THE ABILITY OF COS-B TO MEASURE GAMMA-RAY BURSTS*

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Abstract. The COS-B satellite for gamma-ray astronomy, launched on 7 August, 1975, features as part of the main instrument a 1.1 m^2, 10 mm thick, plastic scintillator for the vetoing of charged particle events. This detector which has an average effective area of 360 cm^2 for gamma rays in the interval 0.1 to 1 MeV has been instrumented to detect and record the temporal structure of cosmic gamma ray bursts.

The instrument will be sensitive to gamma bursts down to 3% of the typical intensities measured by the Vela satellite system. The best time resolution achievable is 1.6 ms.

The satellite will be placed in a 100 000 km eccentric orbit and with absolute timing accuracies of fractions of a millisecond achievable, a long base line is available for the triangulation of the source position, given comparable data from other satellites.

1. Introduction

The observation of gamma-ray bursts of cosmic origin was first reported by Klebesadel *et al.* (1973). More than 20 short bursts of photons in the energy range 0.1–1.5 MeV have been detected in the data records of the Vela satellites from August 1967 to June 1973. The burst durations range from less than 0.1 s to some 30 s with time integrated flux densities in the region of 10^{-4} to 10^{-5} erg cm^{-2} in this energy interval. Searches of the data experiments have revealed the detection of some events correlated with Vela measurements.

The bursts observed so far exhibit a wide variety of temporal behaviours, often with two main pulses in a single event and often with statistically significant fine structure at or possibly below the 16 ms resolution of the Vela detector system.

According to Strong *et al.* (1974), the source locations of nine of the gamma bursts have been determined from a knowledge of the onset time of the bursts measured at

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each satellite, but with an accuracy of only several degrees. Three locations have been determined unambiguously and six have been assigned a pair of directions, one being the true direction and the other its mirror image in the orbital plane of the satellites. Given these poor statistics, there appears to be no strong correlation with galactic features and, combined with a three-halves power law test of the signal strengths, it is concluded that the sources are distributed more or less uniformly throughout the sampled volume.

The energy spectra of six of the bursts have been determined from IMP-6 data by Cline *et al.* (1973). The pulse spectra can be represented by exponentials in the energy range observed with characteristic energies near 150 keV. The pulse spectra appear to be superimposed on a softer, slower decaying component with a characteristic exponent of the order 75 keV. One event, 14 May, 1972, was observed down to 10 keV by instruments on OSO-7 as reported by Wheaton *et al.* (1973). Until now there has been no correlation with transient phenomena observed by ground-based optical or radio astronomers.

A review of the observational data to mid-1974 has been made by Strong (1974).

Many theories have been put forward, but are not reviewed here. Clearly, before the suggested theories can be adequately tested, more observational data are required, including:

(i) source location, unambiguously, to a precision much better than one degree initially, but to arc seconds if correlations with radio and optical observations are to be attempted,

(ii) temporal structure to the highest resolution throughout the duration of the burst,

(iii) energy spectra, over as wide a range as possible, sampled as rapidly as possible to relate spectra and temporal structure,

(iv) size spectrum.

Obviously these data can be obtained with a major effort in the production and operation of new specialized instruments, but with the attendant time scale and cost implications. However, at short notice the COS-B experiment has been instrumented to give information in the period 1975–1978 on source locations (given other observations for burst confirmation and triangulation) and temporal structure. The COS-B orbit is highly eccentric with an apogee height of 100 000 km, providing a large baseline between COS-B and other instruments. A timing accuracy of better than 1 ms can be achieved.

2. Gamma-Burst Detection

The COS-B experiment described by Bignami *et al.* (1974) features a dome-shaped, 1.1 $m^2 \times 10$ mm thick plastic scintillator (SPF) viewed by nine photomultipliers for the rejection of charged particles, referred to as the anticoincidence counter or ACO (Figure 1).

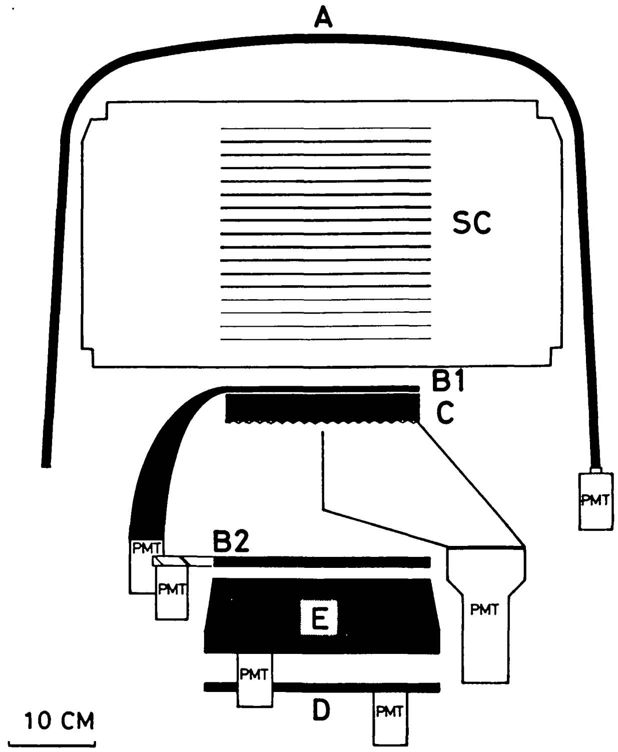

Fig. 1. Schematic of the COS-B experiment showing the anticoincidence dome A which is instrumented to detect γ-bursts.

The sensitive area of the ACO for gamma rays in the energy interval 100–1000 keV has been determined with radioactive sources. The ACO is sensitive at 100 keV, reaching a maximum at 700 keV, and then decreasing at higher energies due to the influence of an upper threshold set to reject energetic charged particles.

Using the energy spectrum suggested by Cline *et al.* (1973), i.e. $I = I_0 \exp(-E/E_0)$ $\mathrm{cm}^{-2}\,\mathrm{keV}^{-1}\,\mathrm{burst}^{-1}$, and maintaining consistency of those bursts whose spectra have been measured, a 'standard burst', with $I_0 = 1$, $E_0 = 150$ keV and a duration of 1 s, has been defined, to evaluate the performance of the ACO detector and to establish the design of the gamma-burst electronics.

Table I indicates in 100 keV intervals, the number of photons expected per cm^2, the effective area of the ACO and the number of counts expected for a standard burst. In total 76 photons cm^{-2} and some 27 000 counts are expected, resulting in an average effective area for a gamma burst of 360 cm^2.

A simple triangular count-versus-time profile has been adopted for the standard burst (Figure 2) with a rapid rise $\ll 1$ s and a slow fall of 1 s. For a 1 s burst of 76 photons cm^{-2} at the detector, the peak counting rate for such a profile must be 152 $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, yielding a count rate of 54.5 kHz in the ACO.

Figure 3 shows a block diagram of the electronics for the production of the 'burst event trigger' (BET). An analogue system has been adopted. Signals from the ACO lying between the lower threshold (~ 75 keV) and the upper threshold T_2 (~ 800 keV),

TABLE I

Energy, keV	100 –200	200 –300	300 –400	400 –500	500 –600	600 –700	700 –800	800 –900	900 –1000	
γ cm^{-2} from standard burst	37.5	19.2	9.70	4.98	2.56	1.31	0.674	0.345	0.177	76
Sensitive area, cm^2	212	360	500	650	775	900	975	1000	900	
Expected count	7950	6912	4850	3237	1984	1179	657	345	159	27 273

(1) Burst spectrum: $I = I_0 \exp(-E/E_0)$ γ cm^{-2} keV^{-1} burst^{-1}.
(2) Standard burst: $I_0 = 1$, $E_0 = 150$ keV, length 1 s.
(3) Average effective area 27 273/76 $\approx$ 360 cm^2.

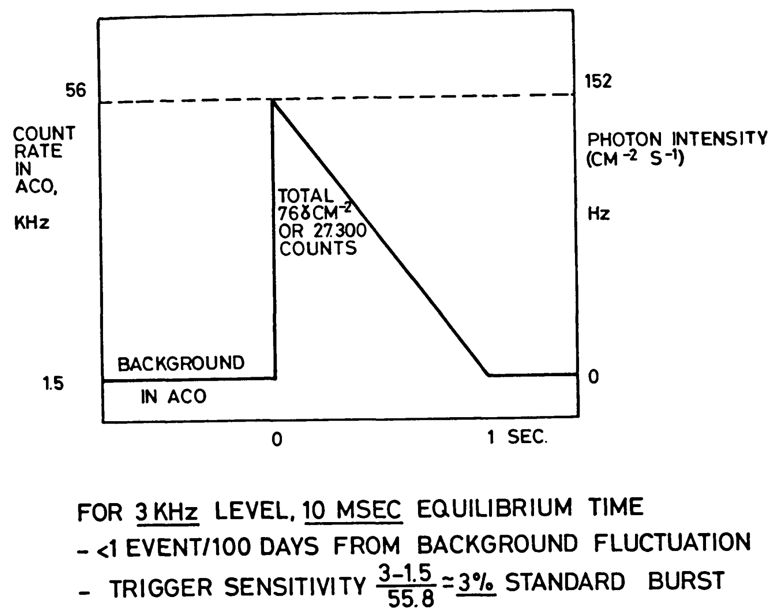

Fig. 2. The standard burst profile on which the electronics was based.

are routed to two ratemeters (selectable by telecommand) R_3 and R_4 having equilibrium times of 10 and 30 ms which will trigger the discriminator T_{11} at 3 kHz and 2 kHz, respectively. A selectable prescaler permits additional operational flexibility in orbit.

The average background noise from the photomultiplier tubes is approximately 1.5 kHz, and with R_3 set at 3 kHz, a spurious trigger rate of one in 100 days can be expected. The minimum burst frequency required to trigger the system is 1.5 kHz, which therefore yields a triggering sensitivity of the order 3% of a standard burst. Triggers from slowly varying phenomena (e.g., solar flares, background fluctuations) are avoided by an AC-coupling between the ratemeters and the discriminator with a time constant of 0.8 s.

On receipt of the BET from the triggering electronics, the 'burst event pulses' (BEP) are recorded and routed via the data handling electronics to a buffer memory.

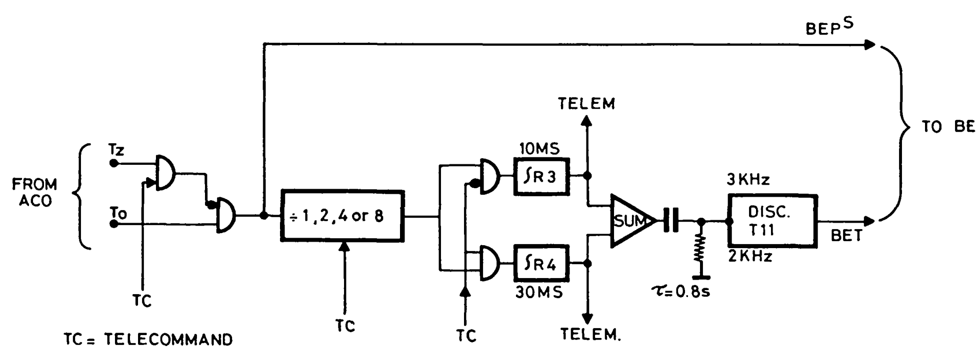

Fig. 3. Block diagram of the electronics for the production and regulation of the burst event trigger.

3. The Data Handling and Formatting Electronics

The spacecraft data-handling subsystem features a buffer memory for the smoothing of the data from the randomly occurring spark-chamber events to the steady rate demanded by the telemetry. On the generation of the BET, 768 8-bit words of this memory are erased and subsequently loaded with the gamma-burst event data. The gamma-burst message contains in addition to the event data, a start label of 24 bits, a time label of 24 bits for the occurrence of the BET, to a resolution of 0.4 ms and an end label of 32 bits.

The gamma-burst data-handling electronics (BE), has been designed to cope with the wide range of temporal behaviour observed in gamma-ray bursts compatible with the constraints of the limited buffer capacity. The BEPs are handled in two ways according to their rate. If there are more than 64 BEPs in 1.6 ms, an 8-bit word (the count word) is produced. 64 was chosen as giving reasonable statistical accuracy. One bit is used as a flag, the other seven contain the number of counts accumulated over 1.6 ms in compressed form (from 9 bits to 7) with a dynamic range up to 480 counts. If there are less than 64 BEPs in 1.6 ms, an 8-bit word (the time word) is produced which gives the time code corresponding to the end of accumulation of 64 counts, with a time resolution of 0.4 ms over the interval up to a maximum duration of 50 ms. In fact, the noise count rate of 1.5 kHz means that 64 counts will be accumulated in about 40 ms. Thus the BE can adapt itself according to the rate of increase of the burst and its intensity, to give a good definition of the event, within the framework of the existing COS-B instrumentation.

To provide information on the burst profile, prior to the generation of BET, a small memory stack of 18 8-bit words is included in the BE. This memory is continuously filled from the top, thus providing an internal delay up to a maximum of about 700 ms in the transmission. When the BET is received, the data words are transferred from the bottom of the memory stack to the buffer memory. These data will permit a refinement to be made of the burst onset time which otherwise would be determined only by the response of the trigger circuitry.

When the transfer of the 768 8-bit words of the gamma-burst message is complete, the experiment switches back to the normal gamma-ray mode. For a large burst, with the electronics always in the count mode, then only the first 1.2 s can be observed. For a small burst, with the electronics always in time mode, burst lengths up to 33 s can be studied.

An example of the performance of the BE is given in Figure 4. An input burst profile of BEPs for which the burst-rise time constant, plateau length, burst-fall time constant, peak and background levels can be specified, is generated by a variable-frequency pulse generator under computer control. The figure shows an input profile approximating to a 'standard burst' and the reconstituted profile from the output data. The transition from count mode to time mode is clearly visible at $\sim$40 kHz.

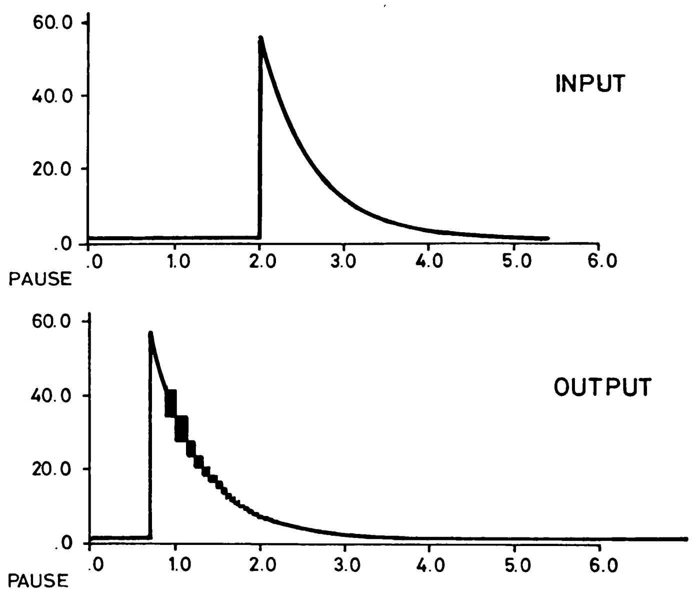

Fig. 4. Simulated standard burst and the response of the electronic system.

4. Conclusions

Although the COS-B programme was relatively far advanced, i.e. within 18 months of launch, it has been possible within the physical constraints to provide two small electronic modules, the gamma-burst detection electronics and data-handling electronics, to measure gamma bursts, using the existing detectors. By virtue of the large area of the detector, in conjunction with the appropriate electronics, COS-B will be sensitive to gamma bursts down to a few per cent of typical bursts previously observed. Burst onset times can be determined to approximately 1 ms, and with the flexible data-handling system a wide variety of burst profiles can be studied with a time resolution of 1.6 ms and good statistical accuracy. A determination of the energy spectrum of a burst could not be undertaken, because of the limited buffer size and the non-uniformity of the ACO due to its geometrical configuration.

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