MACE TELESCOPE

Camera and Subsystems

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The objective of MACE camera is to detect the faint and short Cherenkov light pulse. The imaging camera of the MACE Telescope consists of 1088-PMTs based pixels. Along with the PMTs, the entire instrumentation for the camera is mounted in the focal plane of the telescope. It has been designed with state-of-the-art technologies within the constraints of space, weight, environmental conditions and power.

The real time event processing requirements are met using compact FPGA (Field Programmable Gate Arrays) based units and embedded processor units. Only cables for communication and power are routed to the camera from ground station.

Subsystems

The various sub units of MACE Camera Data Acquisition System (DAQ) and their location on the telescope are presented in this article alongside other important related aspects. Various components of the entire chain of instrumentation, equipment and computer systems involved in an observation run are physically placed in four different locations. Along with camera electronics, other peripherals components such as network switch, junction boxes, motor controller for camera lid etc are also mounted on the camera structure.

The control room equipment implemented mainly using server computers and storage servers, are designed for total automation of MACE telescope with remote login facility. Control cabin electronics mainly houses the power supply units and provides the isolated 48V DC power to camera. LED (Light Emitting Diode) calibration system mounted at the centre of the telescope mirror basket is used for the relative calibration of the PMTs.

The camera hardware has been qualified to stringent environmental conditions and ESS (Environmental Stress Screening) qualified fabrication of camera provides reliable system with minimum maintenance requirement.

Imaging Camera

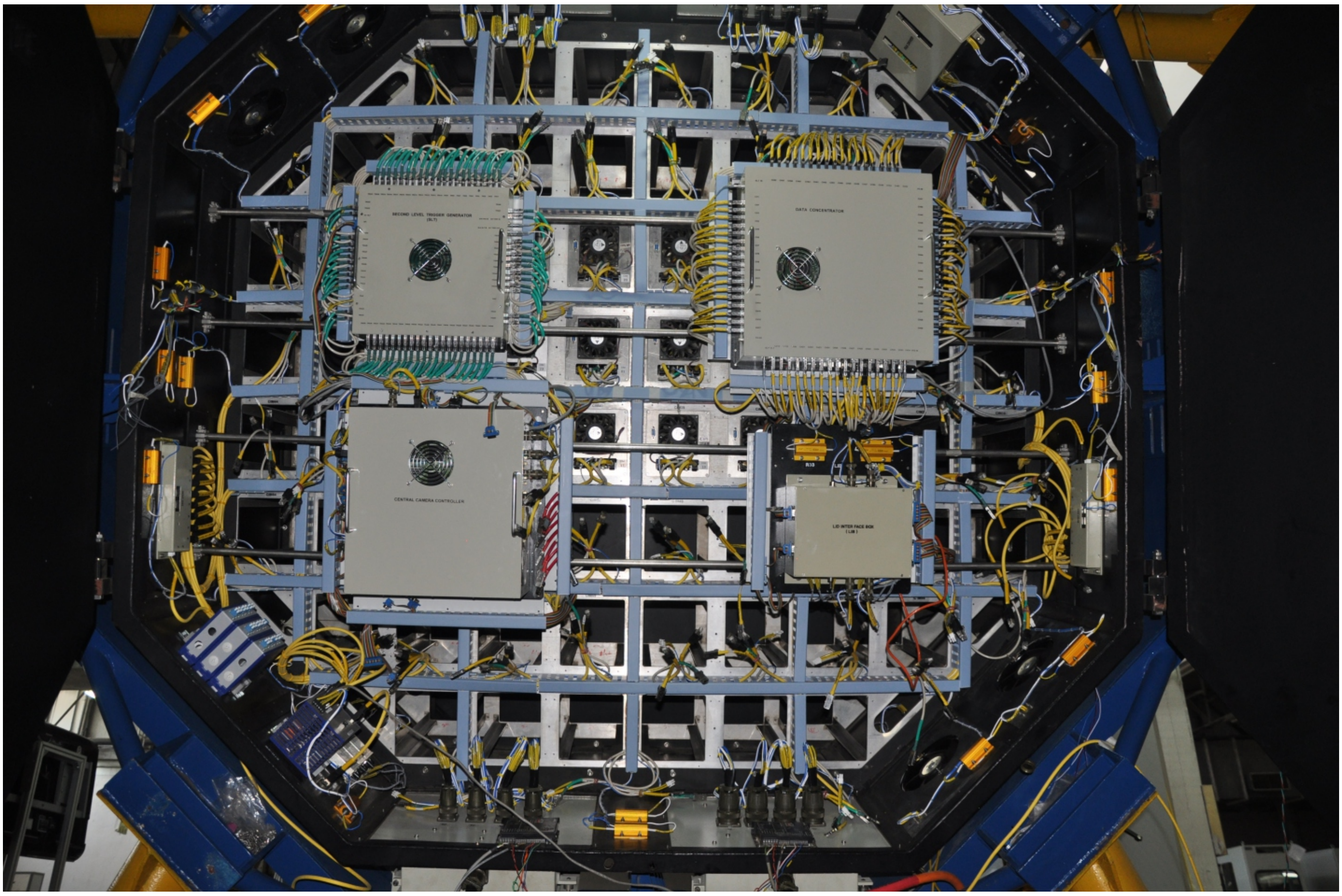
The MACE camera comprises front-end electronics consisting of 68 Camera Integrated Modules (CIM), and 3 back-end units called DC (Data Concentrator), CCC (Central Camera Controller), and SLTG (Second Level Trigger Generator). Each CIM is having integrated electronics for sixteen pixels. The modular concept also allows easy maintenance. Each CIM houses 16 PMTs and the front-end electronics consisting of VDN (Voltage Divider Network), HV (High Voltage) supply, pre-amplifier, main amplifiers, threshold discriminator, scalar, analog memory and pulse profile digitizer for sixteen pixels. It also houses FLT (First Level Trigger) logic, event acquisition block, high speed data link interface and a local controller. Preamplifier has been employed at the tube base.

The wide band, low noise preamplifier is based on a MMIC (Microwave Monolithic Integrated Circuit) and provides a nominal signal voltage gain of ~10 with output pulse rise time of less than 2 ns. Each pixel of the imaging camera needs to be gain matched closely to ensure event triggering homogeneity. For the MACE camera, the gain matching is achieved by biasing each PMT through independently programmable HV supplies.

Generally, each HV supply is programmable in the range from 0 to –1350V with ~ 0.4V voltage setting resolution and has output voltage and anode current read-back facility. The basic HV supply consists of a step-up, self-oscillating push-pull inverter, 8-stage Cockcroft-Walton multiplier and an error amplifier for output regulation.

Second Level Trigger Generator (SLTG) detects time-space coincidence across nearby pixels in the trigger region based on the first level trigger information from various CIMs and generates system-wide trigger signal. After receiving the trigger signal, CIMs start acquisition and send event data to the DC. In each CIM the PMT signal from all the sixteen channels are sampled continuously at 1GSPS (Giga Samples Per Second) and stored in an analog memory ASIC, Domino Ring Sampler (DRS) which has 9 channels with 1024 cells each.

The 9th channel is connected to the SLT signal and used for timing reference and delaying the sampling for region of interest readout. When SLT signal arrives, the sampling stops and sampled values are readout at lower rate of 33MHz in region of interest mode with Flash ADC (Analog to Digital Converter). Efficient data processing algorithms have been implemented in CIM and accumulated charge data for each pixel along with



THE POWER CONSUMPTION during experiments with the telescope is estimated to be ~4kW.

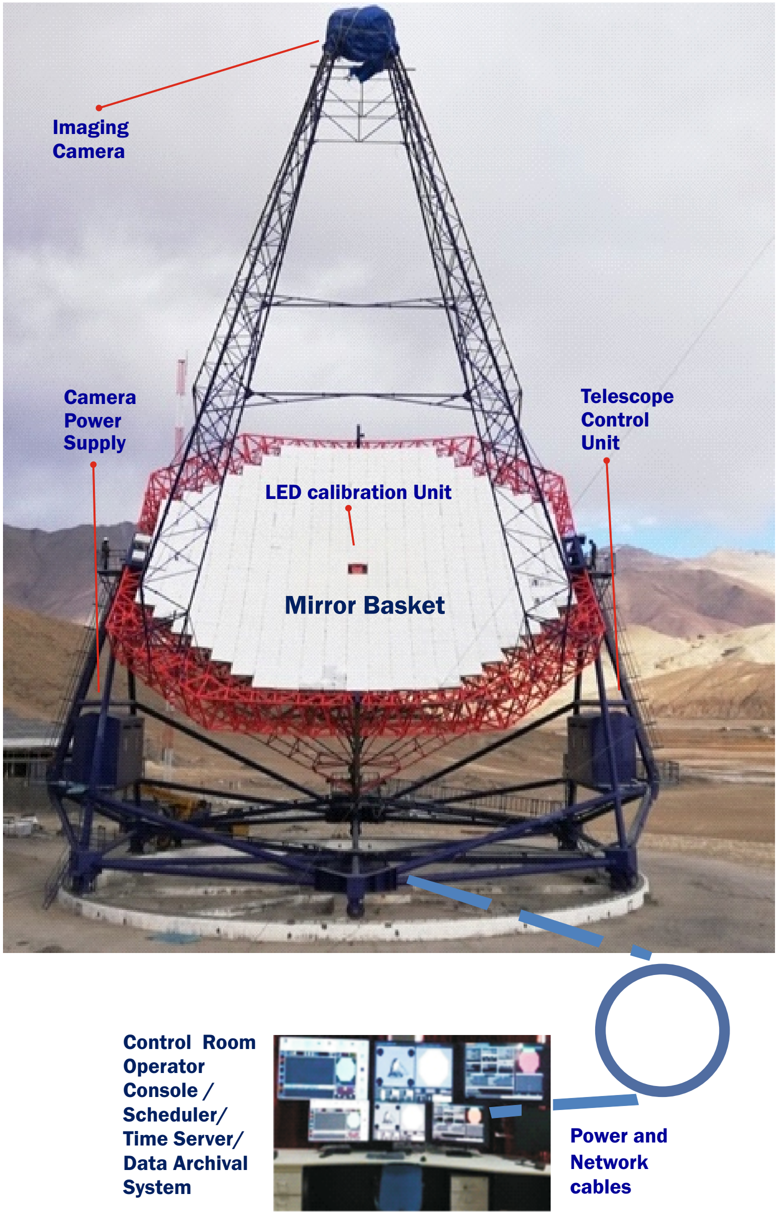
profile of hit pixels is formed in the CIM data packets. DC collects these data packets from all the CIMs and prepares camera event packets. DC is a proprietary form-factor card designed around PC104plus SBC (Single Board Computer) and has FPGA based event data processing for high throughput. DC collects data coming over dedicated LVDS (Low Voltage Differential Signalling) links from all the CIMs and event data is written to dedicated FIFOs (First In First Out) with a capacity to hold about 32 events. The data links to individual CIM are proprietary serial LVDS links operating at 200Mbps, while the link to ground station is 1Gbps Ethernet link.

DC also implements the time stamping scheme. Time stamp is attached to each event based on IRIG-B time code signal from a master clock installed in the control room. The master clock is synchronized to GPS (Global Positioning System) and serves as time server for the entire telescope over NTP protocol. As the time code accuracy of 1 micro-second is required, unmodulated output signal from the master clock in IRIG-B00 format is used. The TTL (Transistor Transistor Logic) level signal is converted to optical and sent over fibre to camera, where it is converted back to TTL to connect to DC. The CCC provides the interface between Operator Console at ground-based control room and carries out the control and status logging of the MACE camera electronics. The CCC consists of four blocks SBC (Single Board Computer), CCC micro controller card, FPGA section and power supply & I/O section. CCC is interfaced to the MACE Operator Console with Ethernet link. The DC is interfaced with CCC with RS 232 link for command interface. The CCC links all 68 CIM modules with I2C link and auxiliary (RS485) link. The SBC used in the CCC is a PC104 plus unit.

The SBC uses ISA (Industry Standard Architecture) bus to interface to FPGA section and various control blocks are implemented in VHDL (Very High Speed Integrated Circuit Hardware Description Language) for interfacing SBC with DC, SLTG, LED calibration unit, Lid Controller (LC). CCC is designed to operate in harsh weather conditions prevalent at Hanle, Ladakh. Rigorous FMEA (Failure Modes and Effects Analysis) and Reliability analysis of CCC has been carried out and the estimated MTBF (Mean Time between Failures) of CCC was found to be 83 years.

Control Cabin Electronics

Control cabin electronics, situated in the telescope structure, houses twin 19-inch power supply racks. The power supply system consists of Ultra Isolation transformer, 230V to 48V DC power supply modules in redundant configuration, high power diode for redundancy, DC filter modules and a PLC (Programmable Logic Controller) module



▲ MACE TELESCOPE with Data Acquisition System (DAQ) sub units.

for remote ON/OFF and status logging. The power supply units provide the isolated 48V DC power to camera. Total maximum power consumption at camera end is 6.5kW. The estimated power consumption during experiments is around 4kW. The total 230V input power provision to power supply unit is 10 kW. The photograph of the power supply rack of MACE is given in the following pages.

IN each calibration run, the telescope's camera is illuminated by 1000 uniform light flashes at a frequency of 200Hz.

LED Calibration System

The pixels of the camera have non-uniformity in gain due to variation in intrinsic gain of PMTs and variation in amplifier stage. LED Calibration system is responsible for the relative gain calibration of the camera pixels. The main requirement of the calibration system is to uniformly illuminate the MACE camera. Light flux should be sufficient to cover the whole dynamic range of the channels and shape of the optical pulse generated by the calibration system must be matching with the Cherenkov light pulse.

In case of MACE calibration system, the fluency of photons emitted during 8-10ns by an assembly of synchronized blue LEDs is used for relative gain calibration of the Imaging Camera. The relative gain calibration equalizes the response of different devices to the same mean value, when subjected to the same input signal. The main component of the calibration system is a pulsar which provides five high-speed pulsars to drive ultra-fast blue LEDs with variable intensity in order to calibrate the whole dynamic range of the PMT based camera.

The pulsar along with LEDs is housed at the centre of the telescope basket, which has a transparent window towards the camera, through which light can pass to the camera. The light pulses emitted from LEDs are passed through a diffuser to homogenize the light flux produced by the LEDs at the camera.

Trigger circuit of calibration system receives the start of trigger from the CCC, after it generates a train of LED pulses based on the configuration parameter. Configuration includes number of LEDs to fire, frequency of LED pulses and number of pulses per calibration cycle.

The rise time of the LED voltage pulse is 3ns and its pulse width at 50% of its peak value, FWHM (Full Width Half Maximum), is 8ns. Relative gain calibration data are usually taken at periodic intervals during the observation run. Typically, in each calibration run, the camera is illuminated by 1000 uniform light flashes at a rate of 200Hz.

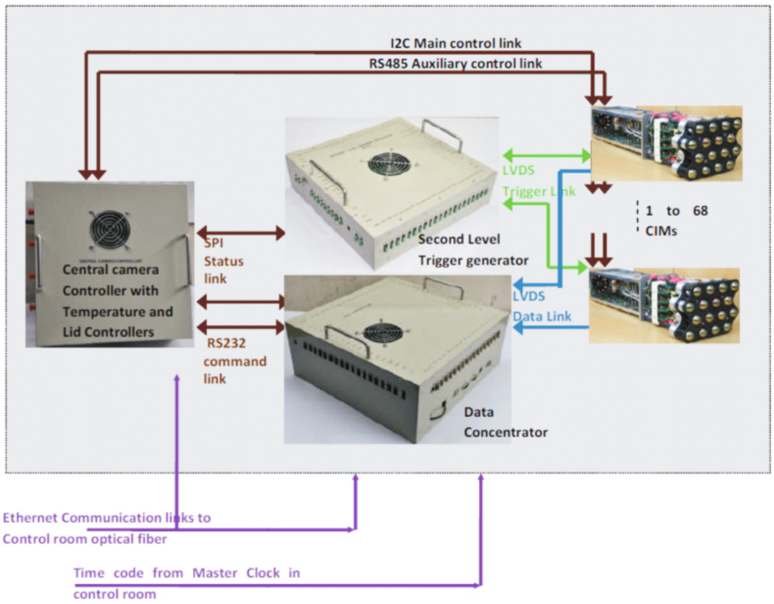
Mechanical Aspects

The mechanical housing of the imaging camera is indigenously designed and manufactured in-house at the Centre for Design & Manufacture, BARC. During observation at night the camera is taken to the top to point to the required source. During non-observation time and maintenance, the camera is kept in the parking shelter. The Camera housing is an octagonal shaped enclosure fastened securely on a camera mounting bracket to the four booms of the telescope.

Conclusion

Regular source observations are being carried out. Data integrity and module errors were diagnosed and resolved. The overall event control sequencing scheme is optimised for timing. Fine tuning of delay timing in SLTG unit was carried out in nano-second range to align pulses within readout window of signal digitization. The features for auto recovery mechanisms due to various abnormal conditions were implemented and tested. The system was operated

Parameters	Values
Maximum size of camera	2230mm X 2140mm X 1350mm
PMT panel size	2000mm X 2000mm
No. of CIMs, PMTs, PMTs per CIM	68, 1088, 16
Camera coverage angle	4°
Pixel pitch (triangular) and resolution	55mm, 0.125°
Max. Intra-CIM gap at front panel	2mm
Maximum Array of CIMs (at mid)	10 X 8
CIM insertion/removal design feature	Modular Type design
Materials of Camera Housing	Al 6061 T6, Ti Gr 2, SS 304, SS316, 17-4 PH Steel, Al Honeycomb, Phosphor Bronze, EN36A, silicone gasket ABS Plastic, Cellular Silicone
Frontshutter/lid	Overlapping honeycomb panel
Front shutter/lid mechanism type	4-bar mechanism motorised
Gear box	Worm wheel, GR 25:1
Max. Weight of CIM (Populated)	8.5kg
Max. Weight of camera	1300kg



▲ BLOCK SCHEMATIC of the camera electronics.

▲ CAMERA Integrated Module (CIM).

▼ POWER Supply rack.

▲ MACE CAMERA in parking shelter.

both locally and remotely from BARC, Mumbai and the operating procedures for Camera operation are well established.

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