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# OCTAL CHANNEL AMPLIFIER-DISCRIMINATOR BASED ON ASD-8 (ASIC) FOR TIMING MEASUREMENTS WITH DRIFT CHAMBERS

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## 1. Introduction

The increased number of the drift tube / chamber electronics channels and high count rate per channel require the following: a) low noise since gas gain reduction is encouraged to prolong a detector life, b) small power consumption and high density because detector electronics has become more complicated but the space needed for its placing is decreased. TDCs and readout boards are often installed on the detector and data transferring to the DAQ is performed with twisted pair cables or optoelectronic links. Requirements for a higher reliability and cost reduction become harder.

The electronics for timing measurements with gaseous detectors should use a current sensitive type of PreAmplifier (PA) with low input impedance. An accuracy about hundreds of μm ( r.m.s ) can be achieved when the rise time $\tau_r$ is < 10 ns and electronic noise is < 2000 $e^-$ at gas mixtures with typical drift velocity of ~ 50 mm/μs.

Today designers use for similar aims bipolar technology which can provide : a) the highest value of $g_m$ among all existing technologies and b) a low noise for short processing time. In most cases there is a common emitter (CE) circuit at the head stage that allows one to reach high amplification and good S/N ratio /1, 2/. The parameters of short amplified pulses after PA are given by / 3 /:

$$\tau_r = C_\Sigma\, C_c \,/\, g_m\, C_f^*, \quad \tau_f = R_f\, C_f^* \text{ and } V_{out} = Q_{in} / C_f^*,$$

where $C_f^* = (C_f + C_\Sigma/g_m R_c)$ – effective feedback capacitance;

"f" denotes components in the feedback loop chain, "c" – – in the collector one; $C_\Sigma$ is the total input capacitance, $g_m$ – transistor transconductance.

According to these expressions a large value of the open loop gain $g_m R_c$ will oppose the influence of $C_\Sigma$ variation on a $\delta$ - pulse response. This also allows one to achieve a smaller input impedance at a high value of amplification ~ $R_f$. As regards $t_f$, since $R_f \gg R_{in}$, it should be shortened ( by a shaper ) as well as a $t^{-1}$ component which appears due to the positive ion motion ( by a detector tail cancellation circuit) / 3, 4 /.

As detector pulses have usually random distribution in time, their infinite width ( fall time ) is a reason of high count rate limitation because of the probability of pile - up effect. This effect leads to the error $\sigma_{pileup}$ of a discriminator triggering because of pulse amplitude fluctuations. This error can be estimated from Campbell formula and is ~ $\sqrt{n\tau}$ / 5 /. Therefore, it is possible to eliminate it significantly by the respective shaping.

The serial $\sigma_s$ and parallel $\sigma_p$ noises are one more reason of amplitude fluctuations. Since they are not correlated between themselves, then $\sigma^2_{noise} = \sigma^2_s + \sigma^2_p$ and $\sigma_\Sigma^2 = \sigma^2_{noise} + \sigma^2_{pileup}$. As a rule a discriminator with the fixed threshold is used for the described application. It gives a timing error of $\sigma_t = \sigma_\Sigma : dV/dt + \Delta$ / 6/, where $\Delta$ is residual jitter of the discriminator ( for gaseous chamber electronics it is enough to assume $\sigma_t \sim \sigma_\Sigma : dV/dt$ ).

The above - mentioned errors are to be summed up with the normal intrinsic error of a fixed threshold discriminator which is proportional to the $V_{thr}$ value and appears due to the distortion of a signal amplitude spectrum. The implemented discriminator should have a matching sub - nanosecond accuracy to prevent the position resolution degradation.

If the detector wires are long enough to be considered as a long transmission line then PA input impedance has to be matched with characteristic impedance $Z_{wire}$ ( ~ 300 Ohm ) / 4 /. A close value of $R_{in} = R_f/g_m R_c$ is realized, as a rule, in PA implemented in the CE scheme. $R_{in}$ will operate as a pure resistance of the constant value at $R_f C_f = R_c C_c$.



Noise reduction is also important since a) a signal amplitude is not high if the charge of a few ( or one ) electrons from a particle track is used (that is necessary for good spatial resolution), b) a charge collection time is short compared with the positive ion drift time. The fraction $Q_t$ of the total charge induced on a wire is the function of time and may be not over 20 % for a short measurement time / 3, 5 /.

For the case of short input pulses it is preferable to express noise as the equivalent input charge:

$$\overline{ENC^2}_p = [\, 2 e^- I_b + 4kT/R_f \,] \int [\, W(t) \,]^2 \, dt,$$

$$\overline{ENC^2}_s = C^2_\Sigma \; 4kT \, ( r_s + 1/2g_m ) \int [\, W'(t) ]^2 \, dt,$$

where $r_s = r_b + R_{prot}$, $r_b$ - base spreading resistor,
$W(t)$ - weighting function.

The series noise component at relatevily small $C_\Sigma$ and $r_s$ is small enough and parallel noise contribution is dominant. However, its yield is not large for our case because the magnitude of $\int [\, W(t) \,]^2 dt$ is of a small value since it is proportional to the measurement time.

High luminosity (or channel occupancy) and high background are another reason to prefer low noise electronics in order to get capability of operation at low gas gain.

2. Amplifier - Discriminator AD8 - H/1

Such multichannel electronics cannot already be realized on the market standard ICs or fully completed readout system as PCOS / 7 /. Although providing high performances they are often far from the optimum of particular applications, consume too large power and relatively expensive. Development of ASIC ( Application Specific Integrated Circuit ) based devices is another solution to construct tens of thousands detector electronics channels.

The distinct advantages of such ASIC are: 1) increased density by combining more circuity into the package, 2) increased reliability (smaller discrete components and external connections), 3) reduced power consumption ( ASIC has the optimized structure), 4) lower cost per channel ( however, when large quantity of the samples are fabricated) / 8, 9 /.

We have performed a test of the ASIC ASD8 / 3, 10 / considering to employ it for development of a drift chamber electronics / 11/. ASD8 has been implemented in the analog bipolar process and contains 8 identical channels, including the preamplifier, the shaper and the discriminator. The advantages of this IC are in combining of high bandwidth $t_r < 8$ ns and small $P_D < 25$ mW/channel, as well as low noise < 1000 $e^-$.

Additionally, differential structures are used in the ASD8 in all the stages, which allows one to provide RF suppression at the input and prevent parasitic coupling of outputs with inputs. PreAmp has a large value of the open loop gain $g_m R_c$ and is implemented as cascode to eliminate Muller effect. Shaper serves to eliminate PA fall time and to reject the detector ion tail. The differential outputs ( open collectors ) can provide a current up to the value of 3 mA into the loaded resistor. The discriminator consumes small $P_D$ along with the required sub - nanosecond resolution.

The developed Amplifier - Discriminator AD8 - H/1 has been investigated on the drift chamber. The chamber has a drift cell size - 2.5 x 2.5 mm , wire length - 70 cm, diameter of sense wires - 30 μm, potential and cathode ones -100 μm. Gas mixture of He + 30 % isobutan has been used.

Block - scheme of the device is shown in Fig. 1. There is a diode ( BAV 99: $\tau_r < 6$ ns, $C < 1.5$ pF ) protection chain at the input of each channel. Serial capacitance $C_s$ is not necessary in principle if signal wires are under the ground potential. But without it a protection chain is to be more complicated. For relatively low count rate per channel ( hundreds of kHz ) its influence - base level shift - will be negligible. Besides that it is possible to place here a HV capacitance when it is necessary.

Taking into account small threshold variations ( ∓10% ) for a single chip, that is a normal phenomenon for the implemented technology / 3, 8, 9 /, $V_{thr}$ is common for all 8 threshold



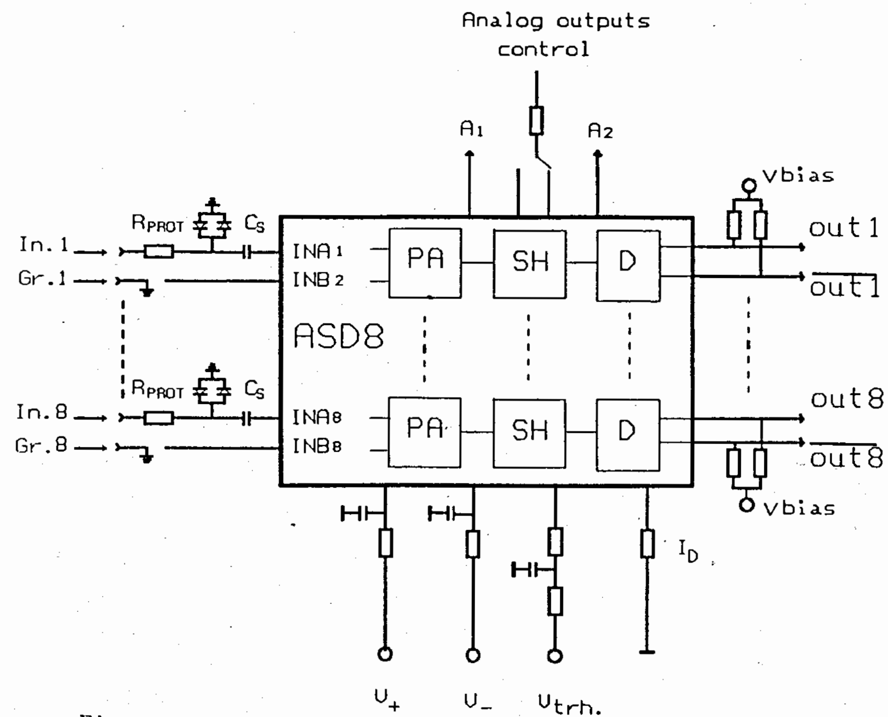


Fig. 1.
Block - scheme of the Amplifier - Discriminator AD8 - H/1.
A1, A2 - outputs of analog signals before and after the shaper (with the detector tail cancellation)

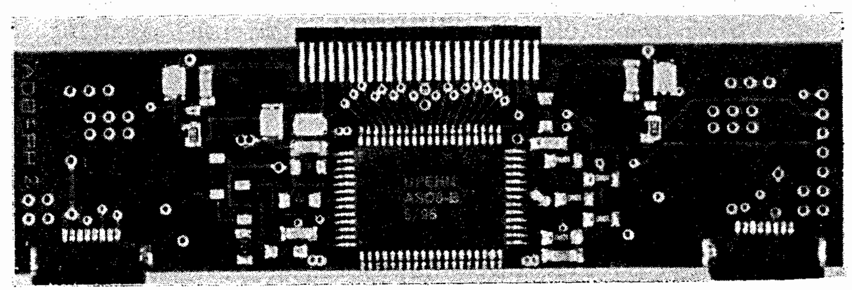

Fig. 2. Common view of the AD8 - H/1

inputs. Voltage $V_{thr}$ goes to the respective inputs through a simple resistive divider which is possible due to their rather high impedance. The resistor divider also serves as a lowpass bandwidth filter.

The ASD8 outputs can directly drive a cable providing the voltage swing up to $I_d \times \rho$ at the outputs. It is also possible to install resistors ( or R - matrix) biased on a $V_{bias}$ at the outputs of the IC. By varying independently the values of R, $I_d$ and $V_{bias}$ one can obtain the output pulses suitable for a closely located TDC - chip. This approach is simple, it reqiures a small additional power consumption and allows one to get simultaneously a slower rise / fall time of the output pulses . The latter must reduce the output / input parasitic coupling. For short pulses the maximum loading capacitance ( we consider to meet one ranging of ( ~ 10 - 30 pF ) will depend on the maximum output current ( 3 mA). The $V_{bias}$ voltage ranging of $\mp$ ( 1 - 3 ) V can be obtained from the respective power supply existing on the card.

A special forming of the output signal width after the discriminator is not arranged on the cards. Typically this value is expected to be more than 20 ns for the detector signals. For monitoring the analog outputs before and after shaper we use respective pins of the ASD8 which feed a simple cable driver ( $\rho$ = 50, 100 Ohm ) placed on the board when it is necessary.

The PCB has rather simple trace layout and can be implemented in 3 - layer board using one - side component mounting. The common view of the AD8 - H/1 is shown in Fig. 2.

## 3. Measured performances

A number of parameters that charactirize the achievable timing accuracy has been measured for the developed cards AD8 - H/1.

The noise performance was measured using the method proposed in ref. / 12 /. The established threshold was near the expected operating point, around 1.5 fC. The discrete input capacitance of 10 pF represented a probable $C_{in}$ which can exist because of the detector and transmitted line. The amplitude of input signals is varied from 0% to 100% efficiency when the output formed pulses fed a pulse counter. Considering the finite width of the transition region of about 1.5 fC to the electronic noise, one can



determine the equivalent noise ( 6 $\sigma$ ) at the card input. The measured charge gain was about 10 mV/fC, therefore one can estimate the equivalent noise charge corresponding to ~ 1500 $e^-$ (Fig.3).

This value is near intrinsic noise of the used IC. This means that the designed PCB doesn't contribute a noticeable extra electronic noise or background at a wide BW. To eliminate RF pick - up (not strongly predictable, but surely expected since ASD8 is a fast chip ), were added the holes for the extra connectors to arrange powered analog ( detector's ) and digital ( power supply's ) grounded connection on the board. According to our experience it is also useful to shield the input cables. Following the recommended rules, we have employed the existence of pseudo - differential inputs to minimize synphase pick - up and crosstalk by tracing into the second PA input a line which is parallel to the signal input one. As mentioned earlier, a slower rise and fall time cause the influence reduction of the outputs to the inputs.

The minimum operating threshold may be ~ 1 pC regarding the noise feature. The measured linear amplitude dynamic range is about 1 - 12 fC, but timing accuracy should not be limited for the moderate count rate since a shape of pulses at the discriminator inputs exhibits a constant flat top up to 100 fC of the input charge without any pulse irregularities.

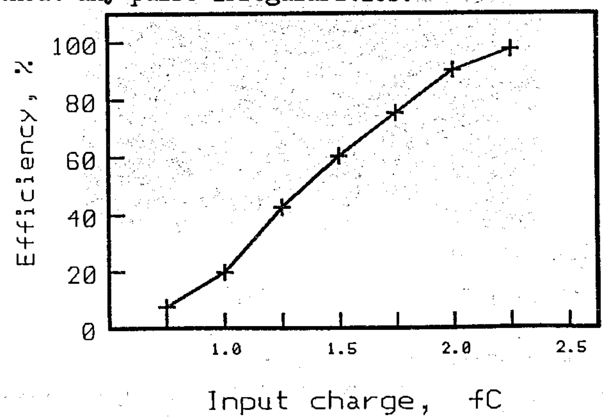


Fig. 3. Dependence defining noise features
$C_{in}$ = 10 pF, $V_{PA}$ = 2.5 V, $R_{prot}$ = 50 Ohm

a)

b)

c)

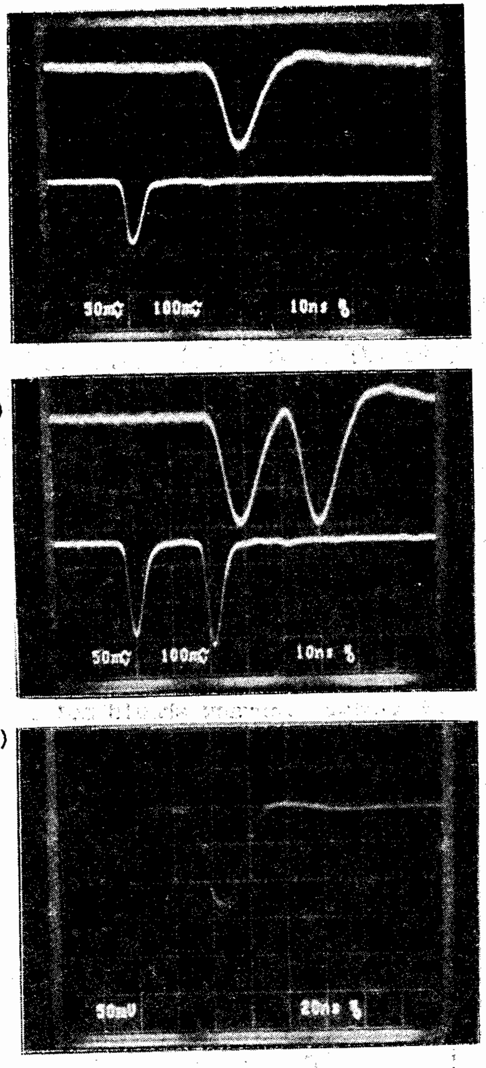

Fig. 4.

Oscillograms of pulses

a) top - output pulse from the pulser,
bottom - input pulse after the shaper;

b) (a) items for the pair of pulses;

c) output pulse from the drift chamber obtained with $^{55}$Fe



The measured variations of the threshold values for the same chip (e.c. the card) lay inside ∓10 %. These data were obtained as a result of using 10 IC ASD8 preliminarily tested and selected.

Timing capability can be derived from oscillograms shown in Fig. 4. One can observe a rather sharp rise and fall time of the detector signals monitored after preamplifier and detector tail cancellations. This shape allows one to count on a sub - nanosecond accuracy and up to 50 - 100 ns double pulse resolution under operating conditions.

We have achieved a stable operation at low threshold ~ 1 fC due to a low noise and effective suppression of RF pick - up. The 600 V ( HV ) plateau of the drift chamber efficiency has been obtained with the $^{55}$Fe radioactive source and 200 V - for $^{90}$Sr ( in this case β - particles of high energy were selected with two scintillation counters) as shown in Fig.5. The signal amplitude in the latter case was almost by 2 orders less than that in the former one, then one may consider that only a few of the electrons that first arrived were registered.

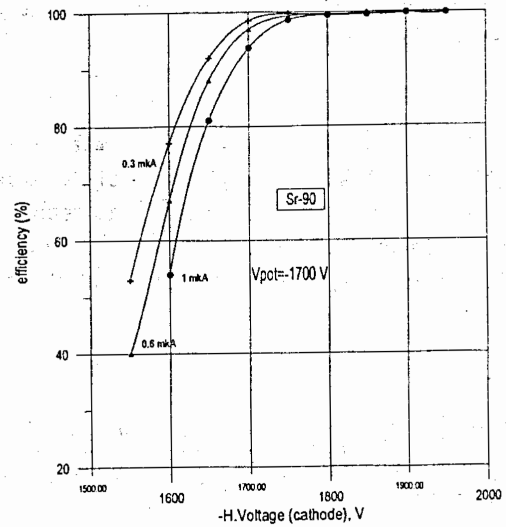


Fig. 5. Plateau of the drift chamber efficiency versus HV, obtained with $^{90}$Sr using OR of the AD8 - H/1 output signals

The slow dependence of $V_{out}$ on $C_{in}$ was observed that is in a good agreement with a large value of the PA open loop gain $g_m R_c$ = 170.

The power dissipation of the device is less than 30 mW per channel including the RC - filters and the output I - to - V converter.

The AD8 - H/1 is proposed to read out data from the mini - drift chambers of the HADES experimental setup / 13 /, where accuracy of 100 μm ( r.m.s. ), count rate ~ 100 kHz and $P_D$ < 50 mW per channel are expected.

## 4. Conclusions

The Amplifier - Discriminator AD8 - H/1 based on ASIC ASD8 has been developed and tested on the drift chamber. High homogeneous and stable parameters have been obtained as well as a low power consumption. The device contains a small quantity of discrete components. AD8 - H/1 is proposed for high accuracy timing measurements with drift chambers.


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