Multiproject Array of GaAs MMIC Front-end Amplifiers for Detection in Accelerator Physics.

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Abstract

The present paper describes an array of GaAs monolithic front-end amplifiers, to be used in a large number of applications in present and future high-energy physics experimental apparatus. A transimpedance amplifier of 66 dBohm gain for optical data transmission between 0.3 and 1.2 Gbit/s have been realized. Two types of front-end voltage amplifiers for amplification of gas detector discharge pulses are presented too. Fast rise times (less than 200 ps) with 30 dB voltage gain, to amplify the weak charge pulses from gas detectors, have been reached.

Introduction

For the scopes of G.A.M.E. (Gallium Arsenide Microelectronics Effort) project, in collaboration with I.N.F.N. (National Institute of Nuclear Physics) an array of GaAs monolithic front-end amplifiers has been realized. In particular the project is correlated to the LHC (Large Hadron Collider) experimental apparatus at the CERN of Ginevra.
Present and future experiments in the field of high-energy physics are requiring a new generation of electronic front-ends. In fact, an increasing flux of ionizing particles which pass through the detectors, and, in general, a larger flux of data to be processed will require larger bandwidths in electronic devices. As a consequence front-end electronics should guarantee a gain-bandwidth product as high as possible. Moreover this electronics should exhibit low sensitivity to radiations. These requirements are today not fully satisfied with traditional silicon technology, in terms of reception and transmission speed, gain performance and radiation immunity.
The GaAs monolithic microwave technology can provide adequate solutions to these problems, even if the originality of the new applications does not allow the designer to reuse well known methods tested in different fields. The new applications require the development of original solutions for topologies and materials of microelectronic systems.

Modelling of the foundry GaAs devices

Before the project phase, an accurate linear and non linear modelling of the Alenia Foundry GaAs low-noise and power MESFETs up to 20 GHz has been performed. A bias and size dependent linear model as equivalent small-signal circuit of low-noise MESFETs was accomplished. This allowed safe design of complex circuits in which several active devices are connected. Passive devices such as planar capacitors and spiral inductors were accurately tested and modelled too. All measurements were performed directly on wafer.

The optical front-end amplifiers

The optical fibers offer clear advantages for data transmission respect to electrical cables such as lower attenuation, large distance-bandwidth product, combined with an intrinsic electromagnetic coupling immunity, low weight, size and cost.
In large experimental apparatus of high energy physics the use of optical fibers is of basic importance for the very large number of data channels used (millions), and the very high data rate (Terabits/s).
The application of fibers in complex experimental apparatus is generally based on a large number of links, each transmitting at a speed between 0.3 Gbit/s and 1.2 Gbit/s over a distance up to 1 km. For this kind of application, quite different from standard telecommunications, a new transmission system, based on a new transceiver chip [9], has been realized by the INFN. It is a monolithic integrated transceiver module in GaAs full-custom VLSI technology of 0.6 μm, characterized by 32 bit parallel word fully asynchronous transmission, 0.5 to 1 Gbit/s tunable frequency range, 100 Mbyte/s data rate, Manchester decodification, fully digital clock recovery, 32 parallel input-output. We need to place a front-end amplifier with 300-1000 MHz bandwidth and 60 dBohm transimpedance gain before the transceiver module. This equipment is provided for timing and high speed data transmission in the next LHC experiment of the CERN. Data stream should

be 100 Gbit/sec (1000 optical link at 1 Gbit/sec).

The front-end amplifiers are composed by two transimpedance stages, separated by monolithic decoupling capacitors, and a buffer stage; each gain stage has parallel feedback and common-source or cascode configuration [4][5][7]; both topologies should be characterized by very little sensitivity to parameter spreading caused by radiations impinging on GaAs. Finally, equivalent input noise current should be lower than 10 pA/√Hz, even if noise specification was not given.

The front-end amplifiers for gas detectors

Another kind of front-end amplifier suited to amplify the output signal of the RPC gas detectors (resistive plate chamber with Freon) in the LHC experimental apparatus has been realized. Discharges occur in the gas when it is crossed by ionizing particles; however current limitation in the high resistive electrodes cause the use of traditional detectors with very high fluxes of ionizing particles was limited by the maximum rate, currently of about 100 Hz/cm^2. The basic idea indeed to improve the rate capability is that a substantial part of the large amplification, more than 10^8, occurring in the gas in the standard RPC operation, can be transferred to the front-end electronics, which is thus required to have a much larger amplification than the existing one, and at least the same bandwidth to avoid any loss in timing performance [8]. The output signal of a gas detector is a weak voltage pulse having an amplitude of about 100 μV and a pulse width of 300 psec. This requires a rise time around 200 psec at least.

The front-end amplifiers were designed as four cascaded stages [6], each one having a cascode topology [1][2][3], and a buffer stage; input impedance is high while output is matched to a 50 ohm load overall the bandwidth; it should perform high voltage gain with low power dissipation and small size, assuring the required rise time, that is almost equivalent to a 2 GHz bandwidth. In spite of the monolithic decoupling capacitors, low frequency operation should be guaranteed down to 10 MHz. An additional cell is suited to increase the fall time of the amplified impulse.

Fabrication

The circuits were fabricated using ALENIA's low noise ion-implantation based GaAs MMIC processing technology. The active layer has a sheet resistance of approximately 280 Ω/sq and a thickness of 0.2 μm. The process includes 0.5 μm Al Schottky gates, Si_3N_4 overlay capacitors and ion implantated resistors. The wafer thickness is 120 μm with via-holes. GaAs MESFETs have 0.5x100 and 0.5x200 gate periphery, an Idss of 200mA/mm^2, and cutoff frequency of 20 GHz. The microphotographs of the two chips are presented in Fig.4 and Fig.8.

Results and experiments

On-wafer measurements of s-parameters, power dissipation, and DC bias sensitivity, by mean of a cascade station, have been performed. However on chip measurements, including RF shunt capacitors on bias pins, in order to evaluate the right frequency performance of devices, have not made yet.

In Fig.1-3 the simulated and two measurement results of the transimpedance amplifier are shown. But for s_{22}, all experimental parameters show very good matching with simulated ones, thanks to the available accurate modelling of foundry devices and good performance of its technological laboratory. A transimpedance gain of 64 dBohm was evaluated from s-parameters (G_{tr}=50*s_{21}/(1-s_{11})) over a bandwidth from 300 MHz to 2 GHz. In fact 1 GHz specification for bandwidth must be satisfied with an input PIN diode shunt capacitance of 1 pF. The s_{22} disagreement from simulated one (Fig.2 boxed points) is due to the bad filtering performance of dc bias probe for measurements on wafer, as demonstrated including into the simulation the parasitics introduced by the dc probes (Fig.2 continuous line). However, a reflection coefficent less than -10 dB is assured anyway. Power dissipation does not overrate 400 mW.

A second set of measurements was performed on the voltage pulse amplifiers and the results are plotted in Fig.5-7. S_{22} shows good output matching. S_{11} is that of a high impedance input stage. A voltage gain of 30 dB is demonstrated and -3 dB bandwidth is over 2 GHz, that means a rise time less than 200 psec. Finally a power dissipation of about 500 mW has been measured.

Conclusion

GaAs technology is now maturing quite rapidly and so, coupled with advancement in circuit techniques, the development of a family of monolithic front-end amplifiers specially suited for high energy physics experimental apparatus has been possible. Amplifier designs with settling times approaching 200 ps are successfully achieved together with low cutoff frequency under 10 MHz, in spite of monolithic decoupling techniques; s_{21} of almost 30 dB has been demonstrated. A transimpedance amplifier for a new on fiber data transmission technique has been realized. These results constitute an encouraging step towards the development of GaAs fully integrated systems in future experiments in the field of high energy physics.

Acknowledgments

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Transimpedance amplifier

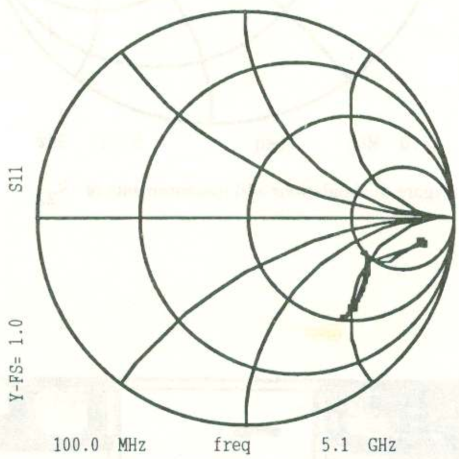

Figure 1: simulation and measurements of S_{11}

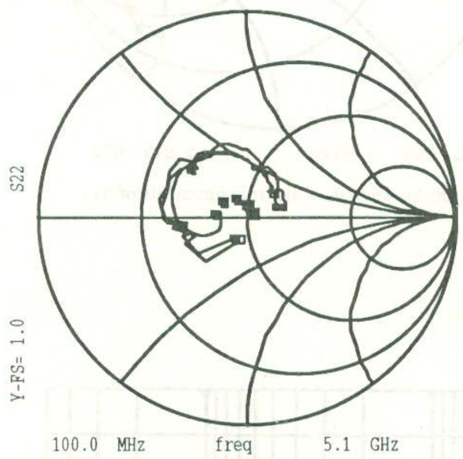

Figure 2: simulations and measurements of S_{22}

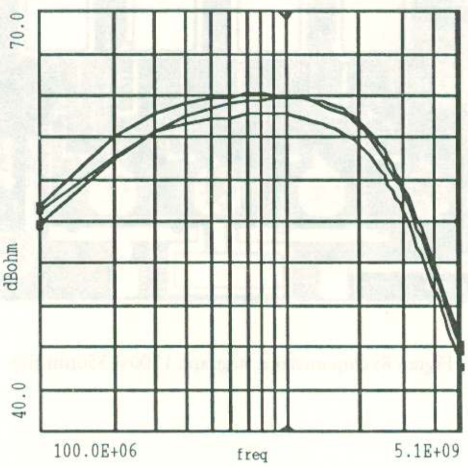

Figure 3: simulation and measurements of transimpedance gain

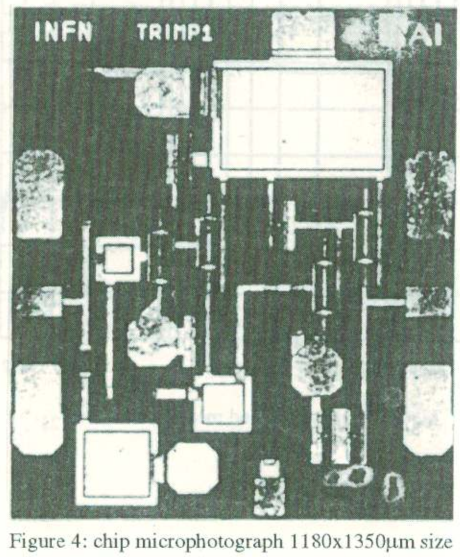

Figure 4: chip microphotograph 1180x1350μm size

Pulse amplifier

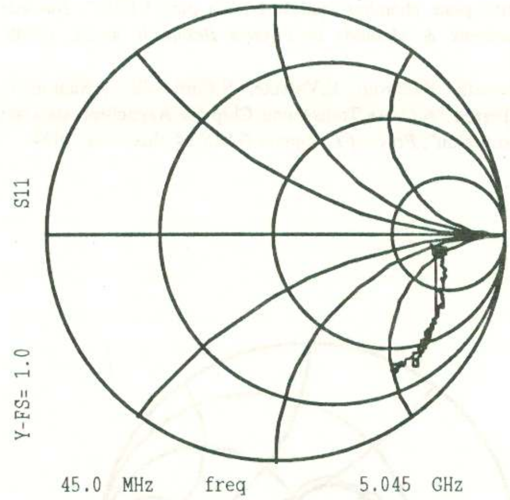

Figure 5: simulation and measurements of S_{11}

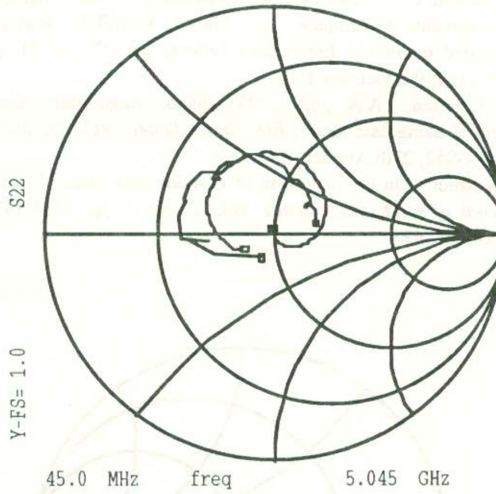

Figure 6: simulations and measurements of S_{22}

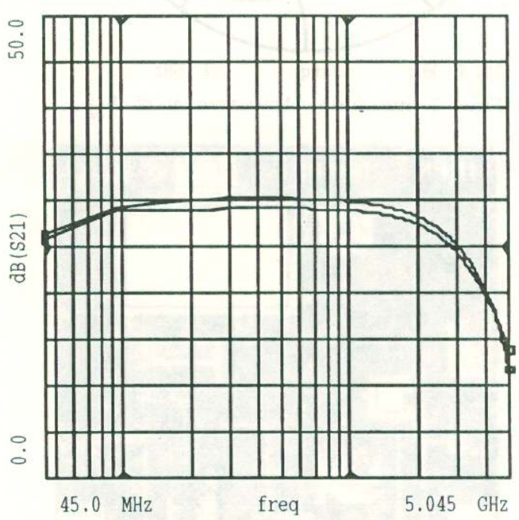

Figure 7: simulation and measurements of S_{21}

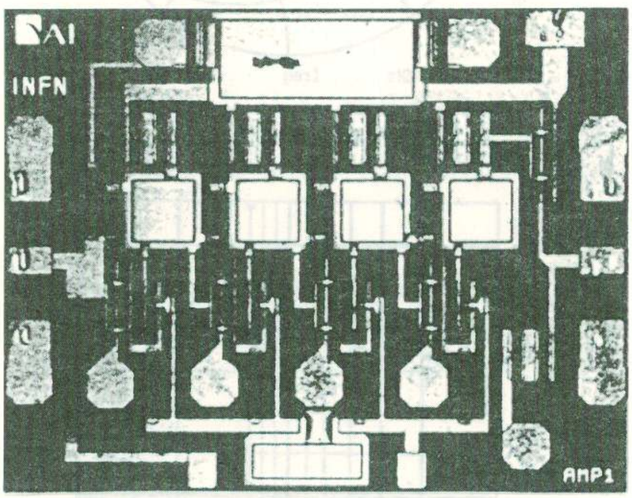

Figure 8: chip microphotograph 1700x1350μm size