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The Camera of the MAGIC-II Telescope

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Abstract: The MAGIC 17m diameter Cherenkov telescope will be upgraded with a second telescope within the year 2007. The camera of MAGIC-II will include several new features compared to the MAGIC-I camera. Photomultipliers with the highest available photon collection efficiency have been selected. A modular design allows easier access and flexibility to test new photodetector technologies. The camera will be uniformly equipped with 0.1 degree diamter pixels, which allows the use of an increased trigger area. Finally, the overall signal chain features a large bandwidth to retain the shape of the very fast Cherenkov signals.

Introduction

The 17m diameter MAGIC [1] telescope is currently the largest single dish Imaging Atmospheric Cherenkov telescope (IACT) for very high energy gamma ray astronomy with the lowest energy threshold among existing IACTs. It is installed at the Roque de los Muchachos on the Canary Island La Palma at 2200 m altitude and has been in scientific operation since summer 2004. Within the year 2007 MAGIC is being upgraded by the construction of a twin telescope with advanced photon detectors and readout electronics. MAGIC-II [2], the two telescope system, will have a reduced analysis energy threshold and the overall sensitivity in stereoscopic/coincidence operation is expected to increase by a factor of 2-3.

To decrease the energy threshold of IACTs, the overall light collection efficiency for Cherenkov photons has to be increased. The camera of MAGIC-II will therefore be equipped with optimized Winston cones and with photo detectors with the highest possible quantum efficiency (QE). Increased QE PMTs [3] will be used in a first phase and an upgrade to very high QE hybrid photo detectors (HPDs) [4] is planned in a second phase.

The entire signal chain from the PMTs to the FADCs is designed to have a total bandwidth as high as 500 MHz. The Cherenkov pulses from γ-ray showers are very short (1-2 ns). The parabolic shape of the reflector of the MAGIC telescope preserves the time structure of the light pulses. A fast signal chain therefore allows one to minimize the integration time and thus to reduce the influence of the background from the light of the night sky (LONS). In addition a precise measurement of the time structure of the γ-ray signal can help to reduce the background due to hadronic background events [5].

The design of the MAGIC-II camera

A modular design has been chosen for the camera of the MAGIC-II telescope (see figure 1). Seven pixels in a hexagonal configuration are grouped to form one cluster, which can easily be removed and replaced. This allows easy exchange of faulty clusters. More importantly, it allows full or partial upgrade with improved photo detectors. The 3.5^o diameter FoV will be similar to that of the MAGIC-I camera. The MAGIC-II camera will be uniformly

Figure 1: Technical drawing of the MAGIC-II camera design. The modular camera consists of 163 clusters with 7 pixels each.

equipped with 1039 identical 0.1^o FoV pixels in a round configuration. This allows an increased trigger area of 2.5^o diameter FoV.

The Camera Housing

The outer dimensions of the round shaped camera are 1462 mm in diameter and 810 mm in thickness. Since the camera is placed in the focus of the reflector at a distance of 17.5 m from the elevation axis of the telescope structure, the overall weight of the camera mechanics and electronics must be minimized. Most mechanical components are therefore made of aluminum. A total weight of 600 kg including all mechanical and electrical components is aimed for.

A Plexiglas window on the front side of the camera protects the light sensors from adverse weather conditions. The chosen Plexiglas 2458 has a transmission of 94% at large wavelengths slowly decreasing to 88% at 310 nm and a sharp cutoff at 280 nm.

The central part of the camera body consists of 2 cooling plates. The temperature of the camera electronics is very efficiently stabilized by cooling liquid running through pipes inside the cooling plates. In addition the cooling plates hold the PMT clusters in place. The clusters are inserted from the front side of the camera into holes in the cooling plates (see figure 1).

In the space surrounding the cooling plates various electronic elements will be installed to distribute the electrical power, the slow control signals and a trigger for electrical calibration pulses.

The 5 V power supplies for the camera electronics are mounted in 2 boxes attached outside to the main camera housing. Low noise switching power supplies by the company Kniel are used to reduce the noise on the camera signals. In order to minimize the weight of the power supplies and to limit the required cooling power, electronics with low power consumption have been used inside the camera. The total the camera electronics will consume about 1 kW power.

In total 169 clusters of 7 pixels each can be installed in the camera housing. While 127 clusters will be fully assembled, 36 clusters in the outer region of the camera will be only partially equipped with PMTs. In addition there is space for 6 clusters in the outer corners of the camera. They can be used to test new photon detectors without disturbing the normal data taking.

The photon detectors

In the first phase increased QE PMTs will be used. The Hamamatsu R10408 6 stage PMTs with hemispherical photocathode typically reach a peak QE of 34% [3]. The PMTs have been tested for low afterpulsing rates (typically 0.3% at 4 photoelectrons level), fast signal response ($\sim$1 ns FWHM) and acceptable aging properties.

In a second phase it is planned to replace the inner camera region with HPDs [4] produced by the Hamamatsu company. These advanced photo detectors feature peak QE values of 50% and will thus significantly increase the sensitivity for low energy showers. The flexible cluster design allows field tests of this new technology within the MAGIC-II camera without major interference with the rest of the camera. Upon successful test the whole central region of the camera will be equipped with HPDs.

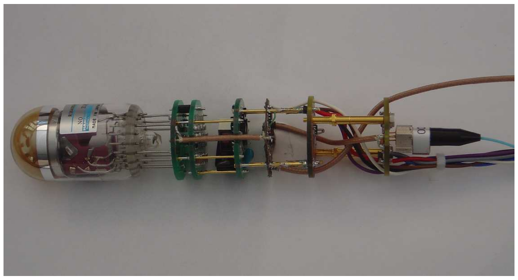

Figure 2: A fully assembled PMT module.

Winston cone type light guides, which concentrate the light onto the sensitive part of the photon detectors, are used to minimize the dead area between pixels. Only light coming from the direction of the mirror dish is concentrated, while light incident at large angles does not reach the photon detectors. Both the input window and the output window of the MAGIC-II Winston cones are hexagonal in shape. The 6 reflecting surfaces connecting the edges of the input and output windows can easily be bent in an ideal parabolic shape optimizing the light concentration and cutoff properties. Round cutoffs at the output window ensure perfect coupling to the spherical surface of the PMTs.

The PMT clusters

Hamamatsu delivers PMT modules which include a socket with a Cockcroft-Walton type HV generator. The PMT socket and the round shaped opto-electronic circuit boards for the front-end analog signal processing are assembled to form a compact pixel module (see figure 2). The opto-electronics cicuit amplifies the analog PMT signal and converts it into an optical signal for transmission to the digitization and trigger electronics in the counting house. In addition, monitoring circuitry is included which provides readout of relevant operating parameters such as average PMT current, PMT operating voltage, and pixel temperature.

The PMTs will be operated at a rather low gain of 2×10^4, allowing operation of the telescope under moderate moon condition without damaging the PMTs. The PMT output signal is transmitted over a short 50 Ohm coax cable and converted to a voltage signal at the input of a 50 Ohm impedance amplifier. A $\sim$1 ns wide PMT pulse produced by a single photoelectron generates a pulse with an amplitude of typically 160 μV at the amplifier input. Signal amplification of about 25.5 dB is provided by a broadband single stage amplifier designed around a SiGe MMIC gain block (Sirenza SGA 5586Z). The noise figure is 3 dB over the whole bandwidth from 100 kHz up to 800 MHz. The gain flatness inside the pass band is better than 1 dB. This ensures sufficient signal to noise ratio and accurate reproduction of the PMT pulses in the transmitted optical signal. The power consumption of one signal is in the range of 400 mW.

Protection circuitry is included at the amplifier input to guard against potentially destructive input voltages from the PMT. Since the generated voltage polarity of the PMT signal pulses is negative, a bias offset scheme is implemented, extending the available dynamic range and lowering supply voltage requirements. Calibration pulses of adjustable amplitude can be injected over a 500 Ohm resistor at the input of the amplifier. This allows functionality and linearity tests of the whole signal chain after the PMT.

Conversion to an optical signal with a transmission wavelength of 850 nm is done via a 2.5 Gbit/s Vertical-Cavity Surface-Emitting Laser (VCSEL) from Avalon. The VCSELs are biased with 3 mA to achieve low mode partition noise. The optical output is realized using a directly pigtailed $50/125$ μm multimode fiber ending at a LX5-connector at the backplane of the cluster. In order to prevent drift of the optical power during operation, temperature variations of the VCSELs must be minimized. Therefore, all VCSELs are coupled to a temperature stabilized cooling plate with a nominal variation of less than 1^o C on the surface. Additionally, the temperature of the VCSELs is monitored and output as an analog voltage signal. The bias current for the VCSELs is injected using a decoupling network. The current is supplied by an external circuit located in the cluster body. Output and input impedance of the amplifier and the VCSEL, respectively, are matched to a value of about 50 Ohm in order to reduce signal reflections.

The total dynamic range of the signal chain is 60 dB. The lower limit of the dynamic range is

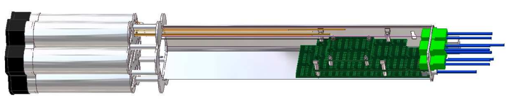

Figure 3: The technical drawing of one cluster of MAGIC II Camera.

dominated by the noise generated by the VCSELs, which is constant for a given bias current and temperature. The upper limit is set by the maximum linear output power of $\sim 3V$ (IP1dB = 18.5 dBm) that can be supplied by the amplifier.

A cluster consists of 7 pixel modules and a cluster body (see figure 3). The pixel modules are inserted in electrically shielding aluminum tubes, which are fixed to a front plate that also holds the Winston cones. A plate with heat pads is connected to the VCSEL cooling plates at the back of the pixel modules via heat transfer rods. It ensures good thermal contact to the water cooling plates of the camera housing. The cluster body behind the pixel module part is an aluminum box, which incorporates the control electronics, the power distribution and a test-pulse generator.

The slow control of the camera

The slow control of the camera controls the operation of the camera and reads several monitoring parameters. The HV of each pixel can be set individually and the PMT current and HV as well as the temperature at the VCSEL can be continuously monitored. In addition the slow control operates the lids in front of the Plexiglas window and steers the power supplies of the camera.

A slow control cluster processor (SCCP) board will be installed in each cluster body. A flash programmable processor on the SCCP board monitors and controls the PMT electronics via 12 bit resolution DACs (digital to analog converters) with a voltage range between 0 and 1.25 V and 12 bit resolution ADC (analog to digital converters) with a voltage range between 0 and 2.5 V. In addition it steers the amplitudes of the calibration pulses gen-

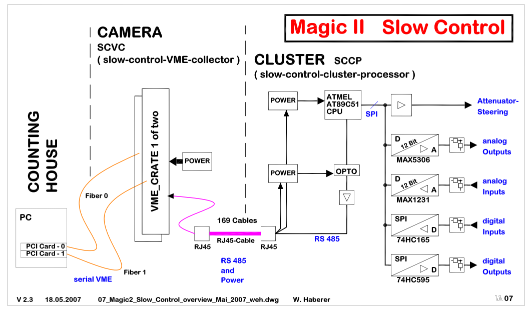

Figure 4: The conceptual design of the MAGIC-II slow control

erated in a separate test-pulse generator board sitting below the SCCP board.

Each SCCP board is connected to a VME collector board in one of 2 specially designed VME crates inside the camera. The RS485 read/write signals and the 5 V power for the SCCP board are transmitted using standard LAN cables with RJ45 connectors. Data is transferred at a rate of 1920 Bytes/s using RS232 protocol. The pixels can thus be monitored at a rate of 10 Hz. The VME crates are connected to the camera control PC in the counting house via an optical PCI to VME link. The concept of the MAGIC-II slow control is shown in figure 4.

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References

[1] E. Lorenz, *New Astron. Rev.* **48** (2004) 339;
[2] F. Goebel, et al., these proceedings;
[3] C. Hsu, et al., these proceedings;
[4] T. Saito, et al., these proceedings;
[5] D. Tescaro, et al., these proceedings;