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GASPLEX A LOW-NOISE ANALOG SIGNAL PROCESSOR FOR READOUT OF GASEOUS DETECTORS

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Abstract

A 16-channel, low-noise analog signal processor, specially adapted to gaseous detectors has been designed and manufactured with an industrial CMOS 1.5 µm n-well process. Although the circuit is named Gasplex, indicating its primary application, it can also be used in various other applications. A dedicated filter performs the deconvolution of the detector signal. The long hyperbolic shape, due to the motion of the ions, is approximated by a sum of three weighted exponential functions. This special signal shaping is implemented in the feedback path of a multiple-loop amplifier. Testing of fabricated chips at a power consumption of 10 mW/channel resulted in a noise of 580 e− r.m.s. at 0 pF additional input capacitance and 500 ns peaking time, with a slope of 15 e−/pF. The gain is 10.3 mV/fC over a linear dynamic range of 0 to + 200 fC and 0 to −100 fC. The peaking time is adjustable from 400 ns to 650 ns and the analog output can be read out at a speed of 10 MHz with a capacitative load of 50 pF. The first application of this device will be the readout of the OMEGA RICH detector at CERN.

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1 INTRODUCTION

For reasons of channel density, readout simplicity, and low power consumption, many users of gaseous detectors were interested in using analog monolithic electronics, based on the same principle as the Amplex [1]. This well-known circuit uses the continuous-time technique for the analog sub-blocks, where the peaking time of the shaped signal works as a delay, allowing an external trigger to memorize the information by a track-and-hold circuit. The main design task was then to develop a filter, specifically adapted to the signal from gaseous detectors, which exhibits a long tail due to the slow motion of the ions produced by the avalanche process in the gas. This time-dependence will be briefly described.

A functional block diagram is given in Fig. 1. The Charge Sensitive Preamplifier (CSA) has been calculated to accept large detector capacitances, and to have a good compromise between the noise level at 0 pF load and the noise slope in terms of input capacitance. This aspect will be discussed, as well as the original approach, which used a large-value linear resistor to produce a long decay-time in order to cover the largest part of the detector signal.

After the CSA, a deconvolution filter compensates the logarithmic form of the charge signal, and feeds the shaping filter with a quasistep function. This novel circuit is described, as well as the semi-Gaussian shaper. This processing allows a new signal to be handled after 4 μs without pulse-height distortion and baseline instability.

Finally, Gasplex also provides an individual channel calibration circuit with a precision of ±1.5%. The input/output logic signals are ECL levels in order to minimize parasitic feedthrough.

2 SIGNAL PROCESSING FOR GASEOUS DETECTORS

In a gaseous detector, the ion cloud released by the avalanche around the anode wire induces current as long as it drifts in the electric field from the anode to the cathode. The ion velocity is approximately proportional to the local field strength. For a given field configuration, imposed by the chamber geometry, the charge close to the anode can be approximated by $q(t) = Q_0 A \mathrm{Ln}\,(1 + t/t_0)$ and the current by $i(t) = I_0 B/(1 + t/t_0)$, where Q_0 is the total ionic charge and A, B and t_0 are constants depending on the detector geometry and the electric field. As shown in Fig. 2, only a fraction of the total charge Q_0 is collected within integrating times of a few hundred nanoseconds, typically used for such detectors, whilst the whole ion drift time will last for several tens of microseconds.

Processing of the signal is required in order to anticipate in some tens of nanoseconds the pulse height expected after the integrating time. This processing must provide the best signal-to-noise ratio that can be achieved for a given occupation time of the shaped signal, and it must cancel the hyperbolic tail to ensure a baseline return to better than ±1%.

3 CHARGE PREAMPLIFIER AND ACTIVE FEEDBACK RESISTOR

The CSA stage can be divided into two parts: the folded-cascade stage and the feedback resistor circuit which stabilizes the DC level and defines the decay time constant. The Gasplex was designed to operate over a large range of detector capacitance. A value of 50 pF was chosen as detector capacitance for the purpose of calculating the size of the transistors. To

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minimize the part of the noise associated with this capacitance (series flicker and thermal noise), and to keep a reasonable power consumption, we chose a p-channel input transistor with the minimum process length of 1.5 μm and a width of 9000 μm. This size corresponds to an input capacitance of 15.4 pF, well-matched to the optimal value $C_{in} = Cd/3$. The input transistor operates in moderate inversion, and has a transconductance (g_m) of 6.5 mA/V at a drain current of 300 μA. The size of the folded transistor was chosen to give a small output conductance, in order to have a large open loop gain A_{v_0} and thus keep the amplifier insensitive to the input capacitance spread. This resulted in $A_{v_0} = g_m/g_{ds} \sim 3000$.

Figure 3 shows the measured Gasplex noise performance as a function of total input capacitance, the parallel noise component being 340 e^- r.m.s. The measured series noise components can be compared with the expected value given by the usual series noise equations for a RC–CR shaping:

$$ENC_{1/f}^2 = \frac{e^2}{2}\frac{K_f}{C_{ox}^2 WL}\frac{C_t^2}{q^2}$$

and

$$ENC_S^2 = \frac{e^2}{2} KTC_t^2 \frac{2n}{3g_m}\frac{1}{q^2 T_s},$$

where K_f is the flicker noise technology dependent factor, n is the transconductance parameter and T_s is the peaking time of the signal.

For example, for a total input capacitance of 66 pF ($C_{det} + C_{in}$) we measured the series noise component ($ENC_{1/f} + ENC_s$) to be 990 e^- r.m.s., compared with the theoretical value of 795 e^- r.m.s. The measured and theoretical slope of the noise curve are 15 and 12 e^- r.m.s. respectively.

Note that the calculation is done on the CSA, but the measurements are performed on the full chip, thus part of the measured noise originates from the other part of the circuit (deconvolution, shaper, track/hold and output buffer).

In order to be sensitive to the largest amount of detector current, which has an hyperbolic shape developed over several tens of microseconds, the CSA must have a long time-constant. We have engineered its value as $R_f C_f = 20$ μs ($C_f = 1$ pF, $R_f = 20$ MΩ). It is not feasible to implement such a large resistor with a CMOS resistive layer. We used instead an active device made of a small n-well resistor of 50 kΩ, followed by a current divider of 400 designed with a current conveyor (Fig. 4). The noise contribution of the equivalent resistor is determined by the transconductance of the output stage. Its calculated contribution to the parallel noise is 140 e^- r.m.s. The CSA has a rise-time of 36 ns with a detector capacitance of 50 pF. The peaking-time of the shaped signal is insensitive to the value of the input capacitance.

4 CONTINUOUS TIME DECONVOLUTION CIRCUIT

As mentioned in Section 2, the signal delivered by the detector has a long tail due to the slow motion of the ions. The goal of the deconvolution filter is to extract in some tens of nanoseconds the greater part of the charge delivered by the detector. The function of the filter is to recreate a Dirac pulse from the signal given by the detector. Because we have an integrator

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after the detector, it has to rebuild a step function by means of the deconvolution and allow the shaping filter to maintain a stable and precise analog baseline.

The detector can be modelled as a linear system with an impulse response $h(t) = U(t)/(t_0 + t)$ stimulated by a Dirac pulse $i_s(t) = Q_0\delta(t)$, $U(t)$ being a step function. In order to perform the deconvolution, the transfer function of the deconvolver $G(s)$ has to be the exact inverse of the transfer function of the detector $H(s)$: $G(s) = H(s)^{-1}$, where $H(s)$ is the Laplace transform of $h(t)$.

The hyperbolic detector signal current can be represented by the sum of three exponentials [2] with a precision of 1%. Each exponential is modelled by a pole placed in the feedback of a summing amplifier to implement the inverse transformation: $G(s) = V_{out}/V_{in} = A/(1 + \beta A)$; for A large we have $G(s) \sim 1/\beta$.

As shown in Fig. 5, the summing amplifier is made of three differential pairs, each one having its own feedback path, one direct with an internal pole and the two others made with the transconductance of an Operational Transconductance Amplifier (OTA) and an external capacitor ($T_1 = C_1/g_{m1}$, $T_2 = C_2/g_{m2}$, $T_3 = C_{int}/g_{mint}$).

Another condition for fitting the hyperbolic signal, is to weight these exponentials by a gain factor K, the feedback path being now $\beta = K_1/(1 + sT_1) + K_2/(1 + sT_2) + K_3/(1 + sT_3)$. The gain factors $K_1 = 0.2$, $K_2 = 0.3$, $K_3 = 0.5$ are defined by the ratio of the g_m of each pair to the sum of the g_m's. Figure 6 shows the effect of the deconvolution when a Gasplex channel is activated by a delta pulse generator.

5 SHAPER

The shaper circuit shown in Fig. 7 is of the RC/CR^2 type. It is made of a low-pass filter followed by a band-pass amplifier with a quality factor of 0.58, resulting in an almost Gaussian shaping with a circuit of moderate complexity. The first element is the low-pass stage OTA3 loaded by C_3. The band-pass amplifier is made with OTA_4 and OTA_5 and two capacitors: C_4 and C_5. C_4 is connected in the feedback of the AMP amplifier. The signal transfer gain of 5 is given by the ratio g_{m4}/g_{m5}. The time-constants can be varied by a common biasing line to ease the adjustment of the peaking time. The DC output level variation has been measured at 0.1 mV/°C. Owing to the pole given by the time-constant of the CSA, it is necessary to introduce a zero in the transfer function of the shaper. This is done in the band-pass filter with a resistor made in the same way as the feedback resistor R_f of the CSA. The cancellation occurs when the two time-constant are equal: thus $R' = R_f C_f / C_5$, C_5 being 10.4 pF gives $R' = 2\ M\Omega$.

Figure 8 shows the performance of Gasplex when it was connected to a cathode pad of a MWPC, activated by a ^{55}Fe source. The signal returns to its baseline with an error of 2% after 4 µs.

6 CALIBRATION AND PERFORMANCE MEASUREMENTS

The Gasplex provides individual channel access for calibration. A shift register can be used to activate sequentially an analog switch on each channel, which allows a test pulse signal to stimulate the inputs of the circuit through individual capacitors. The good precision of CMOS capacitors permits a calibration accuracy of ±1.5%. The analog output is in low

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impedance during the readout phase only. This feature allows the daisy-chaining of several chips, up to a total of 500 pF of parasitic capacitance at a readout clock speed of 2 MHz; while an individual circuit can reach 10 MHz with a capacitive load of 50 pF.

After including the input parasitic capacitance of the chip, we measured a noise of 580 e^- r.m.s. at 0 pF and a slope of 15 e^- r.m.s./pF. The gain is 10.3 mV/fC over a linear dynamic range (±2 fC) from 0 to 200 fC and from 0 to −100 fC. The peaking time is adjustable from 400 ns to 650 ns and the channel offset spread is ±40 mV around −90 mV.

7 CONCLUSIONS

A 16-channel analog signal processor for readout of gaseous detectors has been designed and manufactured with an industrial CMOS process. A first production run has been bonded in a 48-pin chip carrier. Boards to perform the readout of the WA97 (OMEGA) RICH detector are currently being assembled. Performance is as expected, and the circuits are suitable for a large range of applications. Two variants of the Gasplex circuit have been developed with the same external functionality as the original Amplex; these are the Amplex1.5, which drops the deconvolution filter, and the Gassiplex, where this filter can be switched on or off and the baseline return of the shaped signal has been recently measured at 0.5% after 4 μs.

Acknowledgements

The patience and encouragement given by E. Quercigh, spokesman of WA97, during the prototyping period was much appreciated.

References

[1] E. Beuville, K. Borer, E. Chesi, E. Heijne, P. Jarron, B. Lisowski and S. Singh, AMPLEX, A low noise, low power analog CMOS signal processor for multi-element particle detectors, Nucl. Instrum. Methods Phys. Res. **A288** (1990) 157.

[2] R.A. Boie, A.T. Hrisoho and P. Rehak, Signal shaping and tail cancellation for gas proportional detectors at high counting rates, Nucl. Instrum. Methods Phys. Res. **192** (1982) 365–374.

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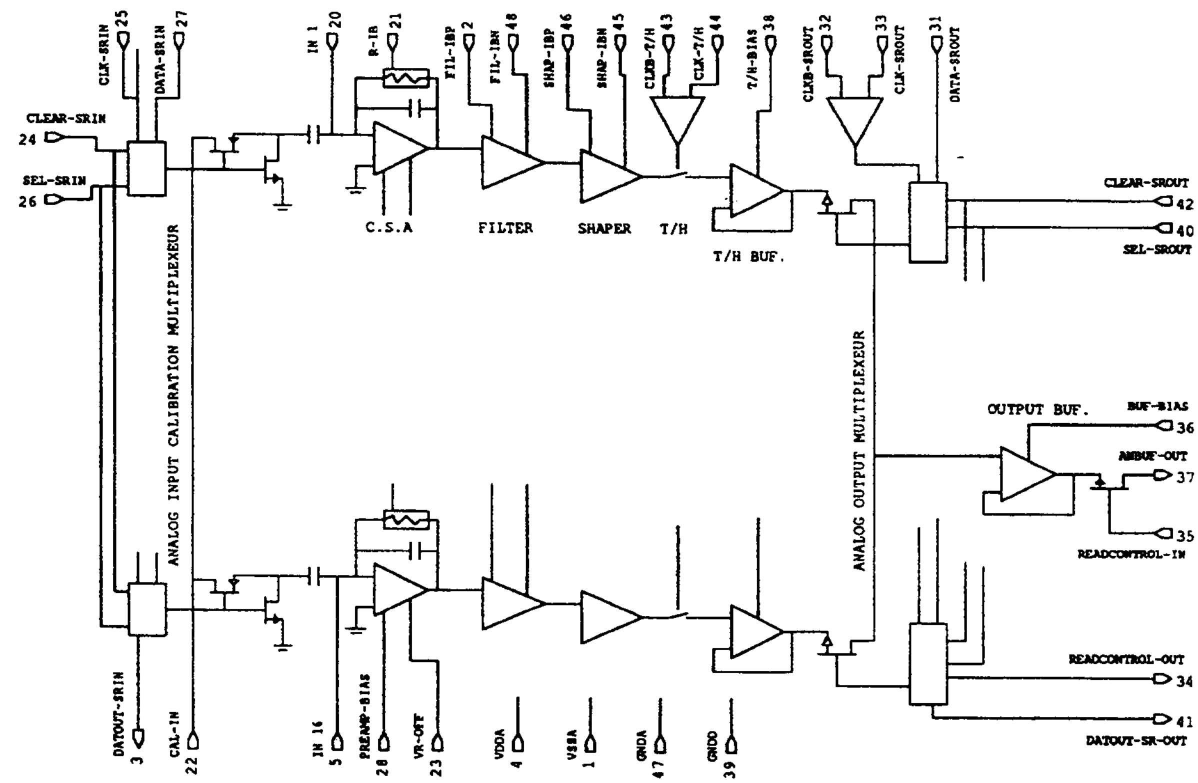

Fig. 1 Gasplex block diagram

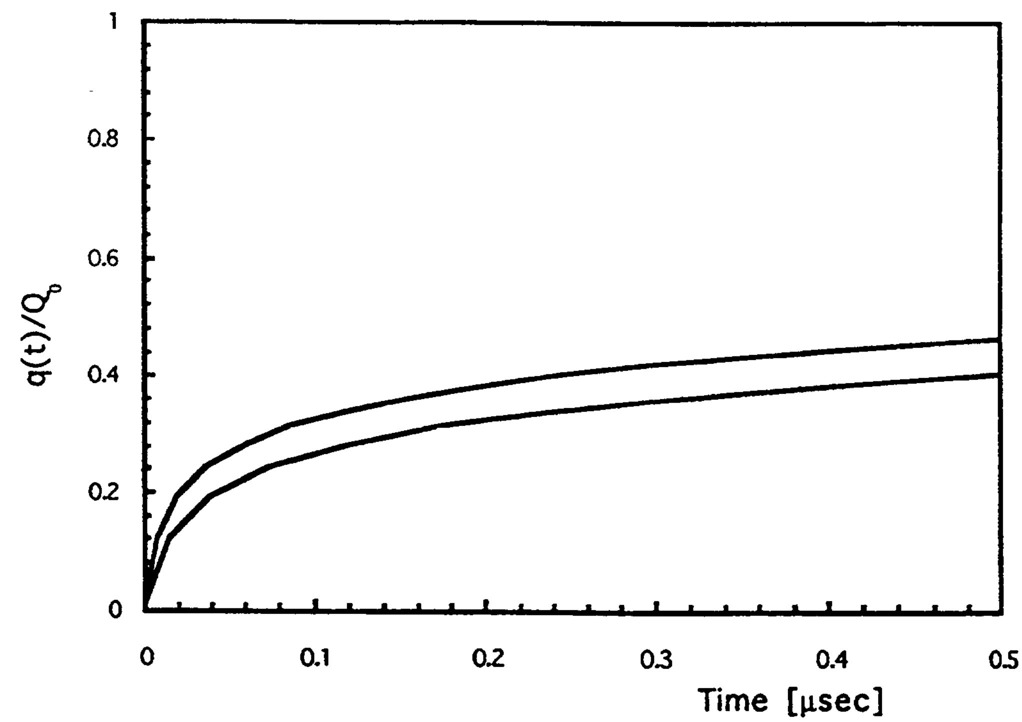

Fig. 2 MWPC charge signal: calculated time variation of the charge induced in a MWPC geometry where the distance between anode and cathode and between anodes is 2 mm and 4 mm, respectively. The initial ion velocities at the anode surface are 2.0 and 1.0×10^6 mm/s, for the upper and lower curves, respectively.

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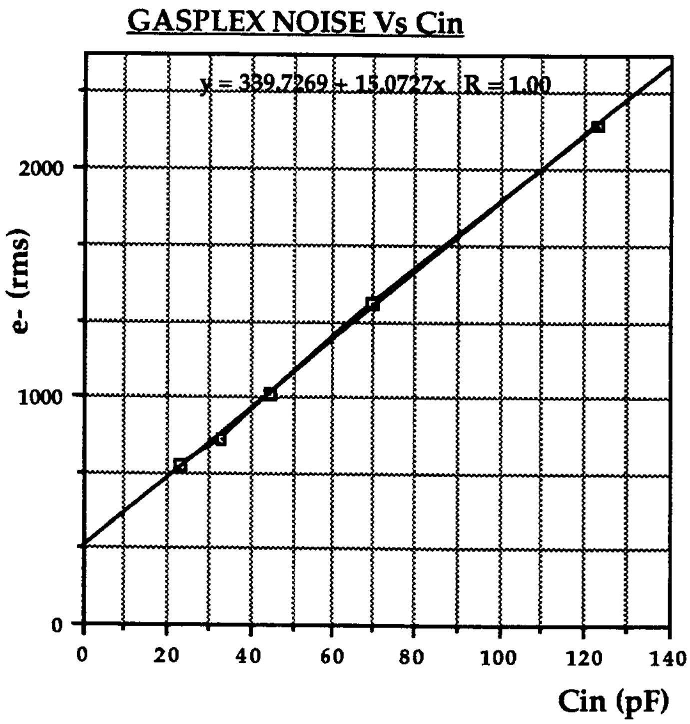

Fig. 3 Measured Gasplex noise vs input capacitance

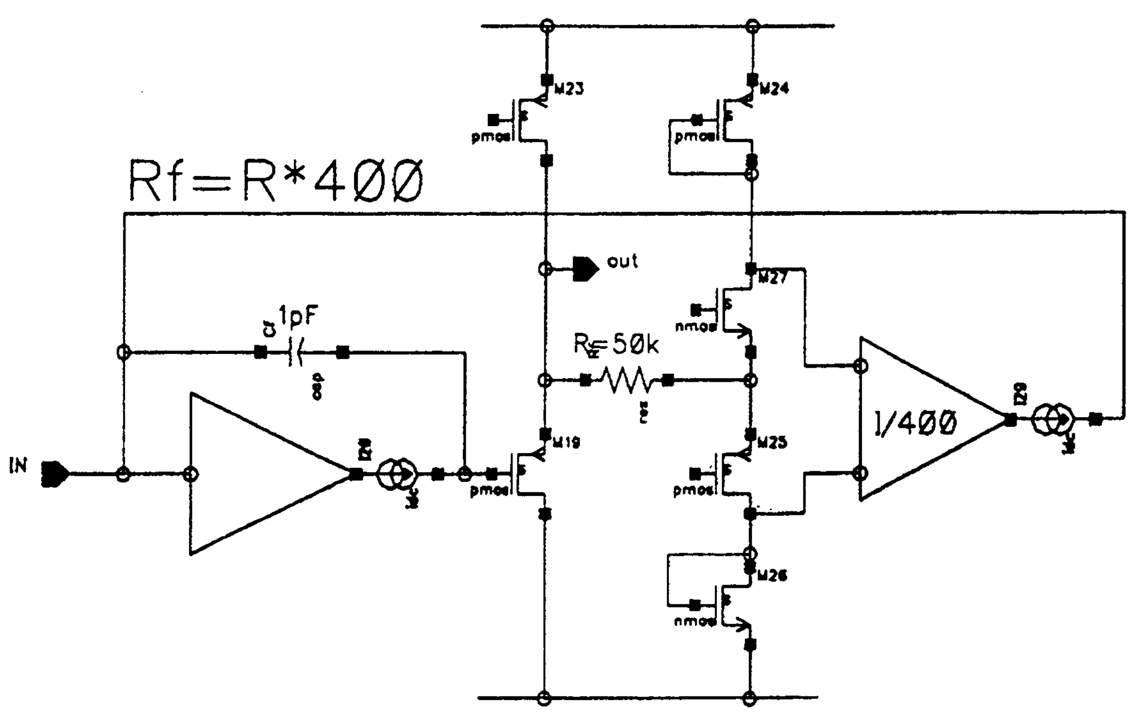

Fig. 4 Block diagram of the 20 MΩ active feedback resistor

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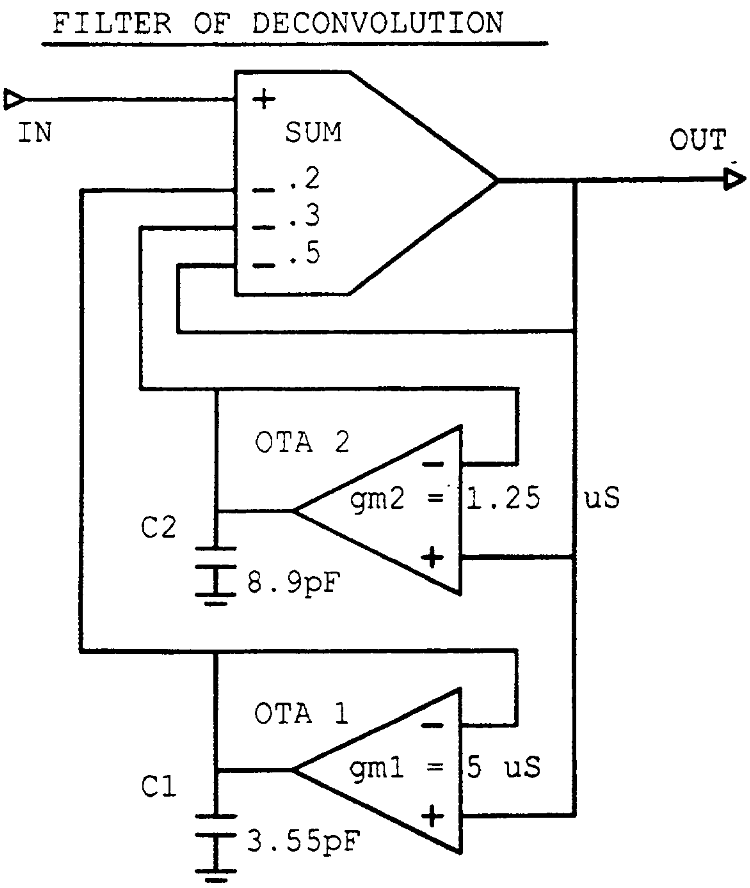

Fig. 5 Block diagram of the deconvolution filter

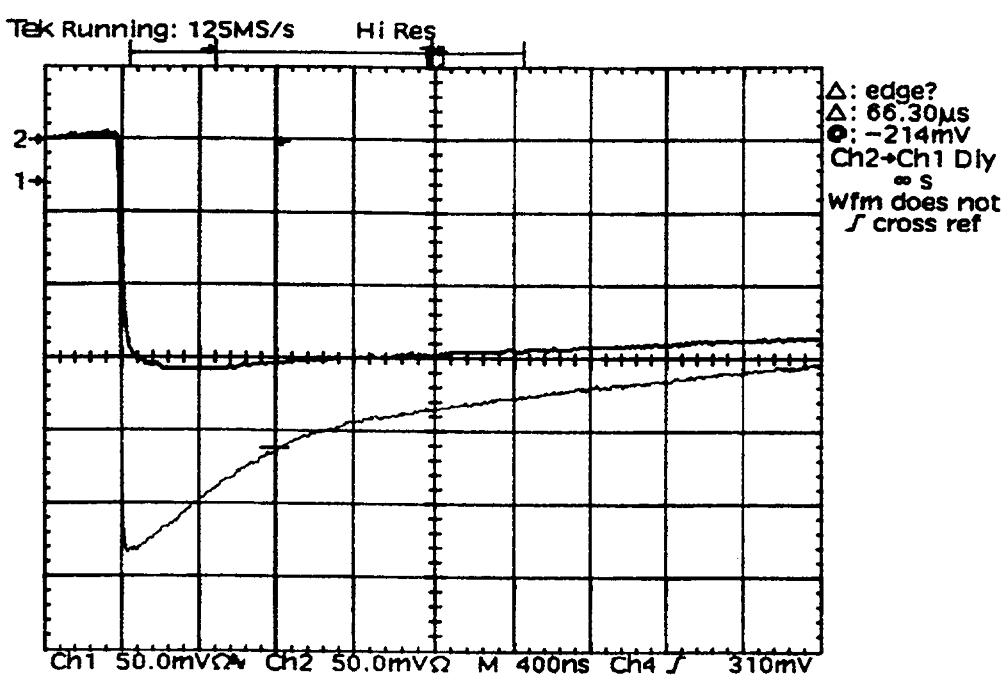

Fig. 6 Action of the deconvolution when a Gasplex channel has been activated by a delta pulse: the upper track is the output of the CSA, the lower track is the ouput of the filter. Both tracks have the same origin.

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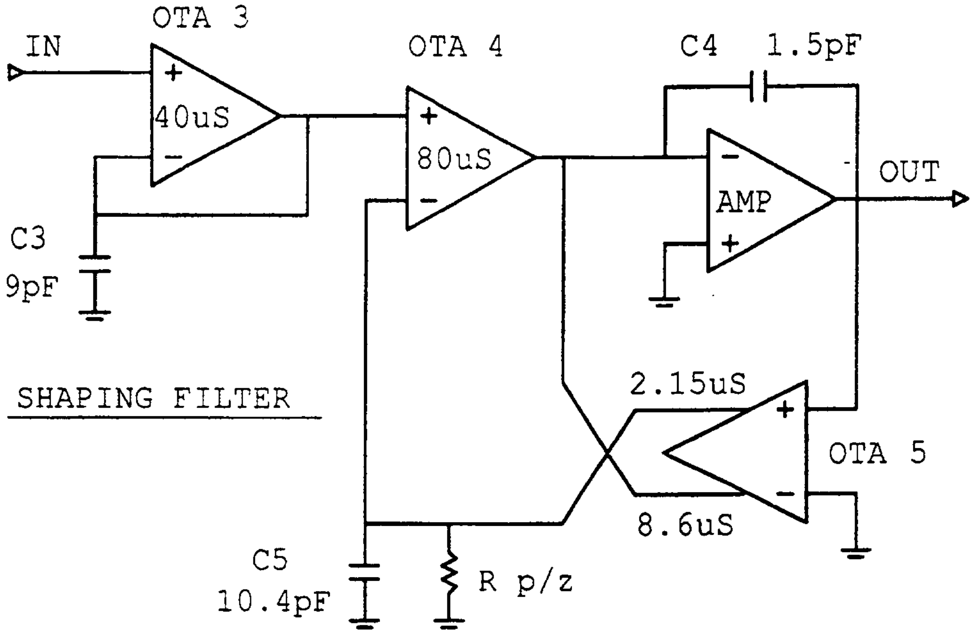

Fig. 7 Shaping filter block diagram

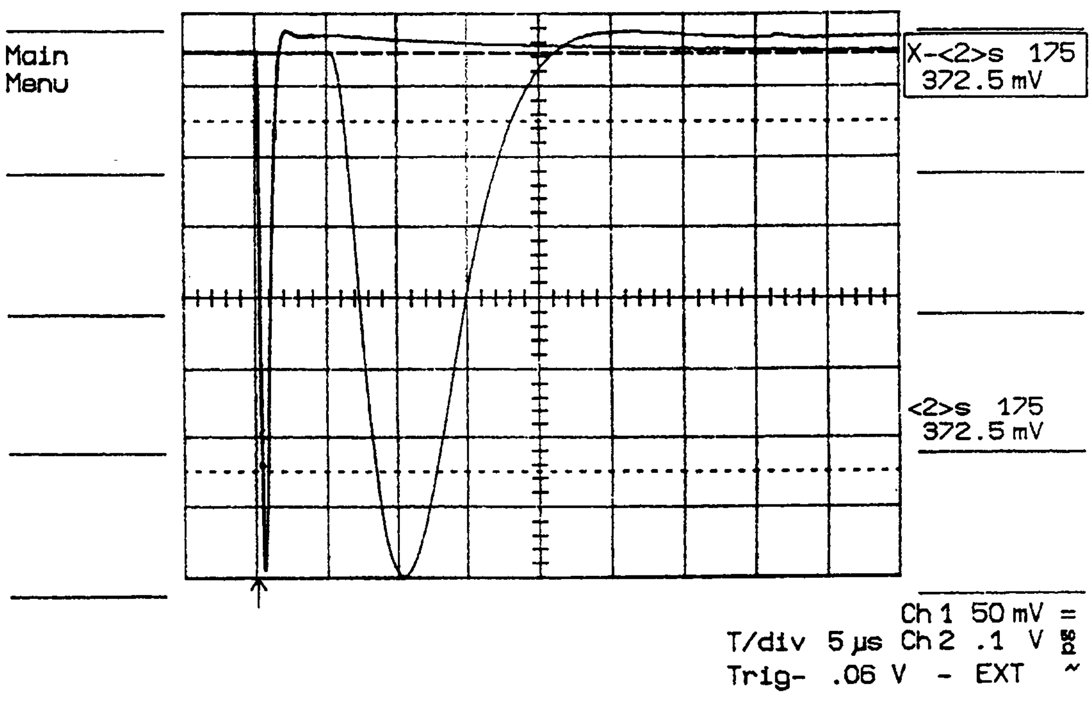

Fig. 8 Shaped signal from a cathode pad of a MWPC activated by a ^{55}Fe source

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