International Journal of Research in Advent Technology (E-ISSN: 2321-9637) Special Issue
National Conference "NCSEEE-2016", 19 March 2016
Available online at www.ijrat.org

Development of Trigger Logic for High Speed Optical Detectors

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Abstract –

Silicon photomultipliers (SiPMs) are a novel type of solid state photon detectors which gives pulses of low amplitude (0.2mV to 0.5mV) and having rise-time of few ns (1ns – 10ns). So a high frequency high bandwidth amplifier is designed in order to cope up with the output of SiPM. The amplifier which is designed in our project has a gain of 26 which brought the signal to order of few mV. Design of discriminator is required to minimize the noise and to extract timing information from it. Design of the discriminator is done using high precision DAC by giving the programmable threshold level and then converting it into correct TTL logic. After converting it to TTL logic by discriminator it is important to calculate the time of flight (TOF) information of SiPM signal. The output of discriminator is given to Time to digital converter (TDC) to calculate TOF and convert it to digital form in TDC and timing information is extracted. This timing information is used as trigger logic in optical detector.

I. INTRODUCTION

The SiPM sensors are nothing but avalanche photo-diodes (APD) operated in reverse biased mode in series with resistors. The combination of APD with resistor is called as a pixel. SiPM sensors that is going to be used has 36000 pixels connected in parallel combination. Thus the output of SiPM is cumulative sum of all the pixels fired at a time. The structure of SiPM is shown below in fig.1

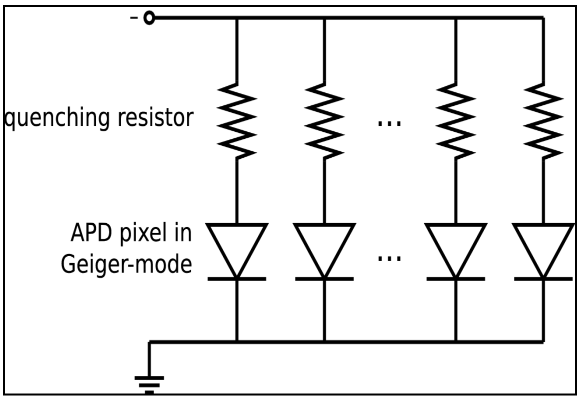

Fig.1: SiPM internal structure

Since SiPMs restoring time depends on the quenching resistors connected in the pixel, it can be varied for detection of photons even at frequency of few Giga-Hertz. Since the signal that was obtained by the SiPM at TIFR, Mumbai was having specifications of 1ns rise time and 10ns fall time, all the circuits that are to be designed for proper extraction of information should be able to operate in few GHz of frequencies. Thus proper instrumentation is needed to acquire the SiPM signal.

$$\text{Bandwidth} = \frac{0.35}{rise\ time} = \frac{0.35}{1 \times 10^{-9}} = 350 \text{ MHz} \quad \text{…. (1)}$$

This project can be categorized into three parts: **Amplifier with Splitter, Discriminator** and **TDC**. The SiPM output is cascaded to preamplifier stage having high bandwidth of few MHz. The **Amplifier** that is designed is using an operational amplifier and a high frequency transistor. The transistor acts as a **Splitter** as well as a low gain amplifier. Here the vital role of **Splitter** comes into picture. Splitter is an electrical circuit which divides input signal into multiple output signals. It basically acts as a buffer with inverted as well non-inverted output. It is used for splitting the input signal if the output impedance of the amplifier is very low and proper termination is not met. One of the output of splitter is given to the discriminator input. The other output is reserved for future purposes. The role of **Discriminator** is to discriminate the input signal from stray noises induced due to EMI and environment. The **Discriminator** is designed using a comparator and a monostable multivibrator in cascade connection. The second input of discriminator is controlled by **DAC** which is in turn controlled by microcontroller. The output of discriminator is given to **TDC** for calculating the time-of-flight of pulse into digital form.

II. BLOCK DIAGRAM

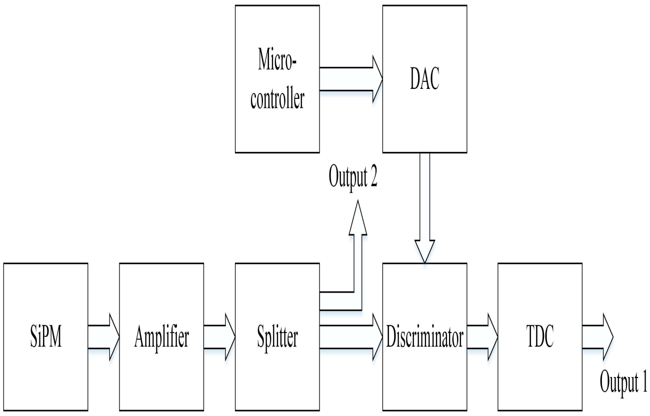

Fig.2: Block Diagram

A. Silicon Photomultiplier (SiPM)

Silicon Photomultiplier's are highly sensitive high speed detector. It is used for various applications like detecting a particular particle, PET scan, etc. In this project it is used to detect a high speed photon. The SiPM sensor is made up of avalanche photo diodes (APD's) in series with quenching resistor. This combination of an APD and a resistor in series is called as a pixel. The APD in SiPM is operated in the geiger mode. In this mode the APD is operated in negative biasing with an extra voltage than the knee point voltage. Due to the extra biasing voltage whenever a photon is incident on the junction of APD it causes avalanche breakdowns giving a gain of 10^6. Moreover the SiPM is immune to stray electric and magnetic fields and function on considerably low voltage compared to photomultiplier tubes. So SiPM is used for this project.

B. Amplifier

Two stage amplifier with OPAMP stage and TRANSISTOR stage was designed in this project shown in fig.3. We have used OPAMP LMH6629 and TRANSISTOR BFR520. The OPAMP gain is adjusted to 23. OPAMP stage has a high input impedance which will not load the source and provide constant gain. At 2nd stage output is taken from Collector and Emitter terminal, fanout1 will be 180º out of phase with respect to fanout2. The gain of Amplifier can be changed by changing biasing resistors. At Emitter terminal and collector terminal gain is adjusted to 0.9 and 2.0 respectively, thus we have split our signal for other future use. We have obtained bandwidth of 50MHz shown in fig.4. The overall gain of 22.6, Emitter gain variation of 3.75% and Collector gain variation of 3.10% as shown in fig.5 (Testing condition: Collector open and Emitter with matched load of 50 Ω).

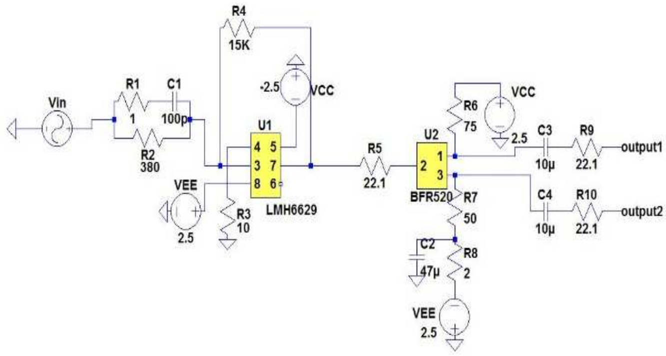

Fig.3. Amplifier with Op-amp and Transistor

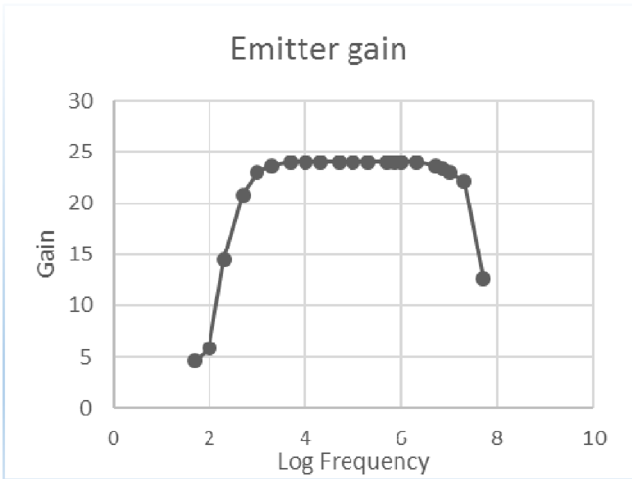

Fig 4.Frequency response of amplifier and splitter

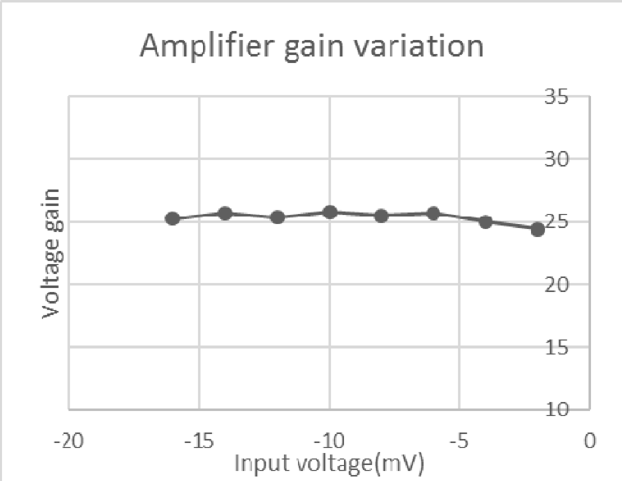

Fig 5. Amplifier gain variation at emitter terminal

C. Discriminator

Discriminator circuit is a circuit that converts analog pulse into a LVTTL logic signal, which is accomplished by the use of a comparator with adjustable threshold in this case. It does not respond to input pulses, below a preset threshold level and produces a standardized LVTTL logic output, if the input pulse height exceeds the threshold. In this project a leading edge discriminator is designed using a comparator and a monostable multivibrator. The negative terminal of the comparator is connected to the threshold analog voltage coming from high precision DAC. The analog input of discriminator is connected to the positive terminal of the comparator. Comparator compares analog input and threshold voltage and generates high logic pulse when input exceeds threshold level.

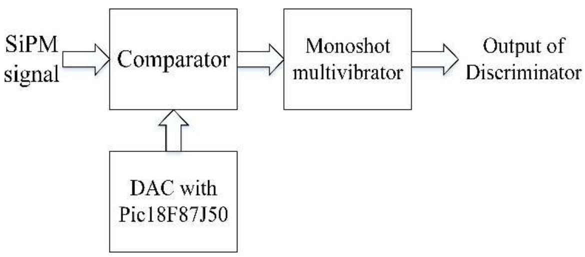

Fig.6: Leading edge discriminator

The leading edge discriminator is immune to jitter noise created due to various stray EMI noises but it is prone to walk error. Due to walk error the pulse width of leading edge discriminator may vary. To remove the effects of walk error, a monoshot multivibrator is attached to leading edge discriminator in series connection. This makes the use for leading edge discriminator just as a triggering device. The trigger pulse of leading edge discriminator cause monoshot multivibrator to give a constant width output pulse. The IC 74LVC1G123 is used in this project as a retriggerable monoshot multivibrator IC. Thus, if another triggering pulse occurs before the fall of previous pulse then it causes the width of that pulse to double.

IC ADCMP601 is used as comparator which has a typical propagation delay of only a 3.5ns. The rise time of this comparator is 2.2ns at 2.5 V biasing thus it has a bandwidth of 159MHz. The reference voltage from the DAC 8168 is connected to the inverting input of comparator whereas the output of amplifier is connected to non-inverting input of comparator. The DAC 8168 is extensively tested before implementing for discriminator. The output of DAC 8168 is calculated using the formula given below.

$$Vout = \frac{Din}{2} \times Vref \ \times Gain \ldots\ldots\ldots\ldots\ldots \quad (2)$$

D_{IN} = Counts of DAC (0 to 16384)
n = It is 14 for DAC8168
V_{REF} = 2.5V in this project since internal reference is used
Gain = 1 for A & B grades and it is 2 for C & D grades of IC DAC8168. C grade is used in this project.

For this project as the threshold voltage for comparator needs to be varied by small amounts, the DAC that is to be used should have a linear output. The output of DAC should vary with equivalent change in the counts that are sent into DAC. The linearity of the DAC that is used is as shown in below fig.

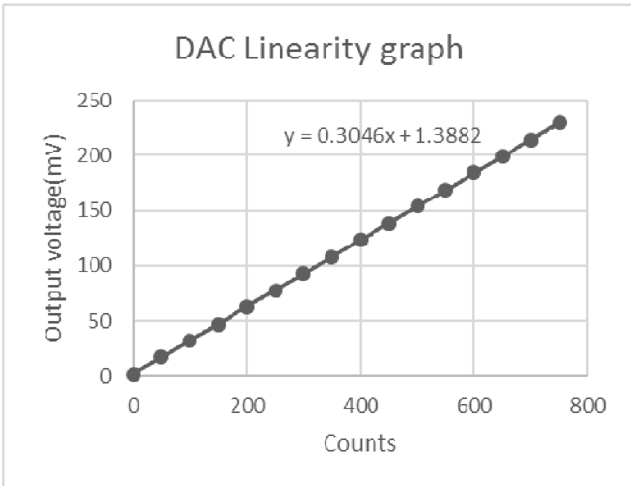

Fig. 7: DAC Linearity Graph

From fig. 7, it can be concluded that the readings taken practically are linear in nature with offset of 1.4mV. Each count corresponds to 0.3046 mV practically and 0.3051 mV theoretically. Thus the theoretical and practical readings are approximately equal. Errors of DAC can be calculated as follows

Error = (Theoretical voltage of 1 count) – (Practical voltage of 1 count)

= (0.3051) – (0.3046) = 0.0005 = 0.5 µV.

% Error can be calculated by dividing error by theoretical voltage of 1 count multiplied by 100

$$\therefore \% \text{ Error} = \frac{0.0005}{0.3051} \times 100$$

$$= 0.16 \%$$

The monoshot multivibrator is retriggerable and the output pulse width can be varied by selecting the proper values of resistor and capacitor. The formula for calculating the pulse width is given by

$$t_w = K \times R_{EXT} \times C_{EXT.} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Where, t_w = pulse width of multivibrator

K = constant

R_{EXT} = external resistor for RC time constant

C_{EXT} = external capacitor for RC time constant

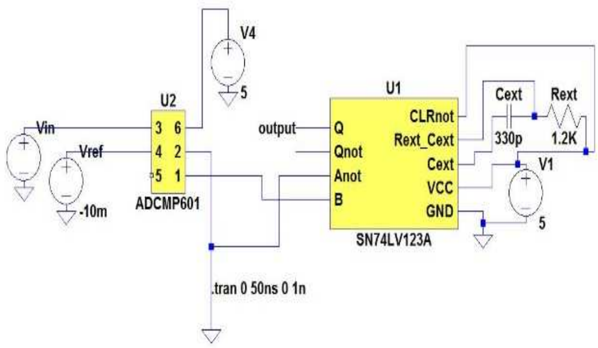

Fig. 8: Discriminator simulation circuit

The final test result of this discriminator is shown in fig.9 the output pulse is shown on the channel 1. The amplifier output is shown on channel 3 and the reference voltage is on channel 4

Fig. 9: Practical test result of discriminator

III. APPLICATIONS:

1) SiPM is used in the application of detection of photons.
2) SiPM is used for detection of various high speed particles.
3) SiPM is used in various medical fields like PET scan, etc.

IV. CONCLUSION

We have designed a high bandwidth (50MHz) amplifier which retains the high frequency shape of the SiPM pulse successfully. Provision for one more output is made for the amplitude analysis of SiPM pulse. The discriminator designed in this project is able to successfully analyze the timing information of SiPM. It also removes the various errors present in the input of discriminator like walk error and jitter error. The time of flight can be easily obtained by attaching TDC to discriminator.

V. ACKNOWLEDGMENT

First and foremost, we express our profound gratitude to Mr. Shashi Dugad (TIFR, Mumbai), Mr. Raghunandan Shukla (TIFR, Mumbai) and Mr. Akhil Kurup (TIFR, Mumbai) in particular for their patience, inspiring guidance, encouragement. We also wish to express gratitude to Prof. (Dr.) C.S. Garde and Mrs. Jayashri Joshi for their constant motivation, support and guidance.

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