LOW POWER BiCMOS CHARGE AMPLIFIER WITH CURRENT CONVEYOR FEEDBACKS

G.Bertuccio, M.Chisari, L.Fasoli, P.Gallina and M.Sampietro,
Politecnico di Milano, Dipartimento di Elettronica, P.za L.da Vinci 32, 20133 Milano, Italy
(email: bertucci@elet.polimi.it and sampietr@elet.polimi.it)

Abstract

Based on a minimum noise approach, a low-power preamplifier and shaper circuit fulfilling LHC requirements is presented. The circuit, integrated in BiCMOS technology and intended to cope with a diamond microstrip detector of about 5 pF capacitance, uses a bipolar transistor input stage to obtain a noise level of about 650 electrons r.m.s. with a peaking time of the output signal of 20 ns. The circuit is powered with single supply at 1.6 V with a total power consumption of 310 μW/ch. The DC feedback and reset of the preamplifier and the shaper architecture are performed by current conveyors that minimize power dissipation because of a current re-use design.

1. INTRODUCTION

In this paper we present original circuit solutions for preamplifying and shaping, demonstrated by experimental results obtained from test chips manufactured by AMS in BiCMOS technology. The presented front-end has the following characteristics:

- single power supply
- low bias voltage operation at 1.6 V
- low power consumption of 0.3 mW/ch
- peaking time of 20 ns
- fast return to zero of about 60 ns
- immunity to variation of detector leakage current

Although the circuit design is flexible and can easily be adapted to various detectors and experimental conditions, we have designed it for a 5 pF detector capacitance, as it is the case in microstrip diamond detectors.

2. THE PREAMPLIFIER

2.1 *Current conveyor feedback*

A schematic of the charge preamplifier section is shown in Fig. 1. It is made of a cascode input stage, an active load and an emitter follower. The feedback path for the signal is provided by the feedback capacitance C_f. The collector current of the follower, proportional to the output voltage through the resistance R, is reduced by a factor γ (in our realisation γ=50) and mirrored to the input node by a MOSFET stage (M5, M6). This novel configuration provides an equivalent feedback resistance of $R_f = R\,\gamma$ so to give a fixed time constant discharge of the feedback capacitance [1, 2]. This configuration also provides the DC base current to the input BJT and a feedback stabilisation of the circuit working point. Thanks to the 100% re-use of the current from the output follower, already available in the circuit, this current conveyor feedback is intrinsically a zero-power added solution. The power consumed by the preamplifier is therefore mainly due to the input BJT collector current, which is rigorously set by noise and bandwidth considerations [3]. In our case, the choice of a peaking time of 20 ns has given an optimum collector current of 90 μA.

The presented current conveyor feedback is based on the same principle already employed in other amplifiers [4] [5], but in our case with an evident much more compact and simple design, with the conveyor practically integrated in the preamplifier circuit itself.

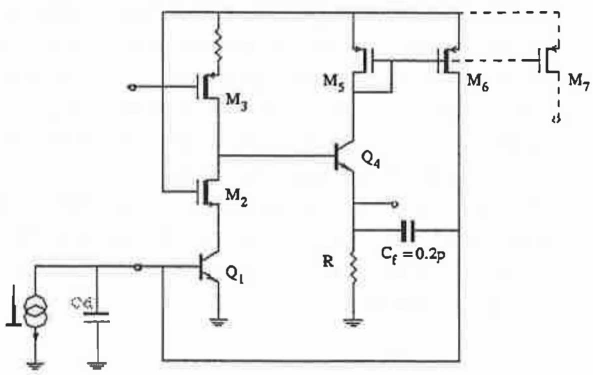

Figure 1 - Schematic of the charge amplifier. The current conveyour feedback is performed by the transistors M5 and M6. The output to the following stage is the current in M7.

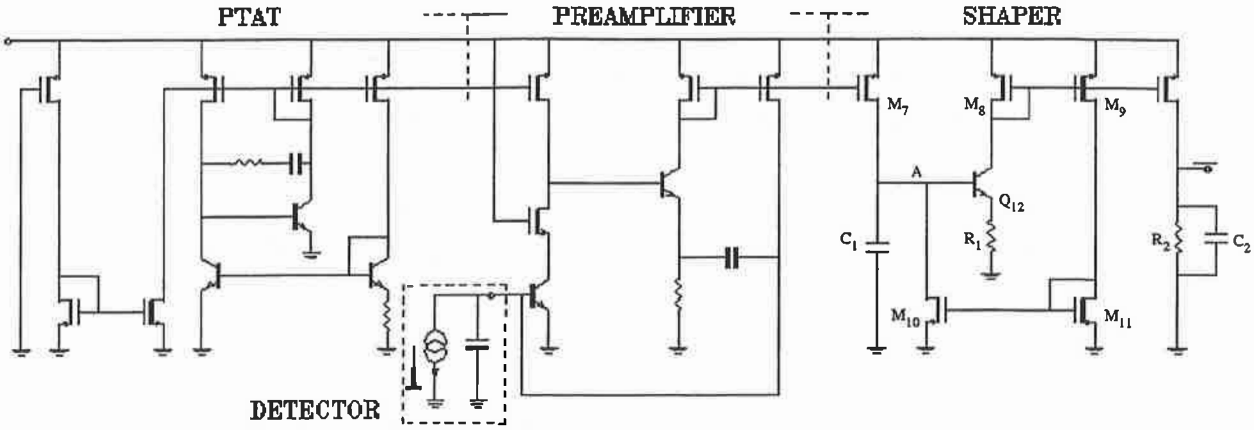

Figure 2 - Circuit schematic of the charge preamplifier, of the shaper and of the PTAT.

2.2 Cold feedback resistance

The noise of the resistance R, of relatively low value (R=1 kΩ in our realisation) and therefore easy to be obtained in integrated technology, is dumped by a factor γ^2 in its spectral power density and is therefore lower by a factor γ with respect to the noise of a feedback resistor of value $R_f = R\gamma$ In addition, the noise added by the MOSFET connected to the input node can be made very small with respect to the shot noise of the base current of the input BJT by properly choosing its W/L factor. In our realisation, this active feedback have a current noise equivalent to a 350 kΩ resistor by occupying the area of only a 1 kΩ resistor plus two MOSFET's.

2.3 First shaping stage within the preamplifier

The key point of having an active feedback resistance, with a much lower noise than a resistor of equal value, is that the feedback capacitance discharge time constant can be chosen to directly produce one of the poles for the pulse shaping. This eliminates the need of a pole-zero cancellation circuit in the following stages of the shaper, with advantages in term of simplicity and stability of the entire amplifying circuit.

Finally, note that the output signal is made available to the following stages as a current signal at M7, with advantages in terms of reducing the noise contribution of the following stages.

3. THE SHAPER

3.1 Active resistor pole

In addition to the first shaping pole already included in the preamplifier, a second pole is obtained by the stage indicated in Fig. 2. This stage is a current amplifier with a bandwidth defined by a pole made with an active resistor. The current pulse, made available from the preamplifier through M7, is integrated on the capacitor C1. The capacitance is connected to a feedback structure (M8-M11) whose effect is to present at the input node *A* a resistance equivalent to $(1/g_{mBJT}+R_1)\cdot\alpha$, where α is the multiplication factor of the two current mirror stages M8-M9 and M10-M11. In our case R_1=2 kΩ, C_1=0.3 pF and α =10 in order to give a time constant of $\tau \cong 10$ ns. This solution allows for the setting of the desired time constant with a minimum area occupation. In our case, for example, the proposed solution should be compared with a resistor of about 30 kΩ.

3.2 Current amplification architecture

The use of MOSFET's only in current mirror configurations makes the circuit almost insensitive to variations of their threshold voltage, therefore stabilising DC bias, gain and time constant. The mirror architecture makes also available the output signal as a current pulse to drive the following stage. This can be either another shaping stage equal to the previous one (if one wants to introduce one more pole to the overall transfer function, in order to obtain a more simmetrical output pulse) or a final current comparator to detect signal overcoming a given threshold. A current comparator adapted to our circuit and with variable threshold has been designed and is presently under fabrication.

4. EXPERIMENTAL RESULTS

The preamplifier and shaper have been produced in 0.8 μm BiCMOS technology at AMS [6]. Figure 3 shows the experimental voltage pulse at the output of the shaper loaded with R_2=30 kΩ and C_2=0.3 pF. The figure refers to an input charge of 25000 electrons. The pulse has a peaking time of 20 ns and a fast return to zero within about 60 ns, in agreement with the design of the 3

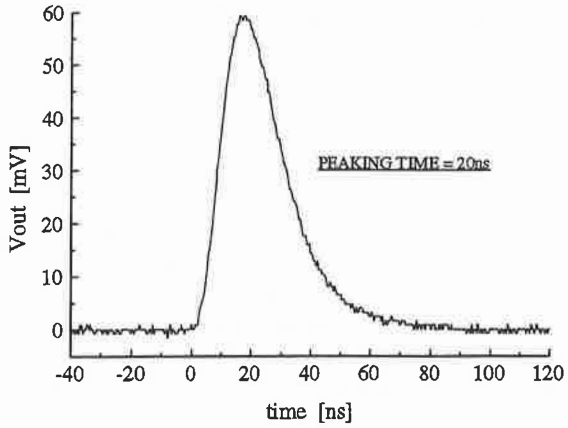

Figure 4 - Experimental voltage pulse at the output of the shaper for increasing number of e

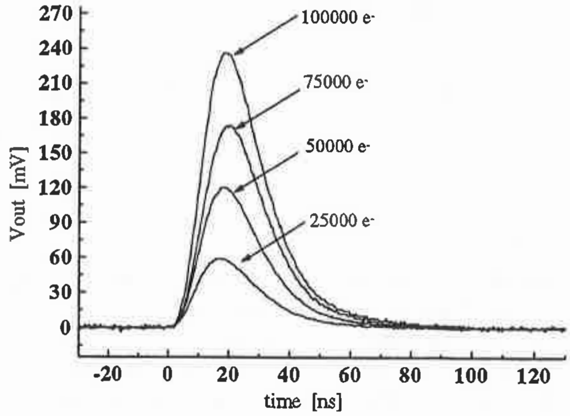

Figure 4 - Experimental voltage pulse at the output of the shaper for increasing number of electrons injected to the input of the circuit.

poles circuit. The pulse is strictly unipolar thanks to the DC coupling of the circuit stages. The dissipated power of a single channel is 310 µW.

Figure 4 reports the output pulses for increasing values of the input charge, showing a output swing of at least 240 mV. This value is imposed by the limited voltage excursion of the gain node of the preamplifier due to the low value (only 1.6 V) of voltage supply. This voltage is the only one required to power the whole circuit. The current source in the preamplifier is obtained using a PTAT (Proportional to Absolute Temperature) circuit, also shown in Fig.2, which can bias a large number of channels, with a negligible power consumption per channel of less than 10 µW/ch..

The chip is under test for noise measurements. The expected value of Equivalent Noise Charge is about 650 electrons r.m.s. with 5 pF input capacitance.

5. ADDITIONAL REMARKS

The presented circuit is almost insensitive to detector leakage current variations since these are summed to the base current of the bipolar input transistor (about 1 µA): a detector leakage current variation from 0 nA to 100 nA would produce an output level shift of only 10%.

Although not directly addressed in our first prototype, the circuit has good potentialities in term of radiation tolerance. This is not only due to its compactness and limited number of transistor used, but also to the choice, whenever possible, of p-MOSFET's, that are more insensitive to radiation in term of both DC characteristics and noise. The n-MOSFET in the preamplifier can be easily replaced by a npn-BJT, with the only drawback of requiring an additional reference voltage for its base; concerning the n-MOSFET's in the shaper, they can be made radiation tolerant by choosing enclosed designs and guard structures [7].

6. ACKNOWLEDGEMENTS

This work has been supported by italian INFN (Istituto Nazionale di Fisica Nucleare) and CNR (Consiglio Nazionale delle Ricerche).

7. REFERENCES

[1] M.Sampietro, G.Bertuccio and L.Fasoli "Current Mirror Reset for Low-power BiCMOS Charge Amplifiers", Proc. of the 8th European Symp. on Semic. Detectors, Elmau, Germany, June 1998

[2] M.Sampietro and G.Bertuccio "Zero-power current conveyor for DC stabilisation and system reset for fast current pulse amplifiers", Electronics letters, 19 (1998), p. 1801.

[3] G. Bertuccio, L. Fasoli, M. Sampietro, "Design criteria of low-power low-noise charge amplifier in VLSI bipolar technology", IEEE Trans. Nucl., vol. 44, no.5, (1997), pp.1708-1718

[4] J.C.Santiard and F.Faccio, "Noise and speed characteristics of test transistors and charge amplifiers designed using a submicron CMOS technology", Nucl. Instr. and Meth. A380 (1996) 350.

[5] R.L.Chase, A.Hrisoho and J.P.Richer, "8 channel CMOS preamplifier and shaper with adjustable peaking time and automatic pole-zero cancellation.", Nucl. Instr. and Meth. A409 (1998), p. 328

[6] Austria Mikro Systeme International AG, Unterpremstatten, Austria

[7] P.Jarron et al. "Radiation tolerant electronics for the LHC experiments", Proc. of the 4th workshop on electronics for LHC experiments, Rome, September 1998.