SILICON PHOTOMULTIPLIERS: A TREND IN UNDER WATER WIRELESS OPTICAL COMMUNICATION

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Abstract- Now days, Under Water Wireless Optical Communication (UWOC) is used for high data rate transmission. Photomultipliers are well known for their very high gain and sensitivity to very low intensity level. At the same time it requires high voltage for operation and very sensitive to magnetic fields. Also, they are expensive too. Silicon photomultipliers (SiPM) would be revolution in UWOC as it can work with very low level intensities, even to a single photon. This paper deals with the interest of using SiPM in UWOC context. Along with the use of photomultipliers, underwater wireless optical communication system with error correction techniques is suggested in this paper. For this Binary reed Solomon techniques is carried out.

Key words- UWOC, SiPM, Error correction codes in communication, Reed Solomon algorithm,Wireless communication

I. INTRODUCTION

The Silicon photomultipliers, (SiPM) coming under the category of solid state devices, are very sensitive even to single photons. They are built from an avalanche photodiode (APD) array on common silicon substrate. This device provides the detection of single-photon events in sequentially connected Si APDs. For a single APD the dimension vary from 20 to 100 micro meters, and their density can be up to 1000 per mm². Each APD in SiPM operates in Geiger mode and they are coupled by a poly silicon quenching resistor [1]. Even though the device works in digital or switching mode, the SiPM is always an analog device. This is possible because all the microcells are read in parallel, making it possible to generate signals within a dynamic range. The supply voltage (Vb) varies between 20 V and 100 V. So thus they need supply voltage 15 to 75 times lower than that of needed for a traditional photomultiplier tubes (PMTs) operation [1]. SiPM provide high gain with low voltage and fast response, they are very compact and compatible with magnetic resonance setups. Nevertheless, still there are several challenges; that means SiPM requires optimization for larger matrices, signal amplification and digitization. [2]

To overcome the lack of proportionality caused by the PMTs, the Silicon Photomultiplier (SiPM) integrates a dense array of small, independent SPAD sensors, each with its own quenching resistor. This independently operating unit of SPAD is called “microcell”. When a microcell in the SiPM responds to an absorbed photon, a Geiger avalanche breakdown is initiated and thus causing a photocurrent to flow through the microcell. Thereby produce a voltage drop across the quench resistor, which in turn reduces the bias voltage across the diode to a value below the breakdown, hence quenching the photocurrent and preventing further Geiger-mode avalanches from occurring. Once the quenching of the photocurrent has occurred, the voltage across the diode recharges to the nominal bias value. The time taken by the microcell to recharge to the full operating voltage is called the recovery time. It is important to note that the Geiger avalanche will be confined to the single microcell it was initiated in. During the avalanche process, all other microcells will remain fully
charged and ready to detect photons. A typical SiPM has microcell densities of between 100 and several 1000 per mm$^2$. The density of the microcell is decided by the size of the microcell [3]. Following section discusses about the pulse shape and fill factor of SiPM. Next section describes the performance parameters followed by the related works. And proposed system is included followed by the conclusion of the work.

II. CHARACTERISTICS OF SiPM

A. Pulse Shape

The rise time of the SiPM depends on the rise time of the avalanche formation and the variation in the transit times of signals from the sensor’s active area. Minimizing this transit time spread by careful design of the tracking can improve the rise time. The capacitance of the microcell will depend upon its area, so the reset time will vary from cell to cell. A 50mm microcell SiPM having a longer reset time than a 10mm microcell SiPM [4]. It is important to note that the microcell can still fire during the recovery time before the overvoltage has recovered to its nominal value, but the gain will be reduced in proportion to the reduced overvoltage. The sensor output is a photocurrent, and the total charge $Q$ generated from an event is

$$Q = N_{\text{fired}} \cdot G \cdot q$$

where $N_{\text{fired}}$ is the number of fired microcells. $G$ is the gain and $q$ is the electron charge. The total charge is equal to the integral of the photocurrent pulse.

B) Fill Factor

The fill factor indicates the percentage of the surface area of SiPM sensor that is sensitive to light. Because of the structure of the SiPM, each microcell needs to be separated from its neighbor for the optical and electrical isolation purposes. And also some surface area is required for the quench resistor and signal tracks. All of these considerations results in so called ‘dead space’ around the microcell [4]. A higher fill factor (larger microcells) results in higher PDE and gain, and have higher capacitances, longer recovery times and lower dynamic range. A lower fill factor (smaller microcells) results in lower PDE (Photon detection efficiency) and gain, and also in lower capacitances, shorter recovery times and higher dynamic range.

III. SiPM PERFORMANCE PARAMETERS

A. Gain

The amount of charge created for each detected photon, which is a function of overvoltage and size of the microcell, is said to be the gain of SiPM sensor. Each microcell in the SiPM generates a highly uniform and quantized amount of charge when avalanche is generated by an absorbed photon in the active volume [6]. The gain can be calculated from three values, they are over voltage, micro cell capacitance and the electron charge. The way in which the SiPM operates is unique so accurate measurement of gain is possible. Each of the detected photon produces a highly quantized output pulse. Charge from each pulse is integrated results in a charge spectrum. In the spectrum the separation between each pair of adjacent peaks is constant and will denotes the generated charge from a fired microcell. This can therefore be used to determine the gain accurately [5].

B. Photon Detection Efficiency and Responsivity

The photon detection efficiency (PDE) is a measure of SiPMs sensitivity and is a function of wavelength of the incident light, the applied overvoltage and microcell fill factor. The PDE differs slightly from the quantum efficiency (QE) due to the structure of microcell of the sensor. The PDE is the statistical probability of interaction of an incident photon with microcell to produce an avalanche, and can be defined as:
\[ G = C \Delta V \quad \text{q PDE}(\lambda,V) = \eta(\lambda) \cdot \varepsilon(V) \cdot F \]

Where \( h(l) \) is the quantum efficiency of silicon, \( \varepsilon(V) \) is the avalanche initiation probability and \( F \) is the fill factor of the device[5]. The PDE can be calculated from the responsivity of the sensor. The responsivity is the average photocurrent produced per unit optical power. The responsivity is expressed in Amps per Watt (A/W).

IV. RELATED WORK

Newly emerging applications, like delay sensitive network applications (online real-time gaming) and high throughput network applications drive the development of next generation optical networks including optical components and algorithmic and systematic design. Signaling control and connection management are provided by NCM (Network Control and Management), undergoing tremendous technology evolution for supporting newly developed advancements like cross layer algorithms, different modulation schemes, coding techniques and various optical components [23]. The feasibility of using SiPM in optical communication was mentioned in [18],[19]. There is a possibility to develop the OpenFlow controller with new capabilities. These include convergence of packet-circuit optical networks and QoT-awareness which can help to drive the next generation optical networks as well [21]. Newly developed NCM systems usually support sophisticated network operations, such as optical performance monitoring, low-latency network service re-provisioning, and situation-aware routing and wavelength assignment [22]. The retimed decomposed inversion-less serial Berlekamp-Massey (BM) architecture for Reed Solomon (RS) decoding. The key idea is to apply the retiming technique into the critical path in order to achieve high decoding performance [20].

V. PROPOSED SYSTEM

A. Proposed system

Even though the usage of photomultipliers increases the speed of optical communication, there may occur unexpected errors in the data which are transmitted through the channel. So there requires a proper encoding and decoding of the data for the reliable transmission. Binary Reed–Solomon codes (BRS) are a group of forward error-correcting codes. They have many applications in which the most prominent include consumer technologies such as CDs, DVDs Blu-rayDisc, QR Codes, data transmission technologies [13]. The Reed–Solomon code belongs to the class of non-binary cyclic error-correcting codes. This code is based on univariate polynomials over finite fields and can detect and correct multiple symbol errors. By using these types of codes we can simply detect and correct up to \([t/2]\) symbols. A sequence of \( b + 1 \) consecutive bit errors can affect at most two symbols of size \( b \), thus it can also be used as a multiple-burst bit-error correcting codes. There are mainly two specialized forms of reed Solomon codes-Cauchy RS and Vander monde-RS, and can be used to avoid unreliable transmission. In the encoding process, a code of RS\((N, K)\) is assumed and results in \( N \) codewords of length \( N \) symbols each storing \( K \) symbols of data, that are being generated, and are then sent over an erasure channel. Any combination of \( K \) codewords which are received at the other end is able to reconstruct all of the \( N \) codewords [14]. At the decoder end, it only knows the set of values in which the encoding method was used to generate the codeword's sequence. The decoding procedure uses a method like Lagrange interpolation on various subsets of \( n \) codeword values taken \( k \) at a time to produce potential polynomials repeatedly, until a sufficient number of matching polynomials are produced to reasonably eliminate any errors in the received codeword. In the current strategy, the distributed systems are commonly used. In the disturbed storage system the data’s are stored at the bottom of the system. At the same time erasure code technology can improve the reliability of the system. BRS encoding can replace the CRS encoding due to the advantages in performance.
B. Blockdiagram

![Generalised block diagram of UWOC system using SiPM and Error correcting method](image)

**VI. CONCLUSION**

The silicon photomultiplier (SiPM) is a radiation detector with which provide extremely high sensitivity, high efficiency, and very low time jitter. It is based on the principle of reversed biased pn diodes and can directly detect light from near ultra violet to near infrared. SiPMs are designed to have high gain and high detection efficiency so that they can produce output current pulse with a very low time jitter even when a single photon impinging on a pixel. These can be employed in all applications where we need to measure and quantify low light or low radiation levels and quantified with high precision.

A Binary Reed Solomon encoding can be effective in the optical fiber communication system as there are more chances of the distortion of the signal or the data loss. A UWOC system with which using photomultipliers and error correction technique would be a added advantage to the existing communication system.

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