

# Digitally Controlled Biased Amplifier for Nuclear Timing Spectroscopy

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**Abstract**— In this paper, we are introducing a digitally controlled biased amplifier for nuclear timing spectroscopy. Time to Amplitude Converter (TAC) is a device that gives an output signal with amplitude proportional to the time interval between the generated input "start" and "stop" pulses. The amplitude information from the TAC is often applied to a Multichannel Analyzer (MCA) for time intervals, commonly called a timing spectrum. The time coincidence spectrum obtained shows that the spectrum is away from the origin. Also, when the signals within a particular range are amplified; they seem to get into the saturation mode thus making it unavailable with the actual signals required for processing. In order to avoid the amplified signals to go into the saturation mode conventional analog biasing techniques are used. The conventional analog biasing techniques have been studied, and it is observed that the resolution obtained is comparatively poor. Also, the MCA's are computerized and if direct computerized data is obtained, it would be more beneficial to control MCA operations. In order to obtain good resolution and digitized control of the time coincidence spectrum, a new digitally controlled biased amplifier circuit has been introduced, where the current output of the biasing Digital to Analog converter (DAC) and gain DAC is obtained.

**Keywords**— TAC, time coincidence spectrum, DAC, Biasing DAC, gain DAC, Multiplying DAC, analog biasing techniques, Arduino.

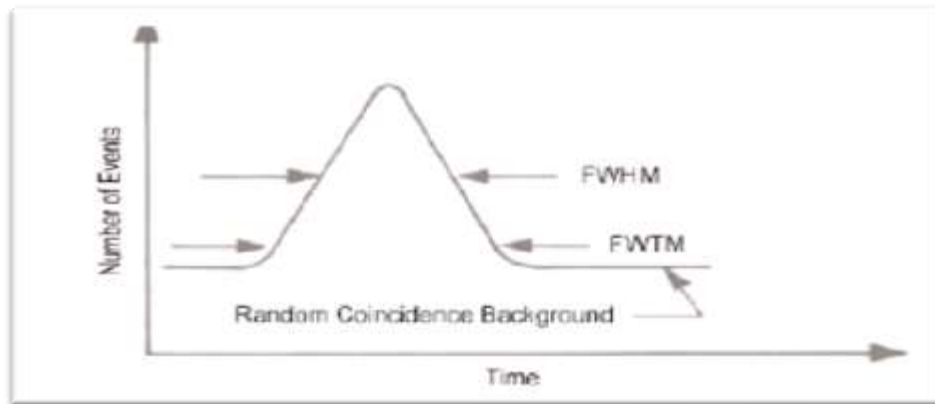
## 1. INTRODUCTION

Time spectroscopy involves the measurement of the time relationship between two events [1]. A particularly difficult problem in timing is to obtain a signal that is precisely related in time to the event. A time pick-off circuit is employed in order to produce a logic pulse at its output which is precisely related in time to the occurrence of the event [2]. Ideally, the time of occurrence of the logic pulse from the time pick-off element is insensitive to the shape and amplitude of the input signals. The TAC produces an output signal with amplitude proportional to the time interval between the start and stop pulses. The further study of this output called time coincidence spectrum shows that the spectrum obtained is away from the origin and hence there is a need of biased amplifier for improving resolution. Conventional analog techniques used by far are controlled manually and have poor resolution. Hence, a new circuit is designed wherein a biased amplifier with digital offset and gain control is used in order to obtain higher resolution in timing spectroscopy. A hardware circuit is implemented and tested in laboratory, the results show that improved resolution can be obtained by digitally controlling the current output of the biasing DAC and gain DAC.

## 2. TIME COINCIDENCE SPECTRUM

TAC is a device that gives an output signal with amplitude proportional to the time interval between the generated input "start" and "stop" pulses. The amplitude distribution of the output pulses is then usually by a MCA. It is thus a measure of the distribution of time intervals between start and stop pulses and is often referred to as "time spectrum".[3]

The amplitude information from the TAC is often applied to an MCA for time intervals, commonly called a timing spectrum. Fig 2.1 indicates an accumulation of the data and type of timing spectrum that might be produced by coincident gamma rays. The shape of the timing spectrum is critically important in time spectroscopy. The timing resolution must be high (the timing peak must be narrow) so that the time relationship between two closely spaced events can be measured accurately. It is important that the narrow width of the spectral peak be maintained down to a small fraction of its maximum height to ensure that all truly coincident events are recorded.



**Fig 2.1: Timing coincidence spectrum**

The timing coincidence spectrum obtained as seen in Fig.2.1, shows that the spectrum is away from the origin. Also, when the signals within a particular range are amplified; they seem to get into the saturation mode thus making it unavailable with the actual signals required for processing. These types of results are obtained in the conventional biasing techniques available till now. Hence, in order to obtain good resolution of the number of events against the time coincidence spectrum there is a need to introduce a new technique in which a bias amplifier can be controlled digitally. Depending on the DAC used the resolution obtained can vary within a wide range of signals thus making it useful in many applications. Before the new technique is introduced, details about the bias and the conventional biasing techniques are discussed.

## **2.2 Role of biased amplifier in timing spectroscopy**

The timing coincidence spectrum obtained shows that the peak of the spectrum obtained is far away from the origin and the resolution obtained is comparatively very poor. Also, the Multichannel Analyzers are computerized and it would be more beneficial if we obtain direct computerized data to control operations in the Multichannel Analyzer for further processing. The results obtained in the conventional biasing techniques available till now are analog. Hence, in order to obtain good resolution of the number of events against the time coincidence spectrum there is a need to introduce a new technique in which a biased amplifier is controlled digitally. Depending on the Digital to Analog Convertor (DAC) used the bias voltage and spectrum resolution obtained can be varied within a wide range of signals thus making it useful in many applications.

## **2.3 Conventional Biasing Techniques**

The conventional biasing techniques means the basic technique where the output obtained varies as per the varying reference voltage. The voltage here is varied with the help of a potentiometer, thus this being the analog technique.[4] This particular section deals with the two basic techniques, with negative reference voltage and with positive reference voltage.

### 2.3.1 Biasing Technique with Positive Reference Voltage

The circuit diagram shown in Fig.2.2 shows a positive varying reference voltage given as reference voltage at the inverting terminal of the operational amplifier.

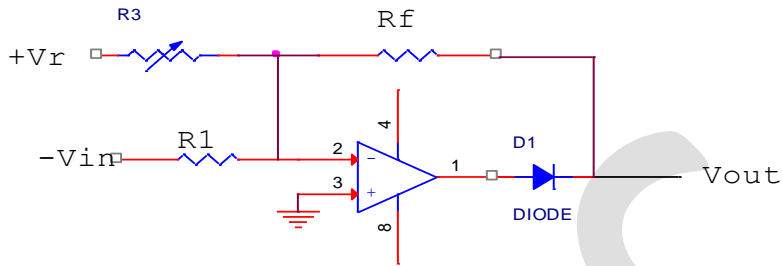


Fig.2.2 Biasing technique with positive reference voltage

A negative unipolar pulse is fed at the input. The operational amplifier inverts it. As the voltage biasing voltage varies, the output varies. And when the reference voltage exceeds the input voltage, the diode acts in the reverse bias and clips off the negative pulses, giving the desired output. Fig.2.3 shows the output waveforms for the circuit shown in Fig.2.2.

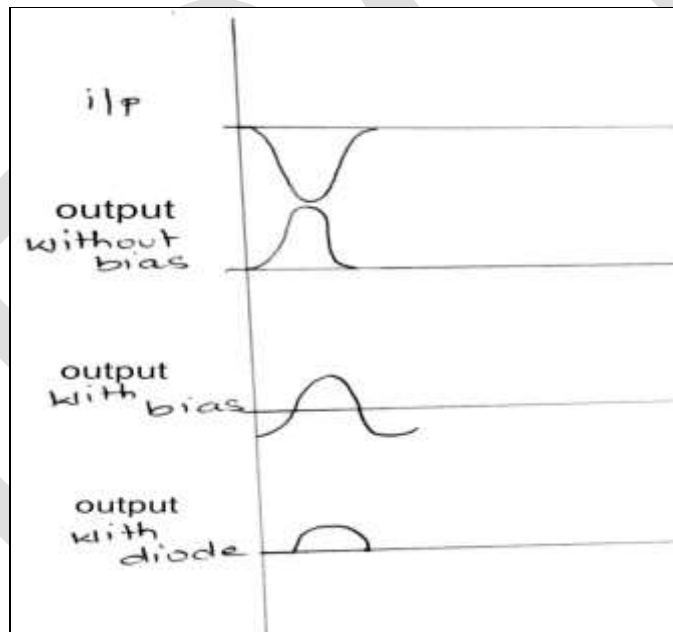
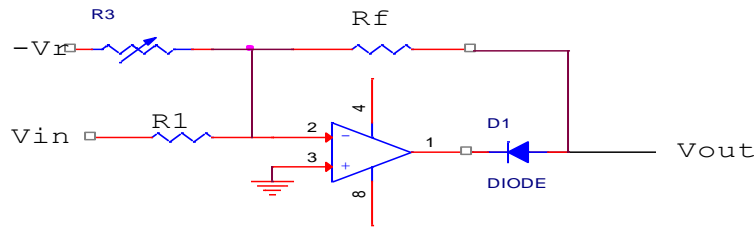


Fig2.3 output for biasing technique with positive reference voltage

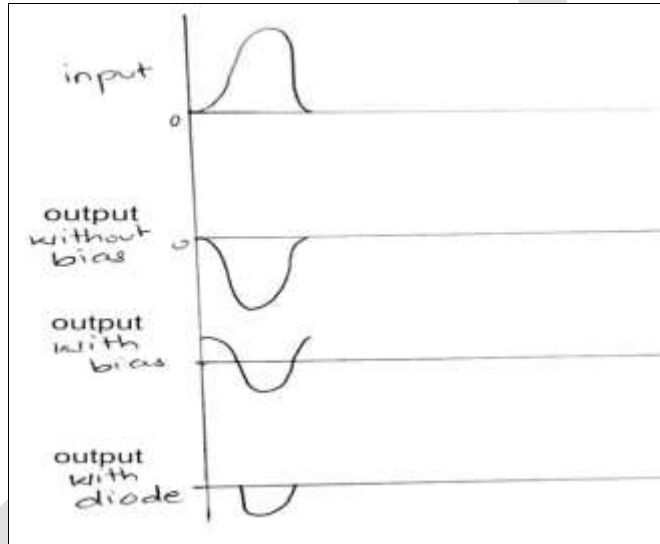
### 2.3.2 Biasing Technique with Negative Reference Voltage.

The circuit diagram shown in Fig.2.4 shows that, a negative varying reference voltage is given at the inverting terminal of the operational amplifier. A positive pulse is fed at the input. The operational amplifier inverts it. As the voltage biasing voltage varies, the output varies. And when the reference voltage exceeds the input voltage, the diode acts in the forward bias and clips off the positive pulses, giving the desired output.



**Fig2.4 Biasing technique with negative reference voltage**

Fig2.5 shows the output waveforms for the circuit diagram shown in Fig.2.4.

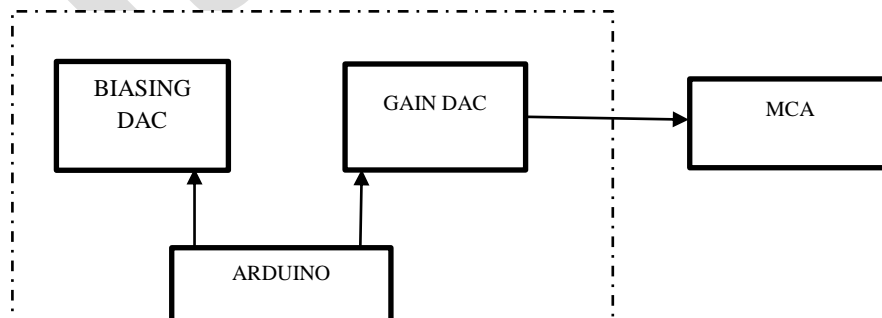


**Fig2.5 output for biasing technique with negative reference voltage**

### 3. DIGITALLY CONTROLLED BIASED AMPLIFIER FOR NUCLEAR TIMING SPECTROSCOPY

The conventional way of controlling bias is to control the bias manually using a potentiometer. Since all the Multichannel Analyzers are computerized, the automated control becomes beneficial. Thus the basic need for digital control is to obtain automated results.

The block diagram of the digitally controlled biased amplifier for nuclear timing spectroscopy is shown in Fig.3.1



**Fig.3.1 The dotted box shows the block diagram of digitally controlled biased amplifier.**

Fig.3.1 shows the block diagram that is implemented, which helps to obtain a biased amplifier with digital gain and offset control in order to obtain a very high resolution in nuclear timing spectroscopy. The block diagram consists of four major blocks, namely:

- **BIASING DAC:** The basic function of the biasing DAC is to remove the offset and to bring the time coincidence spectrum towards origin. The digital code of the DAC is varied by the Arduino board. Working of Arduino board is described in detail later.
- **GAIN DAC:** The gain DAC deals with the amplification of the required part of the spectrum, where both biasing DAC and gain DAC give the current output, so as to get the full scale voltage division of the spectrum.
- **ARDUINO:** The Arduino circuit board is known as a physical or embedded computing platform which means it is an interactive system, which through the use of hardware and software can interact with its environment.[5]
- **MCA:** Multichannel Analyzer classifies the pulses as per their height giving their amplitude spectrum.

### 3.1 Digitally Controlled Biased Amplifier Circuit

The schematic of the newly implemented circuit of a digitally controlled biased amplifier for nuclear timing spectroscopy is shown in Fig 3.2:

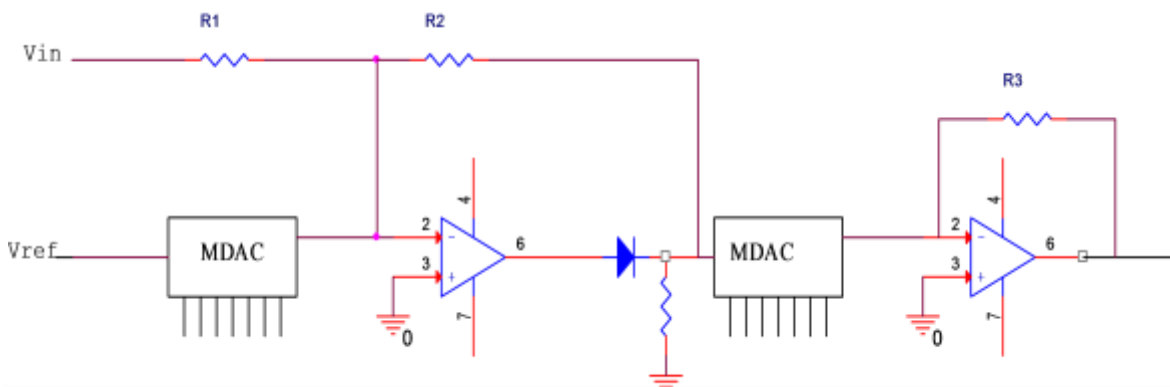


Fig 3.2 Digitally Controlled Biased Amplifier Circuit

As seen in the circuit diagram, the circuit can be studied in two parts, wherein the first part or the first Multiplying Digital to Analog Converter (MDAC) and the operational amplifier deal with the removal of the offset and helps in bringing the spectrum towards origin. And the second MDAC deals with the variation of the gain. The digital code of both the DACs is varied by the use of an Arduino circuit board.

### 3.2 Multiplying Digital to Analog Converter

All digital-to-analog converters provide an output proportional to the product of the digitally set gain and an applied reference voltage.[6] A multiplying DAC differs from a fixed-reference DAC in that it can apply a high-resolution digitally set gain to a varying wideband analog signal. MDACs are ideally suited for varying reference applications, where the user wants to digitally condition an ac or arbitrary reference voltage.7541A multiplying DAC has been used in this particular circuit.. The Burr-Brown DAC7541A is a low cost 12-bit, four-quadrant multiplying digital-to-analog converter.[7] Laser-trimmed thin-film resistors on a monolithic CMOS circuit provide true 12-bit integral and differential linearity with current output over the full specified temperature range.DAC7541A is

a direct, improved pin-for-pin replacement for 7521, 7541, and 7541A industry standard parts. In addition to a standard 18-pin plastic package, the DAC7541A is also available in a surface-mount plastic 18-pin SOIC.

### 3.3 Arduino

The Arduino is a Physical or Embedded Computing platform, which means that it is an interactive system that through the use of hardware and software can interact with its environment. The Arduino can be used to develop stand-alone interactive objects or it can be connected to a computer to retrieve or send data to the Arduino and then act on that data (e.g. send sensor data out to the internet) [8]. To program the Arduino, use the Arduino IDE (Integrated Development Environment), which is a piece of free software that enables to program in the language that the Arduino understands. In the case of the Arduino the language is C. The IDE enables the user to write a computer program, which is a set of step-by step instructions that can then be uploaded to the Arduino.

## 4. HARDWARE TESTING

### 4.1 Circuit Design

The following figure shows the entire circuit diagram of the circuit built for digitally controlled biased amplifier for nuclear timing spectroscopy. The figure is built with the help of software OrCAD Capture CIS Lite. OrCAD® Capture is one of the most widely used schematic design solutions for the creation and documentation of electrical circuits [9].

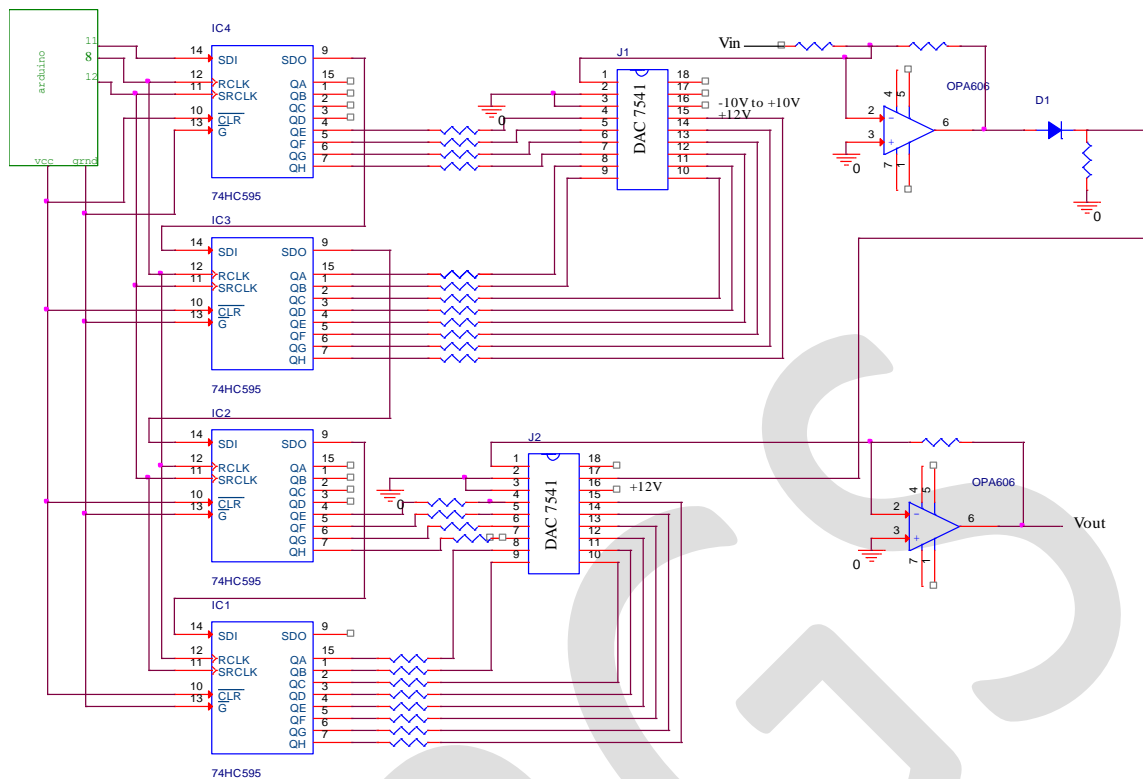
The major components of the circuit are:

- Arduino Uno board.
- 74HC595, 8-bit serial in, serial or parallel out shift register with output latches.
- DAC 7541A, 12 bit Multiplying Digital to Analog converter.
- OPA606, wide bandwidth Operational Amplifier.

The detailed description for the used components is described below:

- Arduino Uno:

The most basic task of the Arduino board in the circuit design is for changing the DAC code digitally, wherein the Arduino board acts as an interface between the circuit and the computing system. Here, Arduino Uno board has been used, whereas one can use any other type of Arduino boards available in the market. With a slight changes in the program built in the C language, the code works easily, thus serving as an extremely user friendly and easily accessible at lower costs interfacing software.



**Fig.4.1 Circuit Diagram for Digitally Controlled Biased Amplifier for Nuclear Timing Spectroscopy**

- 74HC595 Shift register:

The 74HC595 is a high-speed Si-gate CMOS device and pin compatible with Low-power Schottky TTL (LSTTL). [10] It is specified in compliance with JEDEC standard No. 7A. The 74HC595 is an 8-stage serial shift register with a storage register and 3-state outputs. The register has separate clocks. Data is shifted on the positive-going transitions of the shift register clock input (SHCP). The data in each register is transferred to the storage register on a positive-going transition of the storage register clock input (STCP). If both clocks are connected together, the shift register will always be one clock pulse ahead of the storage register.

The shift register has a serial input (DS) and a serial standard output (Q7S) for cascading. It is also provided with asynchronous reset (active LOW) for all 8 shift register stages. The storage register has 8 parallel 3-state bus driver outputs. Data in the storage register appears at the output whenever the output enable input (OE) is LOW.

The DAC7541A is a 12-bit parallel input, whereas the Arduino gives serial output. The serial-to-parallel shifting out is done with the use of 74HC595 shift register [11]. In the circuit, four shift registers have been used, which means the same setup can be used further while using a 16-bit DAC.

- DAC7541A

By offering both flexibility and simplicity, multiplying DACs can be used in a broad range of applications. [12] The benefit of a discrete DAC and op-amp solution is that the op-amp selection can be custom-tailored to suit the application requirements. Multiplying DACs are ideal building blocks for fixed-reference applications, where the user wants to generate a waveform from a fixed DC voltage. They are also ideally suited for varying-reference applications, where the user wants to digitally condition an AC or arbitrary reference voltage.

- OPA606

The OPA606 is a wide-bandwidth monolithic dielectrically-isolated FET operational amplifier featuring a wider bandwidth and lower bias current than BIFET® LF156A amplifiers.[13] Bias current is specified under warmed-up and operating conditions, as opposed to a junction temperature of +25°C. Laser-trimmed thin-film resistors offer improved offset voltage and noise performance. The OPA606 is internally compensated for unity-gain stability.

Hardware is tested after studying the circuit components and design in detail. The results obtained are tabulated along with the output waveforms for the particular input.

#### 4.2 Hardware testing

The input to the circuit is given from the pulse generator circuit. In the laboratory to test the hardware, sinusoidal input of frequency 1 KHz is applied to Vin. The reference voltage for the DAC is given as 8V, since it can be varied from -10V to +10V. The output is observed on an oscilloscope.

Initially, the offset is kept constant for one particular code of DAC, and gain is varied for various different codes. For better understanding and clearer view, the first three MSBs are varied. The biasing DAC code is kept fixed as 512 which is equivalent to 1V, the code in binary form depicted as 0010 0000 0000. For this fixed bias voltage, the code is varied for different values and the readings recorded are as shown in Table4.1:

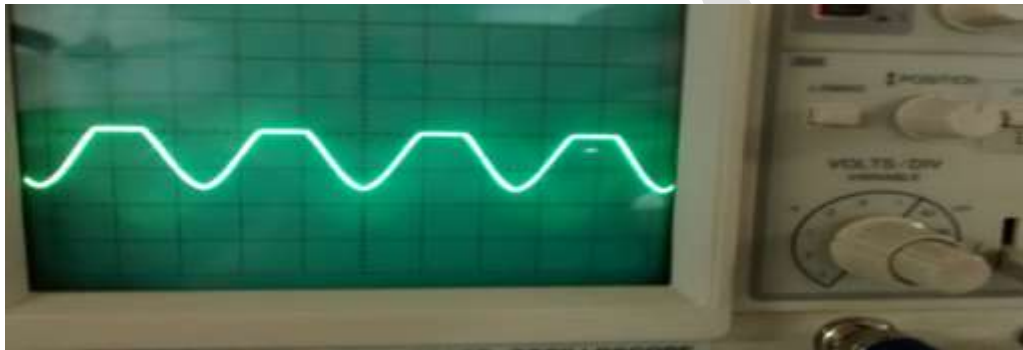
Gain DAC code		Gain voltage (volts)
0000 0000 0000	0	0
0010 0000 0000	512	0.2
0100 0000 0000	1024	0.4
0110 0000 0000	1536	0.6
1000 0000 0000	2048	0.8
1010 0000 0000	2560	1
1100 0000 0000	3072	1.2
1110 0000 0000	3584	1.4

Fig.4.2 shows the output for fixed bias, for DAC code 512, and varying gain, for gain DAC code at 512. Fig4.3 shows the output for fixed bias, for DAC code 512, and varying gain DAC code 3584, it is observed that as the gain varies the amplitude varies proportionally



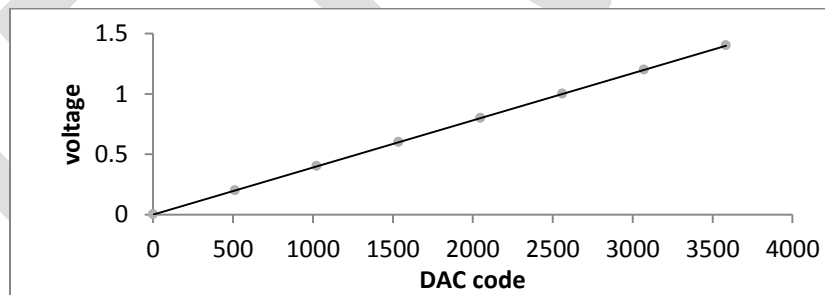


**Fig 4.2 Output for fixed bias DAC code 512 and varying gain DAC code 512**



**Fig 4.3 Output for fixed bias DAC code 512 and varying gain DAC code 3584**

Graph of output voltage Vs DAC code is plotted as shown in Fig.4.4, where the digital code of the bias DAC is kept fixed and the digital code of gain DAC is varied. It is observed that as the digital code increases, the voltage increases proportionally



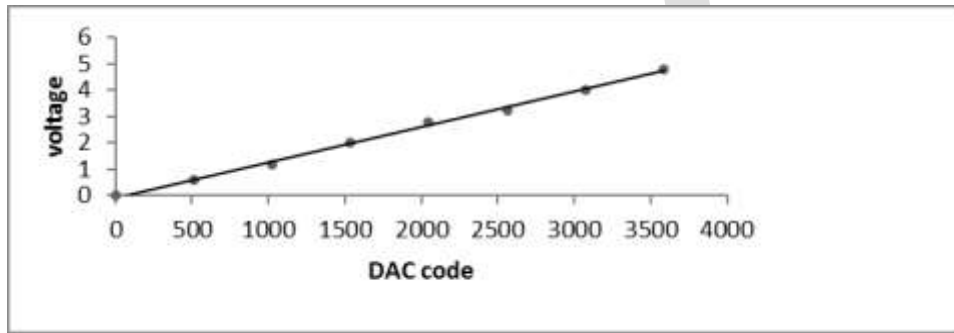
**Fig.4.4 Graph showing output for set of readings with fixed bias and varying gain with bias DAC code = 512**

The biasing DAC code is kept fixed as 1536, the code in binary form depicted as 0110 0000 0000. For this fixed bias voltage, the code is varied for different values and the readings recorded are as follows:

Table 4.2. Set of readings with fixed bias and varying gain with Biasing DAC code = 1536.		
Gain DAC code		Gain Voltage (Volts)
0000 0000 0000	0	0
0010 0000 0000	512	0.6
0100 0000 0000	1024	1.2

0110 0000 0000	1536	2
1000 0000 0000	2048	2.8
1010 0000 0000	2560	3.2
1100 0000 0000	3072	4
1110 0000 0000	3584	4.8

Graph of output voltage Vs DAC code is plotted as shown in Fig.4.5, where the digital code of the bias DAC is kept fixed and the digital code of gain DAC is varied. It is observed that as the digital code increases, the voltage increases proportionally.

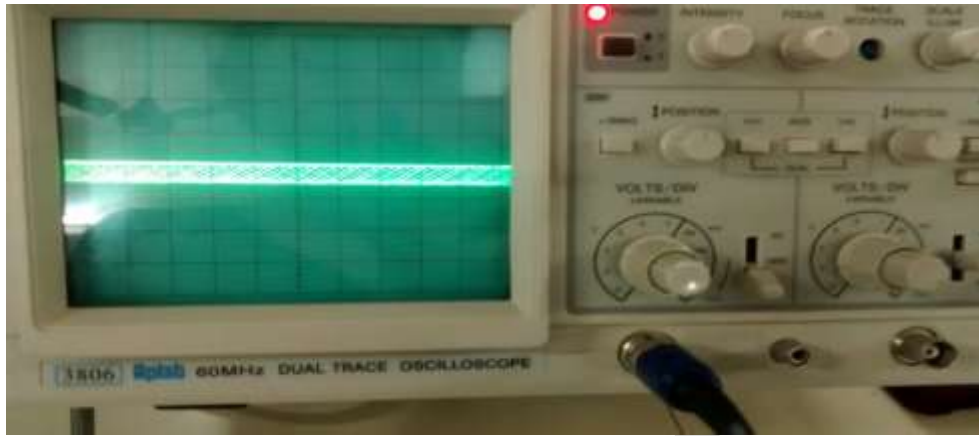


**Fig.4.5 Graph showing output for set of readings with fixed bias and varying gain with bias DAC code = 1536.**

Table 4.3 shows readings for fixed gain DAC code at 512 that is, 0010 0000 0000 and varying bias voltage by varying the digital code of biasing DAC. For clearer results and easy understanding, the first three MSBs of the DAC are varied.

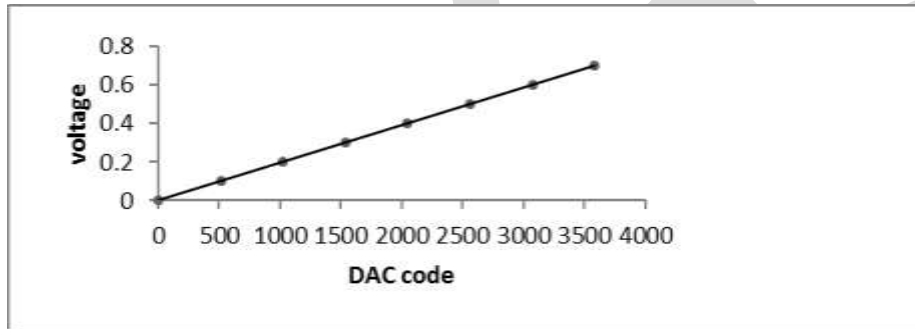
Table 4.3. Set of readings with fixed gain and varying bias with Gain DAC code = 512		
Biasing DAC code		Bias Voltage (Volts)
0000 0000 0000	0	0
0010 0000 0000	512	0.1
0100 0000 0000	1024	0.2
0110 0000 0000	1536	0.3
1000 0000 0000	2048	0.4
1010 0000 0000	2560	0.5
1100 0000 0000	3072	0.6
1110 0000 0000	3584	0.7

The output for fixed gain DAC code as 512 and biasing DAC code as 0 is shown in Fig.4.6. The offset is 0V.



**Fig 4.6 Output for fixed gain DAC code 0 and varying bias DAC code 512**

Graph of voltage Vs DAC code is plotted as shown in Fig.4.7, where the digital code of the gain DAC is kept fixed and the digital code of the biasing DAC is varied. It is observed that as the digital code varies, the voltage varies proportionally.



**Fig.4.7 Graph showing output for set of readings with fixed gain and varying bias with gain DAC code =512.**

Table.4.4 shows readings recorded for fixed gain DAC code and varying Biasing DAC codes. The gain DAC code is kept constant at 1536 that is in binary code it is written as 0110 0000 0000, and the biasing DAC code is varied for the first three MSBs. As the biasing DAC code varies the offset varies proportionally. From the output obtained it is observed that the baseline shifts from the origin, thus bringing the time to amplitude spectrum towards origin from the time to amplitude spectrum.

Table 4.4. Set of readings with fixed gain and varying bias with Gain DAC code = 1536.		
Biasing DAC code		Bias Voltage (Volts)
0000 0000 0000	0	0
0010 0000 0000	512	0.2
0100 0000 0000	1024	0.4
0110 0000 0000	1536	0.8
1000 0000 0000	2048	1.2
1010 0000 0000	2560	1.6
1100 0000 0000	3072	1.8

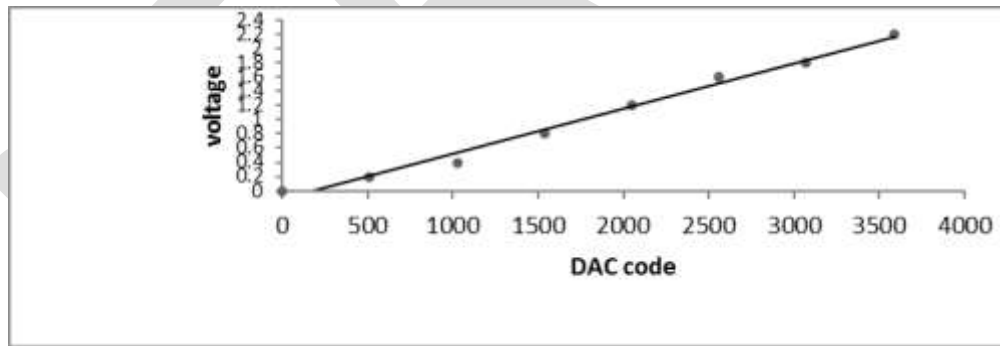
1110 0000 0000	3584	2.2
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The input code to the gain DAC is given as 1536 and the input code to the biasing DAC is given as 1024. The corresponding output is observed as shown in Fig.4.8.



**Fig 4.8 Output for fixed gain DAC code 1536 and varying bias DAC code 1024**

It is observed that the baseline shifts from 0V to 0.4V, as the biasing code varies with respect to fixed gain. And also the amplitude varies as the gain varies with respect to the fixed biasing voltage. Graph of voltage Vs DAC code is plotted as shown in Fig.4.9, where the digital code of the gain DAC is kept fixed and the digital code of the biasing DAC is varied. As the digital code varies, the voltage varies proportionally.



**Fig.4.9 Graph showing output for set of readings with fixed gain and varying bias with gain DAC code = 1536.**

**RESULTS:** It is seen that keeping the bias fixed, the gain can be varied, and keeping the gain fixed, the bias can be varied. The gain varies proportionally as the digital code varies; similar results are obtained for bias.

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## CONCLUSION

The new design introduced, “Digitally Controlled Biased Amplifier for Nuclear Timing Spectroscopy”, thus can be widely used to obtain higher resolution in the timing spectroscopy in applications requiring very high resolutions. This digitally controlled biased amplifier should be useable for multiparameter system by dividing the range of multichannel analyzer into small zones with different biases using biased amplifier.

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