Rutherford Laboratory
CHILTON, DIDCOT, OXON. OX11 0QX

RL-77-106/A

A NEW DISCRIMINATOR PRINCIPLE FOR SLOW NEUTRON COUNTING

P L DAVIDSON

OCTOBER 1977

RL-77-106/A

RL-77-106/A

A NEW DISCRIMINATOR PRINCIPLE FOR SLOW NEUTRON COUNTING

P L Davidson

ABSTRACT

A discriminator for use with scintillator-photomultiplier neutron detectors is described which uses modern fast electronics to give high noise suppression, adequate γ discrimination for many neutron scattering applications, and a response which is insensitive to photomultiplier gain.

Rutherford Laboratory
Chilton
Didcot
Oxon
OX11 OQX

October 1977

CONTENTS

1 INTRODUCTION

The use of photomultipliers coupled to scintillators containing absorbing nuclei is one of the oldest methods of detecting slow neutrons [1]. In particular, ^{6}Li loaded zinc sulphide in a plastic binder has been used for many years and has a number of advantages, e.g., it is thin and thus ideal for time-of-flight applications, it can be made flexible and large areas can be covered at moderate cost. However, it has one major disadvantage compared to other detection methods such as gas counters. This is its poor pulse height spectrum, illustrated in Fig.1(a), which is caused by self absorption of photons produced by the scintillator event in the scintillator itself. Neutrons absorbed near the surface of the scintillator remote from the photomultiplier (PM) produce small pulses which are indistinguishable from the PM noise pulses. Thus if pulse height discriminator levels are set high enough to eliminate the noise pulses, many neutron pulses are lost as well. Some improvement can be obtained by using two PM's in coincidence to view the same event, which greatly reduces the PM noise, but many small neutron pulses are still lost. If, instead of a pulse height analysis of the PM output, a pulse charge analysis is made, a more favourable spectrum results, as illustrated in Fig. 1(b), in which better separation between neutron and noise pulses is obtained. Discriminators using the charge contained in a pulse, rather than the pulse height, have been used to reduce the γ sensitivity of lithium loaded glass scintillators [2].

This report describes a new method of discrimination made possible by modern electronics which allows sophisticated manipulation of fast pulses at low cost.

2 DISCRIMINATOR PRINCIPLE AND CIRCUIT

The PM is capable of detecting single photoelectrons in a time of about 3 ns. In many applications, where the optical coupling between the scintillator and photocathode results in large losses of light, the rate of arrival of photons at the photocathode is such that individual photons or groups of few photons can be resolved and the PM output is in the form

of a train of separate pulses as illustrated in Fig. 2(a). When the optical coupling is good, these pulses pile up and some integration occurs as in Fig. 2(b). With a zinc sulphide scintillator, the light output lasts between 1 and 10 μs. Now if these pulses are passed through a fast AC coupled pulse shaper with an output pulse width of about 20 ns, then in either of the cases shown in Figs. 2(a) and 2(b) a train of standard pulses is produced with constant pulse height, as illustrated in Fig. 2(c). This pulse train has a characteristic distribution in time for neutron events in the scintillator. The PM noise pulses are mostly single electron events (but see section 3.2) which, though they also produce standard pulses, are much more widely separated in time. For example, the mean time between pulses for noise, strong scintillator neutron signals and weak scintillator neutron signals are roughly as follows:-

PM noise	200 μs
Strong neutron pulse	∿ 30 ns
Weak neutron pulse	∿ 100 ns

The new discriminator circuit, on receipt of a pulse (which may be a noise pulse) opens a time window and requires a specified number of standard pulses to occur within the window before an output pulse is produced. The actual sequence of operation is as follows:-

If an input pulse is received a preset time window of between 400 and 800 ns is opened after a preset time delay of between 200 and 300 ns. The delay is required to position the window at the time of maximum pulse rate for a neutron event. A preset number of standard pulses, between 2 and 8, is demanded within the window. If these are not counted, the circuit resets and no output pulse is produced. If they are counted, an output pulse is generated and the circuit is held dead for an appropriate time to avoid the possibility of counting the same pulse twice. The circuit then resets ready for the next input pulse.

The theoretical performance of such a circuit in suppressing PM noise can be estimated as follows. If the noise pulses are assumed to have a mean rate $\overline{n}$, then the probability, p, of k pulses occurring in a time δt is given by:

$$p = \frac{(\bar{n}\delta t)^k e^{-\bar{n}\delta t}}{k!} \qquad (1)$$

For small values of $\bar{n}\delta t$ thus simplifies to

$$p = \frac{(\bar{n}\delta t)^k}{k!} \qquad (2)$$

Thus for an input pulse rate of $\bar{n}$, the output count rate, N, is given by

$$N = \bar{n}p = \frac{\bar{n}^{(k + 1)} \delta t^k}{k!} \qquad (3)$$

For $\bar{n} = 5 \times 10^3$ c-s^{-1} (typical for PM noise) $\delta t = 600$ μs and $k = 4$ we have

$$N = \frac{(5 \times 10^3)^5 \times (600 \times 10^{-9})^4}{24} \approx 2 \times 10^{-8} \text{ c-s}^{-1}$$

or very roughly 1 count per year.

A circuit in use at present is shown in Fig. 3 and operates as follows:

Upon receiving a pulse, gate 1 inverts and applies it to gate 2 which is held in the enabled condition. Gate 3 again inverts and applies the pulse to gate 4 which is also in the enabled condition. The output from gate 4 triggers both the inhibit and delay monostables. The output from the inhibit monostable inhibits gate 4 to prevent later pulses re-triggering either the inhibit or delay monostables during the counting process, while the output from the delay monostable clears and inhibits the counter for a preset time. After this preset delay time the counter is enabled and can count any subsequent pulses within the window generated by the time difference between the inhibit and delay monostables, after which the system resets. If the counter counts the required number of pulses an output appears on the appropriate counter position and triggers both the dead time and output pulse monostables. The dead time both clears the counter and inhibits gate 2 long enough to prevent the system from counting the same event twice. The output pulse generator offers the facility of variable pulse length and either positive or negative output pulses. When the dead-time generator resets, the system is enabled ready for the next event.

3 TEST RESULTS

3.1 Detector Module

The discriminator was used with the neutron detector shown in Fig. 4 which consists of a strip of 0.4 mm thick ^{6}Li-ZnS scintillator supplied by Nuclear Enterprises Ltd. (NE 425), 2 cm wide and 55 cm long, optically coupled to an RCA 8575 photomultiplier by means of a simple tapering box with the inside surfaces covered with aluminised Melinex as a reflector. The PM output was amplified in a Le Croy 612 amplifier and then fed to a Le Croy 621 pulse height discriminator, used in this case simply as a pulse shaper with a standard 20 ns wide output pulse. This output was fed to the new discriminator unit. The detector was tested both on a Laboratory neutron source at the Rutherford Laboratory (RL) and at the Institut Laue-Langevin (ILL) Grenoble. At the latter facility the "Canal Technique" was used which is situated on a thermal guide tube and allowed the detector to be scanned across a small diameter, well collimated neutron beam with a wavelength of 2.4 Å. Measurements of various parameters are described below.

3.2 Electronic Noise

Advantage was taken of a temporary reactor shut down at ILL to check the response of the detector with no neutron sources present. An overnight run of 30 min counting periods separated by 20 mins yielded a total count of 1021 in a total counting time of 9½ hours, i.e. a rate of 107 c-h^{-1}. The PM noise pulse rate measured at the input to the new discriminator was about 5×10^3 c-s^{-1}. The degree of noise suppression was thus about 1.5×10^5. Further measurements at RL have shown that the residual noise rate is due to effects in the PM itself which give rise to bursts of pulses resembling genuine neutron events in the scintillator. The main contribution is considered to be due to residual radio-activity in the envelope of the PM[3]. Tests made with a different PM manufactured with a hard glass envelope (Mullard type XP 2230) showed much reduced noise count and γ sensitivity (see section 3.5). An overnight run with this PM resulted in a noise count of 9 in 16 hours or a noise suppression of about 3×10^7.

3.3 Efficiency

The stopping power of the scintillator itself was found at a neutron wavelength of 2.4Å in a transmission measurement using a 5 atmosphere ^{3}He gas counter. The result was 34% for a thickness of 0.4mm. In the detector module the scintillator is supported on a strip of Perspex 2.5mm thick. This has the effect of backscattering a fraction of the neutrons which were not absorbed by the scintillator, providing a second chance to detect them and producing a small increase in overall detection efficiency. The "stopping power" of the combination of 0.4mm thick scintillator and Perspex was 55%. Various measurements were made of the efficiency of the complete detector. It was completely covered with cadmium and plastic B_4C shielding except for a 1 cm^2 aperture. A collimated neutron beam of diameter ∿ 2mm was used, the absolute intensity being measured by the ^{3}He counter which was 10cm long, with a ceramic end window and its efficiency was assumed to be 100%. For some measurements a thin cadmium absorber was placed in the beam which reduced its intensity to 9% of the full beam.

The first measurements were made using the attenuator and with the detector axis slightly tilted so that the beam did not pass through the PM (see section 3.5). In each case the background measured with the main beam stop in was less than 1% of the signal and was ignored. The results were as follows:

^{3}He counter	- 9200 c per 10s
Centre of scintillator	- 3000 c per 10s - efficiency 32.5%
One end of scintillator	- 3100 c per 10s - efficiency 33.5%

When corrected for perpendicular incidence a mean value of 32% is obtained.

When no attenuator was used the scintillator counter yielded 39,000 c per 10s in the centre and at normal incidence compared to the gas counter reading of 112,000 c per 10s, i.e. an efficiency of 34.8%. By comparing these values with the stopping power of the scintillator itself and the scintillator with Perspex reflector it can be seen that a few neutron pulses are lost in the discrimination process.

3.4 Variation of Sensitivity with PM Voltage

The result of changing the tube voltage from 1600 v to 2200 v with all other parameters constant is shown in Fig. 5. A good "plateau" was obtained.

3.5 γ Sensitivity

The PM itself has a slight sensitivity to γ radiation even when no scintillator is present. The effect is to increase the rate of small pulses in the PM output so that occasionally the required number fall within the discriminator window and a count is recorded. The γ response of the ZnS scintillator is in any case low and a γ event does not produce a time distribution of pulses that the discriminator recognises. Two tests were made, the first exposing the PM, but not the scintillator, to the neutron beam which was accompanied by a γ flux of 8 mR-h^{-1} measured with a hand radiation monitor. The count with the main beam stop closed was 20 c in 10s and with it open, 222 c in 10s. In the second test, a ^{60}Co source was placed near the scintillator with the following results

γ flux mR-h^{-1}	Count in 10s
0	∿ 50
20	∿ 50
50	120
200	544

Further tests at RL using the Mullard XP 2230 tube resulted in the following, much reduced γ sensitivities for the tube itself:

γ flux mR-h^{-1}	Count in 5 mins
0	0
20	0
50	5
500	176

This level of γ sensitivity is acceptable for most neutron counting applications.

4 ALTERNATIVE FAST VERSION

Although the pulse counting technique was originally developed for ZnS scintillator, a faster version of the circuit has been built for use with Li loaded glass scintillator. The decay time constant for this material which is manufactured by Nuclear Enterprises, is specified as 85 ns, that is over an order of magnitude faster than ZnS. The circuit has been tested successfully, reducing the dead time to 100 ns, and making count rates approaching 10^7 per sec feasible. With these short times, noise rejection remains the same, but 1-2% of events are counted twice. This figure can almost certainly be reduced by optimising the working parameters.

5 CONCLUSIONS

The new discriminator is effective in reducing electronic noise in scintillator-photomultiplier detectors to the low level of about 1 $c\text{-}h^{-1}$ per PM. Large areas of scintillator can be viewed with one PM making very large neutron detectors (e.g. several m^2) possible at reasonable cost. The discriminator has high efficiency in registering neutrons stopped in the scintillator and the system is insensitive to PM gain. The γ sensitivity is adequately low for most neutron scattering applications.

Using the fast version and glass scintillator, the higher counting rates obtained will enable the technique to be applied usefully to detectors for the Spallation Neutron Source.

6 REFERENCES

1 Improvements in Thermal Neutron Scintillation Detectors for Time-of-flight Studies.
L A Wraight, D H C Harris, P A Egelstaff. Nuclear Instruments and Methods. 33 (1965) 181-193.

2 Pulse-Shape Discrimination with a Glass Scintillator.
C Coceva. Nuclear Instruments and Methods. 21 (1963) 93-96.

3 The Theory and Practice of Scintillation Counting.
J B Birks, Pergamon Press 1964, p.122.

7 ACKNOWLEDGEMENTS

The author would like to thank M J Jacobe of the ILL for the use of the equipment on the 'Canal Technique' and Mr H Wroe for valuable discussions. The assistance of Mr E M Mott in the production of the electronics is also acknowledged.

8 FIGURES

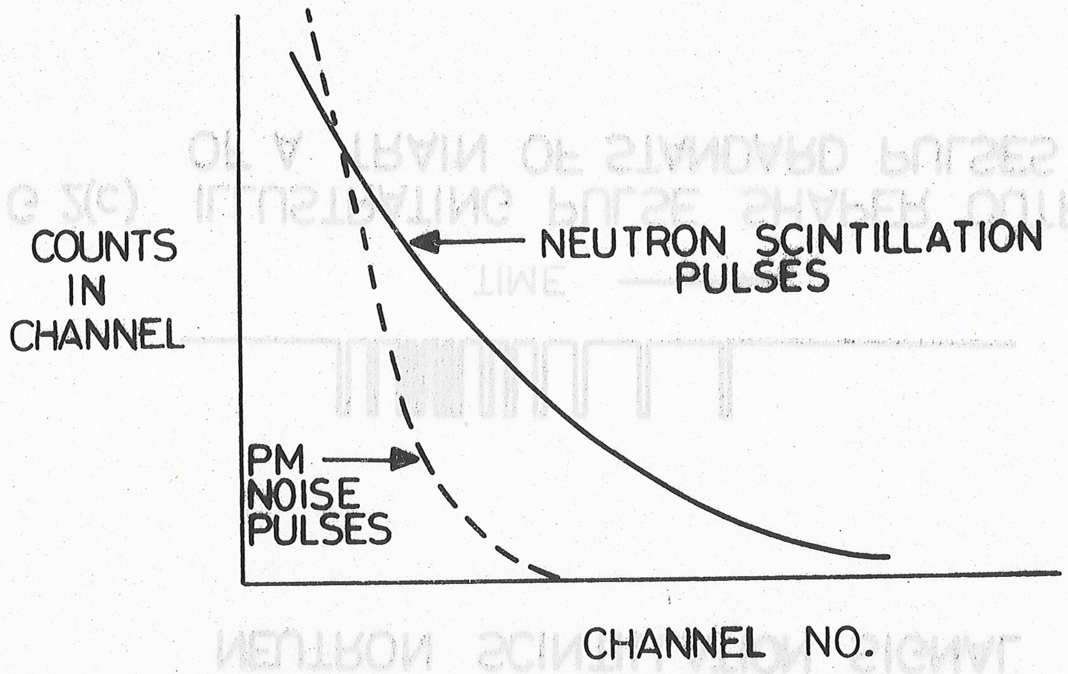

FIG.1(a) SCHEMATIC PULSE HEIGHT SPECTRUM OF $^{6}Li - ZnS$

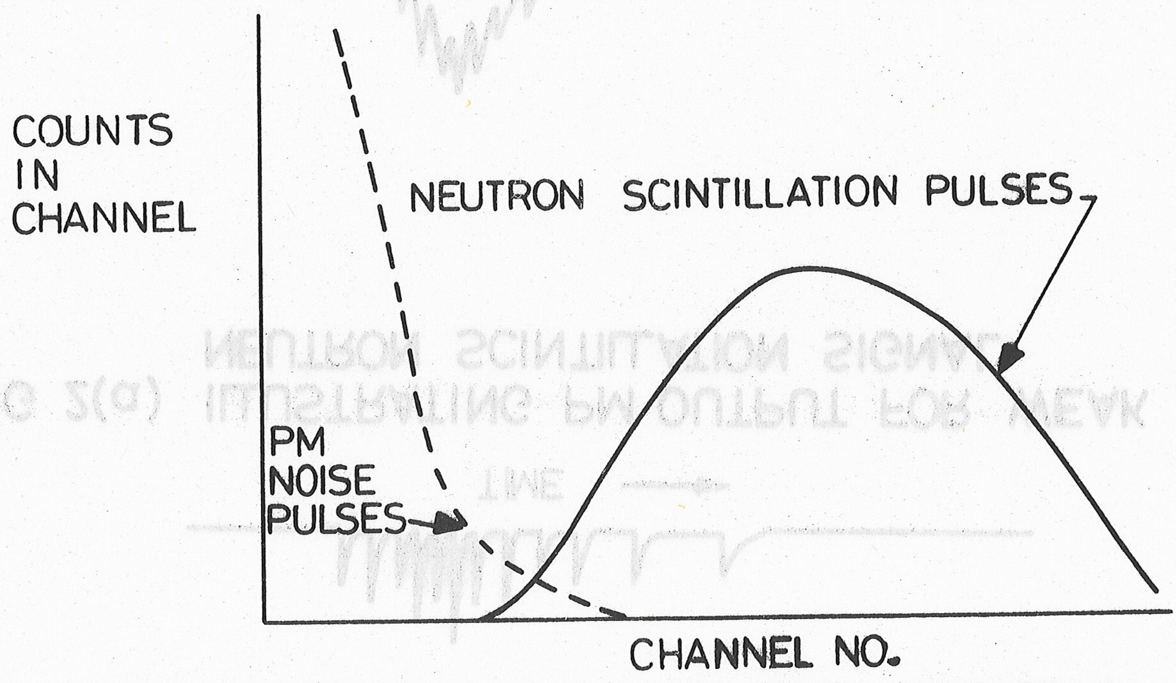

FIG. 1(b) SCHEMATIC PULSE CHARGE SPECTRUM OF $^{6}Li - ZnS$

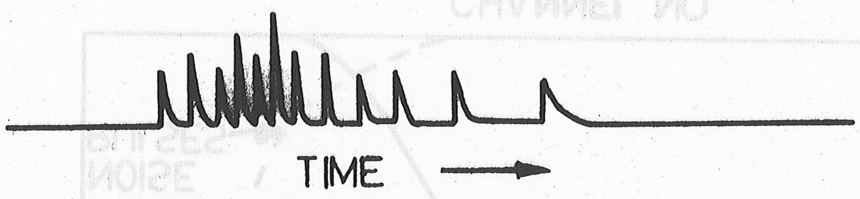

FIG 2(a) ILLUSTRATING PM OUTPUT FOR WEAK NEUTRON SCINTILLATION SIGNAL

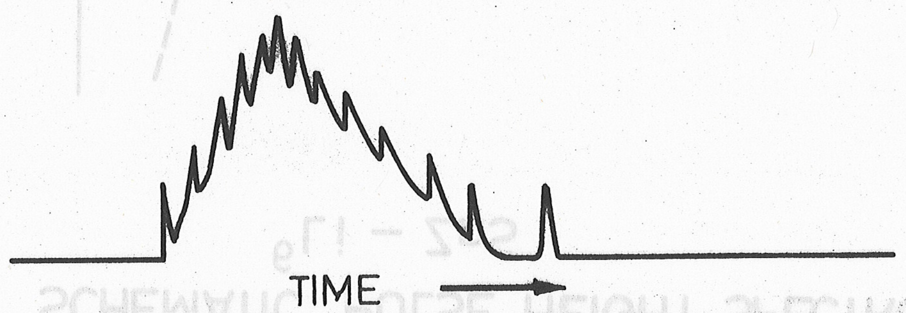

FIG 2(b) ILLUSTRATING PM OUTPUT FOR STRONG NEUTRON SCINTILLATION SIGNAL

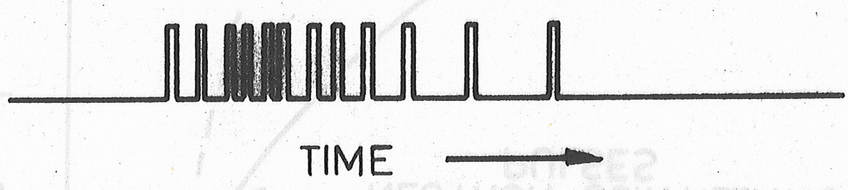

FIG 2(c) ILLUSTRATING PULSE SHAPER OUTPUT OF A TRAIN OF STANDARD PULSES

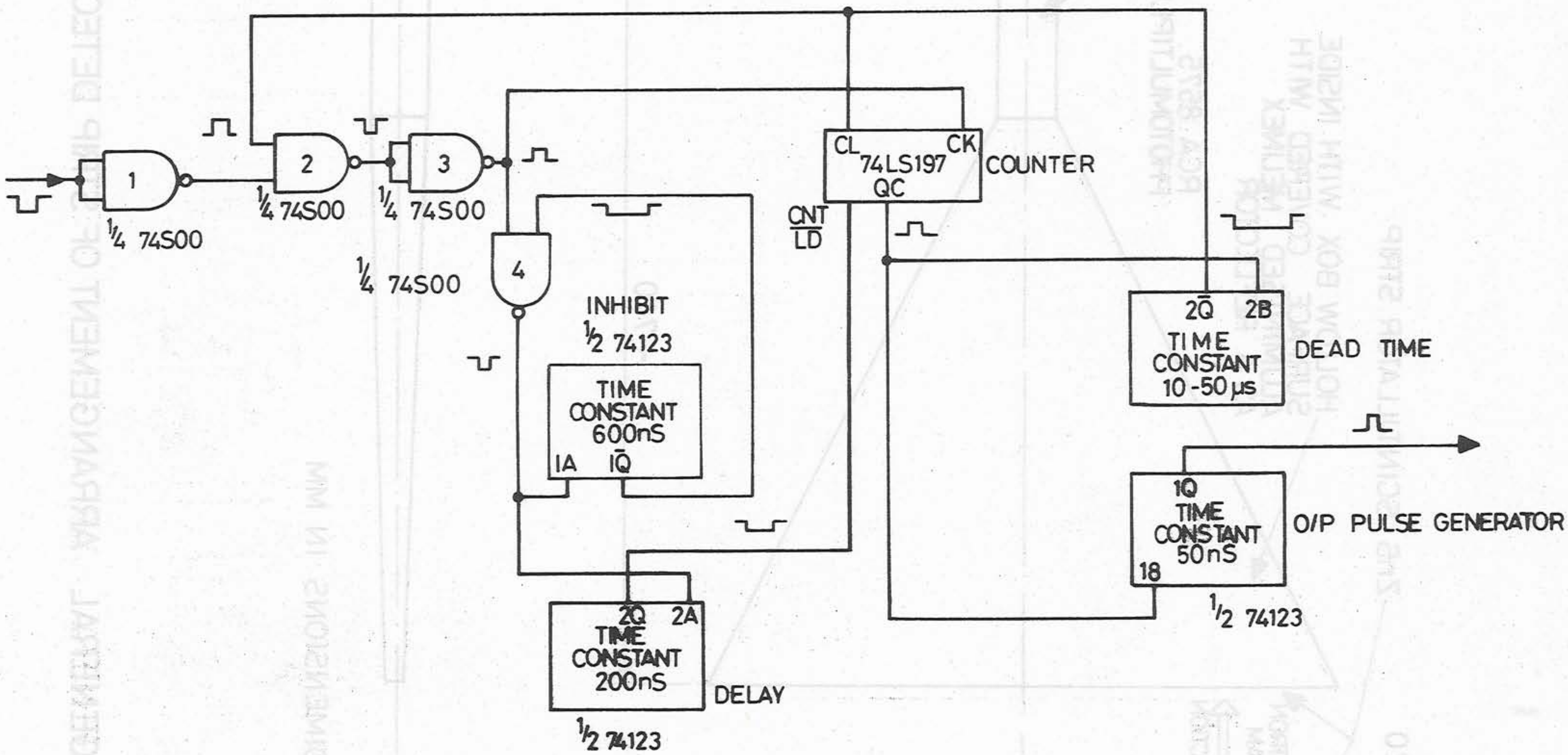

FIG. 3 DISCRIMINATOR CIRCUIT

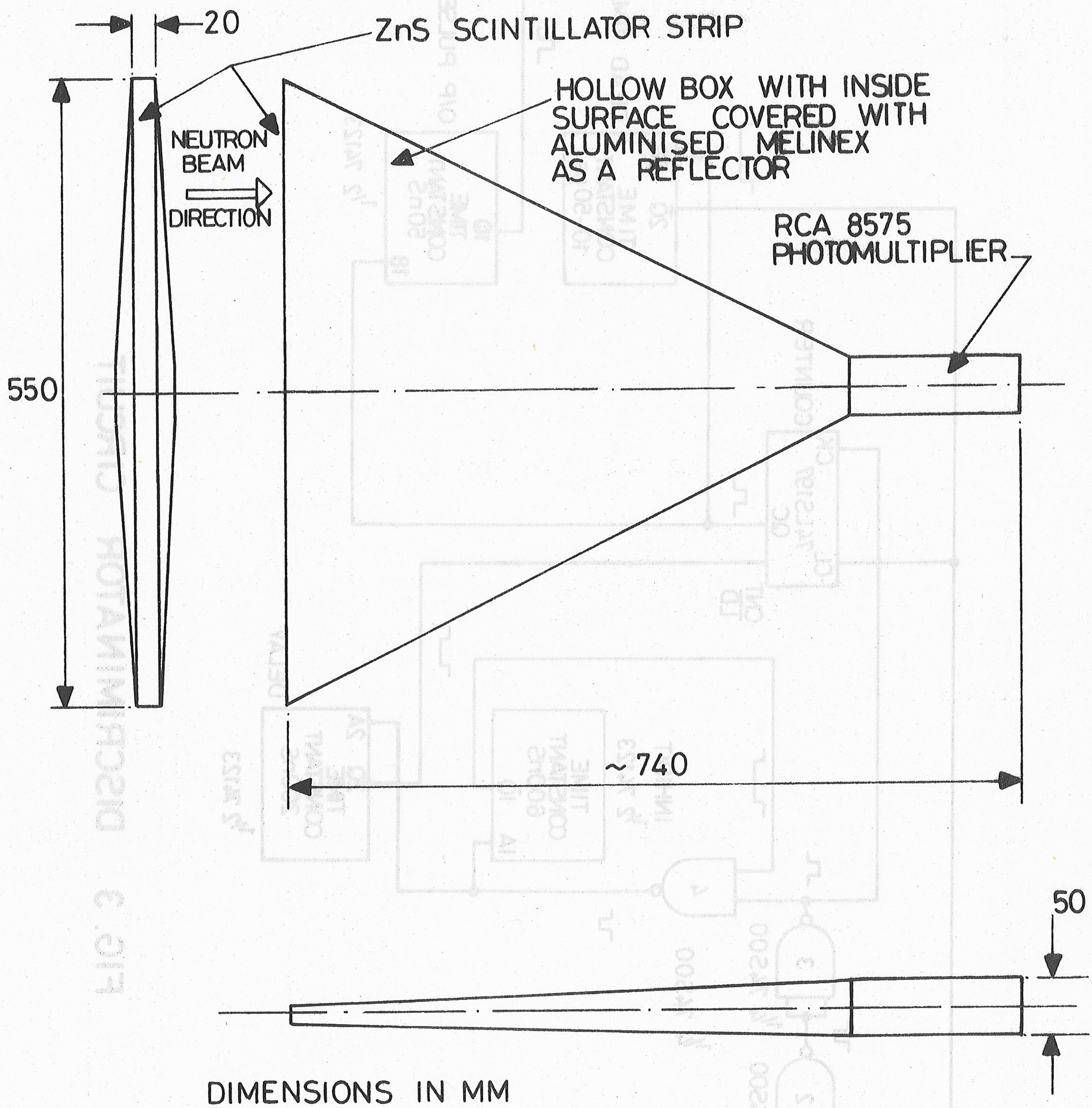

FIG 4. GENERAL ARRANGEMENT OF STRIP DETECTOR

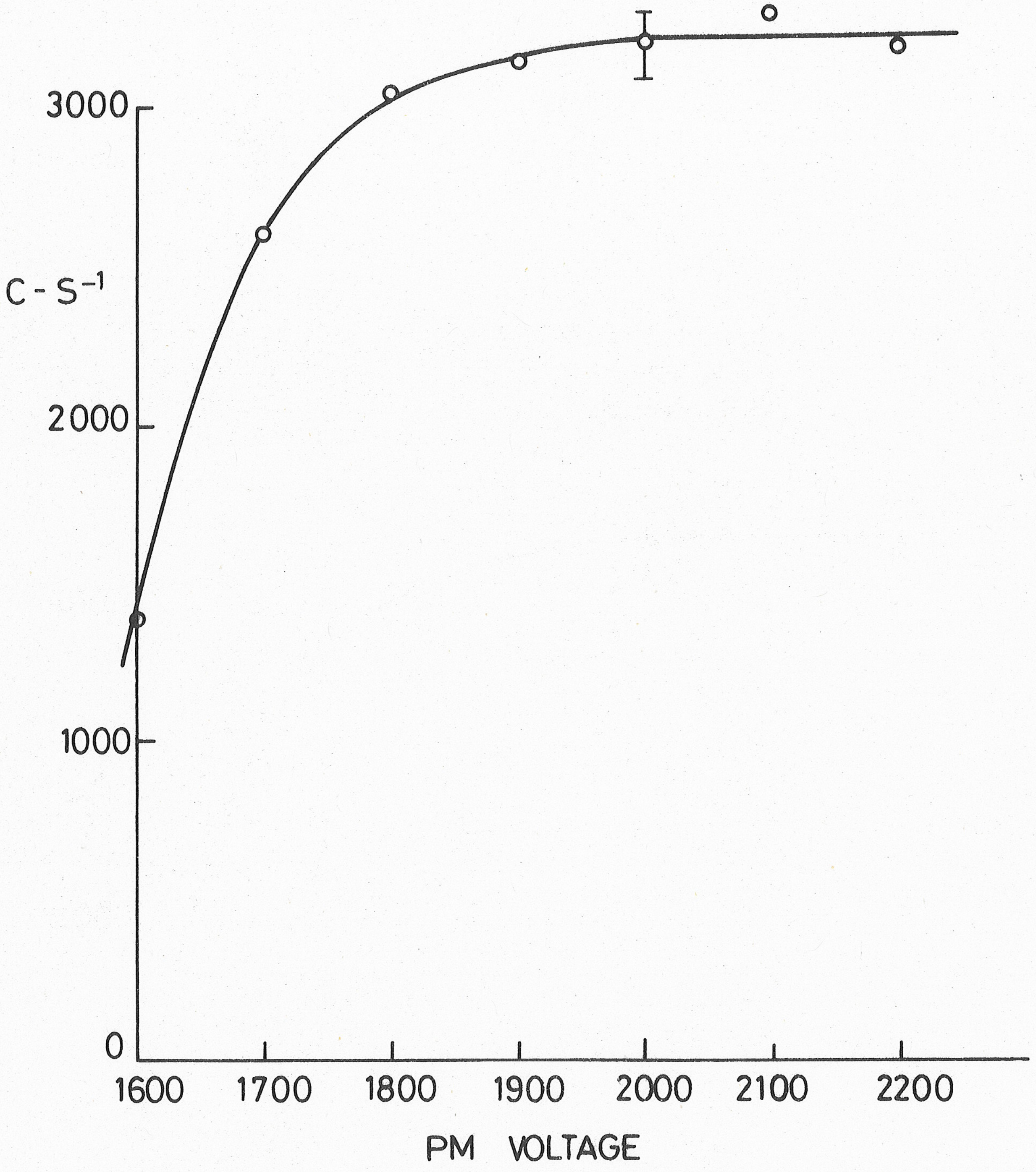

FIG. 5 VARIATION OF SENSITIVITY WITH PM GAIN

FIG. 5 VARIATION OF SENSITIVITY WITH PM GAIN