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^O.

1. Introduction. Application of medium-size shower arrays in astronomical observations is exemplified by the Kiel experiment[1] 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 elabourate 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.
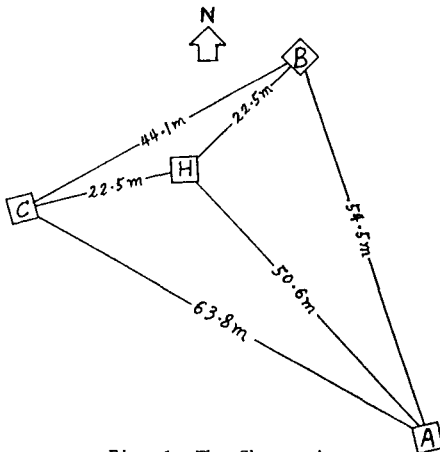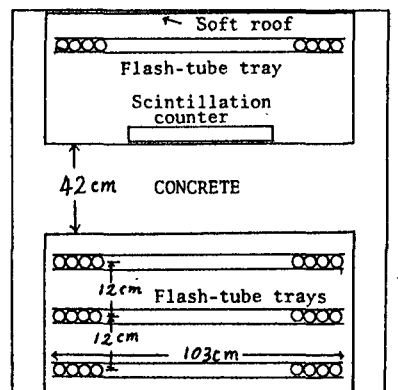

Fig. 1 The Shower Array.   Fig. 2 The Detector Assembly.

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 0.5m x 0.5m x 0.05m and is viewed by
two 2" photomultipliers in contact with the scintillator.
For precise arrival time determination, anti-jitter preamp-
lifiers 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 2m x 1.9cm dia.
and when it fires, its output electromagnetic signal is
picked up by a latch. There are 4 x 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 through-
out. A master pulse is produced by 4-fold coincidence of the
scintillator outputs (2μs 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
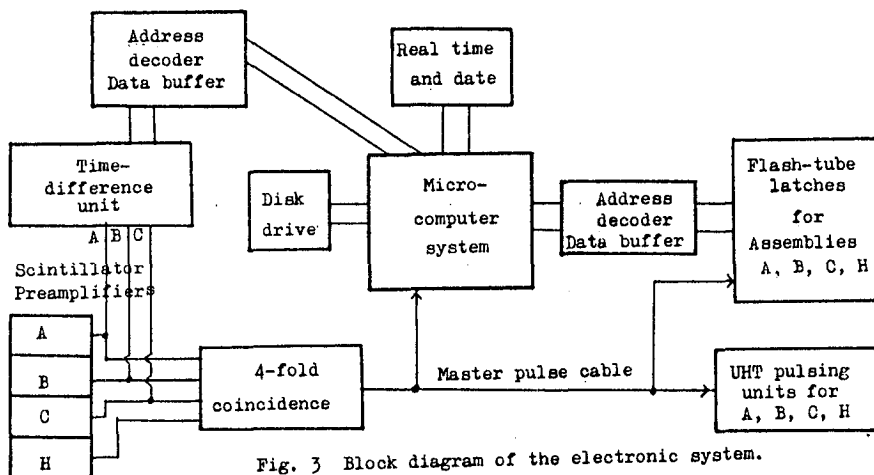acquisition subroutine in the microcomputer.

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
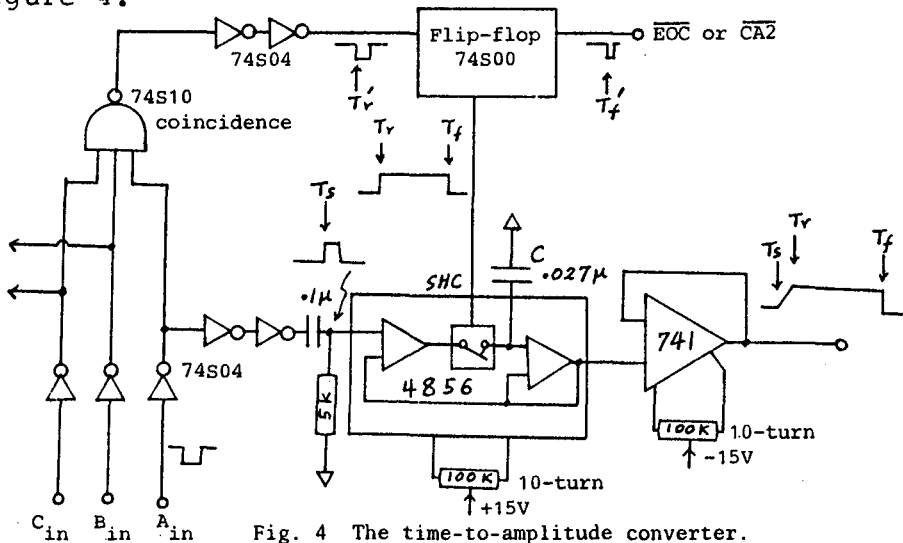and ADC. The TAC and time reference circuits are shown in
figure 4.

Fig. 4 The time-to-amplitude converter.

The TAC is a sample/hold chip (Teledyne Philbrick 4856)
with a charging rate ~ 1.5 V/µs and a drift rate ~ 0.8 mV/s at
the hold state, using a low leakage capacitor C of 0.027 µf.
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
($\overline{EOC}$) 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 $\sim 1°$ 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 spectrum[2],

$$j(N) = 1.95.10^6 N^{-2.7} \quad ,$$

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+δN)	A($\bar{N}$)	$\bar{N}^{-2.7}$A($\bar{N}$)δN
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 $\phi(>9.2.10^4) = 4.7 \text{ hr}^{-1}$.

The effective area of each flash-tube tray is 1.73 m^2 and the expected efficiency of the tubes is ∿85%. Hence on the average, the minimum number of shower particles recorded from each tray is 4 x 1.73 x 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.

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