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KARLSRUHE

April 1968 KFK 773

Institut für Angewandte Kernphysik

Timing Unit for Semiconductor Spectrometers

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KARLSRUHE

NUCLEAR INSTRUMENTS AND METHODS 61 (1968) 109–112; © NORTH-HOLLAND PUBLISHING CO.

TIMING UNIT FOR SEMICONDUCTOR SPECTROMETERS

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Received 18 January 1968

A timing unit is described which has been designed for semiconductor spectrometers where optimum energy resolution is of utmost importance. The circuit is connected between preamplifier and shaping amplifier. Leading edge timing is used for deriving the time signal. Results are shown for a charge-sensitive preamplifier with 150 nsec rise time. Employing a liquid scintillator and a planar 4.9 cm^3 Ge(Li) detector the full-width at half-maximum of the time distribution curve was 6.2 nsec if the semiconductor detector was gated on the 1836 keV full-energy peak from an ^{88}Y gamma-ray source. The circuit has been applied successfully in various high-resolution coincidence experiments. No energy resolution degradation has been observed.

The advances of semiconductor technology during the last few years have made feasible the fabrication of semiconductor counters with increased detector efficiency. Using these devices coincidence experiments with high energy resolution can be performed. Silicon or germanium diodes are successfully applied together with a scintillation counter[1,2]* or another semiconductor detector[3]. In any case a timing signal must be obtained from the diodes. The same problem arises in time-of-flight measurements[4] or in anticoincidence spectrometers[5] which make use of high-resolution semiconductor devices. Crossover timing may be used for all these experiments. However, in most applications long charge carrier collection times and large amplifier shaping time constants are unavoidable. This results in a broadening of the time distribution unless expensive methods such as a double amplifier chain are applied. In addition, in conventional crossover timing the signal is derived from the 50% point of the charge carrier collection function. Since this function varies in semiconductor counters, a considerable time shift is introduced[3,6].

An alternative and preferable procedure is to use a leading edge trigger device which may be set to trigger at a fixed amplitude corresponding to a few percent of the energy available in the timing event. In various applications great success has been achieved by deriving a time signal by means of a pulse transformer between detector and charge-sensitive preamplifier[7]. The secondary pulse transformer signal is fed into a wide-band transistor amplifier and a tunnel diode discriminator. In this way fission products have been analysed with a time accuracy of better than 1 nsec. However, this technique gives no promising results when light particles are to be detected with high energy resolution and when detectors with large sensitive volume are involved. The energy resolution is affected to a large extent and the threshold sensitivity is decreasing considerably with increasing sensitive volume and collection time.

* The list of publications cited here is not exhaustive; only typical examples are given.

The timing unit described in this paper has been designed for those applications where optimum energy resolution is of utmost importance. The circuit is connected between preamplifier and shaping amplifier. Leading edge timing is used for deriving the time signal.

Description of electronic design: The unit consists of five components: an input fan out circuit, an amplifier stage of medium rise time, a delay-line clipping circuit, a wide-band amplifier and a fast tunnel diode discriminator. The circuit diagram is shown in fig. 1. Silicon transistors are employed throughout the system to assure reliability and stability. The whole circuit can be easily soldered on two 105 mm × 120 mm plug-in cards which, together with the clipping cable, fit into an AEC/NIM standard double width module. The power required is +12 V, ~95 mA and −12 V, ~90 mA.

The output pulses from the charge-sensitive preamplifier are fed into the circuit which consists of three dc coupled emitter followers. The input impedance is chosen to match a 100 Ω coaxial line. It can be changed to 50 Ω simply by changing the base resistor of the first stage. The higher impedance is preferred in many applications in order to minimize the influence of the amplitude dependent preamplifier output impedance on the linearity of the spectrometer. The pickoff unit must have a negative input voltage. However, the circuit can be modified without difficulty to accept positive pulses.

The fan out circuit provides three output signals. The first one is fed into the shaping amplifier. A second output is provided for the application of a pulse-shape discriminator. Such a circuit has been described recently[8]. The spectrum shapes of lithium-drifted germanium diodes may be improved by rejecting preamplifier output pulses containing a slow time-constant

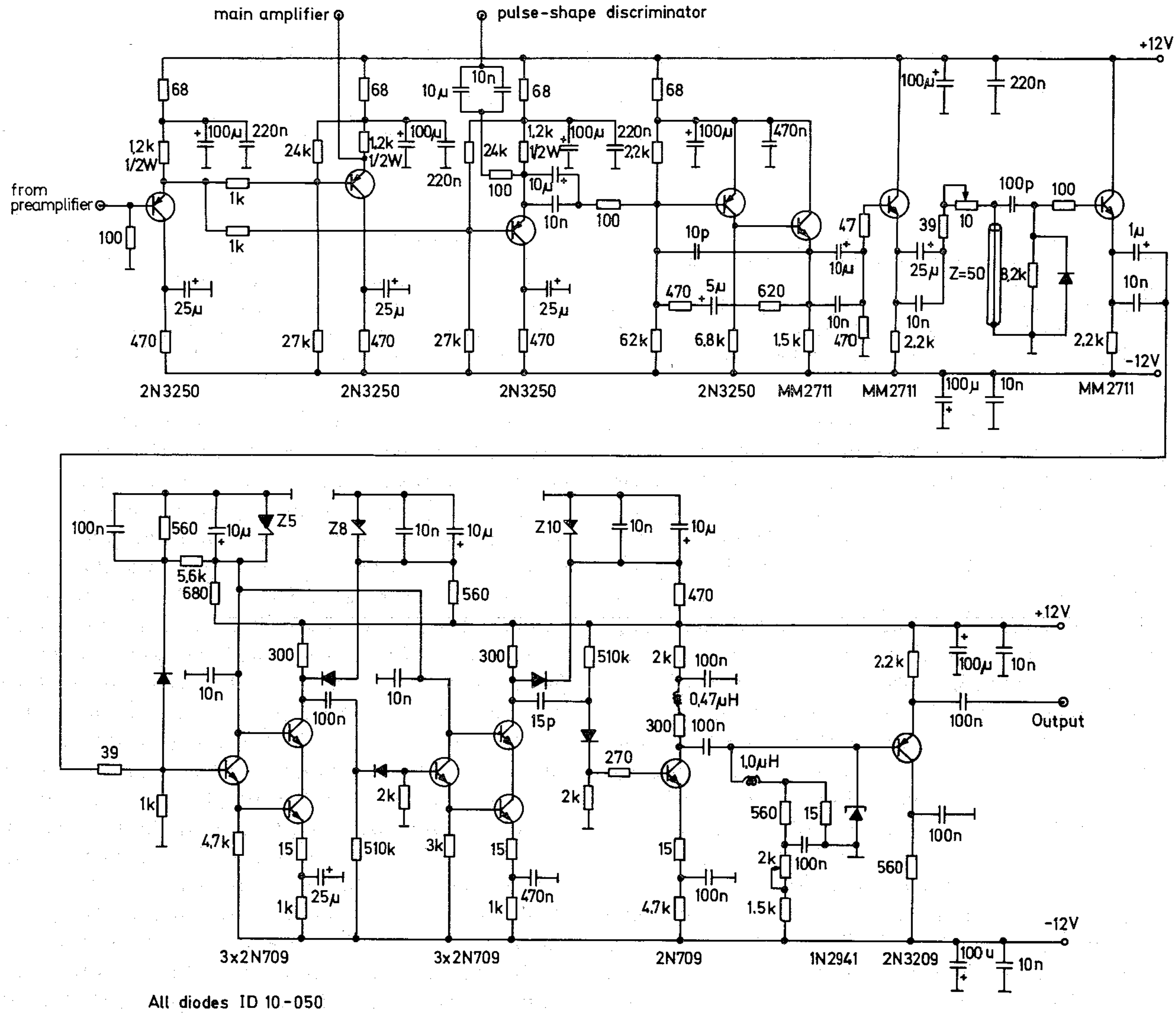

Fig. 1. Circuit diagram of the timing unit.

component. The third signal is used for deriving the time information.

The pulses pass an amplifier stage which has a rise time of about 20 nsec. In several applications this stage may be omitted or the gain of the circuit may be readjusted by changing the resistors in the feedback loop. The optimum conditions depend on the signal amplitude of the preamplifier. The sensitivity of the circuit shown in fig. 1 is suitable for an amplitude of about 100 mV/MeV and a dynamic range from 30 keV to 3 MeV.

The output of the amplifier stage feeds the clipping circuit, where a 50 Ω coaxial line is used for limiting the pulse width. This shaping procedure prevents multiple trigger of the timing unit on the wide input signal and, in addition, enables the circuit to process pile-up pulses. The signal width is determined by the length of the clipping cable and should be as narrow as possible. The optimum depends on the rise time of the preamplifier signals. For terminating the cable a variable resistor is provided in the emitter circuit of the preceding emitter follower. The baseline of the shaped pulses is restored by a differentiating *RC* network with a paralleled diode. This is of utmost importance since the subsequent circuit is sensitive to the first few percent of the pulse amplitude. Pulses which do not return accurately to the steady state baseline may cause multiple trigger of the timing unit.

The subsequent wide-band amplifier consists of two cascode stages each driven by an emitter follower. This configuration is based on design considerations given in [9]) for obtaining maximum bandwidth in transistorized amplifiers. The overall gain is about 100. Biased diodes at the input and at the output of each stage limit the pulse amplitude to a value between 500 mV and 1 V. Appropriate voltage levels are provided by Zener diode networks. Undershoots are reduced by diodes which are positively biased for the signal polarity. Using this procedure limited pulses with a rise time between 3 and 4 nsec appear at the output of the amplifier. These pulses correspond to the initial rise of the preamplifier signals and carry the time information of the detector events. In applications with charge-sensitive preamplifiers of comparatively fast rise times it may be convenient to increase the high-frequency response of the wide-band amplifier by adding an inductor in series to the 300 Ω load resistor and a bypassing capacitor to the degenerative feedback resistor.

Standard output signals are obtained using a fast tunnel diode discriminator. In a preceding *RC* network the trigger pulses are differentiated with a short time constant. The bias current for the tunnel diode is controlled by means of a front panel helipot. In order to minimize time "walk" the discriminator threshold should be set as low as possible. The circuit should trigger on amplifier noise when the level is very near zero. The inductance in the tunnel diode network determines the width of the output pulses. The amplitude is about 400 mV.

Performance: The timing unit was tested employing a charge-sensitive preamplifier with 150 nsec rise time. The results are shown in figs. 2 and 3. Gamma-ray sources of ^{22}Na or ^{88}Y were placed between a liquid scintillator mounted on a 56 AVP photomultiplier and a planar Ge(Li) detector with 7 cm^2 sensitive area and ≧ 7 mm compensated region. The time resolution curves were measured using a fast time-to-analog converter and a 1024 pulse-height analyser. The Ge(Li) detector was gated either on a signal amplitude corresponding to $E \geqq 200$ keV or on the full-energy peaks at 511 keV and 1836 keV, respectively. Simplified block diagrams for these measurements are given in the insets of figs. 2 and

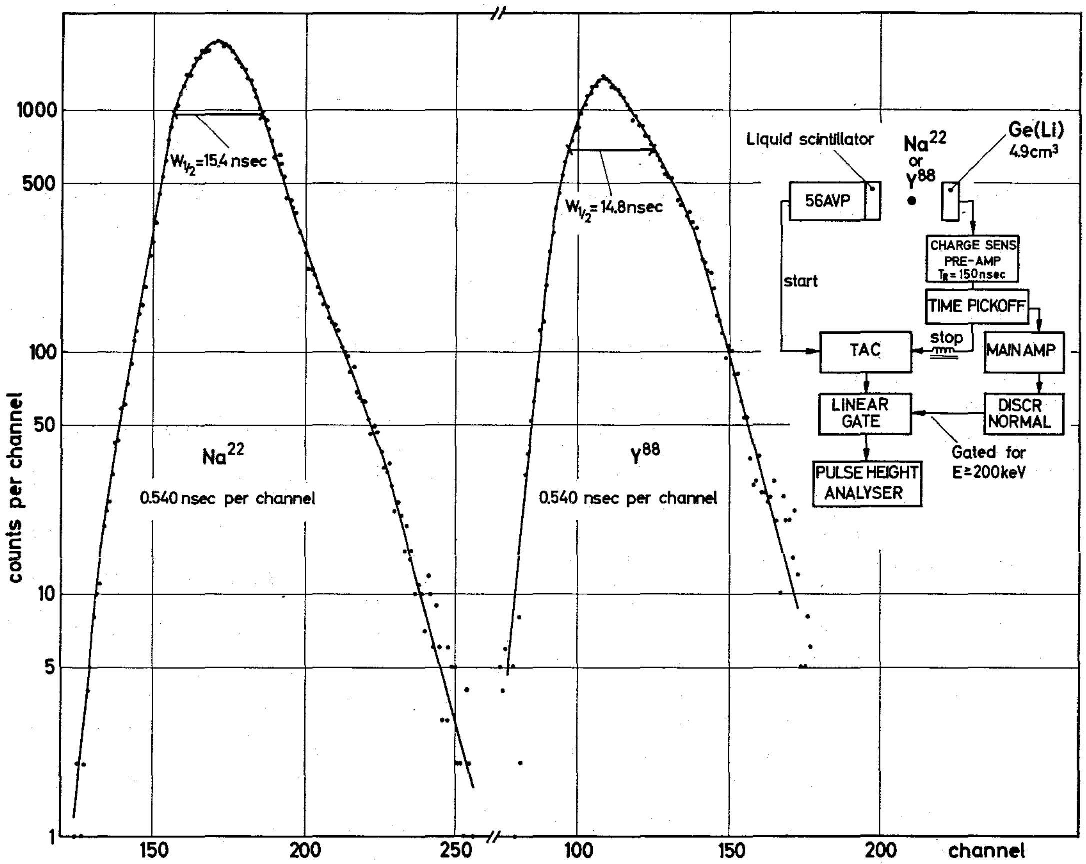

Fig. 2. Time distribution curves observed with a liquid scintillator and a 4.9 cm³ Ge(Li) detector. Rise time of the preamplifier 150 nsec. Ge(Li) counter gated for $E \geqq 200$ keV.

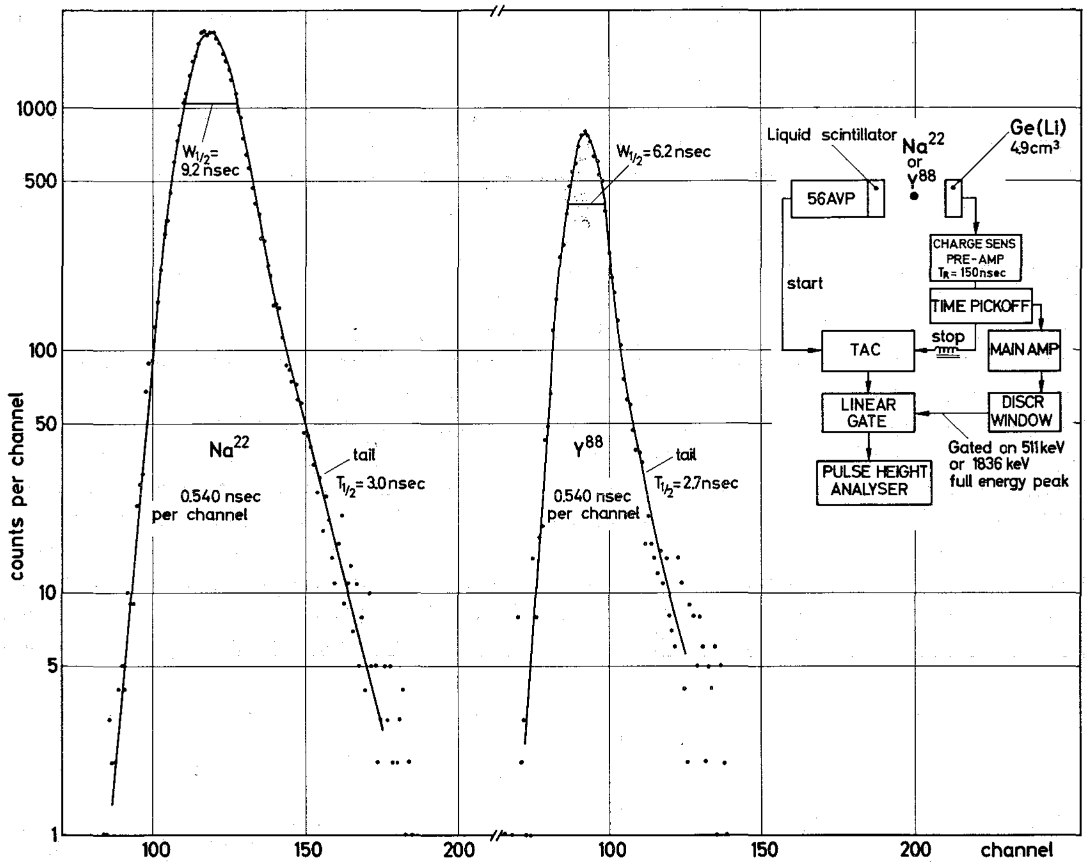

Fig. 3. Time distribution curves observed with a liquid scintillator and a 4.9 cm³ Ge(Li) detector. Rise time of the preamplifier 150 nsec. Ge(Li) counter gated on the full-energy peaks at 511 keV and 1836 keV from ^{22}Na and ^{88}Y, respectively.

3. The time spread for the scintillation counter was about 1 nsec full-width at half-maximum. The data were taken with a triggering threshold at 40 keV in the timing unit. The detector bias was 700 V.

If the Ge(Li) counter was gated for $E \geqq 200$ keV, the observed full-width at half-maximum of the overall time resolution curve was 15.4 nsec for ^{22}Na and 14.8 nsec for ^{88}Y. Gating on the full-energy peaks revealed 9.2 nsec and 6.2 nsec, respectively. Due to time walk with pulse height, tails appear on the time distribution with $T_{\frac{1}{2}} = 3.0$ and 2.7 nsec.

The results shown in figs. 2 and 3 illustrate the ability of the timing circuit to derive reasonable time information in spite of an unfavourable bandwidth of the charge-sensitive preamplifier. Better time resolution is possible by using a preamplifier with shorter rise time and a lower discriminator threshold. A slight improvement may also be obtained with detectors permitting a higher field strength.

The circuit has been applied successfully in various coincidence experiments which require utmost precision in the energy determination[1,2,5,10]. No measurable energy resolution degradation due to the timing unit has been observed.

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