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A FAST-SLOW COINCIDENCE SYSTEM

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A fully transistorized fast-slow coincidence system is described. The triggering of the fast-signal shaping circuits happens at zero crossover of the slow input-signals. The device exhibits a 4 ns fwhm physical prompt resolution curve and allows a fast coincidence with 8 ns resolving time at 100% efficiency to be used.

1. Introduction

In nuclear physics as well as in positronium physics it is sometimes necessary to detect γ-rays with good energy-resolution and high detection-efficiency.

For this purpose scintillator crystals, coupled with suitable photomultipliers (like 6342, or 153 AVP) are commonly used.

On the other hand it can be needed to detect γ-rays with high time-resolution, as in time-of-flight or positronium life-time measurements.

In this case the detectors consist of plastic scintillators coupled with photomultipliers (like 6810, 56 AVP or, recently, the XP 1020) exhibiting transit time fluctuations and geometrical time-spread rather small.

When both energy resolution and time resolution, joined to high detection-efficiency, are required, it is necessary to apply suitable electronic techniques[1–3]), in order to time as accurately as possible pulses which, carrying energy information, are essentially slow because coming from inorganic scintillators.

If this is done, a fast coincidence can be used, thus realizing a so called "Fast-slow coincidence system".

This fast-slow technique is based upon the possibility of deriving fast pulses, in the nanosecond range, from slow ones that are proportional to the energy, exploiting either the first photoelectrons due to the event to be timed (leading edge method)[4,5]), or the zero crossover of the amplified signal[6,7]).

The former method yields a high time-resolution[8]), but in our apparatus we have employed the latter method because it is independent from the signal amplitude.

Bertolaccini et al.[2]) in fact, with their apparatus based upon the leading edge method, get a prompt resolution curve of 2.6 ns at 100% coincidence efficiency, if a photopeak amplitude selection is made; without that selection the fwhm becomes 5.3 ns and the coincidence resolving time at 100% efficiency about 20 ns.

2. Apparatus

The block diagram of the realized fast-slow coincidence assembly is shown in fig. 1.

The detectors are photomultipliers Philips 153 AVP equipped with 1″ × 2″ NaI(Tl)scintillators. The output pulses are fed into double-delay-line clipped amplifiers, each output signal of which is injected into two channels.

Along the first channel, the slow one, after an amplitude discrimination, the signals are sent to a slow coincidence, with the aim of roughly reducing the chance pulses and enabling the second channel, the fast one, to form suitable signals to be sent to the fast coincidence.

The apparatus has a dead time of 10 μs, mainly determined by the amplifier recovery time.

We have designed and realized the electronic circuits concerning the fast channels, while the slow channels are commercially available (Laben) circuits.

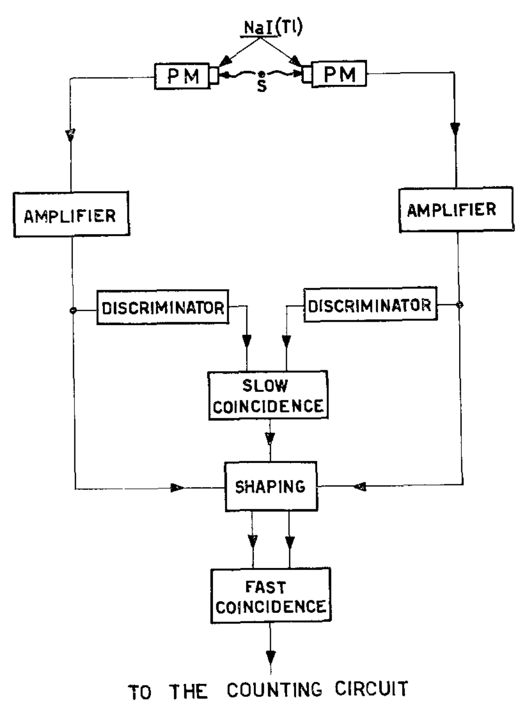


Fig. 1. Block diagram.

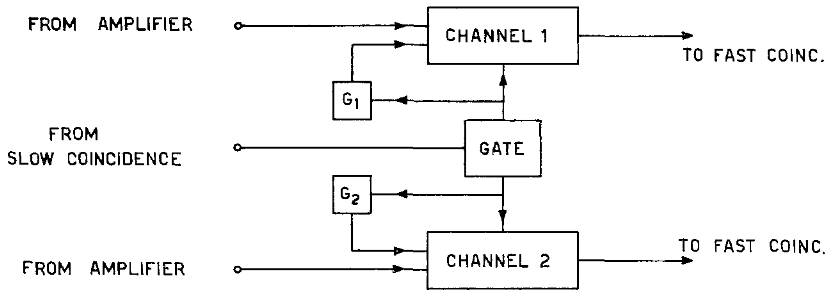


Fig. 2. Shaping circuit block diagram.

3. Fast circuit description

3.1. General

The logical scheme is shown in fig. 2, while in fig. 3 are reported schematically the main waveforms showing time relationships.

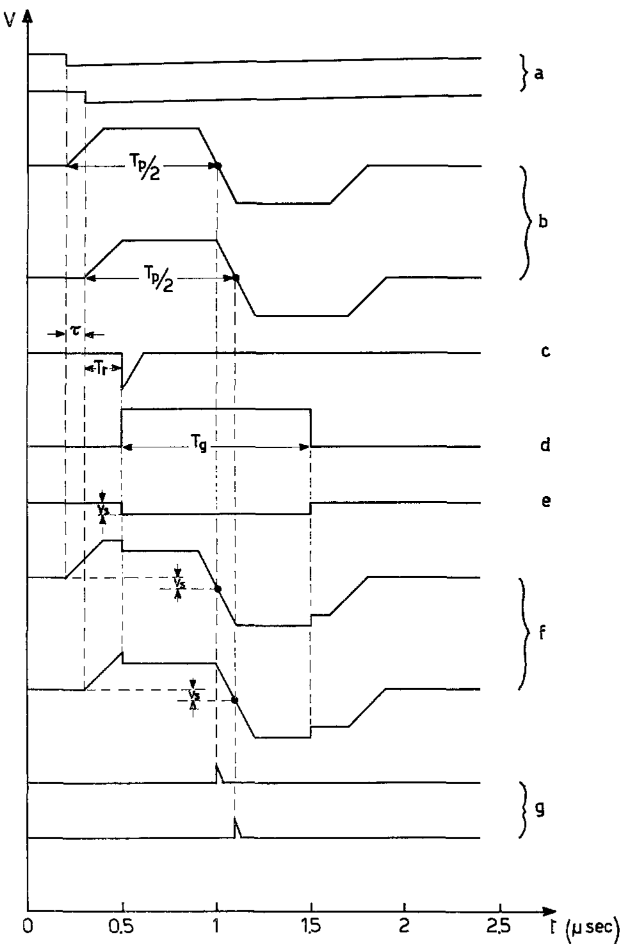


Fig. 3. Typical waveforms vs time. a. Photomultiplier output signals; b. Amplifier output signals; c. Slow coincidence output signal; d. Gate circuit signal; e. Adding step pulses; f. Shaper input signals formed by the superposition of (b) and (e); g. Resulting output fast signals.

The blocks marked Channel 1 and Channel 2 represent the shaping circuits producing the fast signals to be sent to the fast coincidence.

As these timing signals (g in fig. 3) have to be generated at zero crossover of the bipolar pulses (b) coming from the amplifiers, the shaper threshold must be set at zero level. But, in this condition, any disturbance would trigger the circuit. In order to avoid this undesired event, a gate multivibrator has been added. It is fired by the slow coincidence output pulse (c) and enables the fast channels to sense the input signals. In this way the shaping circuits deliver output pulses only if they are due to events taking place within the slow coincidence resolving time.

The same gate output pulse (d) drives also the blocks G1 and G2; these are two current pulse generators producing accurately-adjustable negative step pulses (e) which allow the triggering of the fast circuits to occur exactly at the zero crossover of the signals to be timed.

Let's note that, although the input thresholds are at zero level throughout the entire gate-duration, the shapers trigger at the right moment owing to the input signals that, already present at the gate pulse arrival, keep the input voltage levels positive until the signals themselves zero cross at a well determined instant (f in fig. 3).

About the time relationships between the various signals, it must be noted that the gate signal has to arrive before the first input signal has zero crossed. This can be analytically expressed in terms of time intervals by

$$\tau + T_r < \tfrac{1}{2}T_p,$$

where (fig. 3) τ, the slow coincidence resolving time, is the maximum permissible delay between two input signals of interest, T_r is the fixed delay due to the coincidence itself, and T_p the input signal durations.

As a first consequence τ must be smaller than $\frac{1}{2}T_p - T_r$.

The gate pulse must on the other hand be present at zero crossover time and it must cease when the first

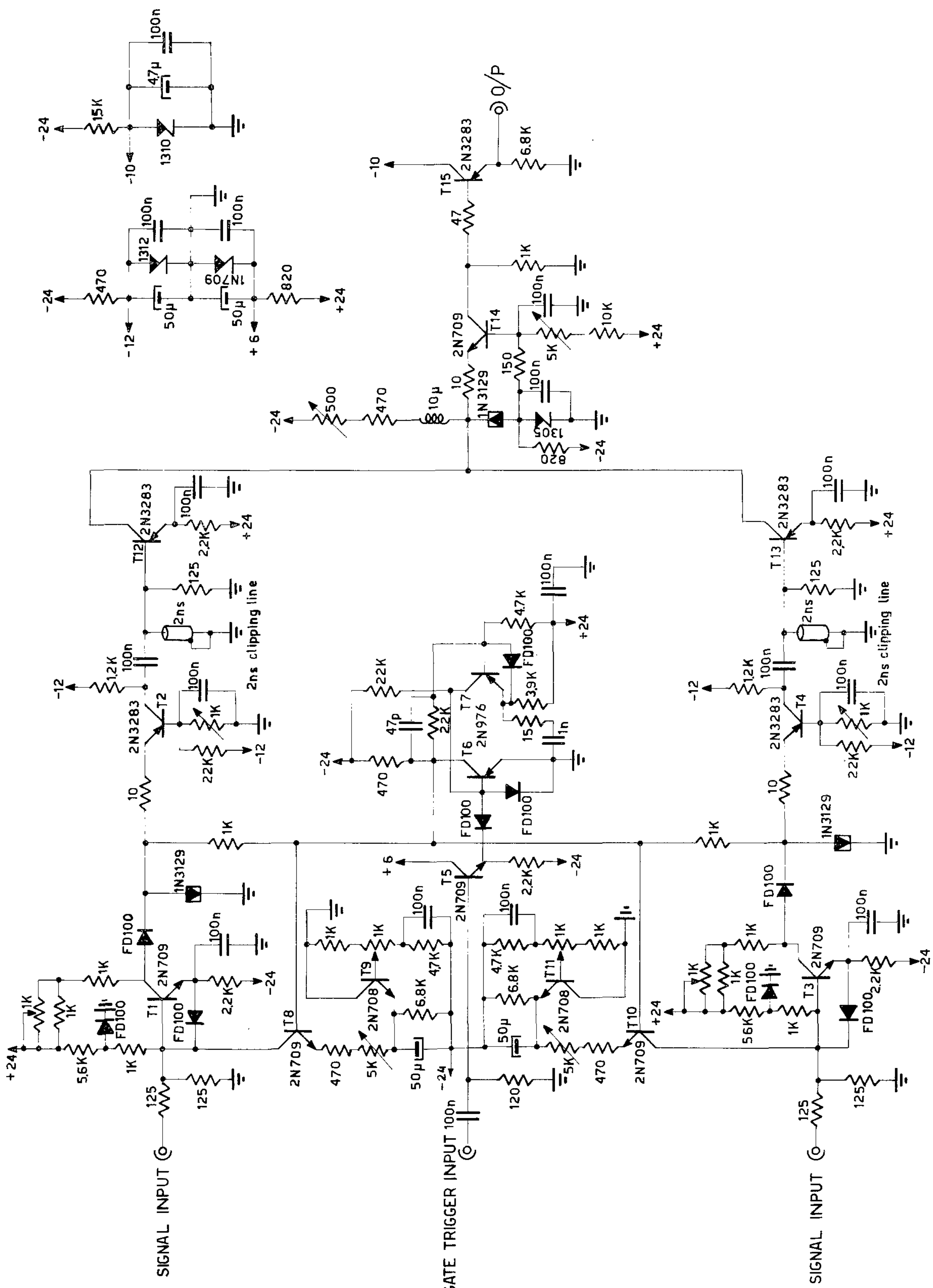


Fig. 4. Shaping circuit and fast coincidence schematic diagram.

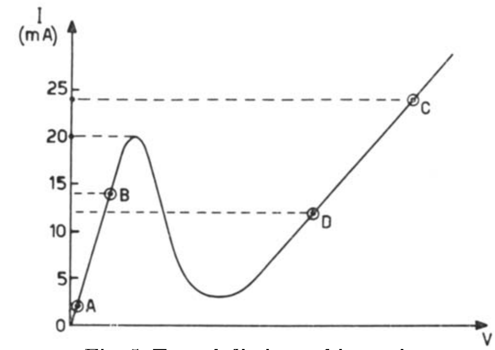


Fig. 5. Tunnel-diode working points.

input signal has ceased. Its duration T_g must therefore satisfy the following conditions

$$\tfrac{1}{2}T_p - T_r < T_g < T_p - (\tau + T_r).$$

In our case, with $T_p = 1.6\ \mu$s and $T_r = 0.2\ \mu$s, we have made $\tau = 0.2\ \mu$s and $T_g = 1\ \mu$s.

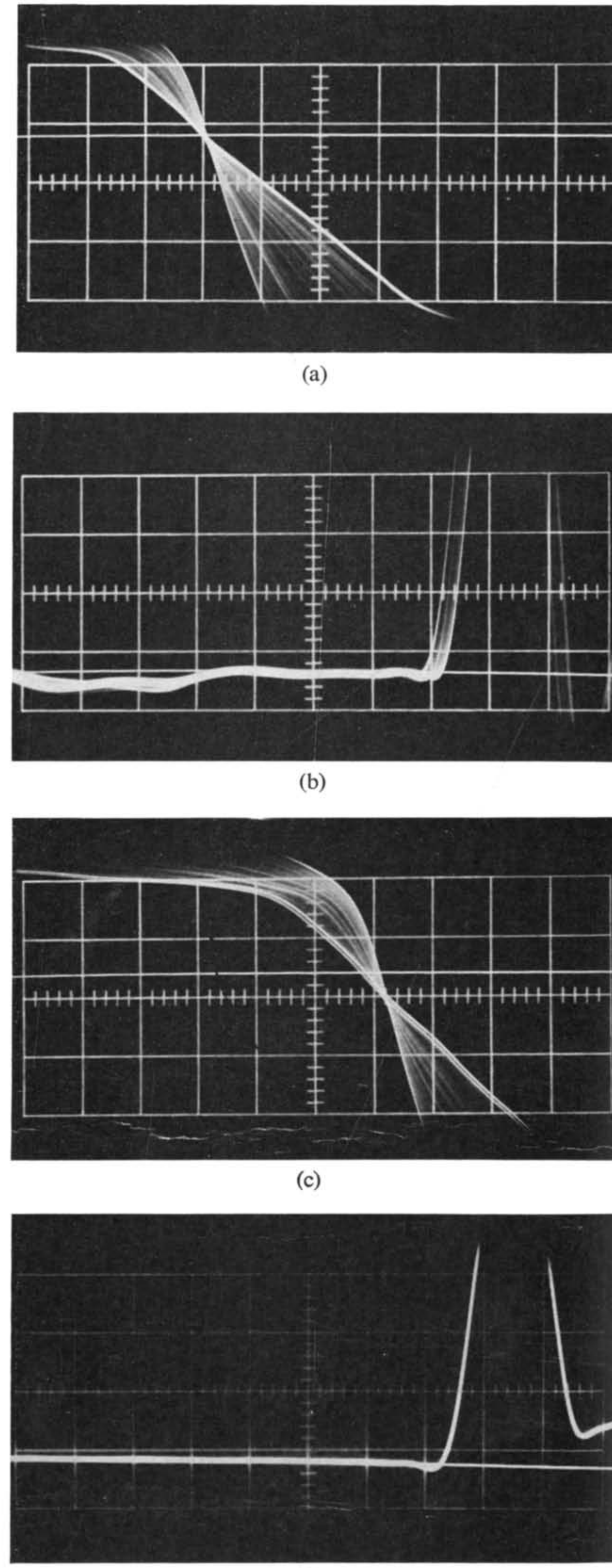
3.2. Fast shapers

Owing to the circuit symmetry in the following discussion we will refer to the upper channel of fig. 4.

Since the voltage across a tunnel diode is negligible, the + 24 V power supply and the T1 collector resistor act as a 24 mA current generator. Under quiescent conditions, the input transistor T1 is conducting 10 mA. 12 mA out of the remaining 14 mA are flowing through the 1 kΩ resistor, connecting the tunnel diode to the transistor T6, which is cut off, and the last 2 mA flow through the tunnel diode, which is biased at point A of fig. 5.

A negative-going voltage at the gate input causes T6 to saturate and the 12 mA current to be diverted into the tunnel diode, that now is carrying 14 mA (point B in fig. 5).

In these conditions any voltage applied to the input, able to cut off the transistor T1, forces the remaining 10 mA to flow through the tunnel diode which switches rapidly to the point C, and remains there until the end either of the gate signal, whose duration depends upon the values of C and R at the T7 emitter, or of the input signal. In our case the gate signal stops before the input signal, so that the last operating point D in fig. 5 corresponds to the presence of the input signal only, which will cease later.



(a)

(b)

(c)

(d)

Fig. 6. Oscilloscope pictures (2 V/cm and 10 ns/cm) showing: a. Particular of the signals at the input without added step; b. Resulting output signals exhibiting time shift; c. Input signals with added step; d. Resulting output signals unaffected by time shift.

As far as transistors T8 and T9 are concerned, they form the current pulse generator necessary to make the input threshold zero in presence of the signal to be timed.

T9 acts as a continuously and finely variable voltage generator, adjustable by means of a multiturn potentiometer and T8 constitutes just the current generator. The latter, which is normally cut off, is driven by the gate circuit pulse, which jumps from -12 to 0 V, so that the current pulse carried during the gate duration T_g can be accurately adjusted simply by setting properly the voltage at the T9 emitter.

The effect of this step pulse added to the input can be seen in fig. 6, where are reproduced four oscilloscope pictures. They show clearly the circuit behaviour with and without the added step.

Fig. 6 a,b refer to the circuit with T8 disconnected. The input signals are properly crossing at zero level (represented by the continuous line in fig. 6a), but the shaper output (fig. 6b) exhibits a time shift of about 2 ns due to the fact that the input threshold is different from zero.

Instead, when T8 is working, the signal crossover happens at a fixed point, shifted below the zero level (fig. 6c) and corresponding to the threshold level; now the shaper output pulse appears sufficiently fixed in time (fig. 6d) as required by a proper operation.

3.3. Fast coincidence

The shaper pulses, clipped to 2 ns, are sent to transistors T12 and T13, each conducting 10 mA. They take away almost the entire current supplied by the generator formed by the -24 V power supply and by the resistors preceding the inductor. Therefore, only if both are cut off, the tunnel diode, having a 20 mA peak current, is allowed to switch, then supplying a negative output pulse.

It must be taken into account that, for signals whose duration is smaller than the rise time of the coincidence input transistors, the resolving time depends upon the tunnel diode biasing current.

4. Performance

The following tests have been carried out on the described apparatus.

4.1. Electronic intrinsic resolution

To perform this measurement a slow pulse generator and a time-to-height converter[9]) were used. The generator output pulse was applied to the input of both amplifiers while to the THC were sent the shaper output pulses, one as start signal and the other, suitably delayed, as stop signal. Analyzing the THC output pulses with a multichannel, which was set for a conversion of 50 ps/ch, the curve of fig. 7, showing a width at half maximum of 150 ps, has been obtained.

4.2. Zero crossover performance

The arrangement is shown in fig. 8. The purpose of the test is to appreciate how much the zero crossover and a proper threshold-centering can overcome the amplitude effects upon the time shift. The amplitude of the input signals was varied of 80% in a range cor-

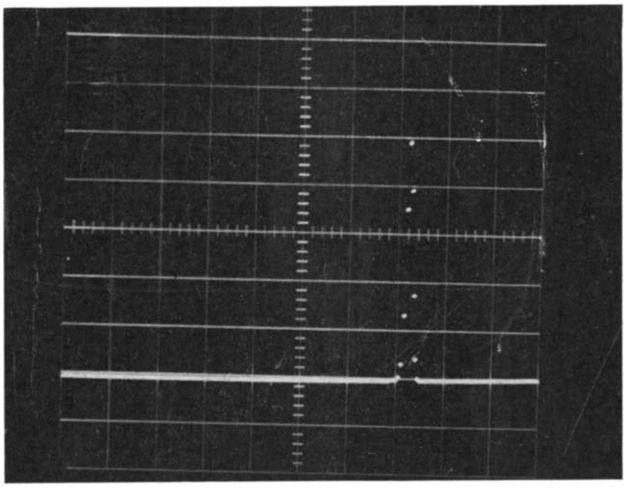


Fig. 7. Multichannel CRT display of the electronic intrinsic resolution (50 ps/ch).

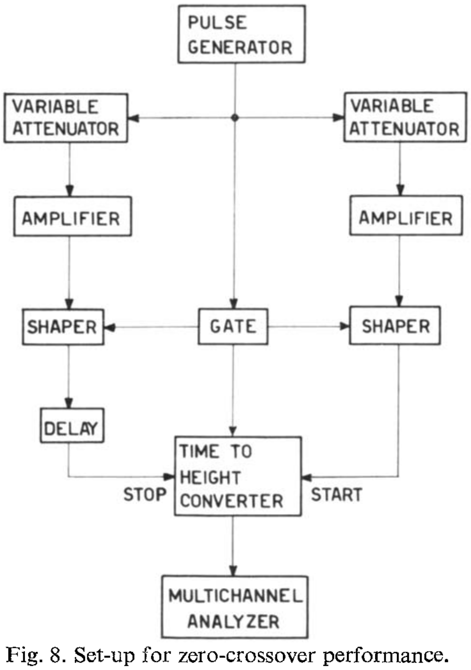


Fig. 8. Set-up for zero-crossover performance.

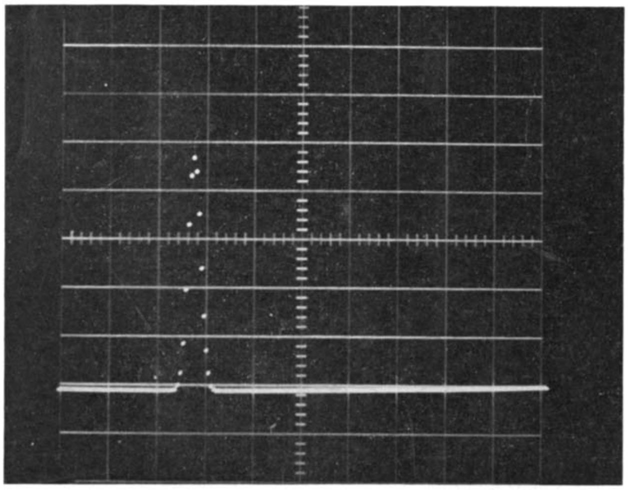


Fig. 9. Displayed curve in the condition of fig. 8 (50 ps/ch).

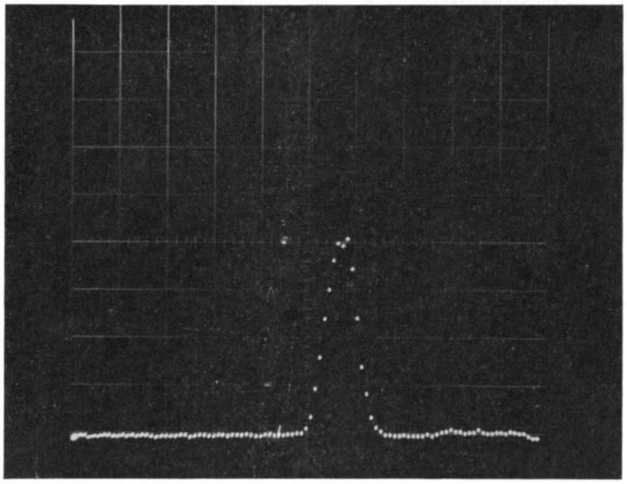


Fig. 10. Prompt resolution curve in working conditions (0.5 ns/ch).

responding to the amplitudes of the photomultiplier pulses. The obtained curve (fig. 9) exhibits a fwhm of 300 ps.

4.3. Prompt resolution

This measure recalls the one taken for the instrinsic resolution. The difference consists in the presence of the detectors, which mainly contribute to the time shifts, and of a ^{60}Co source, which emits simultaneous γ-rays. Operating as before, the multichannel analyzer, set for a conversion of 0.5 ns/ch, yields a 4 ns fwhm time curve (fig. 10).

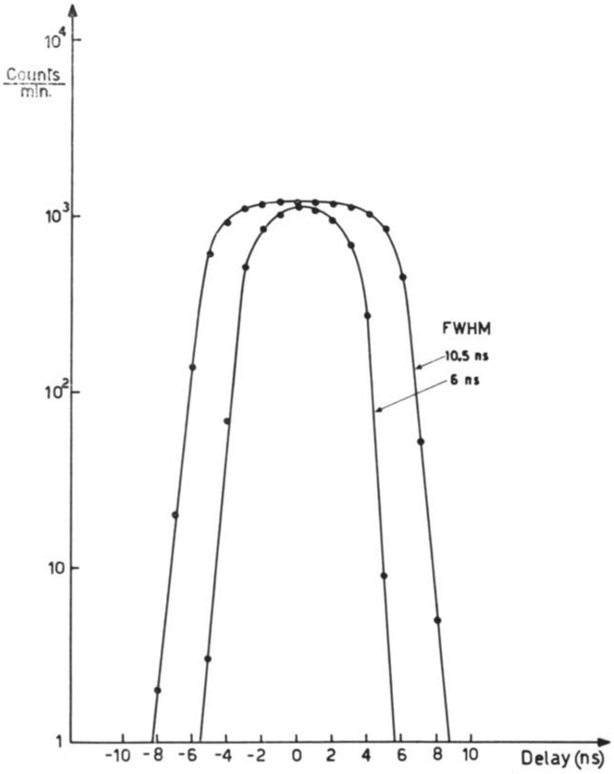


Fig. 11. Delayed coincidence curves.

4.4. Fast coincidence resolving time

This final test has been performed with the entire apparatus in working conditions (fig. 11) and the ^{60}Co source. Clipping the shaper fast signals to 2 ns, a coincidence curve, 10.5 ns wide at half maximum with 100% efficiency has been obtained.

Adjusting the coincidence tunnel diode biasing, it is possible, still at 100% efficiency, to reduce to 8 ns the width at half maximum.

At 95% efficiency the curve at half maximum exhibits a 6 ns width.

5. Conclusion

Owing to the simplicity of the design logic, the realization of the apparatus does not present particular difficulties.

Moreover it is possible its extension up to four channels. The fast coincidence needs in fact only two other input transistors, while the slow coincidence is really a quadruple one, which, however, can be used as a double or a triple one.

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