CHAPTER -III

EXPERIMENTA SETUP

3.1 INTRODUCTION:

A new experimental setup has been developed in the miniarray Research Laboratory, UHE Cosmic Ray Research, Gauhati University Guwahati, Assam, INDIA. Based on a method as suggested by Prof. John Linsley, for the detection of EAS, this unconventional, cheap and novel technique has been successfully used to study the UHE(≥10^{15}eV) Cosmic Rays by measuring arrival time spread i.e. thickness of the shower front (σₜₚ) and the particle density (ρ) of the secondary particles from EAS produced by primary particles in the atmosphere[14]. Studies of optical pulses produced by UHE cosmic rays is done using optical detectors run along with the miniarray. The experimental setup consists of fast timing particle detectors, optical detectors, necessary electronics and microprocessor based data acquisition system and computer interface. Fig.3.1 shows the block diagram of the experimental setup and the data acquisition system. This experimental setup is performed by recording the time spread up to 2.5 µS with an accuracy of 10nS.

To detect the UHE Cosmic Rays an array of eight plastic scintillation detector is setup inside a hut at the roof top of the Physics Building covering a carpet area of 2m². A Photomultiplier (PMT) (Type 9792KB, 13 cm diameter) is installed at the centre of the mini array to record optical pulses in association with the detection of UHE cosmic Rays as recorded by the mini array. All the amplified pulses are carried to the Data Acquisition System (DAS) in to the control room.

3.2: DETECTORS:

In the present experiment particle detectors as well as optical detector are used,

(1) Particle detectors of the miniarray.

(2) Optical detector.

3.2.1: THE PARTICLE DETECTORS:

Each detector unit consists of one fast photomultiplier tube (EMI-9807B), a plastic scintillator block of size 50x50x5 cm³ having a photomultiplier base, a pre-amplifier unit and a
light tight enclosure along with a PMT unit as shown in the fig.3.2. The PMT's are extremely sensitive light detectors which was first developed by Curran and Baker in 1944, provides a current output proportional to intensity of incident light. They detect light at the photocathode which emits electrons by the photoelectric effect. These photo electrons emitted by the photocathode are electro statically accelerated and focused into the dynode which produces number of secondary electrons, i.e. each electron liberates a number of secondary electrons which are, in turn, accelerated and focused on to the next dynode. The process is repeated at each subsequent dynode and the secondary electrons from the last dynode are collected at the anode.

A organic scintillator of polyvinyltolune crystal are used as a scintillation counter. During the passage of a charged particle through the scintillation block, internal states of the atoms are disrupted and light is emitted usually in a kind of domain effect yielding enough light, i.e. atoms are excited but then de-excited and they emit light which falls on the photo cathode. Most of the excitation energy quickly transform into heat and about 20% is stored by fluorescence centre of meta stable energy levels and eventually reappears in the form of light. Scintillators have many desirable general characteristics namely- linearity to energy, fast time response, pulse shape discrimination and variety in materials (organic and inorganic types) etc. The light emission from scintillators can be characterised by the expression,

\[ N = A \exp \left( -\frac{t}{\tau_f} \right) + B \exp \left( -\frac{t}{\tau_s} \right) \]

Where \( \tau_f \) and \( \tau_s \) are the fast and slow components and \( A, B \) are given by a functional form [35],

\[ A = N_0 f(\sigma, t) \]

The shape of \( f(\sigma, t) \) has a Gaussian shape. The ratio of the fast and slow components depends on the scintillator material and the type of radiation interacting on it. Resolution of the scintillator is 20% with decay time of 4nS, light output 50% that of anthracene and maximum wavelength of emission 4340Å. A fraction of the light emitted is lost by the re-absorption in the phosphor or trapping within the boundaries of the phosphor by total internal reflection. The remaining portion of light is then collected by photocathode of the photomultiplier tube. Photomultiplier Tube are used to quantify low light levels, sent continuously or occurring in short-duration bursts. It has large collection area, high gain, linear
D₁ - D₈ - Particle Detectors
Č - Čerenkov Detector

Fig.: 3.1: Block Diagram of the Experimental Setup.
Fig. 3.2: Fast Scintillation Detector.
behaviour, fast time response and the ability to detect single photons give the photomultiplier
distinct advantages over other types of light detectors. The PMT used in the miniarray is a round
face end window type with a semitransparent bi-alkali photocathode having maximum sensitivity
in the blue region of the spectrum. The dark current is low, (1nA - 1400V) and the maximum
overall gain is $7.1 \times 10^6$ with the rise time of 2nS. Fig.3.3 and fig.3.4 show the voltage divider
networks for the electron multiplication. The chain current is 0.45mA and the chain consist of 12
stages. The anode is biased with a positive high voltage and cathode is grounded. The
photomultiplier tubes are operated at an anode potential of +1800V supplied from a variable
high voltage unit (EC1L,HV 4800E). A momentary negative pulse is produced across the anode
load resistance due to the sudden potential drop produced by the instantaneous current pulse
which is then coupled to the pre-amplifier unit. The unequal anode potential requirements for the
different PMT's are adjusted by using potentiometer in series with the branching network,
generally 10 to 15 kilo-ohm resistances are used for this purpose. Fig.3.5 shows the circuit
diagram of the fast scintillation pre-amplifier. This pre-amplifier unit is a double stage
differential amplifier designed around μA733 video amplifier operated at ±6.5V D.C. supply
derived from the low voltage unit. The rise time of the amplifier is 2nS with an overall band
width of 200MHz and the gain of the amplifier of each stage is 10. The amplifier has a power
amplification stage consisting of two N-P-N transistors 2N 2222A coupled to the amplifier unit
through a capacitor 0.01μF. The power amplification stage is used to compensate for power loss
of the output pulse in the cable when it is transmitted to the control room for further processing.

3.2.2: ČERENKOV DETECTOR:

The Čerenkov detector system comprises the following,
(a) A photomultiplier tube (EMI 9792KB) with an appropriate dynode chain.
(b) Pre-amplifier.

(a) Photomultiplier Tube:

A photomultiplier tube (type EMI 9792KB) of 130mm diameter photocathode with an over
all gain of $0.7 \times 10^6$ is kept vertically pointing towards the sky. The unit is protected form
sunlight as well as star light by keeping it in a light tight box. During the recording period the top
cover of the box is opened to expose the PMT. The atmosphere in this case taken as medium for
production of Čerenkov radiation. Fig.3.4 shows the voltage divider network of Čerenkov
detector for electron multiplication. The chain consists of 9(nine) stages with a chain current

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Fig. 3.3 Voltage divider network for 9807B Type PMT
Fig. 3.4 Voltage divider network for 9792KB Type PMT
of 0.5 mA. The cathode is grounded and the anode is biased by a positive high voltage. This PMT is operated at an anode potential of 1400V supplied from a high voltage unit (ECIL, HV 4800E). The chain resistance were of high stability type with a tolerance of 1% and they are soldered directly to the base socket.

The requirements of the voltage divider networks are fast rise time and decay times with as little ringing as possible in order to reduce the double firing of the discriminators. To reduce the ringing due to mis-match, a low value variable resistor is connected in series at the input of the pulse amplifier and adjusted for best results.

(b) Pre-amplifier:

To reduce noise, the detector pulses are amplified by a fast suitable amplifier connected near the PMT. Fig 3.5 shows the circuit diagram of the fast scintillation pre-amplifier. This pre-amplifier unit is a double stage differential amplifier designed by using a monolithic differential input, differential output, wide band video amplifier. This linear integrated circuit μA 733 operated at ±6.5V D.C supply derived from the low voltage unit. The rise time of the amplifier is 2nS with an overall band width of 200MHz and the gain of the amplifier of each stage is 10. The amplifier has a power amplification stage consisting of two N-P-N transistors 2N 2222A coupled to the amplifier unit through a capacitor 0.1 μF. The emitter follower outputs provide low output impedance, and enable the device to drive capacitive loads. The power amplification stage is used to compensate for power loss of the output pulse in the cable when it is transmitted to the control room for further processing.

3.4.: CONTROL ROOM ELECTRONICS:

The detector pulses from the scintillation detector and optical pulses from the Čerenkov counter are initially amplified at the detector station and transmitted to the control room through 50Ω coaxial cable (RG 58U) and following units are used to process in the control room.

3.4.1: EIGHT CHANNEL DISCRIMINATOR:

A modified multi channel discriminator board is designed and fabricated using high speed voltage comparators for the present experimental set up. The reference voltage is produced precision reference source RF01 and LM 301 and this stable
Fig 3.5 Circuit diagram of fast scintillation pre-amplifier.
Fig. 3.6 Circuit diagram of one channel discriminator with pulse
reference voltage works as the source of discriminator level at the input of the comparator. The pulses from the detector are fed into the inverting input terminal of the high speed comparator U2(LM 361) and the bias is set by the ten turn preset. As the incoming pulse crosses the discriminator bias in the comparator input, the unit produces the logic pulse. The circuit diagram of one channel of the discriminator with pulse shaper is shown in the figure (3.6).

The output of the discriminator is shaped into two separate pulse widths by using IC 3 and IC 4 (Mono stable Multivibrator). One of them is of 20nS which is used for recording of air shower events. The another one has pulse width 700nS. This pulse is generally used for counting purpose at a pre-determined intervals, controlled by the microprocessor 8086.

To obtain stable operation and proper pulse shapes, a good high frequency technique is necessary. The circuit pattern was printed on both sides of double side PCB and suitable spacing is maintained at ground potential throughout the circuit. Components were soldered like surface mount device. Figure 3.7 shows the typical output pulses of the discriminator corresponding to an event trigger captured by the Digital Storage Oscilloscope. CH-1 shows the discriminator output while the CH-2 gives the trigger pulse.

3.4.2: TRIGGER UNIT:

For recording optical pulse in association with UHE Cosmic Ray events, the wave forms are captured under some prerequisite criteria. These criteria’s are,

(a) The particle detector pulses are triggered by the Čerenkov pulse and must be present within the time window 2 μS.

(b) The hardware trigger requiring particle in the range two or above within the 2 μS time window.

(c) The minimum arrival time spread between the particles must be 100nS. The trigger unit is shown in fig.3.8.

The trigger circuit design on an idea by [85] and shown in the figure 3.8 performs the function required under (b). The output pulse train from the OR gate charge the capacitor C5(220pF) through the diode D1(IN 914) for a time period determined by the timing pulse at the CMOS Gate, U4 (4016-Quadruple Analog Switch). The timing pulse is generated by applying the pulse train to U3(74121) which is at present set to 2μS by preset P2. The gate pulse discharges the capacitor at the end of 2μS
Fig. 3.7: A typical output pulses of the discriminator corresponding to an event trigger.
period. The voltage at the capacitor varies as the number of pulses received in the 2μS duration. This voltage across C5 is fed to a high speed voltage comparator U8(LM 361) and the trigger pulse is generated by the U5(74S74- Dual Edge Triggered Flip-Flop) and U6(74LS11- Triple 3-Input Positive–And Gate). The 2μS Gate pulse is inverted and brought to the CLK2 input of the flip-flop and both the outputs are combined by U6 to ensure that the trigger pulse is generated at the end of 2 μS period.

3.4.3.: THE DIGITAL STORAGE OSCILLOSCOPE AND GPIB INTERFACE.: A Digital Storage Oscilloscope (DSO, Tektronix, TDS, 520A, 500MHz, 500MSample/Sec.) is connected through the General Purpose Interface Bus Adapter (NI Spy, National Instrumentation) for recording the optical Čerenkov pulse in association with the UHE Cosmic Ray events. The optical as well as particle detector wave forms are recorded by the DSO and written to files in the computer hard disk. We are recording the optical pulses within 2μS time window in association with events as satisfies the pre-requisite criteria. This is done by setting the DSO in the real time single acquisition mode. When the event trigger occurs with optical pulse, the DSO stops the acquisition and wave forms are available in the wave form memory of the DSO and are then transferred to the computer hard disk for permanent storage. An optical pulse in association with particle events recorded by the DSO is shown in the fig.3.9.

3.4.4.: MICROPROCESSOR AND MICROCOMPUTER INTERFACE. A Microcomputer based on 8086 microprocessor with a clock speed of 5MHz is used for operation of the detector setup. The unit provides 128KB of battery RAM, Programmable I/O ports(8255), Priority Int. Controller (8259A), Real Time Clock(RTC), Programmable Timer Counter(8253), Keyboard and Monitor Interface. Additionally it provides one RS232C interface using USART 8251. Primary function of the microprocessor is to monitor the operation of the detectors by recording the count rates at predetermined intervals. For this the 8253 receives the Multiplexer(MUX) output pulses from each of the channels through its clock input. The total time of counting is monitored by using 1second timer output of the RTC. This is used as IR02 input of the 8259 and a procedure terminates counting when set time elapses. The microprocessor reads the counts(BCD), stores them in RAM and sends them to the computer for disk storage via RS232 interface.
Fig. 3.9: A typical Čerenkov pulse triggered by miniarray trigger is captured by DSO.
3.4.5.: THE NECESSARY SOFTWARE USED:

The collection rate of the Čerenkov pulses in association with the particle events by the mini array is quite low and the period of recording of optical pulse is also very limited. So it is necessary to run the detector system on a continuous basis over whole night with moonless, cloudless sky condition to collect sufficient data. For this purpose a software is developed which performs the followings,

(i) Optical pulse and particle detector pulses received within the 2μS time window is recorded by capturing the waveforms displayed in the two channels of the DSO, channel one being used for optical and channel two for particle pulses.

(ii) The capture process is initiated once the trigger pulse is received in the auxiliary channel that stops the waveforms in the DSO waveform memory.

(iii) The computer software polls both the serial communication port (COM1) and the GPIB port, receives the waveform data and saves these in the computer hard disk whenever an event occurs.

(iv) When there is no event a counting sequence of the particle detector pulses is started, the number of counts and RTC time is transmitted to the computer for each channel sequentially.

(v) The counter data received are also saved in the computer hard disk as a separate file. The programmes for the microprocessor are developed in assembly language. The programme for handling the RS 232 communication, GPIB and file handling is written in C. The flowchart for the entire software is given in the appendix-III.

The test and calibration of all the detectors and fast electronics circuits will be reported in the next chapter.