40 GHz-NARROW BAND PHOTORECEIVER FOR CLOCK RECOVERY IN 40 Gbit/s OPTICAL TRANSMISSION SYSTEMS

A. Miras, E. Legros, S. Vuye, G.Wanlin, L. Giraudet

CNET-FT, Laboratoire de Bagneux,
196, av. Henri Ravera, BP107, 92225 Bagneux Cedex, France

Abstract

Tunable microwave narrow band amplifiers have been realized on a 38-45 GHz band, for clock recovery in 40 Gbit/s optical transmission systems. These amplifiers are also useful for radio applications on the fiber, by adjusting the center frequency on the 38-42.5 GHz band allocated for communication networks in Europe. Based on a fully stabilised GaAs PHEMT 0.2 μm gate length technology, the amplifiers are designed to match the impedance of a side illuminated AlGaInAs/InP PIN photodiode at their input, and 50 Ω at their output. The center frequency is tunable by 2 GHz steps, the bandwidth is typically 3 GHz and the maximum gain is 29 dB on a 50 Ω load. A photoreceiver module has been assembled by cascading such amplifiers tuned for 39.8 GHz. The photoreceiver transimpedance is 78.5 dBΩ, and the average equivalent input noise is 37 pA/√Hz .

Introduction

Transmissions on optical fibers at bit rate as high as 40 Gbit/s are now studied. For such systems, high performances E/O and O/E interfaces are needed. The 40 Gbit/s multiplexing-demultiplexing can be performed electrically or optically (Optical Time Domain Multiplexing - OTDM). In this latter scheme, part of the optical signal at the receiver end is used for clock recovery. Since the signal is RZ (Return to Zero) coded, it contains a 39.812 GHz (SDH normalization) component in phase with the clock. This signal can be detected and amplified to synchronize a VCO in a Phase Lock Loop (PLL). The VCO delivers a 9.953 GHz signal which is then applied with appropriate reshaping and delaying on a set of four optical gates that select one of the four 10 Gbit/s pulse trains. In such a scheme, 39.8 GHz-high gain, narrow band amplifier with its input matched to the photodetector is then required. The center frequency of the amplifiers is tuned to fit the specification.

MMIC Design

The first stage of the amplifier is matched to a fast photodiode of 60 fF capacitance. The input line and stub lengths have been chosen to get low noise at the gain peak frequency. The circuit contains six stages. MIM capacitors and microstrip lines are used for the matching stages [1]. The output impedance of the chip is 50 Ω. The schematic of the amplifier is given on figure 1.

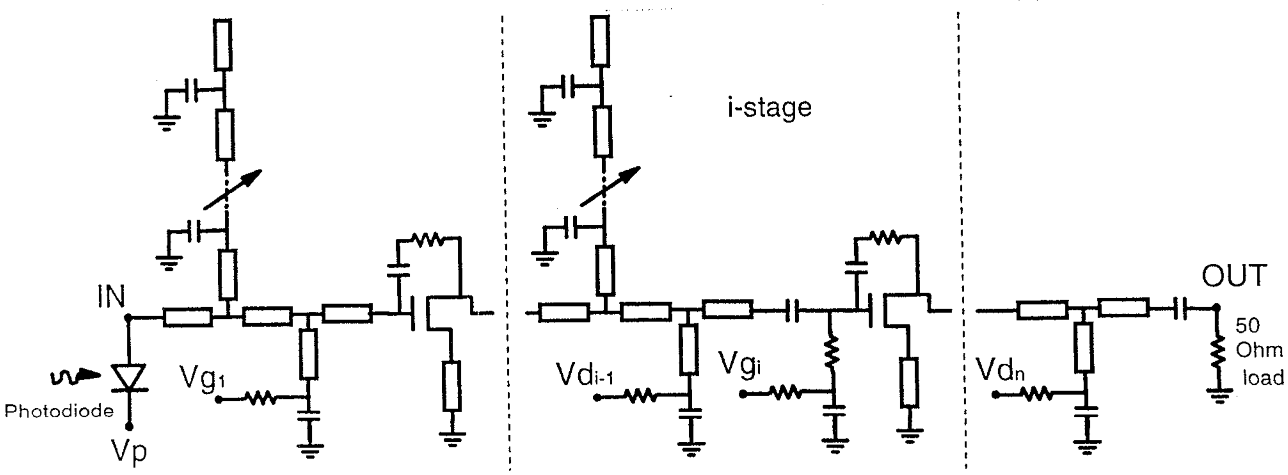


Fig. 1 : Schematic of the amplifier.

0-7803-4603-6/97/$5.00 (c) IEEE

In order to improve the gain, to reduce the noise and to obtain the filtering function required for clock recovery, the amplifier is matched on a narrow frequency band. When this band is small compared to the center frequency, the difficulty is to get the center frequency exactly at the designed value. A tuning concept has been tested, in order to obtain it accurately with one foundry run.

The center frequency is tuned by adjusting the length of an open stub for each stage. The tuning consists in removing air bridges to adjust the required length. The smaller the capacitance of the stub line is, the more sensible the tuning is. To increase the tuning step up to 2 GHz, we should need to choose a very large or long open stub line. But we prefer to add very small MIM capacitors (several femtofarads) placed between the air bridges, which also allows to reduce the size of the open stub.

Except for the first stage, at the input of each transistor, a matching tee junction becomes useless, and is simply replaced by a high value resistance. A negative drain-gate feedback on the PHEMT allows to improve the gain on a larger tuning frequency range, and to reduce the size of the chip by reducing the length of the stabilizing lines between the PHEMT sources and the via-holes.

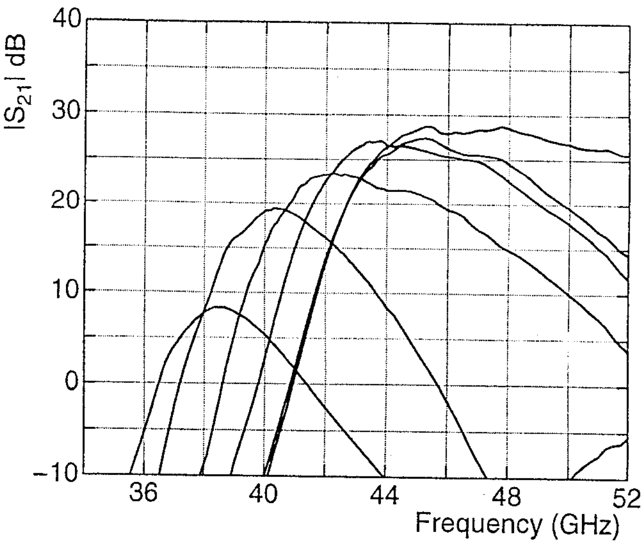
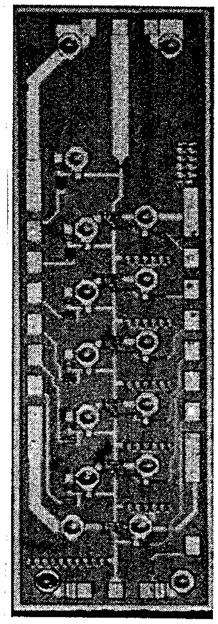


Fig. 2 : Measured gain for different tunings.

Device Characteristics

We used the Pseudomorphic HEMT process developed at Philips Microwave Limeil (D02AH process with 0.2 µm gate length). The Ft of the transistor is 55 GHz.

In order to achieve high speed and high responsivity [2], a side illuminated PIN photodiode has been developed. The structure is grown by MBE on semi-insulated InP substrate and includes an undoped GaInAs absorption layer sandwiched between two AlGaInAs optical confinement layers, n and p type doped, provided to improve the coupling efficiency with the optical fiber. Contact layers are also used for lower series resistances. The fabrication process uses contact lithography and lift-off techniques. Air bridges are used to reduce parasitics. The photodiode responsivity is as high as 0.8 A/W at 1.55 µm (with a 3 µm diameter spot from a lensed fiber), and the intrinsic cut-off frequency is above 40 GHz on 50 Ω.



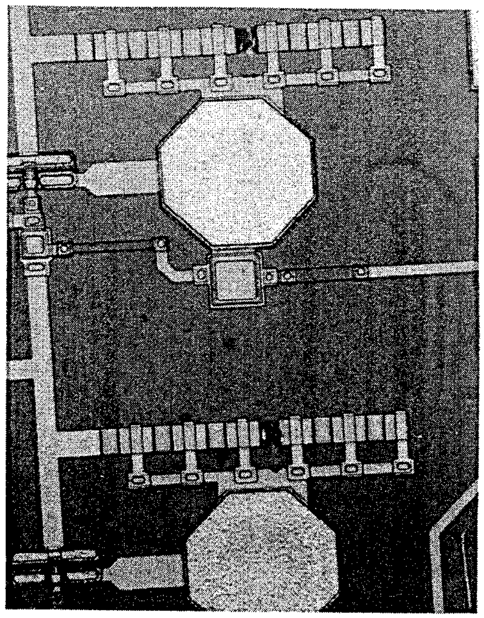


Fig. 3 : Chip photograph. **Fig. 4 : Detail of removed air bridges.**

MMIC Performances

The MMIC chip size is 1 x 3 mm^2, with GaAs PHEMT gate width of 60 µm. Consumption of the circuit is 144 mW. We measured the amplifiers for different tunings. We obtained narrow band amplifiers which are centered on selected frequencies, as shown on figure 2.

The photograph of the chip is presented on figure 3. A detail of an open stub with the air bridges is shown on figure 4. Air bridges are easily removed without damage.

Chips are first optically selected. Then frequency tuning is achieved by removing the air bridges with excellent repeatability. Figure 5 presents the gain measured for eleven circuits resulting from two different wafers, and tuned to get a maximum gain near 40 GHz. For the different circuits of a same wafer, the center frequency and the maximum gain are very close.

0-7803-4603-6/97/$5.00 (c) IEEE

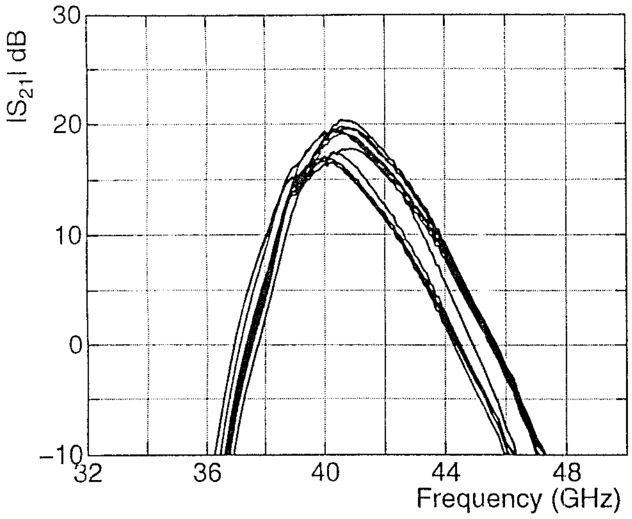


Fig. 5 : Gain of different circuits.

An original and useful aspect of this solution is the possibility to determine the suitable length of the tunable open stub on a demonstrator-circuit, and then to produce accurate narrow band amplifiers with the same design except the removed air bridge (only the interconnection mask has to be rebuilt before production).

For comparison with the tunable circuits shown above, we present a circuit with the same schematic and topology but without the tuning stubs (fig. 6). The gain is 29 dB and the bandwidth is 41-47 GHz. It shows that tuning stubs are better than varicap diodes because of their much lower series resistance which causes no additional attenuation in the tuning circuit.

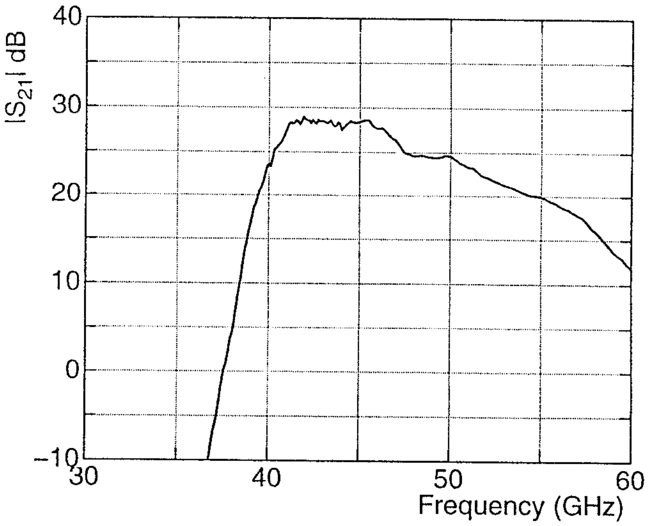


Fig. 6 : Gain of the non-tunable amplifier.

Module Performances

The photoreceiver includes the amplifier circuits and the fast AlGaInAs/InP PIN photodiode, assembled on an

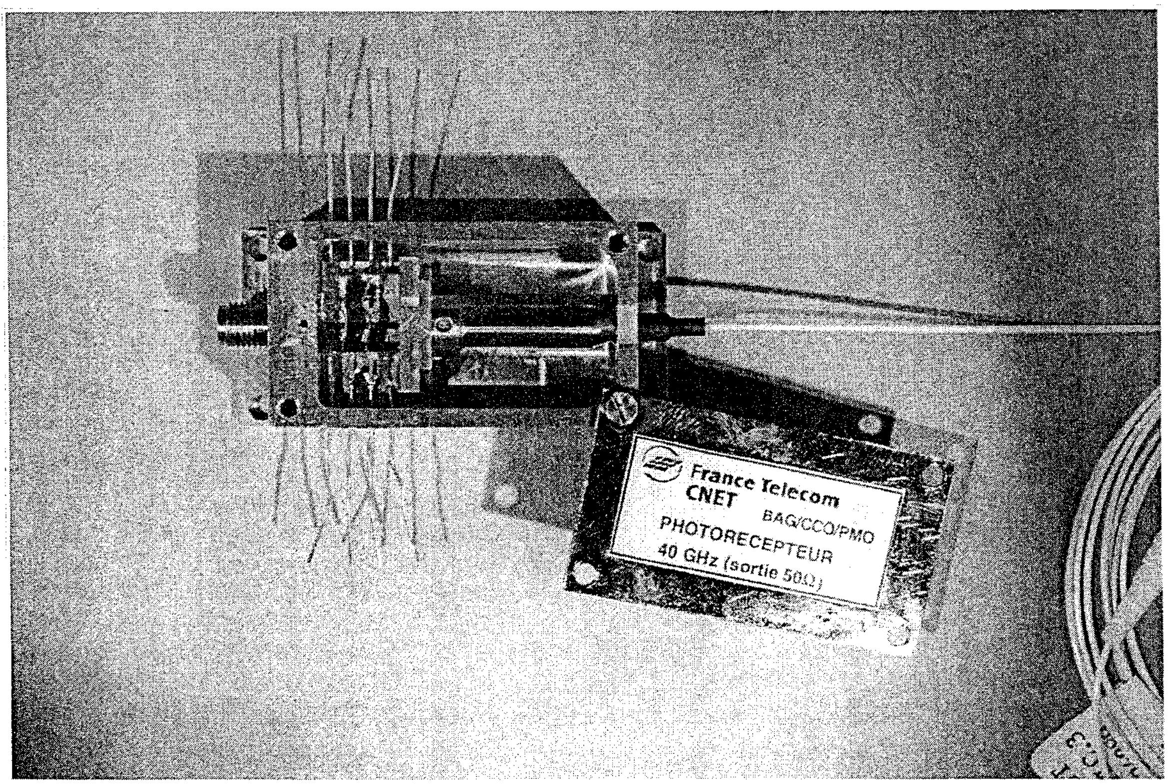


Fig. 7 : Photograph of the photoreceiver.

alumina substrate. As the minimum gain of a circuit is typically 17 dB, two or three chips are necessary to get the required gain [3]. The 50 Ω-S_{11} parameter is low enough at 40 GHz to also use the circuit on a 50 Ω input impedance. RC bias network is efficient enough to connect together the six drains (respectively gates) output biases on a basic dc decoupling circuit on the alumina. So each chip only needs two biases for drain and gate.

The fiber pigtailed photoreceiver (pigtailing performed at CNET-Lannion FCI/CAI) is presented on figure 7. The three amplifier chips were first mounted in a simple, single cavity package. But an oscillation at the frequency of the maximum gain appeared beyond 59 dBΩ, which required to limit the gain of the amplifiers by reducing the drain bias voltage. Introducing dividing walls to separate the chips removes the oscillation. With a good isolation between the chips, we obtain 78.5 dBΩ, without any oscillation. A new package has been designed in order to easily insert dividing walls between the chips.

The photoreceiver transimpedance is 78.5 dBΩ with a 0.8 A/W photodiode responsivity. As a comparison, the photodiode gives 30 dBΩ on a 50 Ω load, without any matching elements. The average equivalent input noise is as low as 37 pA/√Hz at 39.8 GHz (fig. 8). The measured electrical output spectrum for a 39.8 GHz input optical signal is shown figure 9.

The photoreceiver high transimpedance value allows to easily fit the system specification. We present the photoreceiver output power (-1.5 dBm), corresponding to a 40 Gbit/s RZ optical input signal as low as -12 dBm_{opt}. As the specification for the Phase Lock Loop input power range is -10/+5 dBm, the dynamic range of the optical input power to be applied on the photoreceiver is -16.5/-9 dBm_{opt}. The photoreceiver input noise density remains lower than required even with the minimum optical input power.

Conclusion

Tunable narrow band amplifiers have been designed and tested over the 38-45 GHz frequency range. A photoreceiver was assembled using a fast photodiode with three cascaded amplifiers tuned to 39.8 GHz. The photoreceiver is characterized by an excellent sensitivity of 5.3 mV/μW, together with a low noise density (37 pA/√Hz) which makes it quite attractive for clock recovery applications, in 40 Gbit/s optical transmission systems.

Acknowledgements

We would like to thank Alain Poudoulec and Patrick Auvray from CNET FCI/CAI for pigtailing the photoreceiver.

This work is partly supported by the french ministry of education under a MESR contract, and by the ESTHER ACTS european program.

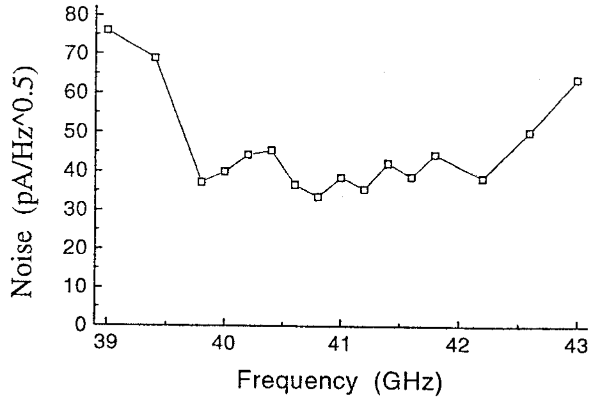


Fig. 8 : Average input noise of the photoreceiver.

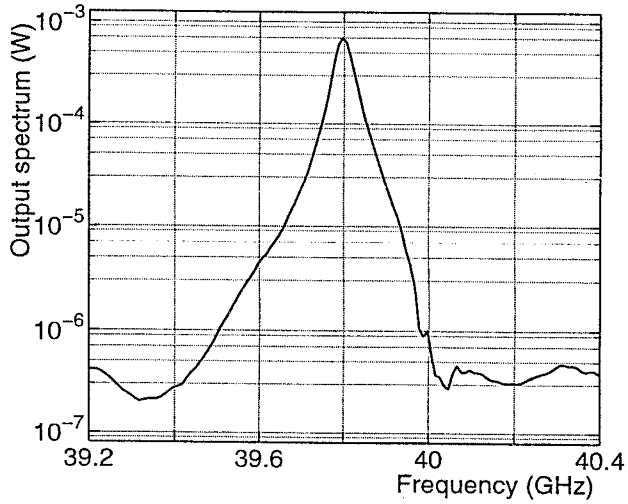


Fig. 9 : Photoreceiver electrical output spectrum.

References

[1] D. C. W. Lo, R. Lai, H. Wang, K. L. Tan, R. M. Dia, D. C. Streit, P.-H Liu, J. Velebir, B. Allen, J. Berenz, *"A High-Performance Monolithic Q-Band InP-Based HEMT Low-Noise Amplifier"*, IEEE Microwave and Guided Wave Letters, vol. 3, No. 9, pp. 299-301, Septembre 1993.

[2] K.Kato, A.Kozen, Y.Muramoto, Y.Itaya, T.Nagatsuma, M.Yaita, *"110-GHz, 50%-Efficiency Mushroom-Mesa Waveguide p-i-n Photodiode for a 1.55-μm Wavelength"*, IEEE Photonics Technology Letters, vol. 6, No. 6, p719, 1994.

[3] K. Maruhashi, M. Funabashi, T. Inoue, M. Madihian, M. Kuzuhara, *"A 60 GHz-band low noise HJFET amplifier module for wireless lan application"*, IEEE MTT-S Digest, pp 13-16, 1996.