Analogue Signal Transmission by an Optical Fiber System for the Camera of the MAGIC Telescope

D. Paneque*,[1] H.J.Gebauer,[1] E.Lorenz,[1] M.Martinez,[2] R.Mirzoyan,[1] T.S.Tran[1]
for the MAGIC collaboration
(1) Max-Planck-Institut fuer Physik, Muenchen, Germany
(2) Institut de Fisica d'Altes Energies, Barcelona, Spain
(*) Corresponding author. E-mail address; dpaneque@mppmu.mpg.de

1. Abstract

MAGIC is a 17 m diameter Air Cherenkov Telescope located on the Canary island La Palma. A system based on multimode graded index fibers is currently being used for the transmission of the very fast (2-3 ns FWHM) signals from the 577 photomultiplier imaging camera to the 100 m distant central data acquisition building, where the signals are digitized. Here we report on the concept and the technical details of such system.

2. Introduction

MAGIC is a 17 m diameter Imaging Air Cherenkov Telescope (see [1,4]) located on *El Roque de los Muchachos*, at 2200 m a.s.l, in the Canary island of La Palma. The transmission of the very fast pulses (2-3 ns FWHM) produced by the photomultipliers (PMTs) to the 100 m distant central data acquisition building (where the signals are digitized) is performed by multimode graded index optical fibers. Optical fibers can transfer the signal with smaller attenuation and dispersion than coaxial cables and besides, they have another important advantages. They are less bulky and one order of magnitude lighter, which reduces the inertia of the telescope and allows a rapid repositioning (necessary for the observation of Gamma Ray Bursts). Many fibers can be packed in a single small diameter cable (we use 72 fibers in a 16 mm ϕ cable). There is no crosstalk, no electromagnetic interference, and fibers are immune to lightening strikes.

The electric pulses produced by the PMTs are transformed into light pulses by means of Vertical Cavity Surface Emitting Lasers (VCSELs) and coupled to multimode optical fibers (62.5 μm ϕ core, 125 μm ϕ cladding) in the camera of the telescope. The optical signals are transformed back into electric pulses by PIN-diodes in the acquisition building after traveling through 162 m fiber. VCSELs are relatively new devices (they started to be comercialized in 1996) and still have some performance problems when operated in linear mode. Nevertheless there is a steady improvement. We would like to mention that similar analogue signal

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transmission systems based on VCSELs and optical fibers have been tested by other groups (see [2,6]).

In this paper we report about the use of VCSELs for converting electrical pulses to light signals and present the performance in noise, linearity and dynamic range that is achieved in the system constructed for the MAGIC telescope.

3. Use of VCSELs in the fast analogue signal transmission

A VCSEL is a laser diode that emits light perperndicular to its surface, rather than from its side, which allows it to produce a low-divergent, circular beam allowing a high coupling efficiency into optical fibers. They have a very low capacitance and high modulation speed (>1GHz). Besides, they have a low lasing current threshold ($\approx$ 3 mA) compared to other type of lasers, which makes them easy to drive, and reduce the power consumption. In addition, they are relatively cheap devices.

The VCSELs used for MAGIC are the multimode type 4080-321 from Honeywell. These lasers have an active area of about $20 \times 20 \mu m^2$, and allow one to produce light pulses with rise and fall times as small as 100 *ps*. They emit at a peak wavelength of 850 nm with a maximum divergence of about 20 degrees, and the typical lasing threshold current is about 3.5 mA (we drive them at 6 mA to ensure that all them are in lasing mode). Another important feature is that for low duty cycles the diodes can be operated up to 200 mA peak current*.

A dedicated setup was built to study the performance of our optical link system. We basically inject PMT like pulses into the transmitter board (these pulses will be denoted *input pulses* from now on) and analyze the electric pulses of the receiver board (*output pulses*).

It was found that the shape of the *output pulse* (2.8-2.9 ns FWHM) is practically the same as that of the *input pulse* (2.7 ns FWHM), *i.e.* our optical link system is able to transfer these fast pulses with almost no distortion†. On the other hand, a study of the amplitude and the area (which is proportional to the charge) of the *output pulse* showed that some VCSELs can be quite noisy and that the relative noise (we use RMS/mean signal) can depend very strongly on the forward current applied to the diode (bias current).

Figure 1a shows the area and the relative noise of the *output pulse* for several bias currents; note that not only the noise can change significantly (appearance of the so called "resonances"), but also the gain of the VCSEL. An explanation for this behavior is the activation/deactivation of transverse modes in the VCSEL affecting the beam divergence angle and producing losses in the

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*Private comunication from Honeywell

†In the telescope, 162 m long optical fibers are used, instead of the 2 m long fibers utilized in this setup. However, no additional effects are expected due to the tiny attenuation of the pulse inside the fiber, 3dB/Km at 500MHz at 850 nm.

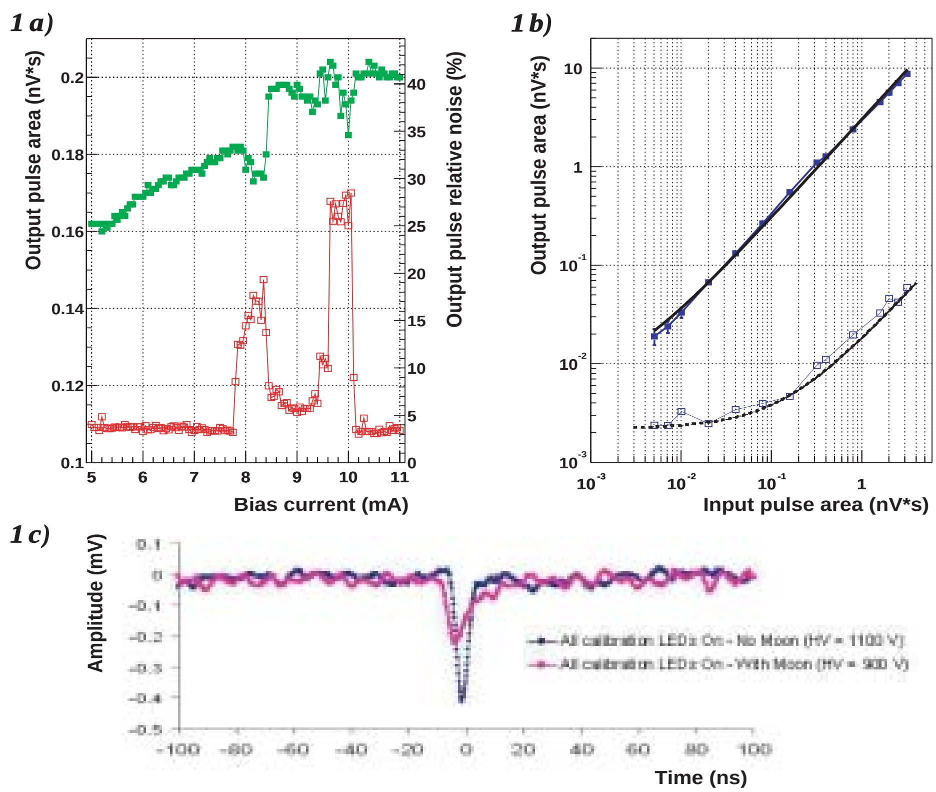

Fig. 1. *1a) Output pulse* charge (filled squares) and noise (open squares) *vs* bias current. The *input pulse* has a gaussian like shape with 40 mV amplitude and 2.7 ns FWHM. *1b)* Output signal *vs* the input signal. Filled squares are used for the measured area of the *output pulse*, the dark continuous line is a simple linear fit. Open squares are used for the measured noise (RMS). The parameterization of the typical RMS *vs* input signal for this type of VCSELs is shown by a dotted line. *1c)* Pulses from one of the camera pixels measured at the receiver board in the acquisition building. The lower pulse was measured in the presence of the moon, and the PMT voltage was reduced by 20% with respect to the nominal value.

amount of light focused into the fiber. Here, the tolerances in the alignment of the laser diode, the spherical lens and the optical fiber play an important role. Each VCSEL has its characteristic dependence on the bias current. Yet we found that, in general, for low bias currents "resonances" and sudden changes in the gain are less frequent.

Because of the features mentioned above, a detailed study was carried out on every single VCSEL. Its performance was studied for several bias currents (5-7mA, in steps of 0.05mA) and during long periods of time (>10 hours). Lasers were rejected whenever they did not fulfill the required specifications (see [5] for details). Very tight selection criteria were applied in order to ensure excellent performance of all those VCSELs that were mounted in the camera of the MAGIC telescope. In the selection, about 30% of all VCSELs were rejected.

4. Performance of the optical link system used in the MAGIC telescope

In figure 1b is depicted the area of the *output pulse* as a function of the area of the *input pulse*. The first and the last point of the plot relates to an input pulse of about 3ns FWHM and 1.5 mV and 940 mV amplitude respectively. The response deviates from a perfect linear behavior by less than 10% in this range of about 56dB. In figure 1b we also show the RMS noise *vs* the input signal. Note that it is well below the measured signal, and that it is in good agreement with the parameterization of RMS noise found for VCSELs of this type (see [5] for details).

The dynamic range of the system is indeed not limited by the transmitter board, but by the receiver board, which starts to saturate (in amplitude) at pulse amplitudes of about 2.5 V, corresponding to about 800 mV amplitude in the *input pulse*. This saturation effect is less significant in the measured pulse charge, where one can extend up to almost 1 V amplitude pulses with deviations from linearity being smaller than 10-15%. Measurements of the dynamic range for the complete pixel chain in MAGIC show a total dynamic range larger than 62 dB (see [3]).

5. Conclusions

The measured performance in noise and dynamic range of the optical link system fulfills the requirements for being used in MAGIC. Such a system is already installed and fully operational in the the camera of the telescope. Figure 1c shows electric pulses from one of the MAGIC pixels measured at the receiver board (just before pulse digitization) in the acquisition building. The light test pulses going to the PMT are produced by a system of LEDs, and have a FWHM of about 4ns.

6. References

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