Nükleer Elektronikte Hızlı zamanlama tekniği

Fast Timing Techniques in Nuclear Spectroscopy

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Hızlı zamanlama tekniği nükleer elektroniğin en önemli konularından biridir. Birbirini piko - saniyeler mertebesinde bir farkla takip eden olayları inceleyebilmek ve bunların arasındaki ilişkileri kurabilmek için, elektronik devrelerin çok hassas bir şekilde kurulması gerekmektedir. Burada konu ile ilgili problemler ve çözüm yolları gösterilmektedir.

Fast time techniques is one of the most important subjects of nuclear electronics. In order to investigate the events which occur within pico-seconds and to correlate them, the electronic circuits must be built very accurately. The present paper discusses the problems involved and their methods of solution.

INSTRODUCTION

Time spectroscopy involves the measurement of the time relationship between the occurance of the two events such as:

a) A precise measurement of the elapsed time between two events.

b) The isolation of the true coincidence events from a background of noncoincident data.

THE FACTORS TO BE CONSIDERED FOR GOOD TIMING

(i) WALK. As shown in fig. 1, although the two pulses are generated by the events which occur at the same time, they cross the

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discriminator level at different times, larger ones earlier, smaller ones later by an amount Δt which is named as walk.

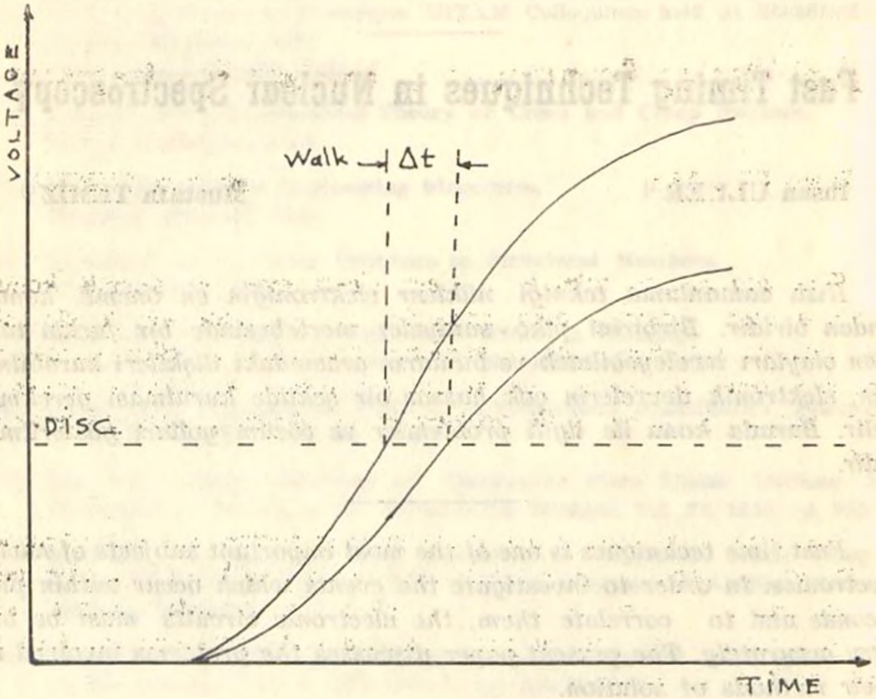

Fig. 1 Walk

(ii) JITTER. The noise on the pulse as shown in fig. 2 is called jitter. Jitter causes the pulse to reach the discriminator sooner or later. As shown in the figure it is indirectly proportional to the slope of the pulse, hence if a pulse is high enough (and if its rise time is short) jitter is small at the steep edges. This may be due to the dedector itself or the electronics used. It depends on the statics too. (The number of photoelectrons in a Photomultiplier is subject to vary, a matter of emission and collection of electrons.)

(iii) Geometrical Effect. The time in which the particles interact with the scintillator may vary due to the geometrical shape of the system and the thickness of the scintillator. Variations between the path length for collection of photons from the scintillator to the P.M. cathode also effects the timing.

(i) Intrinsic Scintillator Characteristics. There is a finite decay time of the light emitting states of phosfor, and the light yield of the scintillator as a fuction of the energy of the dedected radiation.

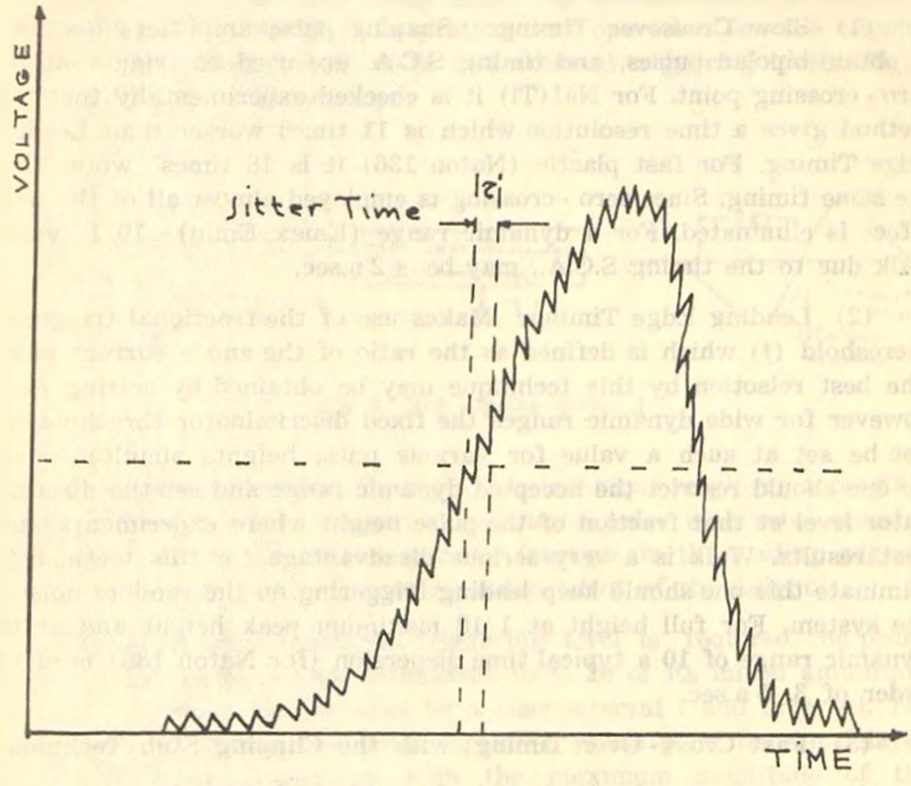

Fig. 2 Jitter

(v) Photomultiplier Characteristic: Transition time variations of the electrons from the cathode of the Photomultiplier to the first dynode, and response of dynodes to the colliding electrons.

(vi) Depletion Layer Geometry. Both rise times and amplitudes may vary in solid state dedectors; this depends on the thichness and homogenity of the depletion layer as well as the energy and the range of the particles to be dedected.

TIMING TECNIQUES

Although the elimination of these factors, especially the first two, depend on the selection of equipment for timing (and money) some tecniques must be applied to obtain good timing. There are five methods of timing:

(1) Slow Crossover Timing: Shaping pulse amplifiers are used to obtain bipolar pulses, and timing S.C.A. are used to trigger at the zero - crossing point. For NaI(Tl) it is checked experimentally that this method gives a time resolution which is 11 times worser than Leading Edge Timing. For fast plastic (Naton 136) it is 18 times worse than the same timing. Since zero - crossing is employed almost all of the walk effect is eliminated. For a dynamic range (Emax/Emin) = 10/1 typical walk due to the timing S.C.A., may be ± 2 n.sec.

(2) Leading Edge Timing: Makes use of the fractional triggering thereshold (*f*) which is defined as the ratio of the anode current pulse. The best relsotion by this technique may be obtained by setting $f \approx 2$; however for wide dynamic ranges the fixed discriminator threshold can not be set at such a value for various pulse heights simultaneously. So one should restrict the accepted dynamic range and set the discriminator level at that fraction of the pulse height where experiments show best results. Walk is a very serious disadvantage for this method. To eliminate this one should keep leading triggering on the random noise in the system. For full height at 1/10 maximum peak height and at the dynamic range of 10 a typical time dispersion (for Naton 136) is of the order of 3, 5 n.sec.

(3) Fast Cross - Over Timing; with the Clipping Stub Technique:

Anode current pulse is clipped with a shorted delay line to produce a bipolar pulse with a zero - crossing, and a fast cross over discriminator is used as the time pick off device. (walk is less than ±100:1 dynamic range). For small dynamic ranges this technique is worse than that of the leading edge timing. To obtain a 10 % fractional triggering threshold the clipping stub should be lengthened so that the reflected signal arrives when the tail of the initial pulse has decayed to 10 % of its full pulse height. Usually severe ringing in the pulse shape occurs in this region making predictable operation virtually impossible. Fundamentally there is another reason why it is not possible to achieve the optimum resolution at a 10 % fractional triggering level with clipping stub technique: The relative statistical amplitude fluctiations are very large for the region far into the tail of the current pulse. These fluctiations will contribute to the time resolution for the clipping stub method causing a broadening beyond the optimum provided by the leading edge of the current pulse. This problem is even more severe with scintillator having a long decay time. For instance this technique is not applicable for NaI(Tl). In pratice best operation for the clipping stub has been found for 50 - 60 % of fractional triggering levels. Fig. 3 gives an idea for this technique.

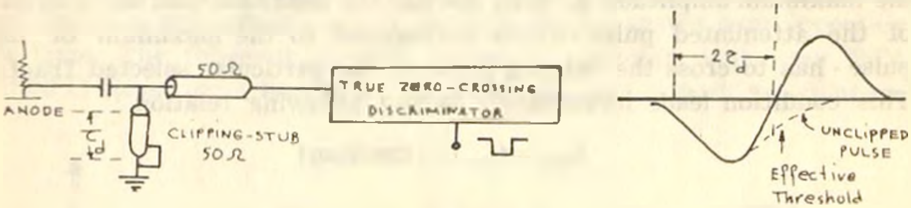

Fig. 3 The clipping stub.

(4) Constant Fraction Timing: This technique employes a constant fraction of pulse height trigger to produce a pulse with zero - crossing phase point at the optimum triggering fraction on the leading edge of the anode current pulse, thus being independent of the height.

Suppose a 20 % fractional triggering level is required, the promt anode current pulse is first attenuated to % 20 of its initial amplitude. The promt pulse is also delayed by a time interval *t* and inverted. The delay time *t* is chosen such that the 20 % phase point on the delayed and inverted pulse lines up with the maximum amplitude of the attenuated pulse. These are added in bipolar form. and the attenuated pulse exactly cancels the delayed and inverted pulse at the 20 % phase point on the delayed pulse if this zero crossing pulse presented to a true zero crossing discriminator, the circuit will trigger at a time defining the 20 % fractional triggering level on the original anode current pulse. In an ideal zero - crossing discriminator, the 20 % phase point will be selected independent of the pulse amplitude and complete walk concelation will be achieved.

In constrast to the realization above M.R. Marer and P. Sperr (1970) give another easier realization. The input pulse Cl is split into two parts.

One part A is attenuated and applied to the inverting input of a fast differential discriminator. The other, *B* is delayed and then applied to the non inverting input of the same discriminator. The output voltage of this discriminator is determined by the difference of the input voltages. This pulse *AB* crosses the threshold voltage of the following gate at V_{HR}, if the voltage at the inputs are equal. From this crossing the timing information from a fraction is derived. In order to derive timing information from a fraction of the maximum amplitude of the input pulse the timing has to be done at the time of occourance of this maximum. i.e. one has to wait with the timing until one knows what the maximum amplitude is. Thus one has the condition that the maximum of the attenuated pulse - which correspond to the maximum of input pulse - has to cross the delayed pulse at the particular selected fraction. This condition leads immediately to the following relation :

$$t_{delay} = t_{rise} \text{ (1 - fraction)}$$

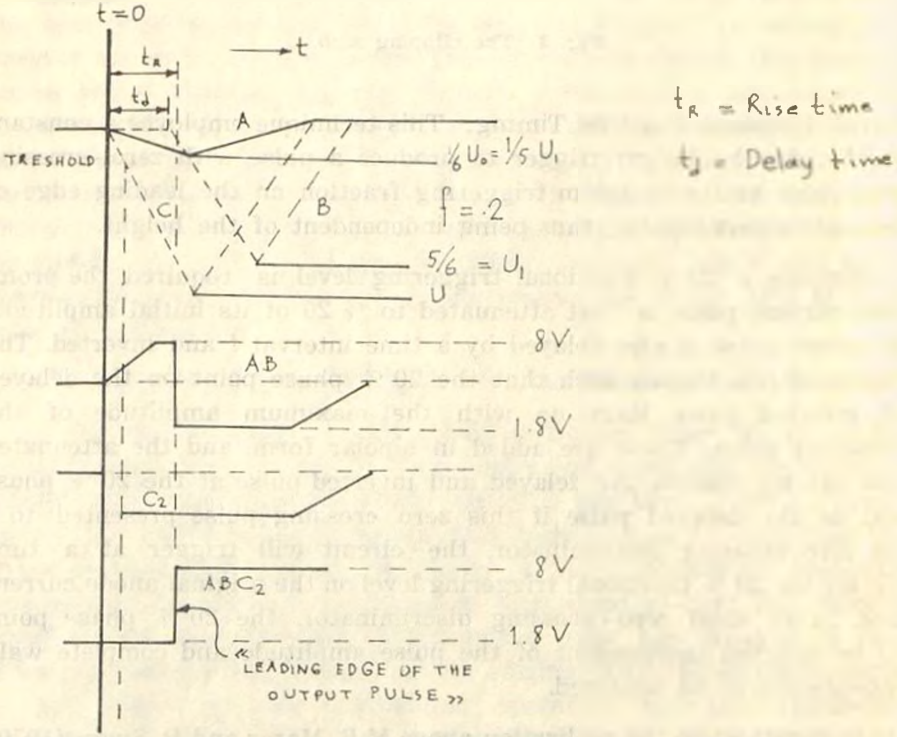

Fig. 4 Constant fraction timing technique.

using the idealized pulse shapes shown below. The validty of the approximation made by assuming such idealized pulse shapes has been checked for various values of the fraction and the delay time. The fractions from 0,1 to 0,5 and ratio of the delay time to the rise time from 0,4 to 1,0 are tried independently. It is found (Morer, Sper) that the time resolution remains essentially constant for fractions between 0,1 and 0,3. For higher fraction (*e.g.*$f=.5$) the resolution deteriorates somewhat, as the above discussion noted. The variation of the delay time did not affect time resolution, as long it is satisfied the given relation within a factor of the two. This seems plausible, since the actual pulse shape is not pointed as our idealization but varies more smoothly with time. The following prompt curve is obtained with two RCA C 31000 D tubes for a narrow range of energy loss in both scintillators.

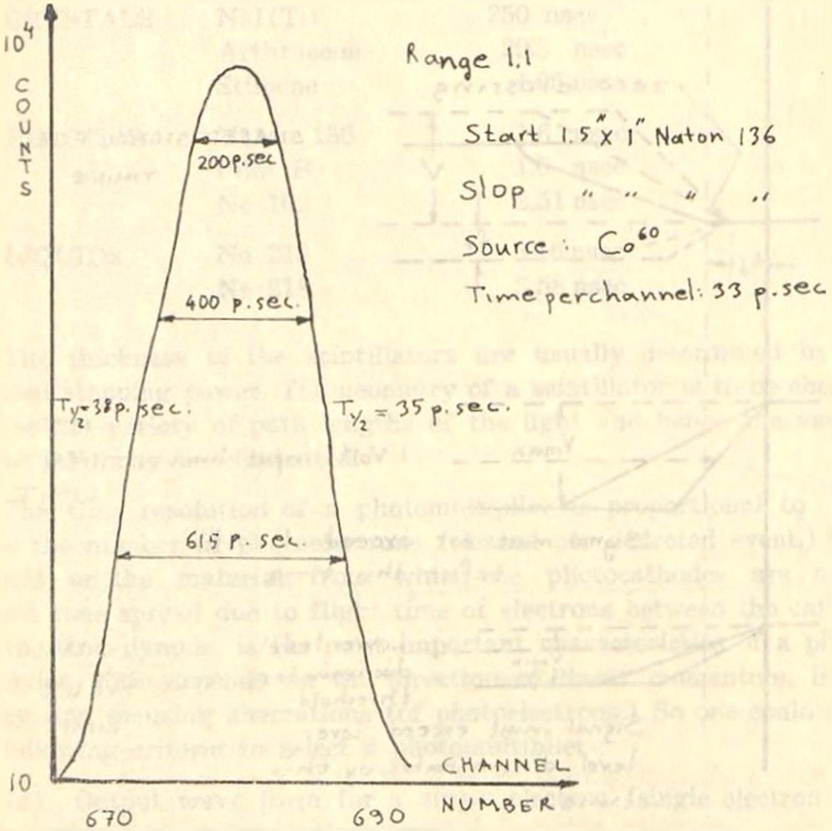

Fig. 5 The time resolution using Naton 136 crystals.

(5) Amplitude and Rise Time Compensated Method. As pointed out before both amplitudes and rise time might vary in solid state dedectors, such as Ge(Li). The difference between this method and the constant fraction T is in the amount of delay of full amplitude with respect to the rise time of the pulse. The following figure (fig. 6) explains the method used to obtain the zero - crossing point.

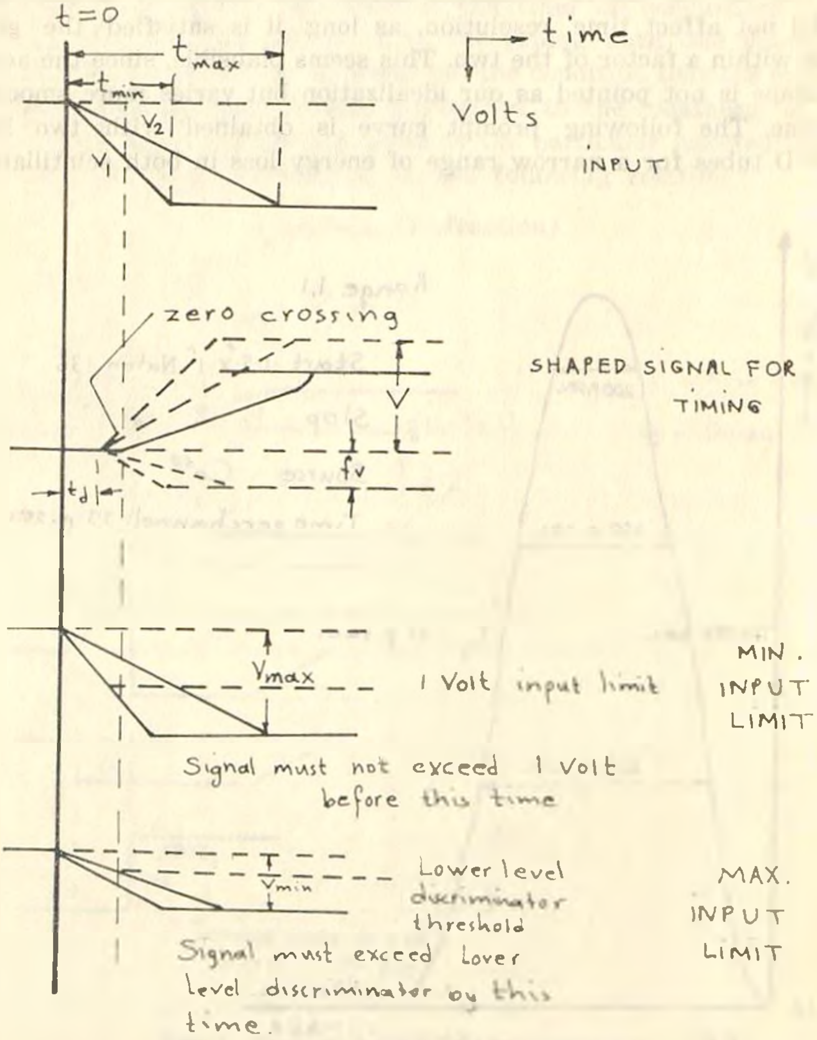

Fig. 6 The pulse shapes illustrating the amplitude and rise time compensated method.

Energy of the pulses which produce the timing spectrum and the dynamic range should be taken into account for the evaluation of the timing performance of a given system. When the dynamic range is set by a S.C.A. in the in the slow channel, it expands the pulses in time, and this lowers the optainable timing resolution.

CHOICE OF THE DEDECTORS AND ELECTRONICS FOR TIMING

(1) SCINTILLATORS AND PHOMULTIPLIERS.

The output of a photomultiplier depends on the fast decay time of the scintillator. Decay time constants for various scintillators have already been investigated:

CRYSTALS	NaI(Tl)	250 nsec
	Arthracene	29.3 nsec
	Stilbene	4.05 nsec
PLASTICS	Naton 136	1.6 nsec
	Pilot B	1.6 nsec
	Ne 102	2.51 nsec
LIQUIDS	Ne 213	3.16 nsec
	Ne 218	3.58 nsec

The thickness of the scintillators are usually determined by the required stopping power. The geometry of a scintillator is to be choosen so that the variety of path lengths of the light and hence the variety of the time may be eliminated.

The time resolution of a photomultiplier is proportional to $N^{1/2}$ (N is the number of photoelectrons released per dedected event.) This depends on the material from which the photocathodes are made. Transit time spread due to flight time of electrons between the cathode and the first dynode, is the most important characteristics of a photomultiplier. This depends on the direction of linear momentum, initial energy, and focusing aberrations (of photoelectrons.) So one could have the following criteria to select a photomultiplier :

(a) Output wave form for a single electron (single electron response) must have a low transit time;

(b) It must have a low transit time spread;

(c) It must have a high quantum efficiency (i.e. high yield of photoelectrons at the photocathode)

A recent research on some photomultipliers with fast plastics is presented by Morrer and Sperr. A summary of their results obtained with two Volvo XP 1021 tubes and with two RCA 31000 D tubes, is given in figure 7 in which the values for the RCA 8575 fall half way between those for XP 1021 and for the C 31000. D tubes and are omitted for reasons for clarity of the figure.

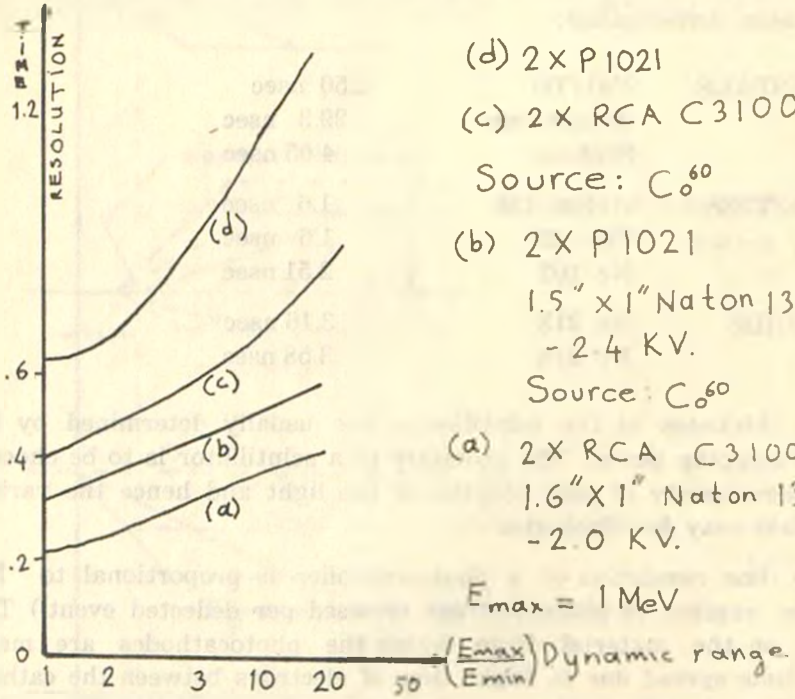

Fig. 7 Time resolution for various detector systems.

(II) SOLID STATE DEDECTORS :

Some important physical proterties of nearintrinsic silicon and germanium are important for timing measurements:

Property	Silicion	Germanium
Instrinsic resistivity (300 K)	230000 Ohm/cm	47 Ohm/cm
Intrinsic carrier concentration (300 K)	$1{,}5 \times 10^{10}/cm^3$	$2{,}35 \times 10^{13}/cm^3$
Electron drift mobility (300 K)	$1450\ cm^2/volt\ sec$	$3800\ cm^2/volt\ sec$
Hole drift mobility (300 K)	$480\ cm^2/volt\ sec$	$1800\ cm^2/volt\ sec$
Hole drift mobility (77 K)	$21000\ cm^2/volt\ sec$	$36000\ cm^2/volt\ sec$
Electron drift mobility (77 K)	$11000\ cm^2/volt\ sec$	$42000\ cm^2/volt\ sec$
Work function	5,0 eV	4,8 eV
Energy loss of minimum Ionizing particles	400 keV/mm.	830 keV/mm.

These numbers can easily show that Ge has many advantages over the silicion. Even the *p* - type Germanium should be much faster than that of the *n* - type Ge, for low, for low temperatures. Clearly for normal temteratures (300 K) these semiconductors will not be efficent. The thichness of the dedector should be adjusted by considering the last property in order to obtain an optimum depletion layer in which the particle is trapped.

The impurities and other imperfections should be avoided to make the recombination as low as possible. In fast pulse applications it is always necessary to ensure that the pulse rise time of the dedector itself is adequately short. Thus it may be necessary to minimize the series resistance of an undepleted layer of silicion, as can be done by appropiate choise of voltage and wafer of silicion thichness. This is particularly important at very low temperatures where the resistivity of the undepleted semiconductor may be far grater than its value at room temperature.

(III) The effect of a dedector pulse rise time which exceeds that of the amplifier is to give a reduced output signal, so the electronics, apart from the dedector itself is to be considered as well. Ortec proposes the following instruments for precise information of time :

(i) Ortec 453 Constant fraction timing.

(ii) Ortec 270 - 271 Constant fraction pulse height triggers.

(iii) Ortec 403 A Time pick off control.

(iv) Ortec 454 Timing filter amplifier.

(v) Ortec 454 + Ortec 453 provides fast timing signals from the surface barrier silicon dedectors and others.

Reference:

1) İ. Uluer and M.N. Khan,
S.D.M.M.A. Bulletin, SEA - 2 (1976) 46

2) M.R. Marrer and P. Sperr, Nucl. Inst. And Meth. 87. (1970) 13

3) Ortec Incorparated, Instruction manual.