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A spectral-ratio based trigger generator for TACTIC vertex elements

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Abstract. An unconventional hardware trigger-generator, based on an on-line estimation of the spectral-ratio of the Cerenkov radiation, has been developed for the three Vertex Elements of the TACTIC γ–ray telescope array. The paper discusses the operational principle of the trigger - generator and the test results from a prototype circuit developed for demonstration purposes.

Key words : Cerenkov radiation, γ–ray telescopes, trigger - generator, threshold energy optimization.

1. Introduction

A 4-element array of Cerenkov telescopes, acronymed TACTIC (for TeV Atmospheric Cerenkov Telescope with Imaging Camera), has been recently set up at Mt. Abu, Rajasthan (24.62^{o}N, 72.75^{o}, 1275m asl) for VHE γ–ray astronomy and UHE cosmic-ray studies (VHE: Very High Energy, UHE: Ultra High Energy). The experimental details of this instrument have been already discussed elsewhere (Bhat, 1997; Tickoo et al, 1999). The 4 x 9.5m^2 area Cerenkov telescopes of the TACTIC array are arranged in a triangular configuration (20m side), with a 349-pixel Imaging Element (IE) disposed at the centre and, 3 Vertex Elements (VE), at the corners of the array. Each VE is provided with a 58- pixel duplex detector-array camera as its focal-plane instrumentation. The hardware-trigger threshold energy for a typical Cerenkov telescope is ultimately decided by the shot-noise induced in the photomultiplier detector by the Light Of Night Sky (LONS). For the IE of the TACTIC, the hardware trigger is generated by demanding that the Nearest-Neighbour Non-Collinear Triplet pixels of the imaging camera (3 NCT trigger-criterion, Bhat et al, 1994; Bradbury et al, 1997) should fire simultaneously (time resolution ~ 20 ns). This leads to an estimated γ–ray threshold energy of ~ 0.7 TeV (corresponding γ–ray image-threshold energy ~ 1 TeV). For the VE, an appreciably lower trigger threshold energy of ~ 0.2 TeV is specified, so that, when operated independent of the IE, a reasonably high sensitivity can be expected, particularly so in γ–ray pulsar searches where the expected periodicity feature in the signal arrival-epoch can help to suppress the random cosmic-ray background (Bhat, 1996).

To achieve the desired reduction in the threshold energy of the VE, their focal-plane instrumentation and the back-end electronics have been appropriately configured to be more compatible with the angular, spectral and timing characteristics of the detected Cerenkov pulses (Fegan, 1996). Thus, as shown in Fig.1, a non-conventional focal-plane instrumentation is used for each VE, consisting of duplex detector-arrays straddling an orthogonally-placed dichroic-filter assembly . The dichroic filters reflect optical wavelengths $\lambda \sim$ 300-450 nm (Blue or B-band) and transmit longer ~ 450-600 mm (Green or G-Band). Each detector array utilises 16 x 52 mm-dia photomultiplier tubes (type ETL 9954A) and 13 x 19 mm-dia photomultiplier tubes (type ETL 9083 for the G-detector and type ETL D921 UVA for the B-detector). The angular size of the larger PMT ($\sim 0.9^{\circ}$) is comparable with the dimensions of γ–ray-induced atmospheric Cerenkov flashes and they are used for generating low-threshold triggers for the VE by demanding a concurrent fulfilment of the following additional conditions : (i) In keeping with the spectral character of the Cerenkov light vis-a-vis LONS (Fig.2), the ratio of the Cerenkov light flux received by a B-detector to that registered by the corresponding G-detector, directly facing each other across the dichroic filter-plate, exceeds an optimum minimum value, R, and (ii) the signal is present in all the 3 VE with relative arrival times which are consistent with the event arrival direction. According to detailed Monte Carlo simulations carried out by us (Sapru et al, 1997), R is greater than 1.4 in presence of the LONS fluctuations ($R \sim 1.8$ in absence of the LONS noise). We discuss here a prototype hardware circuit which has been developed and successfully tested for being incorporated in the TACTIC array for generating the desired spectral-ratio (B/G) triggers.

2. Prototype spectral-ratio detector

Fig. 1 schematically explains how the light radiation, reflected by a VE mirror, is divided into B- and G-bands by the dichroic plate, placed in the focal plane of the reflector. As is evident, the B- and G-band photon pulses are picked up by one or more pairs of B- and G-band

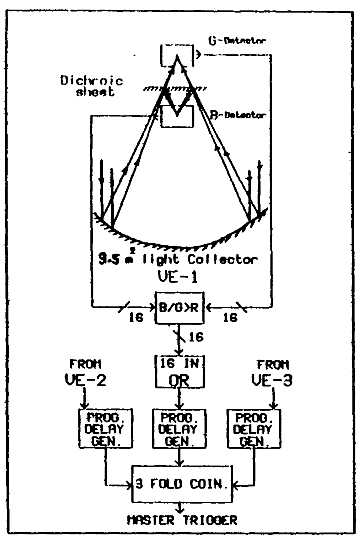

Figure 1. A schematic representation of the trigger-generator scheme proposed for the TACTIC Vertex Elements for γ–ray threshold reduction.

PMT. The resulting voltage signals from the PMT anodes are amplified (χ 10) before being amplitude-discriminated to yield a single's rate of ~ 700 kHz. The discriminator output is fed to a fast coincidence circuit (resolving time ~ 15 ns) to generate a first-level trigger which gates the ratio-detector circuit to check whether the charge received by a Charge-to-Digital Coverter channel (CDC counts) during the neighbouring 10 ns bin from the B-channel amplifier exceeds the corresponding CDC counts from the G-channel amplifier by the preset ratio R. A second-level trigger-pulse is generated in this way from each VE camera. The respective Spectral-Ratio detector outputs from the 3 VE are finally collated for consistency with the expected arrival direction of the atmospheric Cerenkov event and a master-trigger is generated in case this condition is satisfied. This third-level trigger marks the registration of an atmospheric Cerenkov event by the VE.

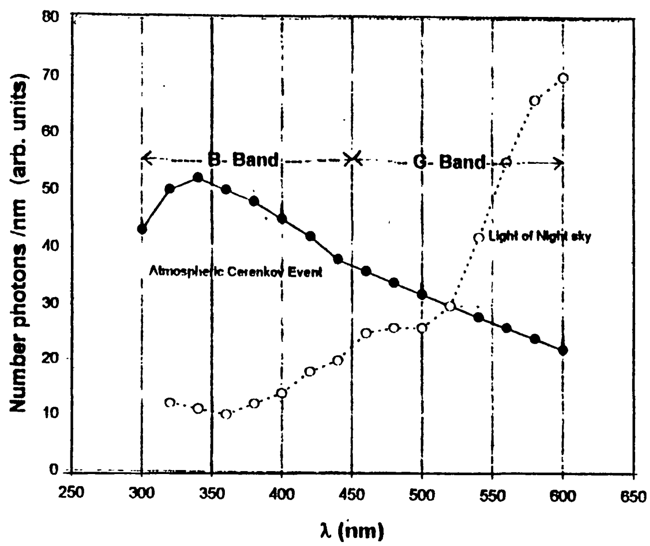

Figure 2. Spectral distribution of the Atmospheric Cerenkov Events (ACE) and the Light Of Night Sky (LONS) background for the wavelength range 300-650nm.

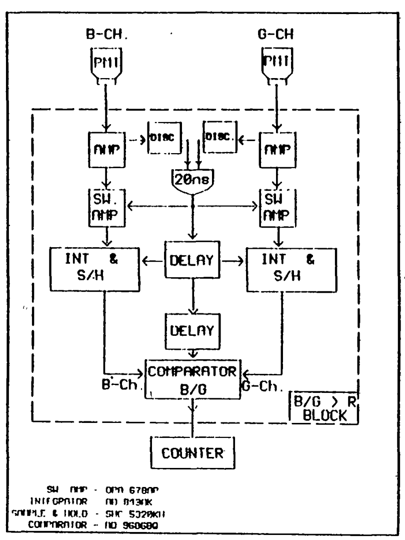

Figure 3. Circuit details of the prototype B/G spectral-ratio detector.

As shown in Fig.3, the prototype Spectral-Ratio detector circuit has been designed around switching operational amplifiers (type OPA 678AP), followed by an intergrating circuit whose output is held fixed for 5 μs by a Sample & Hold (S/H) Circuit. The S/H circuit outputs of the 2 channels are compared using a fast latched-comparator which is made transparent to the input only for a duration of 10 ns, thereby reducing the possibility of accidental noise-trigger. During the testing of the prototype circuit in the laboratory, the photomultiplier detectors of the B and G channels were operated at the same gain and were exposed to a steady source of light. The discriminator output for either channel in this case is exclusively due to uncorrelated shot-noise fluctuations exceeding the preset channel discrimination level. We shall refer to the counting rate of this output as the single channel rate. The conventional 2-fold chance rate (case a) and

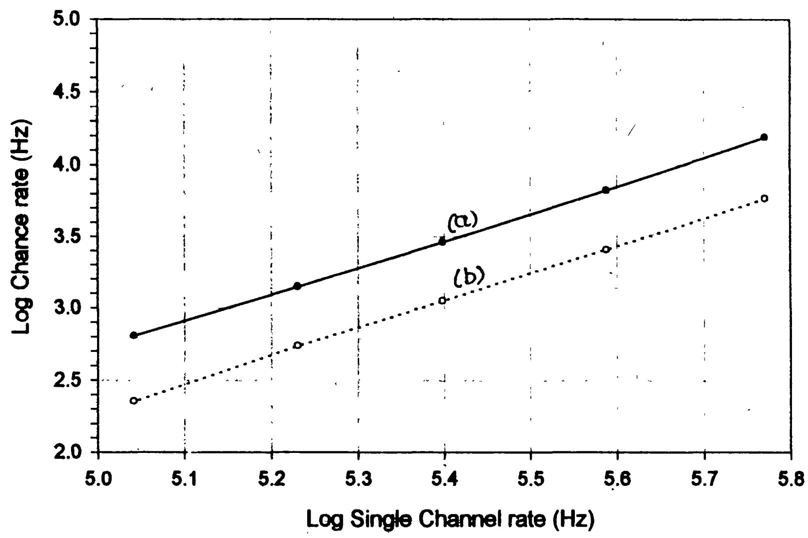

Figure 4. Chance coincidence rate plotted as a function of the single channel rate : (a) 2-fold prompt coincidence, (b) a + B/G spectral cut.

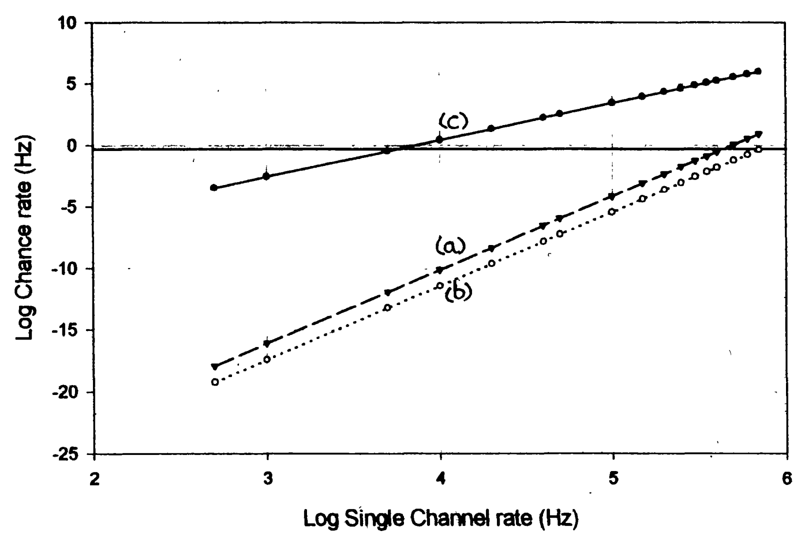

Figure 5. Chance coincidence rate plotted as a function of single channel rate for following three cases : (a) 2-fold prompt coincidence+3-fold delayed coincidence, (b) a+ B/G spectral cut and (c) 3-fold delayed coincidence alone.

the corresponding B/G rate (case b) are compared as a function of the SCR in Fig. 4. It is evident from this figures that for B/G ratio $R \geq 1.4$, consistent with the spectral characteristics of an ACE after duly accounting for the corresponding sky-noise modulation, the B/G trigger rate is a factor 2.7 lower than the conventional 2-fold accidential coincidence rate (case a) for all values of the SCR. This difference leads to a even more significant value (by a factor of 20, as shown in Fig.5) in the 3-fold chance rate, expected at the master trigger level amongst the 3 Ve of the TACTIC. For a representative chance coincidence of 0.5 Hz at the master trigger-level, it turns out that the operational SCR is 430 kHz and 720 kHz for cases (a) and (b) respectively (Fig.5). The corresponding operational SCR (case c), when the above-referred two versions of the 2-fold trigger-generation modes are not used, turns out be 5.6 kHz. This implies that an atmospheric Cerenkov system, using B/G trigger generation scheme, can effectively operate at a significantly lower discrimination level, (and hence lower γ–ray threshold energy) without running the risk of getting excessive shot-noise triggers.

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