TECHNIQUES FOR IMPROVING THE SENSITIVITY OF PROPORTIONAL COUNTERS USED IN X-RAY ASTRONOMY

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The discovery and measurement of cosmic X-ray sources has almost invariably been performed with proportional counters which have large window areas. In the energy range from 1 to 50 keV, proportional counters have advantages over other types of detectors; they provide energy resolution and they can be made relatively easily with very large window areas.

The ability to detect cosmic X-ray sources is determined by the collecting area of the detector, the available observing time and the background counting rate of the detector. The observing time and the collecting area are necessarily limited by the performance and the size of the rocket or satellite. However, the background counting rate is within the control of the experimenter and it is this factor which we have studied and been able to improve.

There are two main contributors to the background counting rate; the isotropic cosmic X-ray flux and the response due to higher energy charged particles and γ-rays, which deposit only a small part of their energy in the proportional counter. The contribution from the isotropic flux can be reduced below that from the higher energy radiation by suitable collimation. In this paper we are concerned with reducing the background contribution from the higher energy radiation.

In 1963 Mathieson and Sanford [1] discovered that it was possible to discriminate between X-ray pulses and background pulses from a proportional counter. Although background and X-ray counts may have equal amplitudes, their pulse shapes differed. They were able to show that the response to γ-rays from Co^{60} could be reduced by one order of magnitude, with the aid of pulse shape discrimination, whilst leaving the response to low energy X-rays unchanged.

It is of course possible to reduce the background from high energy charged particles by using anticoincidence shields. However, charged particles only contribute between 30 to 50% of the high energy radiation in the laboratory and about 30% at rocket altitudes. The remaining contribution from γ-rays cannot be effectively eliminated with anti-coincidence counters. Pulse shape discrimination does, however, offer the possibility of significantly reducing the background from γ-rays and charged particles.

The pulse shape discrimination system which we have developed for rocket payloads is shown in Figure 1. Pulses from the preamplifier are differentiated twice and then passed to the Schmitt trigger. The output of the Schmitt trigger is integrated and its amplitude is then a function of the rise time of the pulse from the proportional counter. Pulses due to cosmic rays or γ-rays have a slower rise time than pulses from X-rays. The comparator generates a blocking pulse for the slower rise time pulses.

The proportional counter which has been developed for rocket payloads is shown

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in Figure 2. The window has an area of 800 cm^2 of 6 μ mylar and it is supported by the egg crate collimator. Two anodes are used and these are mounted parallel along the counter. The performance of the pulse shape discrimination system is shown in Figure 3. We have found that it is essential to check the pulse shape discrimination

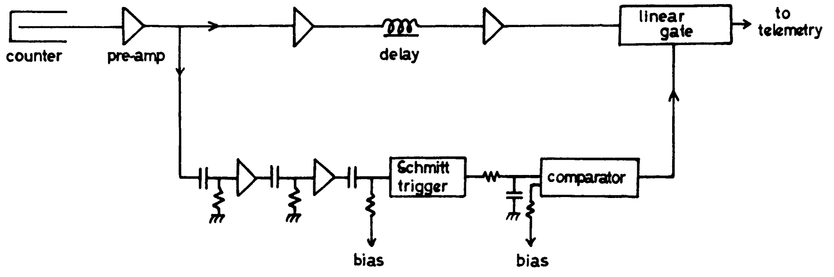

Fig. 1. Pulse shape discrimination system.

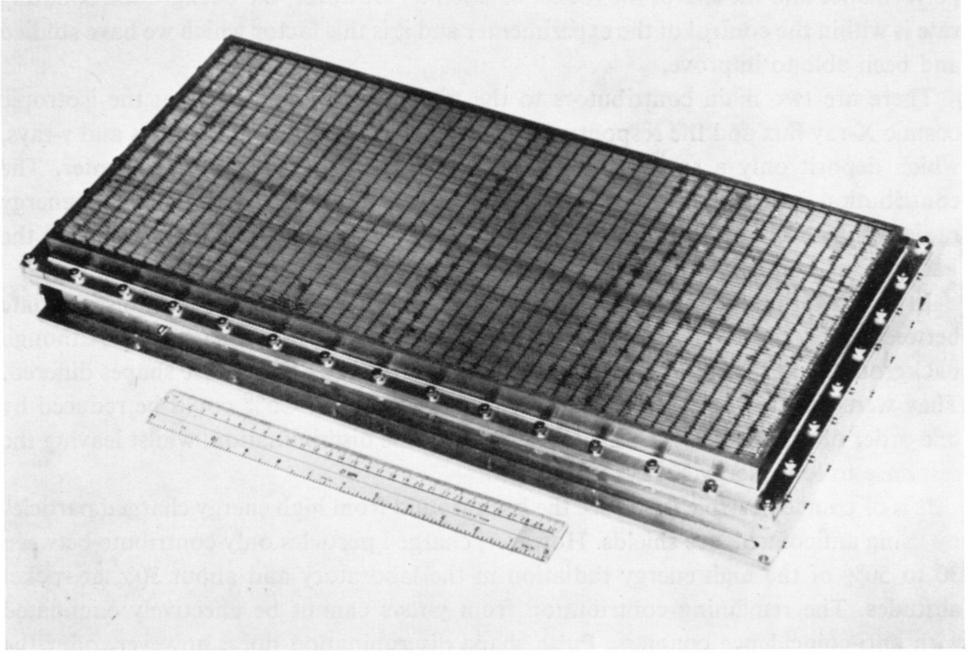

Fig. 2.

system over a wide energy range as it is no trivial problem to ensure that the system is not energy dependent. The top curves are pulse amplitude spectra with and without pulse shape discrimination for sources of Fe^{55} and Pu^{238} which give peaks corresponding to 3, 6, 13.5, 16.5 and 20 keV. The lower distributions, from Cs^{137}, demonstrate the efficacy of the system. At the most probable pulse amplitude the Cs^{137} response is reduced by a factor of 50 while the X-ray response is reduced by only 10%.

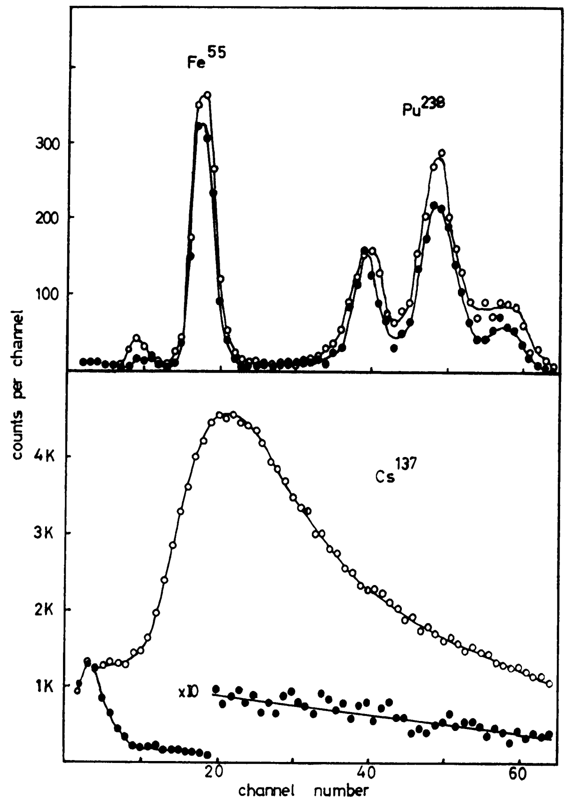

Fig. 3. Pulse shape discrimination with 800 cm² counter.

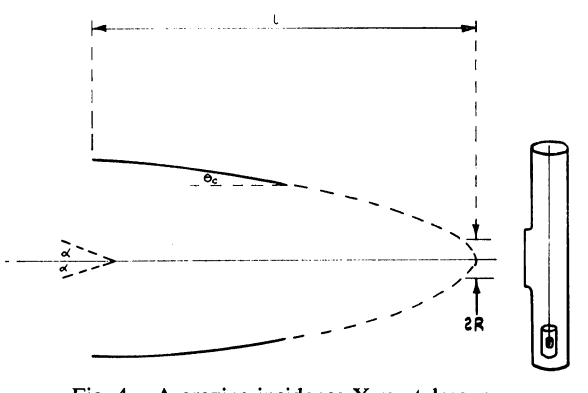

Fig. 4. A grazing incidence X-ray telescope.

Moving to higher energies, the reduction factor is 45 at 10 keV and 40 at 17 keV. The reduction factor gets less below 6 keV until a 2 keV there is little improvement. Similar reductions are achieved in the background pulse amplitude distributions.

At energies below about 3 keV it becomes possible to reduce the background

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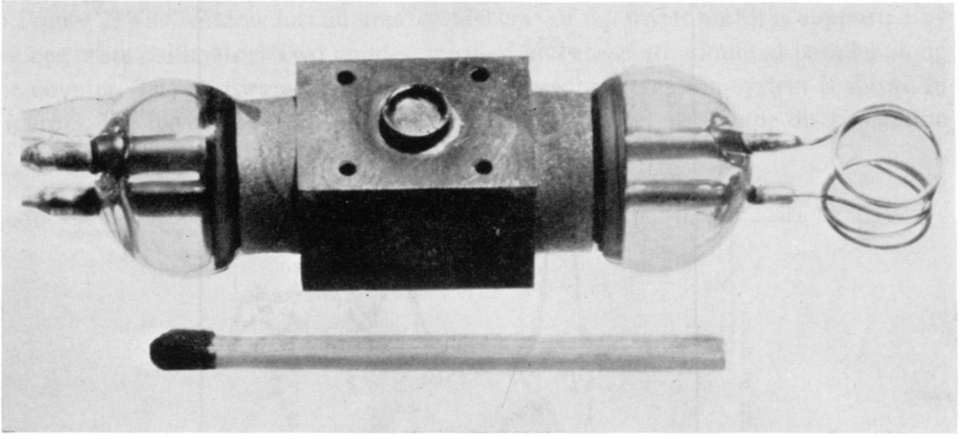

Fig. 5.

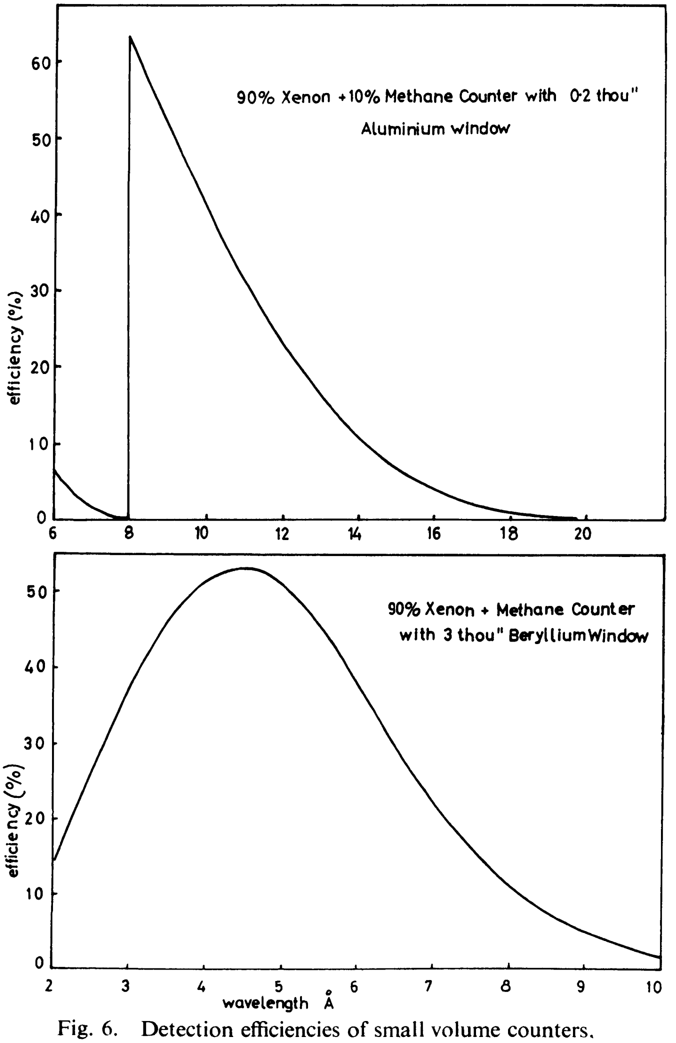

Fig. 6. Detection efficiencies of small volume counters.

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counting rate by the use of grazing incidence collecting mirrors. Figure 4 shows a paraboloid reflector which brings the X-radiation to a focus and is then detected by a proportional counter shown on the right. The improvement in background counting rate is achieved by making the proportional counter as small as possible. A small volume double proportional counter has been developed by 20th Century Electronics for our OAO experiment with grazing incidence mirrors and this is shown in Figure 5. The bottom counter is for calibration purposes and it continuously counts Fe^{55} radiation. The active length of the counter is 1 cm and the cathode internal diameter 0.5 cm.

The photon detection efficiencies of these small counters are shown in Figure 6.

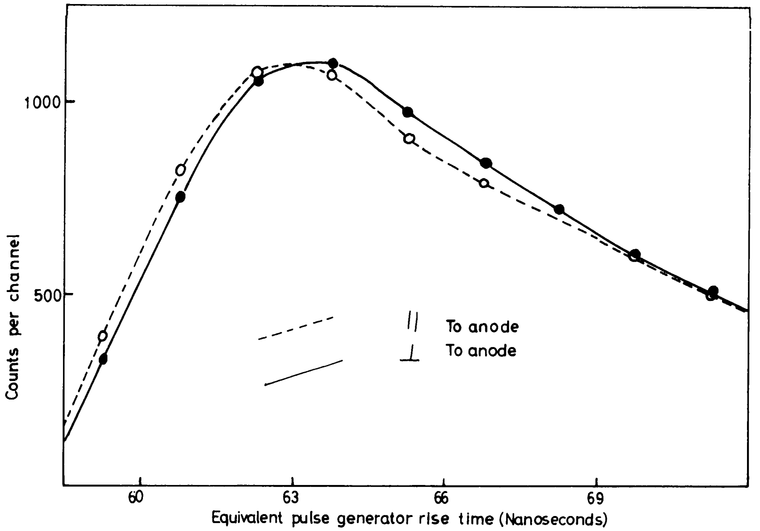

Fig. 7. Pulse rise time distributions for polarized 16.5 keV X-rays.

Two window materials are used; Aluminium 5 μ thick for the wavelength range 8 to 18 Å, and Beryllium 75 μ thick for the wavelength range 3 to 9 Å. Xenon is used for the main filling gas since it enables the highest possible X-ray absorption. The measured background counting rate for these counters in the laboratory is one count in 100 sec. With mirrors effective collecting area of only 10 cm^2 the background performance yields an improvement of a factor of 50 over an equivalent 10 cm^2 window area counter.

We have demonstrated that it is possible to reduce the background counting rate in proportional counters by two methods. These are to some extent complementary since collecting mirrors are useful for X-ray energies less than about 3 keV whilst the Pulse Shape Discrimination system can be employed with large area counters for energies greater than about 2 keV. Pulse Shape Discrimination is however limited to energies where the ejected photoelectron produces a track of ionisation which is small

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compared with the tracks of background radiation. We suggested (1967) that the directions of the photoelectrons, produced by higher energy X-rays in a gas, could be used to measure the polarisation of an X-ray source, the direction of the photoelectron being determined by measuring the rise time of the pulse from a proportional counter. Figure 7 shows pulse rise time distributions for polarised 16.5 keV X-rays. It can be seen that it is possible to detect polarisation by this technique and with a suitably designed detector it may be possible to achieve a very sensitive polarimeter.

References

[1] Mathieson and Sanford: 1963, Proc. Inst. Symp. Nuclear Electronics, Paris p. 65
[2] University College London Proposal for the ESRO TD1 Satellite.