ISTITUTO NAZIONALE DI FISICA NUCLEARE
Sezione di Napoli

INFN/TC–01/10
2 Luglio 2001

DESIGN OF PULSE STRETCHERS FOR THE TIME OF FLIGHT DETECTOR OF THE PAMELA EXPERIMENT

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Abstract

In this note we describe the design and the performance of two possible pulse stretchers to be used in the electronics readout chain of the Time of Flight (TOF) scintillators of the PAMELA experiment.

Published by ***SIS–Pubblicazioni***
Laboratori Nazionali di Frascati

1. INTRODUCTION

The PAMELA telescope [1] will be installed on board of the Resurs-dk1 satellite, for which the launch is foreseen in 2002. The satellite will fly during at least three years with a 70 degrees orbit at about 700 km altitude. The main goals of the PAMELA experiment are the measurements of the antiproton and positron fluxes in cosmic rays, with high statistics in an energy range from 0.1 to 150 GeV, and the search for antinuclei up to 30 GeV/n. The telescope consists of a magnetic spectrometer, a TRD detector, an imaging calorimeter and a Time of Flight (TOF) system.

The electronics described here is part of the TOF readout . The information which the TOF must provide is direction, electric charge and speed of the incident particles. This requires the TOF system to have a flight-time resolution of about 100 ps and a wide dynamic range, as well as a limited power consumption.

The photomultipliers which readout the plastic scintillators of the TOF provide an anode signal proportional to the energy loss of the particles crossing the detector.

The charge integrators collect these currents and provide an output signal proportional to the total current. Consequently, the rise time of the signal at the output of the charge integrators is proportional to the duration of the current flow at the anode. The decay-time of the signal at the output of the charge integrator is related to the exponential discharge time constant of the circuit itself.

In the case of the PAMELA TOF, charge integration rise-time of 15 to 25 ns and decay-time of 300 to 500 ns are expected. The particle energy loss is measured by the peak value of the waveform at the output of the charge integrator. Furthermore, as the input dynamic range is of the order of more than two decades (a factor 300 typically), a 12 bit ADC appears to be a reasonable choice to acquire the charge signal.

Ideally, for a repetitive conversion with a fixed DC input, an ADC should produce the same output code. Adjacent codes however, do appear with reduced frequency. If a Gaussian probability distribution is drawn, the standard deviation is then equivalent to the input rms noise of the ADC. In PAMELA the charge integrators have an exponential decay. Consequently, the ADC cannot be just fed by the charge integrator. This is true even in the case that a track and hold is adopted. Stretching the peak value of the waveform at the output of the charge integrators yields better results, as the effective bit performance of the following ADC is greatly improved.

The availability of modern high-performance low-power and low-cost components such as the AD7472 (a 12 bit ADC which contains a low-noise wide-bandwidth track and hold amplifier) makes the design of the pulse stretcher easier. The settling time of the of the sampling bridge internals to AD7472 is 135 ns and represents the time requested for the internal sampling capacitor to be charged within 1 LSB of its final value. The input signal to the ADC cannot be acquired faster, and, consequently, the acquisition time is just 135 ns.

The PAMELA electronics must be capable to generate a trigger with a roughly fixed delay expected to be within 80 to 100ns from the time the particle crosses (and loses energy into) the scintillator. Therefore, one needs to precisely stretch the peak value of the waveform for not more than 200 ns the at the output of the charge amplifier. This task can be accomplished in basically two ways: by using a classical peak detector or by employing a pulse stretcher. We outline here both options.

2. A CLASSICAL PEAK DETECTOR

In the classical peak detector of Fig. 1, acquisition time and drop rate are the conflicting factors determining the choice of the capacitor value, while the characteristics of the operational amplifier are of paramount importance. The slew rate at the capacitor is (dV/dt) = (I_{out}/C), provided the amplifier could slew that fast. The voltage drop of the peak detector is (dV/dt) = (I_{leak}/C) where I_{leak} is the total leakage current.

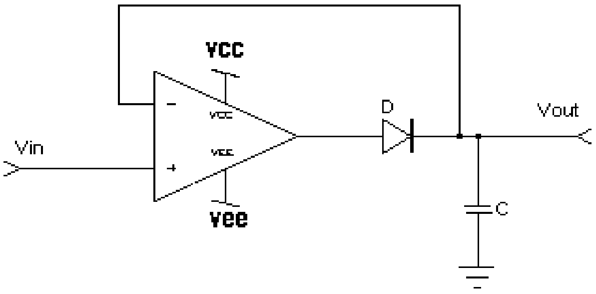

Fig. 1– A classical peak detector.

This classical peak detector has serious problems, as the input bias current of the amplifier and the leakage through the diode D causes a slow discharge (or charge) of the capacitor. Moreover, the slew rate must be adequate, if one has to deal with fast signals. Indeed, if an old fashioned LF356 with 20mA output current, 30µA bias current and 12V/µs slew rate is coupled to a capacitor C of 100pF, the theoretical slew would be (dV/dt) = (Iout/C) = 200V/µs, much faster of the amplifier slew rate. Actually, the amplifier would limit the slew rate to 12V/µs. Further, only taking into account the input bias current of the amplifier and neglecting both diode leakage and capacitor self discharge in 1µs, the voltage drop is $\Delta V = (I_{leak}/C)\Delta T = 0.3$ V. Although most of the modern AD converter have an internal a track and hold, the above drop is a too severe constraint.

Therefore, given the TOF charge integrator capable to swing of 3 V within 20 ns (Fig. 2) a more suitable approach is requested.

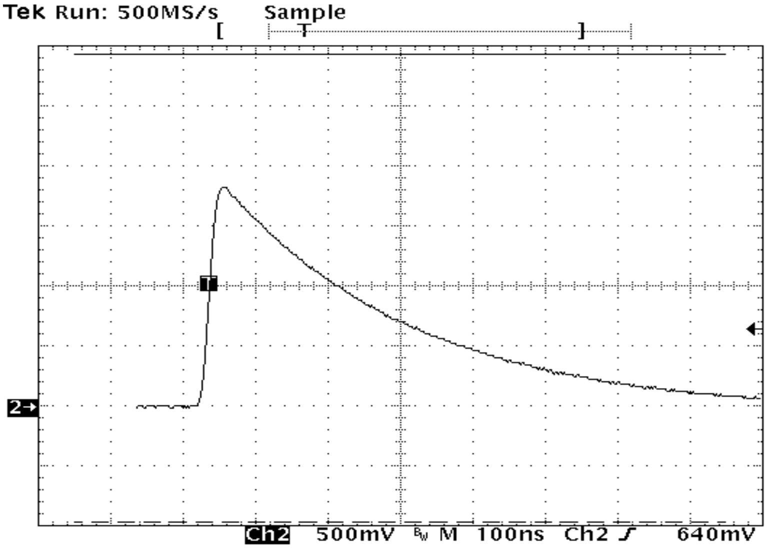

Fig. 2 –Typical charge integrator output pulse.

In Fig. 3 we depict a possible pulse stretcher configuration. A modern operational amplifier (the LM7121, 235 MHz low-power voltage feedback with slew rate of 1300V/µs) drives the holding capacitor C. Within this design the FET buffer (Q1 and Q2) decouple the capacitor from the input of the amplifier, so that it may only discharge through the diode D (which is reverse biased) and through the FET leakage currents, both of the order of 1pA. Q1 and Q2 should be a matched pair. FET Q2 acts as a constant current source. If the two source resistor are equal, the FET has an unit gain.

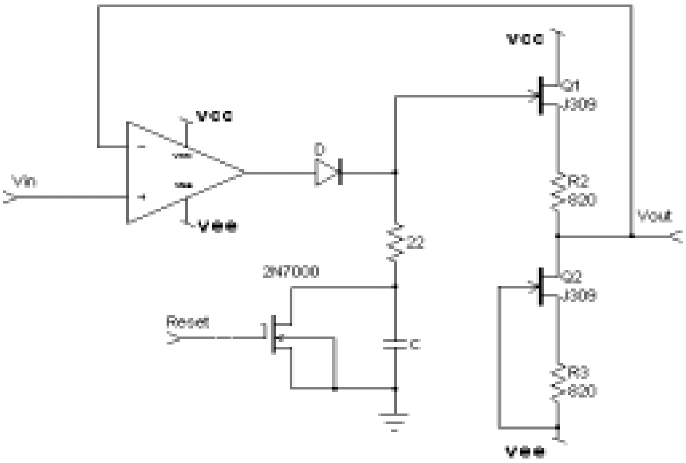

Fig. 3 – A possible pulse stretcher configuration.

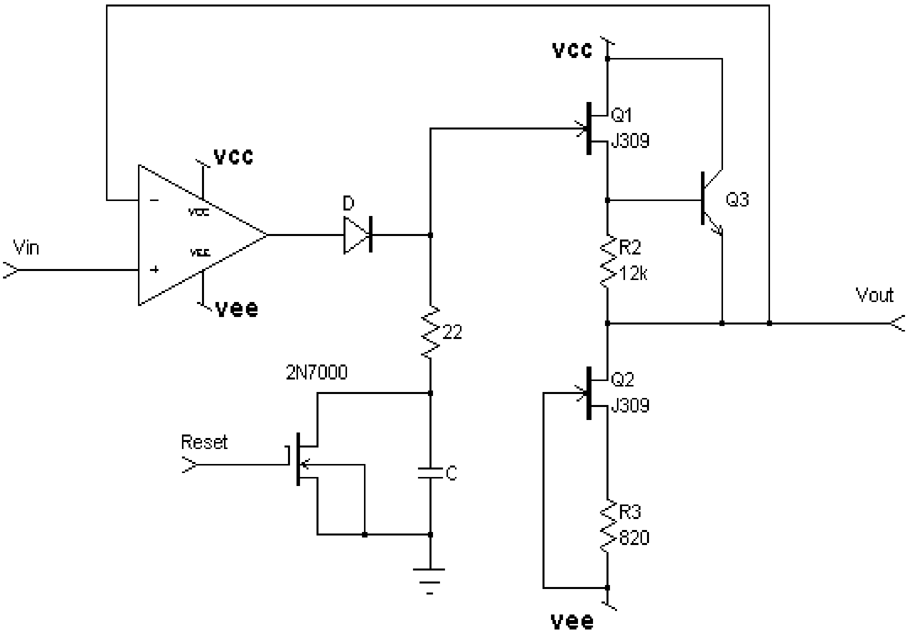

Fig. 4 – An improved circuit.

With an holding capacitor of 100 pF, assuming a leakage current of 1pA through Q1 and 1pA through the diode in 1µs, the voltage drop $\Delta V = (I/C)\Delta T = (2pA/100pF)\ 1\mu s = 0.02$ V. Therefore, in the worst possible case of a trigger generated after 200 ns, the voltage drop becomes 4 mV. For a 12 bit AD converter, whose reference input is held at 2.5 V, the LSB correspond to 0.6 mV. To stay within the LSB of the twelve bit ADC, an hold capacitor of 470 pF is needed. Furthermore, in order to improve the step response of the circuit, a transistor can be used in parallel to the JFET (as shown in Fig. 4), to drive the amplifier input with a low impedence.

The typical input and output signals are shown in Figs. 5.

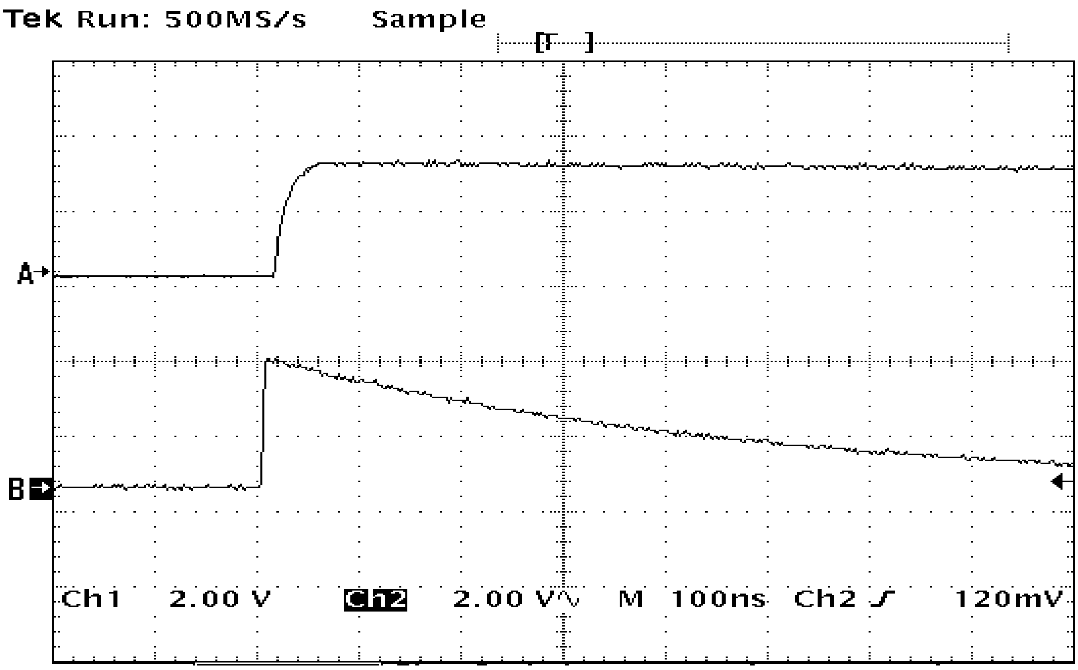

Fig. 5 – B) Input A) output.

The holding capacitor is then reset by the 2N7000. Fig. 6 shows the transfer function of the pulse stretcher presented in Fig. 4.

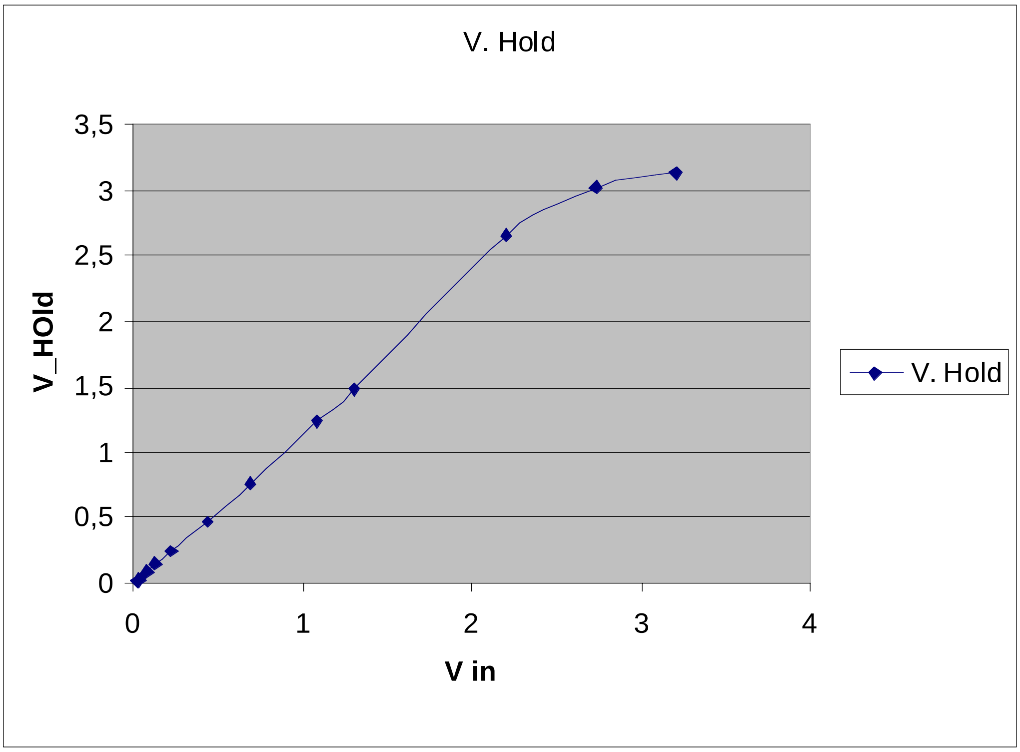

Fig. 6 – Transfer function.

3. AN ALTERNATIVE APPROACH FOR THE PULSE STRETCHER

The pulse stretcher outlined in Fig. 8 operates by charging-up the capacitor at the peak value of the input waveform and then discharges it linearly. As the trigger time delay is fixed, this circuit gives an output which is analogous to that of the classical peak detector.

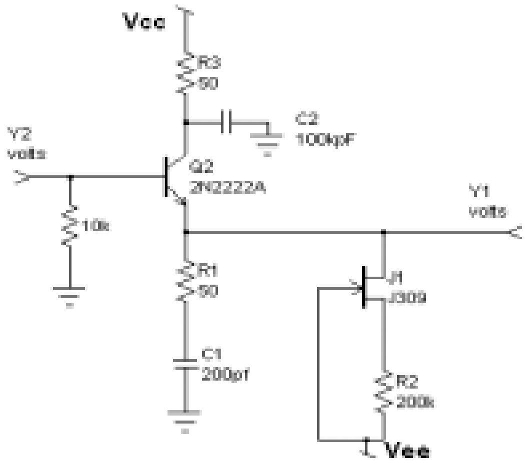

Fig. 8 – Pulse stretcher.

In Fig. 9 we show the output of the stretcher for an input waveform which simulates a typical output from a charge preamplifier stage. This configuration has the important advantage to require only 200μA.

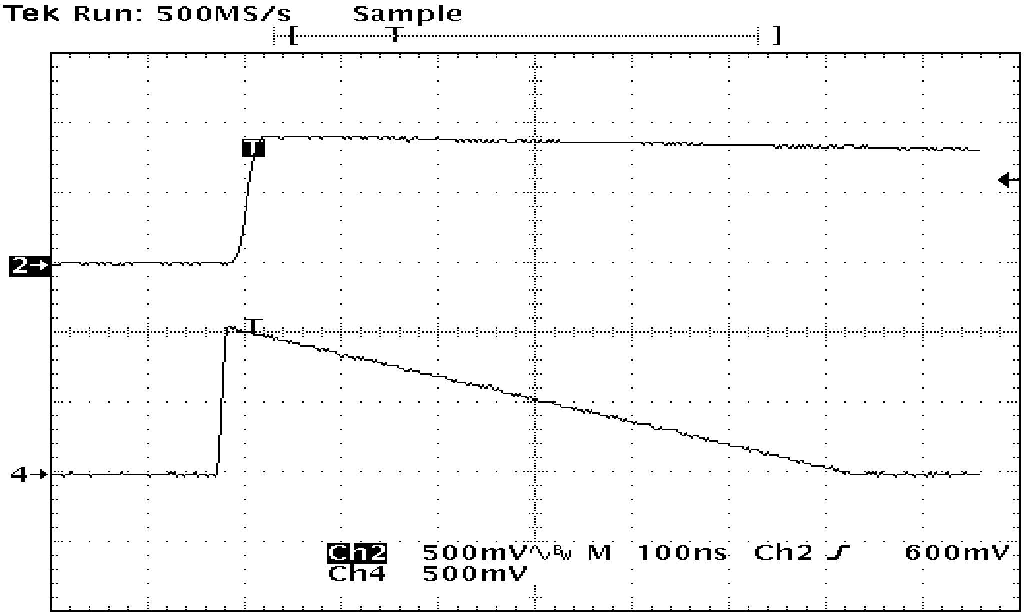

Fig. 9 – Input and output waveform.

The transfer function is depicted in Fig. 10.

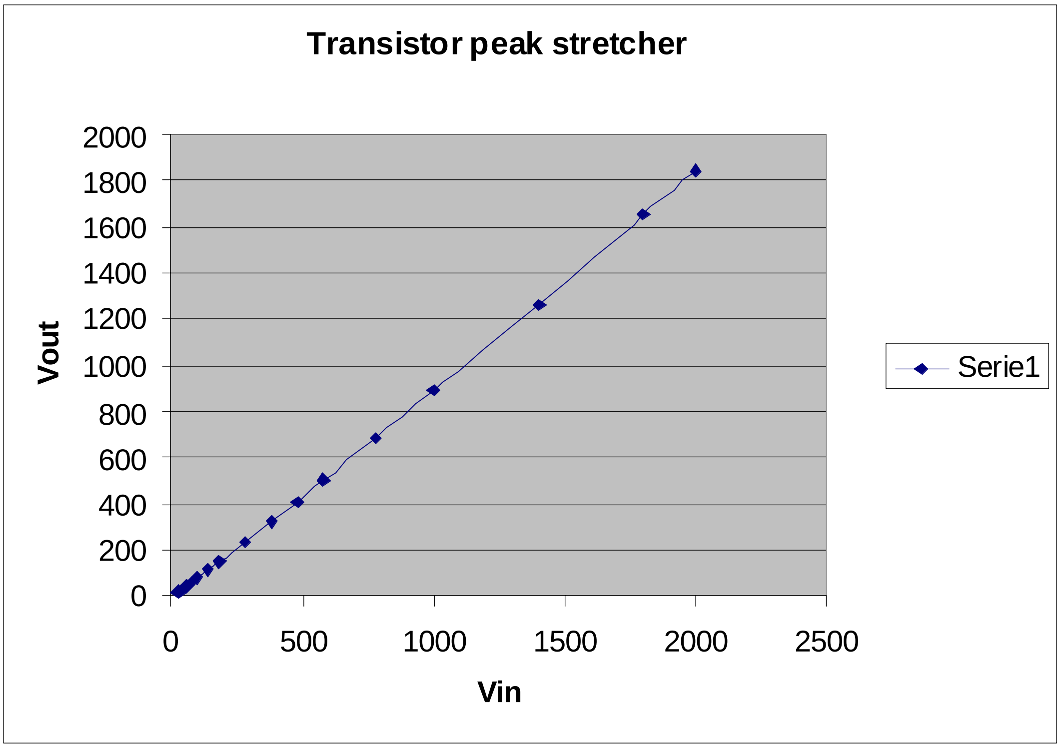

Fig. 10 – Transfer function.

CONCLUSIONS

Two candidates of pulse stretchers to be used for the TOF detector of the PAMELA experiment have been designed and tested. The design well fulfils the experimental requirements. At the time of writing this note, no tests have been made yet, to address the radiation hardness capabilities of the LM7121 amplifier, as required for the application in a satellite experiment.

REFERENCES

[1] O. Adriani et al., Proc. of the 26th IRCC, Salt Lake City, 1996.
[2] Operational Amplifiers Data Book, National Semiconductor.