

Construction of a Cosmic Ray Air Shower Telescope

L.K. Ng and S.K. Chan
Physics Department, University of Hong Kong
Hong Kong

Abstract

The telescope under construction is mainly for the purpose of locating the arrival directions of energetic particles and quanta which generate air showers of sizes $10^5 - 5.10^6$. Both fast timing method and visual track method are incorporated in determining the arrival directions. The telescope is composed of four stations using scintillators and neon flash tubes as detectors. The system directional resolution is better than 1.5° .

1. Introduction. Application of medium-size shower arrays in astronomical observations is exemplified by the Kiel experiment¹ in the detection of high energy gamma rays from Cygnus X-3. This type of continuous observation using ground-base air shower arrays may yield more fruitful results, if it is participated by more stations spreading out at various latitudes. For long term observations, such telescope could be less elaborate than Kiel's. The requirements may just be high directional resolution and ability to measure the muon/electron density ratios of individual showers, in addition to the usual determination of lateral distributions and age parameter. This paper reports a simple air shower telescope which meets the above requirements.

2. Detection system. It consists of four detector assemblies (a required minimum), which are at sea level and arranged as shown in figure 1.

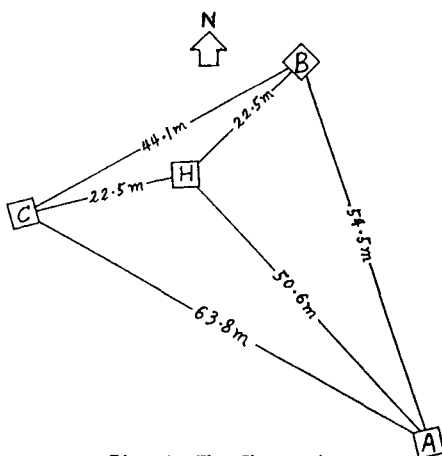


Fig. 1 The Shower Array.

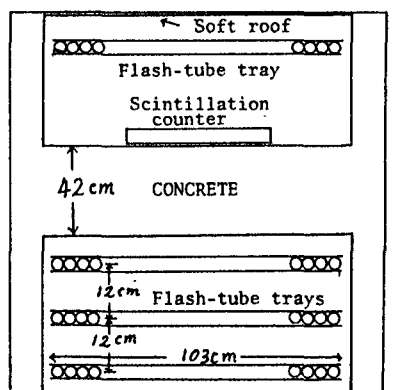


Fig. 2 The Detector Assembly.

Each detector assembly has a soft roof and contains a plastic scintillator, 4 trays of neon flash tubes and an absorber medium as shown in figure 2. The scintillator has

a minimum geometry of $0.5\text{m} \times 0.5\text{m} \times 0.05\text{m}$ and is viewed by two 2" photomultipliers in contact with the scintillator. For precise arrival time determination, anti-jitter preamplifiers described in another conference paper (HE 4.7 - 9) are used.

Each of the four flash-tube trays consists of 48 close packed tubes. Each tube has a geometry of $2\text{m} \times 1.9\text{cm}$ dia. and when it fires, its output electromagnetic signal is picked up by a latch. There are 4×48 latch units in an assembly providing 24 bytes of data per shower per assembly. Clearly, the top tray is for shower density measurement and the bottom three trays are for muon density and direction measurements.

3. Electronics. For each shower, data required from the system include information from the flash tubes, the particle arrival times, and the event time and date. Block diagram of the electronic system is given in figure 3. Communication between each assembly and the central processing station is linked by transceiver buses throughout. A master pulse is produced by 4-fold coincidence of the scintillator outputs ($2\mu\text{s}$ window). The master pulse is used to reset the flash-tube latches, to fire the flash tubes by triggering the UHT pulsing unit, and to start the data acquisition subroutine in the microcomputer.

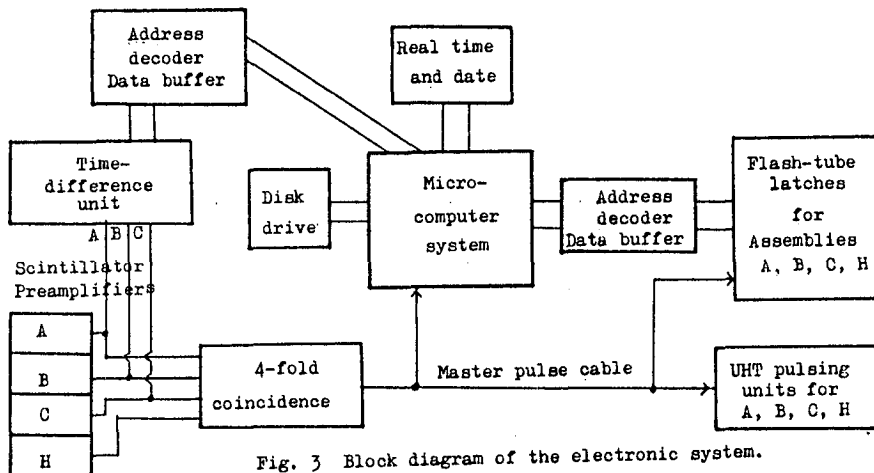


Fig. 3 Block diagram of the electronic system.

However, the key part of the electronic system is the time-difference unit which determines the relative arrival time of particles falling at the scintillators. The arrival time is precisely related to the leading edge of the output pulse from the anti-jitter preamplifier. This leading edge is free from distortion during transmission, because the signal cable is terminated by a matched pair of driver/receiver.

The time-difference unit contains three sets of time-to-amplitude converter (TAC) and analogue-to-digital converter (ADC). The leading edge of an input pulse from one

of the assemblies A, B, C is compared with a common time reference, and the difference is then digitized by the TAC and ADC. The TAC and time reference circuits are shown in figure 4.

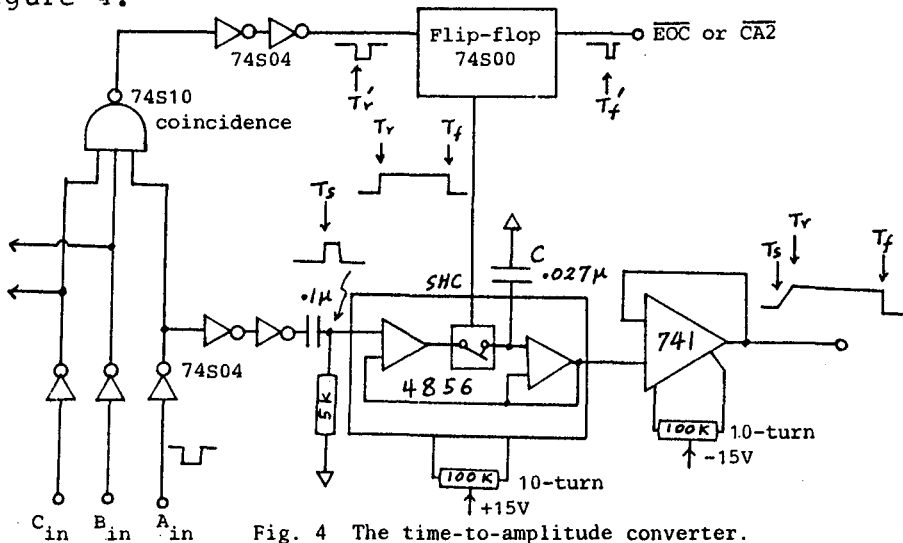


Fig. 4 The time-to-amplitude converter.

The TAC is a sample/hold chip (Teledyne Philbrick 4856) with a charging rate ~ 1.5 V/ps and a drift rate ~ 0.8 mV/s at the hold state, using a low leakage capacitor C of 0.027 μ f. The hold pulse (at SHC) is generated by a fast flip-flop as shown. Its leading edge T_r is the time reference corresponding to the latest leading edge of the three input pulses A_{in} , B_{in} , C_{in} (after triple coincidence). Its falling edge T_f corresponds to either the end of ADC conversion (EOC) or the end of computer processing ($\overline{CA2}$), whichever is the last. When the chip is at the sample state, the capacitor C is being charged up starting from 0 V at time T_s , the leading edge of the input pulse. If there is a shower event, the hold pulse opens the switch at the reference time T_r . Hence C stores a voltage amplitude corresponding to the time difference ($T_r - T_s$). It is held until the falling edge T_f sets in, and the chip starts to sample again.

Digitization is done by a slow but high precision ADC (MC14514) with a reference voltage $+2.48$ V provided by a chip MC1403. This together with the TAC gives a full range of 1999 corresponding to a time difference of 1768 ns. Hence the time resolution is better than 1 ns. The unit is calibrated by using a fast CRO and a signal generator. The various fixed time delays are also determined similarly.

From the geometry in figure 1, a time difference of 2.9ns corresponds to $\sim 1^\circ$ zenith angle. Hence the directional resolution is mainly determined by the time fluctuation in the scintillation counters, including photomultipliers and preamplifiers. The fluctuation is not expected to exceed 4ns. Therefore, the directional resolution is better than 1.5° .

4. Shower rate and efficiency. The minimum trigger density at each scintillator is 4 m^{-2} . Using the differential intensity spectrum²,

$$j(N) = 1.95 \cdot 10^6 N^{-2.7} ,$$

The shower rate is estimated by the expression,

$$\phi = \frac{2\pi}{\alpha+2} \int j(N)A(N)dN, \text{ with } \alpha = 8.6 \text{ at sea level,}$$

and is presented below.

Shower size (N - N+ δ N)	A(\bar{N})	$\bar{N}^{-2.7}$ A(\bar{N}) δ N
9.2 E4 - 1 E5	1.0 E1	0.03 E-7
1 E5 - 2 E5	3.0 E2	4.87 E-7
2 E5 - 3 E5	2.05 E3	6.31 E-7
3 E5 - 4 E5	4.10 E3	4.76 E-7
4 E5 - 5 E5	6.10 E3	3.47 E-7
5 E5 - 6 E5	8.00 E3	2.61 E-7
6 E5 - 7 E5	1.05 E4	2.16 E-7
7 E5 - 8 E5	1.24 E4	1.73 E-7
8 E5 - 9 E5	1.47 E4	1.46 E-7
9 E5 - 1 E6	1.67 E4	1.22 E-7
1 E6 - 2 E6	2.40 E4	7.78 E-7
2 E6 - 3 E6	4.20 E4	2.58 E-7
3 E6 - 4 E6	5.70 E4	1.32 E-7
4 E6 - 5 E6	6.80 E4	0.77 E-7
		Total 41.07 E-7

Hence the shower rate is $\phi (>9.2 \cdot 10^4) = 4.7 \text{ hr}^{-1}$.

The effective area of each flash-tube tray is 1.73 m^2 and the expected efficiency of the tubes is $\sim 85\%$. Hence on the average, the minimum number of shower particles recorded from each tray is $4 \times 1.73 \times 0.85 = 5.9$. The directions of the muon tracks in a muon-rich shower can be used to check the shower direction obtained by the time-difference method.

5. Acknowledgement. The authors are grateful to Professor D.J. Newman for his support and encouragement.

References.

1. Samorski M and Stamm w, Ap.J. Lett. 268 (1983) L17.
2. Hillas A M et al, Phys. Reports, 20C (1975) 79.