

## The Data Acquisition of the MAGIC II Telescope.

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The MAGIC telescope is the largest *gamma*-ray Imaging Cherenkov telescope in the world. It is operating since 2004 at the Roque de Los Muchachos observatory, La Palma, Canary islands. MAGIC-II is the upgrade of this project, consisting of a twin telescope frame with innovative features like new photon detectors to lower the threshold energy further, and an ultrafast signal sampling to reduce the effect of the diffuse night sky background. The new acquisition system is based upon a low power analog sampler (Domino Ring Sampler) with frequency ranging from 1.5 to 4.5 GHz and data are digitized with a 12 bits resolution ADC. The analog sampler, originally designed for the MEG experiment, has been successfully tested on site and showed a very good linearity and single photon discrimination capability. Data management is performed by 9U VME digital boards which handle the data compression and reformatting as well. Every board hosts 32 analog channels plus auxiliary digital signals for trigger and monitor purposes. For a 1 kHz trigger rate and a 2 GHz frequency sampling, the data throughput can be as high as 100 MBytes/s, thus being a challenge for modern data transmission and storage solutions. The data are transferred to PCI memory via Gbit optical links using the CERN S-link protocol and to the mass storage system consisting of a RAID system and tape minilibraries. The data acquisition system design and performance will be described in detail.

### 1. Introduction

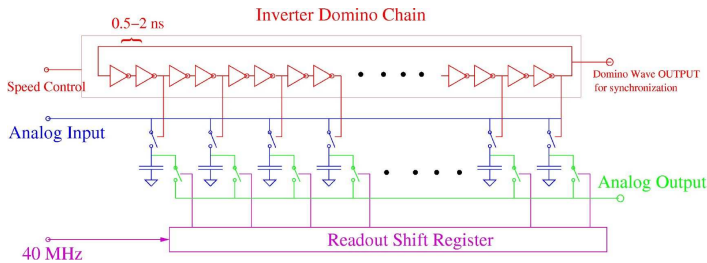
The MAGIC telescope aims at measuring low energy gamma-initiated showers ( $E_{th} \approx 30 GeV$ ) by looking at the Cherenkov light emitted in the atmosphere [1]. This signal is contaminated by background events due to various sources: hadronic showers, local muons, Light of the Night Sky Background (NSB), moon light and bright stars in the field of view of the camera.

The upgrade program of the MAGIC telescope involves the construction of a second telescope (MAGIC-II) which is mechanically identical. Several technological updates are foreseen for MAGIC-II, namely: new photon detectors, either high quantum efficiency photomultipliers or new generation silicon photomultipliers (APD or SiPM); and a new data acquisition system, based on fast (2 GHz) analog samplers, coupled to high bandwidth data transmission. These two changes will allow a more effective suppression of the light of the night sky and a stronger rejection of hadron induced air showers, while efficiently selecting  $\gamma$ -ray showers through using the more accurate timing information.

The Data taking chain works the following way. The new photon detectors collect the 1-2 nsec full width half maximum Cherenkov light flashes. Their output signals are amplified by ultrafast and low-noise transimpedance pre-amplifiers in the camera housing. The amplified analog signals are transmitted over 170 m long optical fibers. In the electronics hut the signals are split. One branch goes to a discriminator with a software adjustable threshold that generates a signal for a 2 level trigger system [2] capable of limiting the trigger rate to  $\lesssim 1$  kHz. The signal in the second branch goes to the new analog sampler described in the next section. The digitized signals are stored by a data acquisition system capable to process a sustained data rate of  $\approx 100$  MB/s. Immediately after the data is taken, thanks to an independent network for the storage, an Online Analysis starts on the data.

## 2. Sampling Electronics

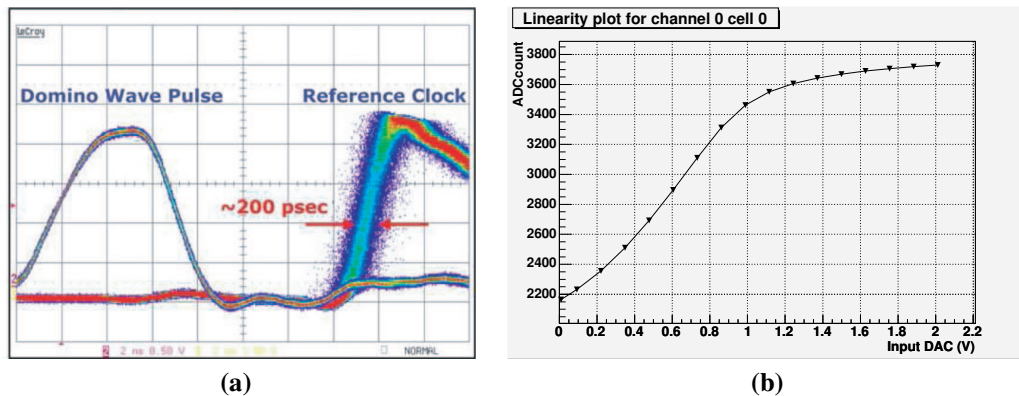
The digitizing core of the Data Acquisition for the MAGIC-II telescope is constituted by the analog sampler developed at the Paul Scherrer Institute (PSI, Villigen-Switzerland) [3], called Domino Ring Sampler (DRS) and now at a second version (DRS2). It is an analog sampler designed with  $0.25 \mu\text{m}$  CMOS technology. An extensive work of characterization has been performed on the Domino chip [4] whose main characteristics are: integration of at least 10 analog channels in one chip; analog bandwidth of around 1 GHz; excellent time resolution, less than 80 picosecond with a sampling frequency of 4 GHz; very low power consumption, around 35 mW per chip; the response of the sampler cells can be calibrated and the useful input voltage can be extended to 2 Volts (twice the range for commercial Flash ADCs).



**Figure 1.** Schematic picture of the Domino sampler. Shown on top is the inverters sequence that originates the Domino wave. The shift register on the bottom enables serially the single capacitors connecting them to the output stage.

The sampler consists of two sections, an analog one for the signal sampling and a digital for control and multiplexing. The analog signal is stored in a multi capacitor bank (1024 cell in DRS2) that is organized as a ring buffer, in which the single capacitors are sequentially enabled by a shift register driven by a high frequency clock internally generated (see Figure 1), called Domino wave. At a 2.5 GHz frequency the sampling window is 400 ns wide. The speed of the domino wave is controlled by an external voltage such that the domino inverters can be seen as a Voltage Controlled Oscillator (VCO). Every turn a pulse is produced for synchronization and monitoring. The phase and

speed of the domino wave are synchronized to an external common reference clock by an on-board PLL, designed around the domino VCO. The sampling signal jitter is less than 200 ps (see Figure 2a).



**Figure 2.** (a) Domino wave frequency jitter. (b) Domino response as a function of the input voltage.

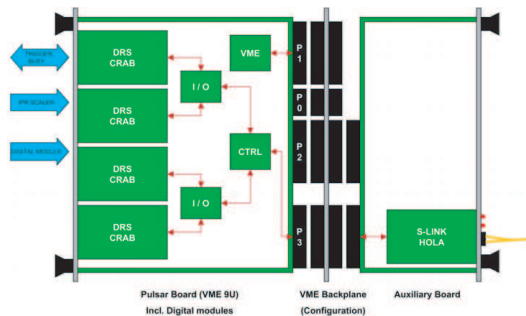
The chip is housed in a PLCC package and mounted on a mezzanine card, also called CRAB (Capacitor Ring Analog Board). Once the external trigger has been received, the sampled signal in the ring buffer is put on an

output stage by a multiplexer and digitized at high resolution (12 bits) at lower frequency (40 MHz). The digital conversion is done by an external ADC. The transfer curve of the output stage is typical of a MOS transistor, with an active region quite linear up to 800 mV, that tends to saturate for larger signals (see Figure 2b). This characteristics turns out to be a useful one since it is a natural signal compression and results in an extension of the response dynamic range. With a calibration procedure that is implemented in the analog mezzanine it is possible to calibrate input signals up to 2 Volt, about twice the range of commercial Flash ADCs.

By using fast sampling frequency and large dynamic range it is possible to reconstruct the shape of individual photons impinging on the photon detector and measure the signal with good precision, allowing for further background rejection.

### 3. Data Readout

The readout system is based on the so called Pulsar board (see Figure 3) that can host up to 4 analog mezzanine boards, for a total of 32 analog channels. Three FPGAs (ALTERA EP20k400) are mounted on each board; they are responsible for interfacing to the CRAB boards and data communication with the transmission board located on the rear VME backplane. Additional digital signals are interfaced via front panel connectors and enter directly in the data acquisition stream. The external trigger signal is sampled together with the analog channels giving a precise time reference, useful for synchronization of different devices or precise time measurement.



**Figure 3.** Schematic drawing of the data readout board.

The whole readout system consists of 18 Pulsar boards that are accommodated in two VME-9U crates, interfaced to the telescope control system by an embedded CPU. The data transmission is performed by optical link drivers (called HOLA), specifically designed for LHC experiments [5]. The optical fibers are interfaced to a PC memory by dedicated PCI cards named FILAR, also designed for LHC purposes.

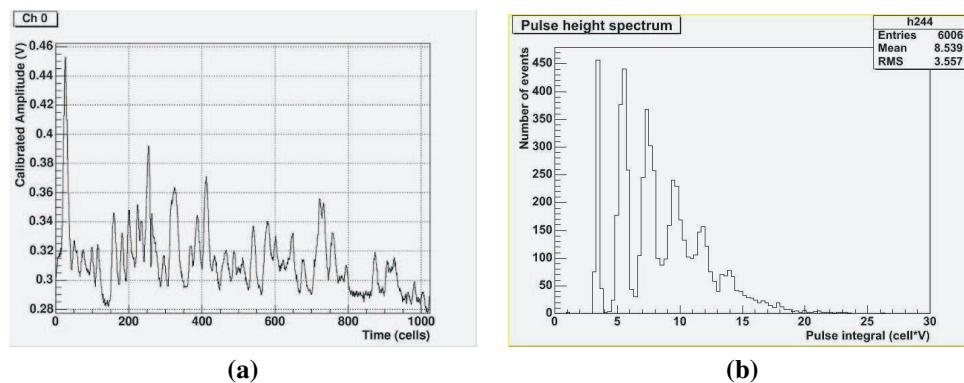
The usage of an ultrafast sampler in Cherenkov telescopes with a large number of channels brings to systems that, at 1 kHz trigger rate, produce a data flow of the order of 100 MBytes/s, the data volume to store being of the order of several Terabytes per night. To cope with such large throughput rates and data volumes a RAID system based on a separate network (probably fiberchannel) is being tested. Such a network (allowing up to 4 Gbit/s access)

together with a file locking filesystem will allow true Online access to the just recorded data, for analysis and archiving. A cluster of computers will start an Online Analysis immediately after the files are closed.

### 4. Performance test

The readout system has been used to measure the night sky background with standard photomultipliers in the MAGIC telescope framework and a work on the characterization of SiPM has just started.

Tests performed on the MAGIC telescope site have shown that it is possible to disentangle the single photoelectrons (phe) and to measure the diffuse light background (40 phe in a 400 ns window) and to obtain a physics meaningful measurement, provided that the photomultiplier signals are sampled at 2.5 GHz at least. In Figure 4a a typical image of the incoming photons is shown. The poissonian nature of this process is verified by the arrival time distribution of single peaks that shows a typical exponential trend.



**Figure 4.** (a) Typical sampling of a MAGIC photomultiplier signal during a 400 nsec interval. (b) Charge spectrum on SiPM with simple integrating algorithm.

The Domino readout can be effectively used for the characterization of very fast pulses, such as those produced by Gieger-mode, APD-based, silicon photomultipliers (SiPM) [6]. Figure 4b shows the preliminary charge spectrum obtained by illuminating a SiPM with a fast-pulsed LED at a low light level. The peaks due to the individual photoelectrons are clearly resolved.

## 5. Conclusions

The upgrade program of the MAGIC telescope is currently under way. Together with the adoption of new photon detectors, the analog signals are going to be sampled by the Domino ring sampling chip. For a 1 kHz trigger rate and a sampling frequency of 2 GHz, the data throughput is higher than 100 MBytes/s, being a challenge for modern data transmission and storage solutions. The data are transferred to PCI memory via Gbit optical links using the CERN S-link protocol and to the mass storage system.

## 6. Acknowledgements

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