MMIC GaAs Transimpedance Amplifiers for Optoelectronic Applications

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Abstract

This paper demonstrates the feasibility of MMIC transimpedance amplifiers able to improve the global performances of an optical link, in terms of gain, dynamic range and noise, over a typical 1 to 20 GHz frequency range. Two MMICs, a distributed amplifier and a photodiode follower using the Bootstrap technique, provide an active matching between 50 Ω and both high impedance of a photodiode and low impedance of a laser. After a single foundry run, the on-chip measurements show a good agreement with the simulation and the first measurements in association with optoelectronic devices are successful.

Introduction

The increasing complexity of microwave systems in the field of Radar, Electronic Warfare and Telecomunications applications, implies the use of more and more microwave links generating losses, weight, volume and coupling effects.

To overcome this problem, optical links represent a good solution thanks to the late technological improvements in optoelectronic devices such as photodiodes and lasers.

Associated to these optoelectronic devices, Microwave Transimpedance Amplifiers represent key components regarding performance optimization (dynamic range, noise figure, consumption, losses....).

In particular, in Electronic Warefare applications where wide frequency range operations are required, transimpedance Amplifiers are a real challenge allowing matching between 50 Ω RF impedance and both high impedance of a photodiode and low impedance of a laser diode over a typical 1 - 20 GHz frequency range.

This paper describes 2 types of wide band Microwave "Transimpedance" circuits using advanced and novel concepts :

- A distributed transimpedance amplifier dedicated to laser matching
- A specific transimpedance amplifier, used for photodiode matching.

These amplifiers have been designed by DASSAULT ELECTRONIQUE and manufactured with the VLN02/HEMT process from THOMSON/TCS. Thank to the use of design methodology the total design/process/test cycle was shorter than 10 months.

Advanced models of lasers and photodiode have been developed by the CNAM (Paris) and implemented by the mean of MDS software. These models have been combined with Transimpedance Amplifiers as simulated by Dassault Electronique in order to prepare the design of the next generation of transimpedance chips, in terms of bandwidth, gain, SWR, noise figure, spurious free dynamic and flatness.

Furthermore, CNET (French Telecom Research Center, Bagneux) and IEMN (University of Lille) have just implemented a first combination of transimpedance chips and optoelectronic transducers, respectively a high speed laser and a high speed photodiode. The preliminary experimental results will be discussed in the paper.

Distributed Transimpedance Amplifier (DTA, laser driver)

a) Design and on-wafer tests

Figure 1 shows the photograph of the distributed transimpedance amplifier. This component uses the wellknown distributed configuration adapted to low output impedance by setting the drain line characteristic impedance at 10 Ω instead of classical 50 Ω impedance. This allows to avoid the commonly used 45 Ω series resistance that matches the low laser diode input impedances (typically 5 Ω up to 20 GHz) but created 10 dB losses at the very beginning of the transmission link.

Transimpedance amplifier and laser devices are directly interconnected in order to reduce parasitic elements. The laser bias current is supplied through an on-chip bias T.

A 7 ± 0.5 dB gain with less than 8 dB input and output return losses have been obtained over the 1-18 GHz range, with 50 Ω at the input and 10 Ω at the output as reference impedances.

On wafer measurements with 50 Ω input/output impedance have been performed and are very close to predicted values with the same port impedances.

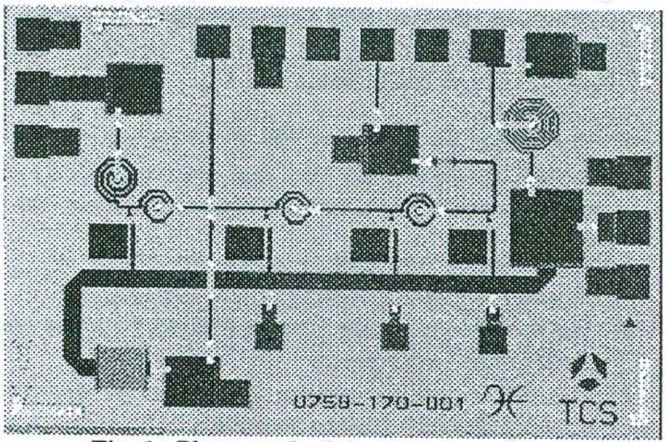

Fig. 1 : Photograph of the DTA laser driver

b) A high speed optoelectronic upconverter for mm-wave radio application - Design and test

The rapid development of wireless networks at millimetre wave frequencies will generate the need for efficient optoelectronic transducers for upconverting IF signals. With harmonic generation and mixing techniques, low frequency drive signals can be used for upconversion. Recently, the concept of using a directly modulated laser in non linear region has been demonstrated and showed interesting results for mm-wave generation and mixing [1].

The CNET has assembled an enhanced high speed optoelectronic upconverter for mm-wave radio applications in the 28/38/60 GHz range with a reduced input driving power (<10 dBm) in a frequency range of 5-10 GHz [2]. This device integrates the distributed transimpedance amplifier (DTA) with a MQW VUG DFB laser on a unique submount. The problem of microwave losses and ease of packaging are overcome due to the circuit compactness. Moreover, this device allows to transpose a digital data signal on the generated mm-wave carrier.

The two components are connected together through a short gold bonding wire to optimize parasitics. Only three bias supplies are necessary : drain, gate and laser. Typical drain voltage is 3 V with 40 mA of current, whereas the gate is biased at 0 V. The laser is current supplied through an on-chip bias T provided by the amplifier circuit (fig. 1). On the bias path via the on-chip T, a 30 ohm series resistance is placed on a short microstrip between the amplifier and the port connector to enable digital modulation. The 1.5 µm DFB laser is realized in the VUG technology [3]. It has a dc efficiency of 0.12 mW/mA and present a damping factor of 0.28 ns and low RC parasitics (< 6 ps) which favour efficient harmonic upconversion [1]. The DFB is configured as follows : the amplified RF signal modulates the laser at a low frequency (5-10 GHz) which is the local oscillator (LO) frequency range. The laser is biased to have its relaxation frequency close to the LO frequency (45 mA) to enhance non linear effects [1]. The modulated output light is focused on a lensed fibre followed by an isolator. The light is detected by a high speed 32 GHz protodetector (PD) before being displayed on an electrical spectrum analyzer.

The CNET investigated the millimeterwave bandwidth (20 - 40 GHz) generated by harmonic and the power obtained by modulating the upconverter in the range of 5 - 10 GHz with a power of less than 10 dBm. For this purpose, the 4th or a higher order harmonic can be used. The typical power detected at 28 GHz and 38 GHz were -23 dBm and -33 dBm respectively for a fixed laser bias (45 mA).

The optoelectronic upconverter can operate as a mixer, if the on-chip bias T path is used for another modulation signal such as an incoming digital signal. The available bandwidth on this port remained relatively flat from 10 KHz to 800 MHz (fig. 2). The open baseband eye diagram received at the photodiode end confirmed the 1 GBit/s capability of the on-chip bias T of the upconverter.

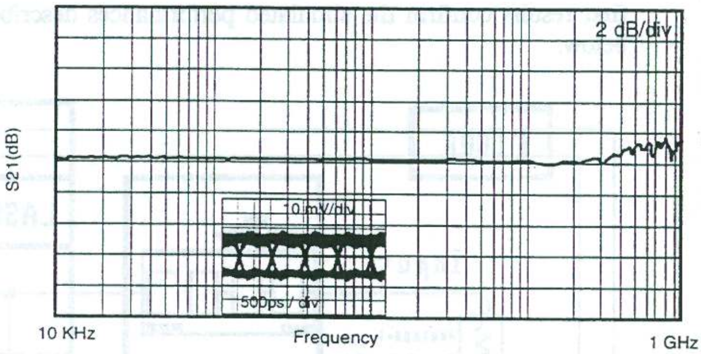

Fig. 2 : On-chip bias T port bandwith; 1 Gbit/s modulation validation test

The Specific Photodiode Amplifier (SPA, photodiode follower)

Figure 3 represents the layout of the SPA. The concept of this amplifier is based on canceling the limiting effect of the parasitic capacitor associated with the photodiode. This technique is here for the first time adapted to the microwave domain. The parasitic capacitor is indeed the main limiting factor in terms of frequency band because it comes in parallel with a very high impedance. To avoid the resulting low cut off frequency, the Bootstrap technique creates a feedback loop aimed at canceling the voltage accross the photodiode, thus leading the photodiode to act ideally as a pure current source. The key component to do so is an ideal amplifier having high input impedance and a voltage gain of 1. A simple common drain FET.will be the best approximation for such an ideal device.

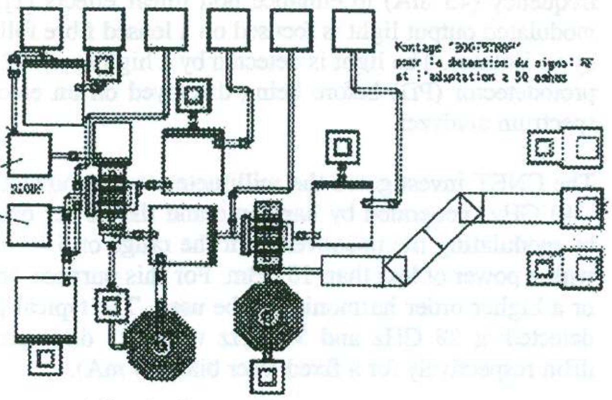

Fig. 3 : Layout of the Bootstrap SPA

A test configuration, allowing measurement between 50 Ω ports, has shown that the calculated performances fit the measurement results.

Preliminary experiments associating the SPA chip with a fast photodiode have been carried out at Lille (IEMN). The first results confirm the simulated performances described below.

GLOBAL LINK PERFORMANCES

Figure 5 shows simulated curves comparing the overall performances of a link (Fig 4) comprising a laser diode, a fiber and a photodiode (as modeled by the CNAM laboratory) in five configurations :

1. The diodes are connected directly to the 50 Ω ports : the performances show very high values for (S11) and (S22), making this configuration impossible for a practical use.
2. Two resistors are used to match the diodes : it is a classical way of use, leading to very high losses.
3. The 45 Ω series resistor is replace by the DTA, showing about 20 dB improvement.
4. The 50 Ω parallel resistor is replace by the SPA, showing about 10 dB improvement.
5. The final proposed configurations that combines the advantage of the DTA and the STA.

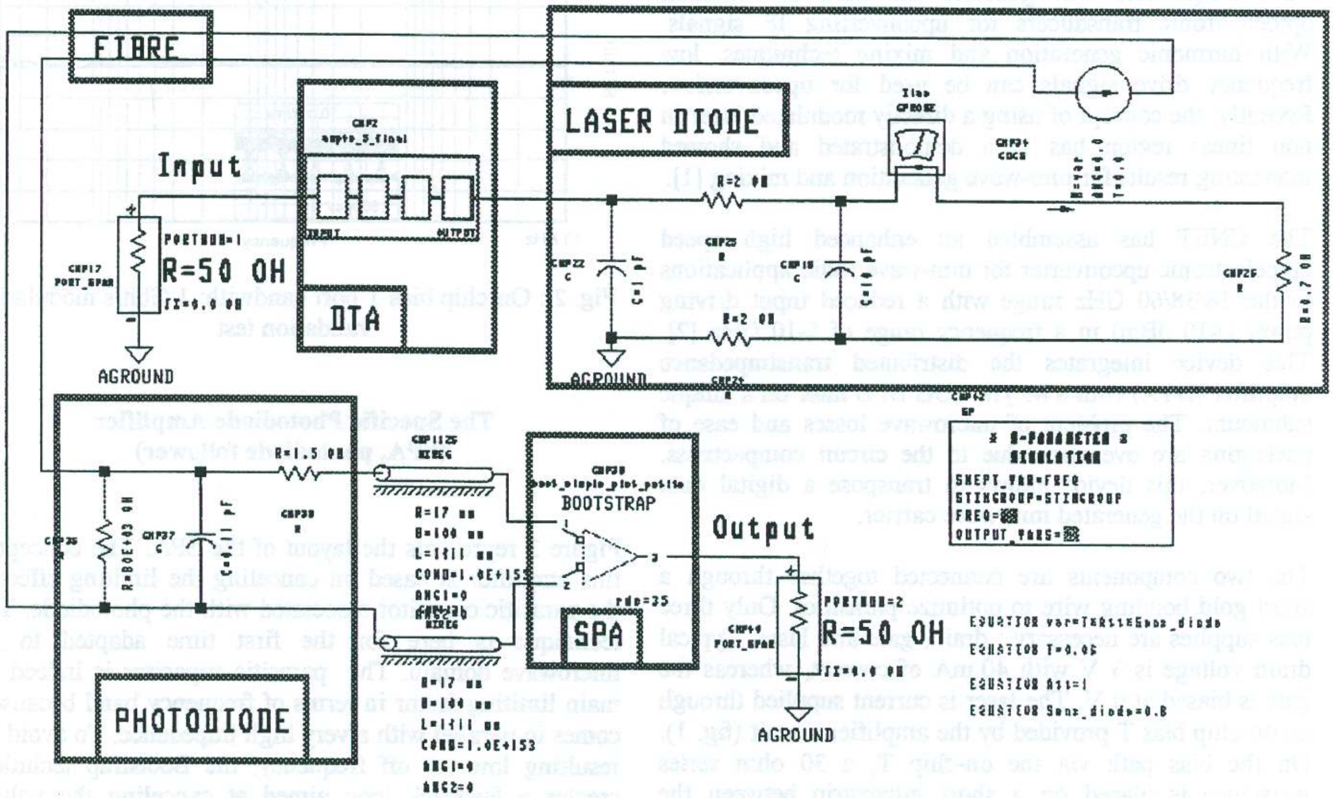

Fig. 4 : Optical link equivalent circuit

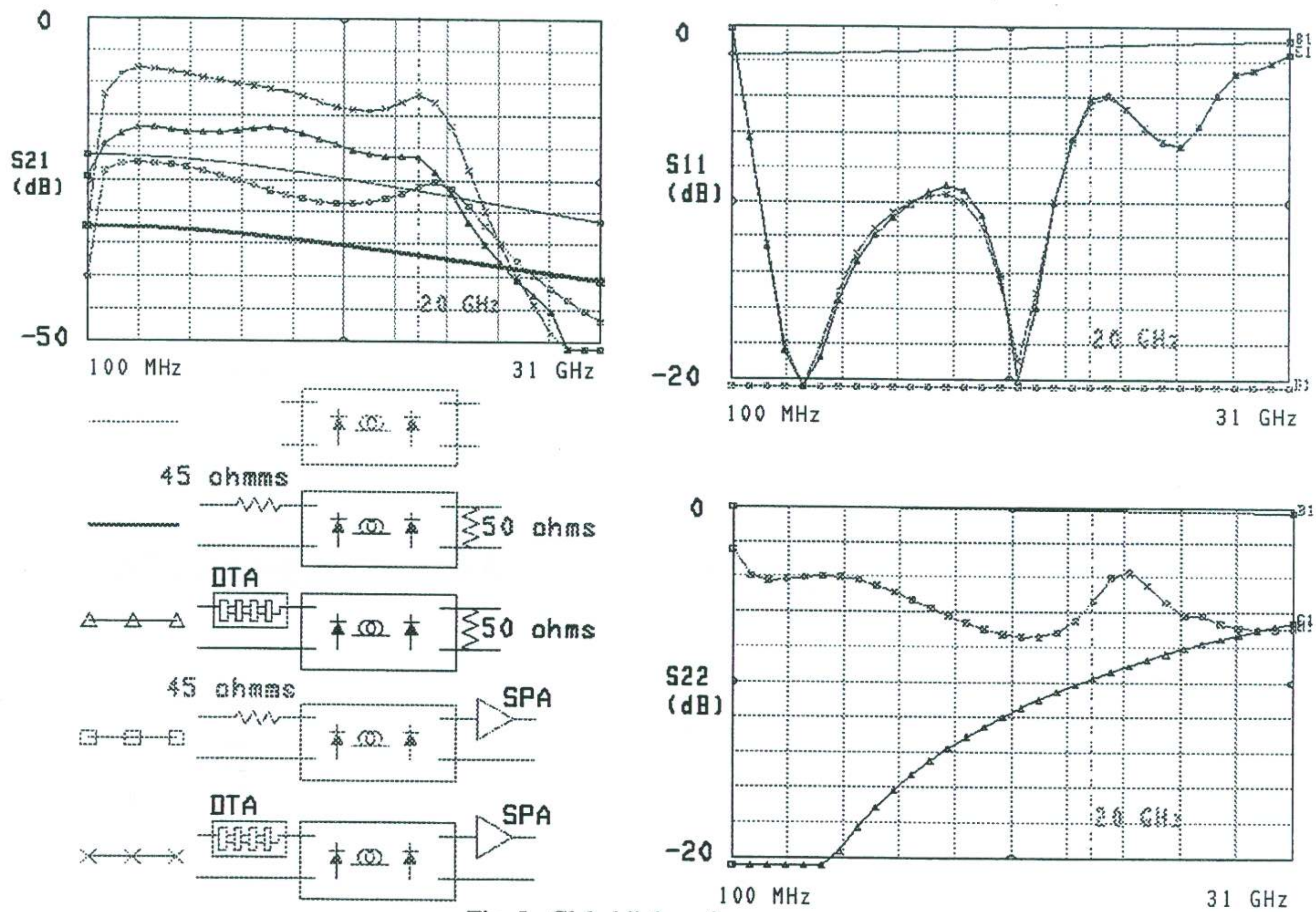

Fig. 5 : Global link performances

CONCLUSION

These very promising devices are key components for Digital and Analog Optical Links. The efficiency improvement, mainly regarding analog applications, will allow to obtain better noise figure and dynamic and will persuade users to prefer this mean of microwave transportation for a lot of applications.

Two chips have been designed and fabricated: one distributed amplifier having 10 ohms as output impedance and one Bootstrap amplifier that reduces the limiting effect of the photodiode parasitic capacitance while matching the link output to 50 ohms. These chips have demonstrated their ability to improve the global link performances by more than 25 dB gain over a 1 to 18 GHz bandwidth. A further step will be to improve input/output matching, gain flatness and bandwidth toward lower and/or lower frequencies.

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