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High-speed visible light communication system based on SiPM

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Silicon Photomultiplier (SiPM) is a photodetector with very high sensitivity, fast response and good performance in oversaturation conditions. When SiPM faces incident optical radiation (sometimes imperceptible for other photodetectors) is able to detect very small variations of light. In this work, we present a SiPM-based optical receiver ables to discriminate small light signals from background noise, while exposed to ambient light conditions without optical filters or another additional optical device. Such device is the core of a new high-speed Visible Light Communication (VLC) system with multiuser capability. This prototype is an innovation in the communications industry, built with technology originally developed for particle physics experiments, a groundbreaking connection between science and industry.

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1. Introduction

VLC [1] [2] [3] is an alternative for wireless communication by using light in the visible range as carrier, with modern LED-based illumination systems. VLC has technical challenges to overcome related to the photodetectors response and performance (e.g., saturation), and furthermore, the multiple access problem typical in wireless optical networks. VLC technologies commonly operate in very controlled conditions and their receivers use PIN and Avalanche Photo-Diode (APD) photodetectors. The conventional photodetectors reach saturation under a high-illumination regime, e.g., presence of background light or communication optical signal. The conventional solution for this problem is the usage of optical filters in order to reduce saturation due high-illumination conditions. The common solution for the multiple access problem relies on the kind of modulation technique. We characterize the response of a particular SiPM (array of APDs) exposed to background light in order to evaluate its robustness. Based on these results we designed a SiPM-based receiver prototype we have named SiPMBR. Moreover, we designed a new VLC cell architecture we have named NVLC, what outstands SiPMBR features and include a novel optical transceiver and the corresponding network devices.

2. SiPM-based receiver and evaluation

The general sketch of the SiPMBR is depicted in Figure 1.

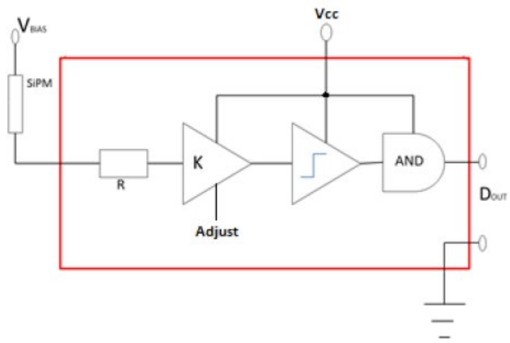

Figure 1: Basic architecture of the SiPMBR protoype.

According to Figure 1, the first experimental stage of the SiPMBR begins with an amplifier block with adjustable offset up to 50% of the supply voltage system, load resistor R $\sim$ 50 Ω (playing the rol of generating a voltage from the SiPM response) and gain K $>$ 40 (in order to generate an output voltage pulse of 3.3 V). Second stage of the SiPMBR (linked to the amplifier block), guarantees a threshold to discriminate pulse height for later recognition of logic digital levels. The use of electrical filters is not recommended for this type of digital signal receivers (unipolar signals) due to distortion of square signals and information loss. It is necessary to add operational amplifiers with excellent Common-Mode Rejection Ratio (CMRR) to avoid noise amplification. The third stage is a voltage pulses-to-CMOS-logic-levels converter, implementing an AND-CMOS gate located between thresholding circuit and signal processing digital device. The receiver output (D_{out}) is a unipolar signal with electrical levels corresponding with the voltage values set in the

third stage. In [4] we present a complete explanation of this development.
We evaluated the SiPMBR performance in background conditions as indicated in [5] [6]. In these experiments we found that the background light impacts the receiver response with a bilateral attenuation effect as shown in Figure 2.

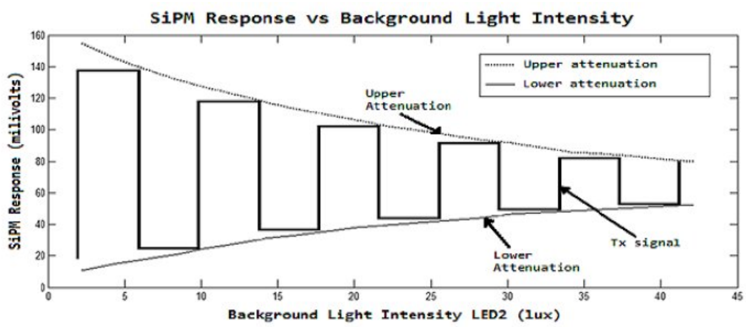

Figure 2: Bilateral attenuation of the SiPMBR response when increasing background light intensity.

This attenuation for the SiPMBR response (V_{up},V_{low}) is parametrized accordingly Equations 2.1 and 2.2 as follows:

$$V_{up} = -A_1 \ln(|I_{bg}|) + B_1 \tag{2.1}$$

$$V_{low} = A_2 \ln(|I_{bg}|) - B_2 \tag{2.2}$$

where I_{bg} is the background light illuminance in lux, and A, B are SiPM intrinsic parameters. Both empyrical relations are still under discussion and the goal is generalization including intrinsic features of SiPM and determine the nature of A and B. The required incident optical power for this SiPMBR prototype is 18.8 μW/cm2 [4] and could be diminished with improvements in the analog electronics stage.

3. NVLC cell architecture

The NVLC cell architecture mentioned before consists of a hybrid tree-star topology formed by a cell supported by an Optical Wireless Multiuser Transceiver (OWMT) ables to deploy multiple cells and distributes them in the NVLC coverage area. All cells are connected to a single Optical Wireless Access Point (OWAP). The downlink is implemented with white LED light and its power is configured for dual purpose, lighting and communication. Each station (user) is connected to an Optical Wireless Network Interface Card (OWNIC), which allows receiving communication from OWMT, and transmits an uplink channel with very low power white LED light, low enough for ensuring do not disturb people using the network. This goal is attained by taking advantage of the unique features like the extremely high sensitivity of the SiPMBR. OWAP and OWNIC have a Communication Digital Controller (CDC) that runs as Ethernet direct interface between user devices and OWMT. The optical interface is implemented with On-Off Keying (OOK) modulation and support up to 150 Mbps in this first prototype, what is larger than the conventional WiFi transfer rate and sets the high-speed feature of this prototype. We test Ethernet communication performance for a 2-user setup, verifying the multiple access capability using the NVLC physical separation concept and parallel access for users.

4. Ongoing work

A novel optical receiver based on SiPM (SiPMBR) has been developed for implementation in VLC, actually under constant improvements based on more sofisticated SiPMs. Such implementations are expected to allow higher transfer rates ($\sim$ 2 Gbps), keeping low optical power and best behaviour for backlight without requiring optical filters. In addition, the NVLC development points to increase the number of users and transfer rate in order to override the maximum of 150 Mbps using NRZ-OOK modulation, which is above the current standard of VLC (modularity is also being improved). The Pulse-Amplitude Modulation (PAM) technique is going to be tested and evaluated as an alternative to achieve even higher transfer rates, while maintaining the concept of cellular architecture as in NVLC.

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