AN 8-CHANNELS GAAS IC FRONT-END DISCRIMINATOR FOR RPC PARTICLE DETECTORS

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ABSTRACT

A front-end discriminator for application in readout electronics of gas chamber particle detectors, composed of a high-gain pulse amplifier integrated with a threshold comparator and an ECL logic buffer, has been designed. An 8-channels full custom chip has been fabricated in GaAs IC technology. The chip turns out very stable, featuring high voltage gain (>1000), gain-bandwidth product (10^{11}) and sensitivity (~50μV), fast rise time (1.5ns), and only 25mW per channel of power consumption, while providing the ECL dynamic to the output pulses.

INTRODUCTION

In the future experiments in the field of high energy physics, such as the planned experiments of the Large Hadron Collider (LHC) in Geneva, the detecting apparatus will require a low power, high gain-bandwidth product front-end electronics, easy to serialize, possibly in a custom version, to keep the cost of a large number of channels very low. Moreover, this electronics should exhibit low sensitivity to radiation. Circuit topologies should be therefore characterized by very little sensitivity to parameter spreading caused by radiations impinging on the semiconductor material.

Beyond the fact that a monolithic approach is necessary to guarantee high yield and repeatibility in a large scale production, these requirements are today not fully satisfied with traditional silicon technology, both in terms of reception and transmission speed, gain performance and radiation immunity. The frequencies of operation are not higher than a few Gigahertz, because settling times less than one hundred of picosecond are not required. Nevertheless, the large number of transistors necessary to accomplish high gains in the Gigahertz range is already asking for components with a 20 GHz cutoff frequency, such as the GaAs MESFET with 0.5μm of gate length [1,2].

GaAs devices have three distinct advantages over Si devices: speed, power and radiation hardness. The speed advantage has determined the large acceptance of GaAs as a material to implement analog integrated circuits operating from the microwave up to the millimeter wave region. In this frequency range, in fact, III-V materials have weak competitors among the available semiconductors. Due to the existence of traditional counterparts (Si), the GaAs position in the field of Very High Speed Digital Integrated Circuits is not equally consolidated. Finally, the radiation hardness properties of GaAs devices becomes fundamental in applications characterized by the presence of ionized particles, such as high energy physics and X-ray diagnosis equipment.

The more challenging task is to use GaAs technology in order to realize, at the same time, complex circuit topologies, analog-digital block integration, multiport and multichannel integration and VLSI systems, typical in silicon technology.

FRONT-END DESIGN OUTLINES

A resistive plate chamber (RPC) detector operating in avalanche mode produces typically a single signal of 5ns FWHM (Full Width Half Maximum) and 1.5ns time jitter, while the pick-up propagation time is 15ns in a 25 Ω impedance environment [3]. The front-end discriminator accepts detector pulses from a pick-up strip, terminated on its characteristic impedance in the opposite side, and for each input pulse that is large enough to trigger it, delivers a standardized logic pulse, related as closely as possible in time to the leading-edge threshold crossing of the input signal. These output pulses should be of standard amplitude and duration, completely independent of all characteristics of the input signal except time of occurrence.

A front-end discriminator is composed of an input amplifier, a comparator with an adjustable threshold, and an output logic buffer. The input sensitivity is equal to the threshold of the comparator, which is typically 30-50 mV divided by the amplifier voltage gain. The threshold, however, may vary with temperature, input signal rise time, and input signal duration. In current integrated discriminators used in particle detectors readout, temperature and rise time dependence of the threshold are negligible, and width dependence, through present, is noticeable only with signal less than 5 ns in duration. For these input signals, which are shorter than the typical pulses produced by a RPC detector, the measured threshold will be higher than nominal [5,6].

The input stage of the front-end is a voltage amplifier; the good time performance of the RPC detectors, utilized for the bunch crossing identification, imposes the amplifier rise time of the order of the RPC jitter time, because the large fluctuation in signal amplitude of the detector (100μV to 0.5 V) generates a jitter time at the threshold crossing of the order of the pulse rise time [6].

The amplifier frequency response is optimized for typical time structure of the avalanche signal according to the following conditions: 1) same risetime for the amplifier and input signals, which is nearly 1.5 ns; 2) minimum return-to-zero time for the output signal. The resulting amplifier frequency response has a maximum around 100 MHz and a bandwidth shaped as reported in Fig.1. The amplifier time response to an avalanche-like input pulse is bipolar shaped, as shown in Fig.2, giving zero integrated charge thus avoiding a possible dependence of steady ouput voltage on the counting rate [5,6].

The high input impedance R_I of the amplifier should be matched to the low impedance R_S of the pick-up strip. Teaming the amplifier with a simple transformer input coupling yields a further voltage amplification factor $n(R_S+R_I)/(n^2R_S+R_I)$, which reaches the maximum for $n^2=R_I/R_S$, if n is the turns ratio of the transformer. Moreover it has been demonstrated that an input transformer coupling can reduce the amplifier's noise figure when the equivalent input noise voltage is much greater than the noise voltage generated by the input noise current through the source impedance [7]. Coaxial air-coupled spiral inductances seem to be a suitable choice, since ferrite materials cannot be used in the high intensity magnetic fields of the high energy physics experimental apparatuses. Conversely lossless LC impedance matching network with the same amplifier bandwidth have high complexity.

The comparator cascaded to the amplifying section generates a standard positive or negative squared pulse from a bipolar shaped one, with less than 2 ns rise and fall time. The threshold value can be adjusted to give adequate immunity respect to the noise. The minimum comparator threshold combined with the amplifier gain fixes the minimum detectable signal amplitude. The extra gain provided by the input transformer results in an increased sensitivity of the discriminator, until the noise voltage level is below the threshold.

CIRCUIT IMPLEMENTATION

A two-channel full custom prototype chip of the front-end circuit has been already realized in GaAs technology [5] (die size 1x1.25 mm^2). This chip was a preliminary step before the 8-channel release, whose schematic and monolithic layout are reported in Fig.3 and Fig.4 respectively (die size 1.5x2.3 mm^2). The MESFET process employed is the Triquint-GIGA D1SS type with 0.6 μm of gate lenght. 20GHz cutoff frequency MESFETs have been chosen for their intrinsic high gain-bandwidth product. Moreover, the GaAs MESFET features the minimum serial-parallel noise at the given frequency band, which is above the 1/f corner [8].

The amplifier is composed of three ac coupled gain stages. The comparator is ac coupled to the amplifying section and composed of three stages connected in differential mode. It outputs a positive or negative squared pulse from a bipolar one, with 500 ps rise and fall time. The threshold value can be regulated to give adequate immunity respect to the noise. The minimum comparator threshold combined with the amplifier gain fixes the minimum detectable signal amplitude at 100 μV. An ECL output buffer is capable of driving a few metre long 100 Ω flat cable connecting the front-end to the local trigger logic.

The circuit turned out to be very robust versus both temperature, power supply and processing variations. Cross talk between channels and oscillations could easily be the result of parasitic couplings between circuit elements as well as package and bonding wires [9]. Stage supplies are separated inside the monolithic area, and strongly filtered on the board before connection. Two channels can be supplied independently, to evaluate cross-talk between two, six or eight channels. The chip was mounted on an 8-channels full-custom test board; skilled solutions have been adopted for the channel and ground layout: channel and ground lines are alternated to strongly filter the cross-talk between adjacent channels, while digital ground is connected only to the output line to avoid the feedback propagation of spurious spikes induced by output rise/fall transitions.

EXPERIMENTAL RESULTS

All measurements have been performed with a TEK_TDS684B digital oscilloscope. A summary of channel characterization is presented. A preliminary measurement of the front-end sensitivity is reported in Fig.5, where an input pulse of 200μV amplitude has been discriminated, with a 1:3 transformer turns ratio. The threshold has been set at a minimum value of 200mV, because the RF noise level was rather high in the measurement setup environment. The overall voltage gain is approximately 1500, although better results can be achieved with higher turns ratios.

The comparator has been also characterised and the results are plotted in Fig.6, where the discriminator frequency performance is shown; the bandwidth is 100MHz, resulting a gain-bandwidth product GBWP>10^{11}. Pulse rise and fall time are also reported. The output jitter time for a variation of input pulse width and amplitude can be seen in Figg.7-8 respectively. The autoshaping capability of the circuit has been demonstrated. The maximum skew time between channels on the test board can be seen in Fig.9; as it can be seen, the channel paths are well equalised. The absence of cross-talk interference between adjacent board channels is shown in Fig.10. Finally, the measured power consumption per channel is 25mW.

CONCLUSIONS

The reported results demonstrated the effectiveness of the approach and the success of the particular effort devoted to the establishment of a design and testing capability in the field of front-end electronics applied to elementary-particle physics.

Moreover, the feasibility of the GaAs monolithic integrated solution as an effective way to solve some of the many problems arising from the readout electronics of multichannel particle detectors, was also demonstrated.

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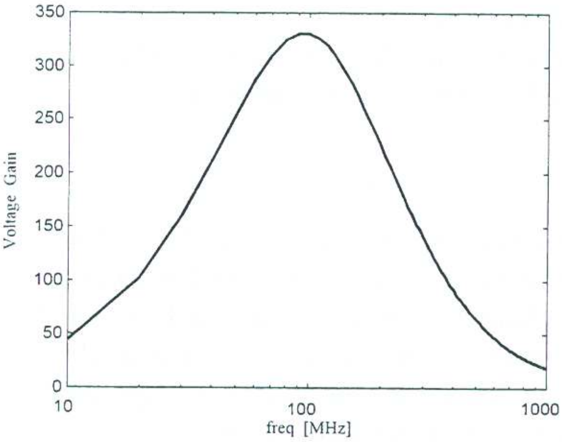

Fig.1. Preamplifier voltage gain vs frequency

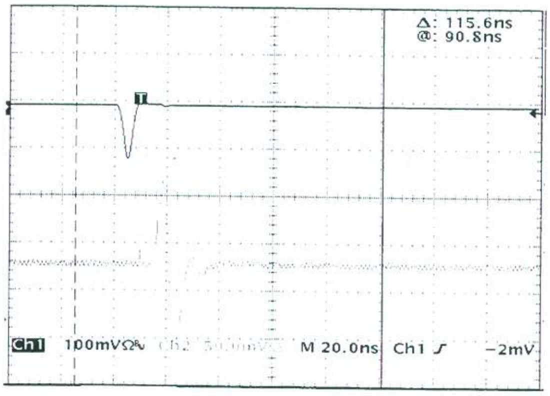

Fig.2. Amplifier response to a triangular-shaped input signal

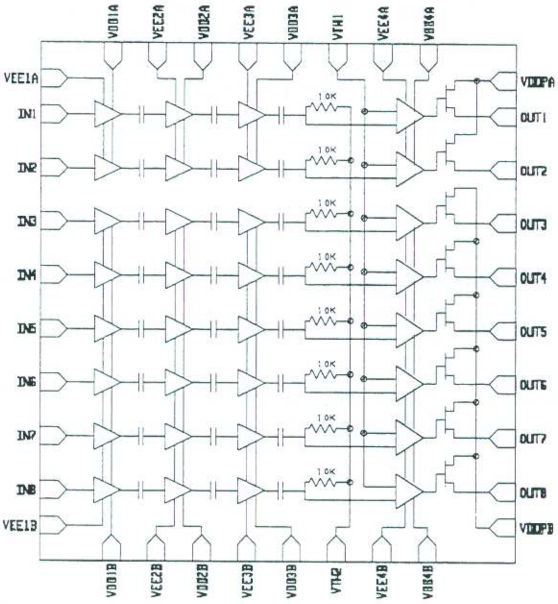

Fig.3. Schematic layout of the 8-channel

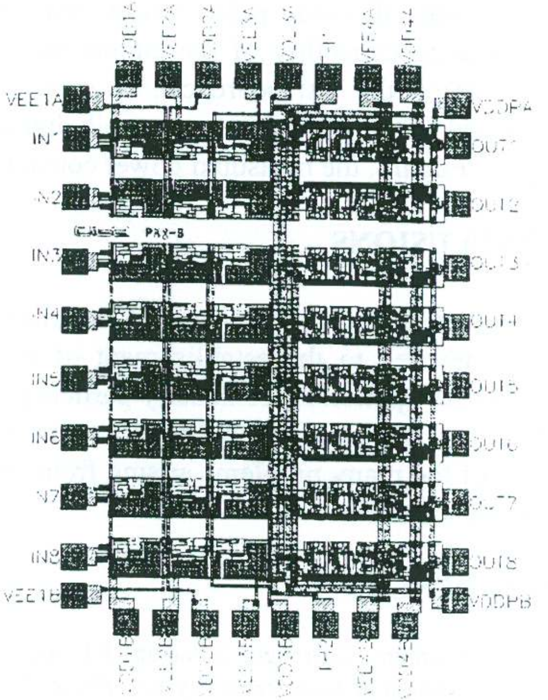

Fig.4. Monolithic layout of the GaAs IC 8-channel front-end (die size 1.5x2.3mm^2).

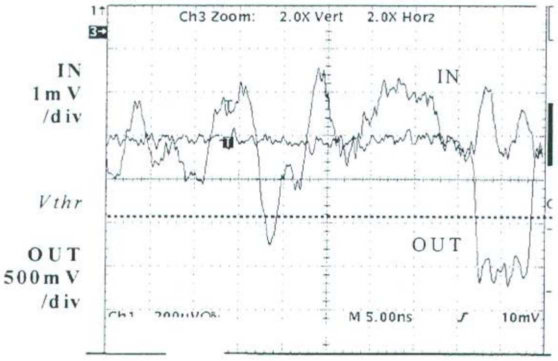

Fig.5. Sensitivity (200µV). The voltage gain is 1500 (transformer turns ratio 1:3).

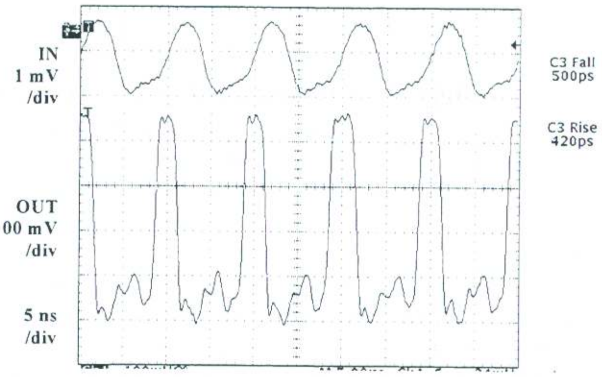

Fig.6. Frequency performance (100 MHz).

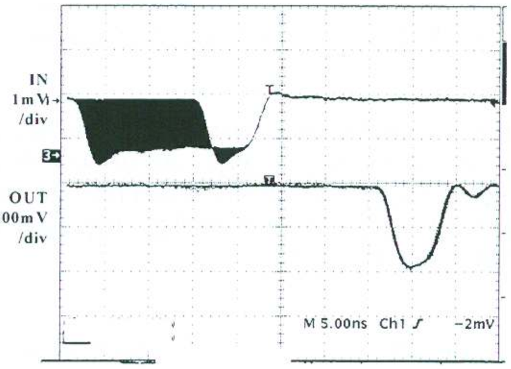

Fig.7. Output pulse shaping for input pulse variation in width (6-20ns)

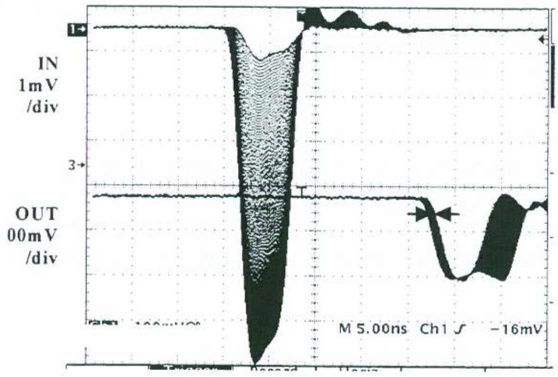

Fig.8. Output jitter time (on the fall) *vs* input pulse amplitude (0.5-7 mV).

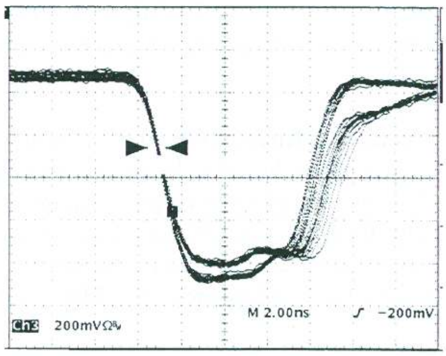

Fig.9. Maximum skew (on the fall) between channels.

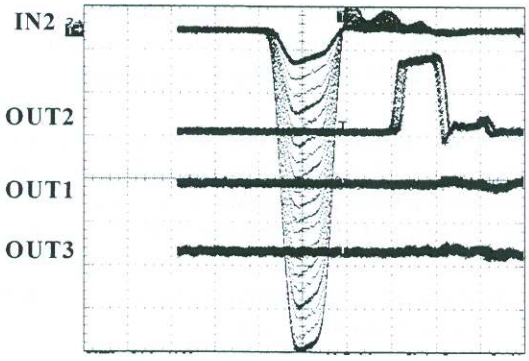

Fig.10. Cross-talk between adjacent channels; input: 1mV/div, output: 500mV/div; time: 5ns/div.