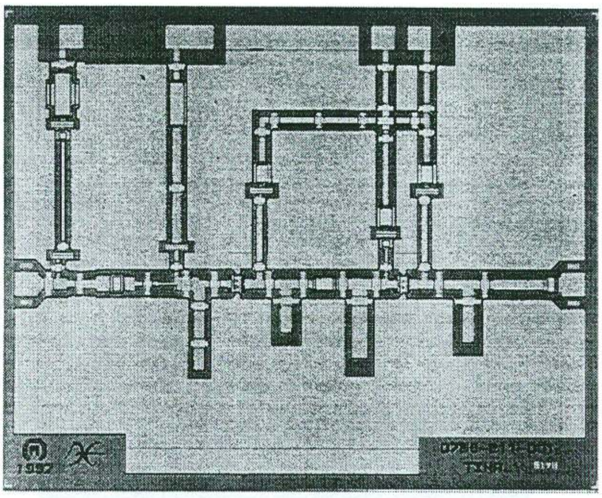

Figure 5 - Layout of the V-band MMIC Transimpedance

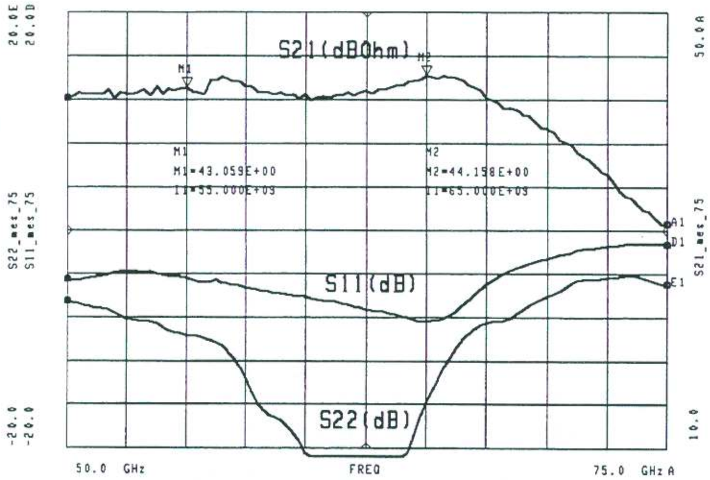

Figure 6 – S parameters Measurement results for the MMIC Transimpedance

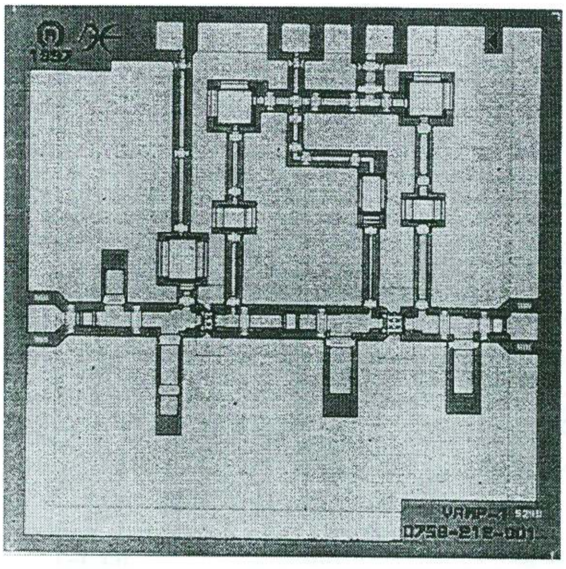

Figure 7 - Layout of the V-band MMIC MPA

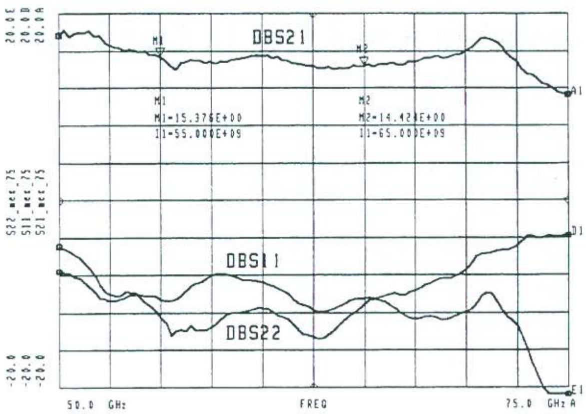

Figure 8 –S parameters Measurement results for the MMIC MPA

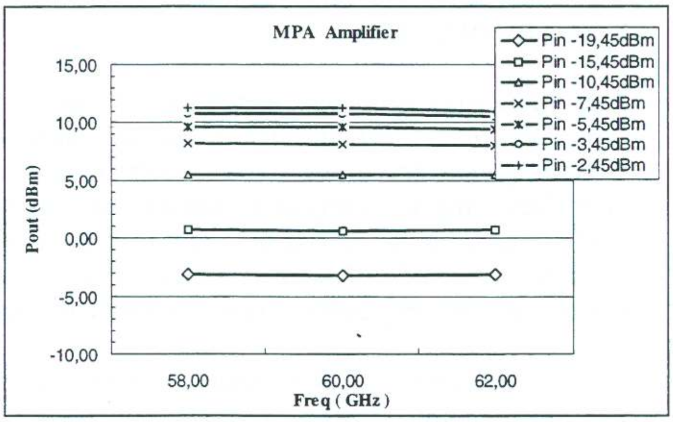

Figure 9 –Power Measurement results for the MMIC MPA

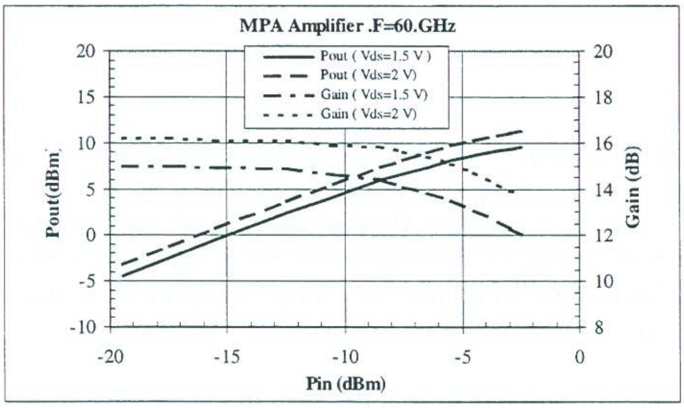

Figure 10 –Power Measurement results at Vds=1.5 and 2V of the MMIC MPA