Indian Journal of Pure & Applied Physics
Vol. 58, May 2020, pp. 380-385

A pulse generation system based on new method for testing performance of high-resolution nuclear spectroscopy systems

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Received 4 May 2020

The paper presents a design and construction of uniform amplitude pulse generator for testing Differential Non-Linearity (DNL) of high-resolution nuclear spectroscopy systems. The paper describes two methods based on two new techniques called DAC Interpolation and Analog Multiplexer based design. A prototype of DAC interpolation technique has been designed and tested. [**]The method based on analog multiplexer and chain of resistors is simulated and the results of which is reported in the paper. The systems produce pulses with step size of 10 microvolt (μV), making them capable for calibrating spectroscopy systems with the resolution as high as 13-bit (8K). The systems are designed using commercially available components. The pulse generation system provides import substitute for commercially available imported models.

Keywords: Uniform Amplitude Pulse Generator, Multichannel Analyzer, Nuclear Instrumentation, High-Resolution Nuclear Spectroscopy Systems, DAC Interpolation, Analog Multiplexers-Chain of Resistors.

1 Introduction

Calibration is an important step to ensure the reliability of the result of any instrument. Calibration of the instrument has to be done on a regular basis for getting accurate results. Testing and calibration of nuclear spectroscopy system are carried out by either conventional method that exercises standard radiation sources and radiation detection setup or by using Nuclear Pulse Generator[1]. The two important linearity parameters, Integral Non-Linearity (INL) and Differential Non-Linearity (DNL) of nuclear spectroscopy systems are validated using nuclear pulse generator. Nuclear pulse generator comprises of Uniform Amplitude Pulse Generator (UAPG) and Precision Pulse Generator (PPG) for testing of DNL and INL of the spectroscopy system, respectively[2]. The calibration system should have better linearity and resolution compared to the system under test.

The UAPG is used for testing the performance of High Resolution MCA (Multichannel Analyzer) as shown in Fig. 1. For this purpose, the output at UAPG is fed to MCA. And the graph of counts collected in individual channels of MCA over a period of time is plotted as shown in Fig. 1.

For the variation in the number of counts in individual channel from their average value gives the DNL performance of MCA. The INL can be calculated based on these DNL spectrum. UAPG can also be used to test the linearity of Analog to Digital Converters.

To test or validate a spectroscopy system, UAPG must generate linear sweeps of duration of few seconds to hundreds of second as shown in Fig. 1. Various analog and digital methods described in the literature for generation of linear ramp are not suitable for calibration and testing of High-resolution nuclear spectroscopy systems[3,4].

Analog methods rely on the use of capacitor as a major component or operational amplifier as an integrator with capacitor in the feedback path[5]. Analog methods need low charging current in pico-amperes and high value of capacitor to generate long sweeps. Leakage current of capacitor and bias current of operational amplifier are significantly large as compared to the charging current (pico-amperes) that affects the linearity of the ramp. Also, minimization of leakage current and bias current requires special techniques and components.

Digital method like Digital Synthesis (DDS) cannot generate step pulses of amplitude other than the resolution provided by Digital to Analog Converter (DAC). It is also dependent on DNL error of DAC and is prone to jitters[6].

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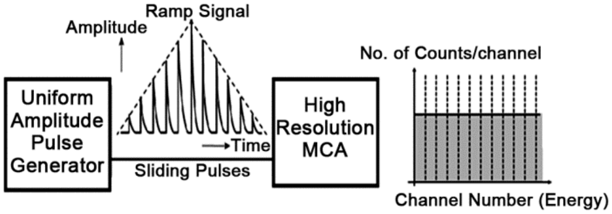


Fig. 1 — Calibration of high resolution MCA (differential non linearity test) and uniform spectrum of MCA.

2 Methods for Testing DNL of High-Resolution Nuclear Spectroscopy Systems

2.1 Design considerations

2.1.1 Determination of resolution of calibration system

Calibration System should have a resolution of less than 1% of quantization step of spectroscopy system under test. For example, a UAPG with expected resolution of 10 µV can validate a 13-bit spectroscopy system as shown in Table 1.

2.1.2 Number of counts in each channel of spectroscopy system and triangular sweep period

For testing an 8K spectroscopy system working at 100 KHz, the calibration system must have resolution of 10 µV as given in Table 1. Also, the spectroscopy system needs to satisfy the statistical variation given by the equation (1)[1].

$$\%\, StatisticalVariation = \frac{\sqrt{n}}{n} \times 100 \qquad \text{... (1)}$$

where, n represents number of counts in each channel.

As given by Eq. (1), to have a statistical variation of less than 1%, the number of counts collected in each channel must be more than 10^4 pulses. The time required for this purpose will depend upon the resolution of the MCA (Multichannel Analyzer), as well as on the frequency of the UAPG).

The total number of counts including all channels for an 8K spectroscopy system, a statistical variation of 0.1% should have at least 8×10^9 counts. The spectroscopy system working at 100 KHz requires 22.22 hours to collect total 8×10^9 counts. A triangular sweep of amplitude range of 0-10 volts with step size of 10 µV, deposits 2 counts in each of the channel. Therefore, the total number of 3906 triangular sweeps is required to collect 10^6 counts in each of the channel. The sweep time of 26 seconds is required to satisfy the calibration requirements of spectroscopy system under test.

Most of the MCAs and Spectroscopy Systems have dynamic range of input voltage of 0-10 volts, hence the pulse generator are designed with similar specification[6,9].

Table 1 — Selection criteria of resolution for Calibration System

Spectroscopy System Under Test (Reference of 10V)		DAC Interpolation Method		
		Selection of Bits		Resolution of Calibration System
Resolution	Quantization Step	MDAC	SDAC	
1K (10-bit)	9.77 mV	3	14	17-bit (76 µV)
8K (13-bit)	1.22 mV	4	16	20-bit (10 µV)
16K (14-bit)	610.35 uV	5	16	21-bit (5 µV)
64K (16-bit)	153 uV	7	16	23-bit (1 µV)

2.2 Designed methods

Following two methods described below in section 2.2.1 and 2.2.2 to test the DNL of spectroscopy system.

2.2.1 DAC interpolation method (multiplying DAC and string DAC)

DAC Interpolation Method overcomes the drawbacks of analog and digital methods described in section 1. The DAC interpolation method for testing of DNL is designed and constructed using two major components such as multiplying DAC and string DAC[2,7]. The block diagram of DAC Interpolation method is shown in Fig. 2.

The steps generated by MDACs are used as reference voltage levels for SDAC. The reference voltage provided to SDAC are interpolated to get desired resolution as an output as shown in Fig. 3. The numbers of bits of MDACs and SDAC are selected in such a way that, MDACs and SDAC gives output levels in millivolts (mV) and microvolts (µV) respectively as shown in Fig. 3.

The number of selected MDACs and SDAC bit decides the major and minor quantization steps respectively. To design a 20-bit system, 4 bits of MDACs and 16 bits of SDAC are selected to get a resolution of 10 µV as given in Table 1.

The digital codes to MDACs are given in such a way that the major quantization steps generated are interpolated and are incremented and decremented to get a triangular sweep as an output of SDAC.

The hardware prototype system shown in Fig. 4 consists of four basic controls such as START, RESET, STOP and Sweep Period Selection to control the generation of triangular sweeps.

START: Starts the sweep.

RESET: It resets the sweep to 0V from any sweep position.

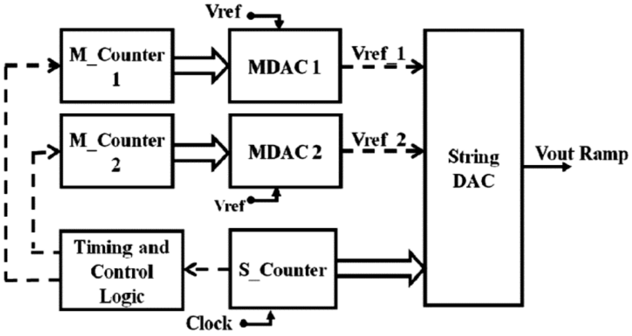


Fig. 2 — Block diagram of DAC interpolation method.

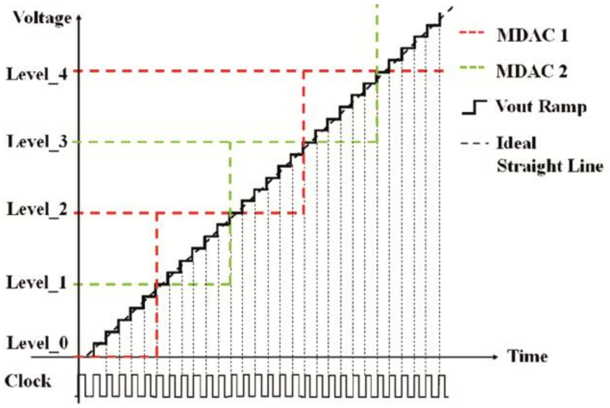


Fig. 3 — Microvolt ramp generation using DAC interpolation method.

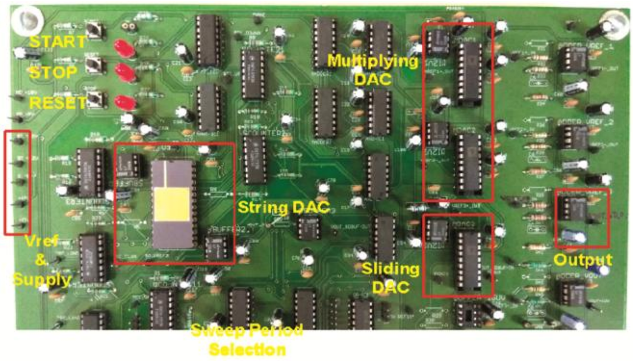


Fig. 4 — Hardware prototype of DAC interpolation method.

STOP: It stops the sweep after completion of current ongoing sweep.

Timing and control circuit takes care of proper synchronization between String DAC and Multiplying DACs operation. To remove high frequency noise from output of SDAC, a passive Low Pass Filter (LPF) is added. Since this is mixed signal processing, analog ground and digital ground are isolated to reduce noise pickup and interference.

DAC Interpolation Method requires a special IC that is string DAC[2]. This method is not capable of giving lower sweep duration of less than 5 seconds. Therefore, a new method is proposed and simulated using Multisim Software v14.0 based on Analog Multiplexers and Chain of Resistors.

2.2.2 Analog multiplexers and chain of resistors based method

The system is designed and simulated to achieve a resolution of 10 µV. This new method uses basic electronic components like resistors, analog multiplexers or switches, programmable counters etc. It can generate sweep times of less than 1 second as the analog switches are available with switching times as low as 10 nano-seconds (ns).

The resolution of the system is decided by the number of resistors in each chain of resistive network and number resistive networks as shown in Fig. 5.

Voltage available across various points in the resistive network (chain-0) are progressively switched and applied at proper points of resistive network (chain-1). This process is continued till last resistive network (chain-n) is reached that results in steps of few micro volts as per the resolution of the system.

The programmable counter associated with each multiplexer generates sequence in such a way that it progressively switches to cover the entire resistive network. The programmable counter for each stage has been programmed in such a way that the output stage increments or decrements in a given order generating triangular ramp. These triangular sweeps are fed to the system under test resulting in uniform amplitude distribution of pulses as shown in Fig. 1.

2.3 Advantages of analog multiplexers and chain of resistors based method over DAC interpolation method

(i) The range of sweep duration is very large, since lower sweep times can be achieved due to low switching times of analog multiplexers or switches.

(ii) It requires low cost commercially available electronic components.

(iii) The circuit is relatively simple and the cost of the system will be low.

(iv) Linearity of the system is dependent on the tolerance of resistive network. Selecting tracking resistors with the tolerance of less than 0.1% ensures high linearity [8].

(v) It does not require special ICs like multiplying DAC and string DAC.

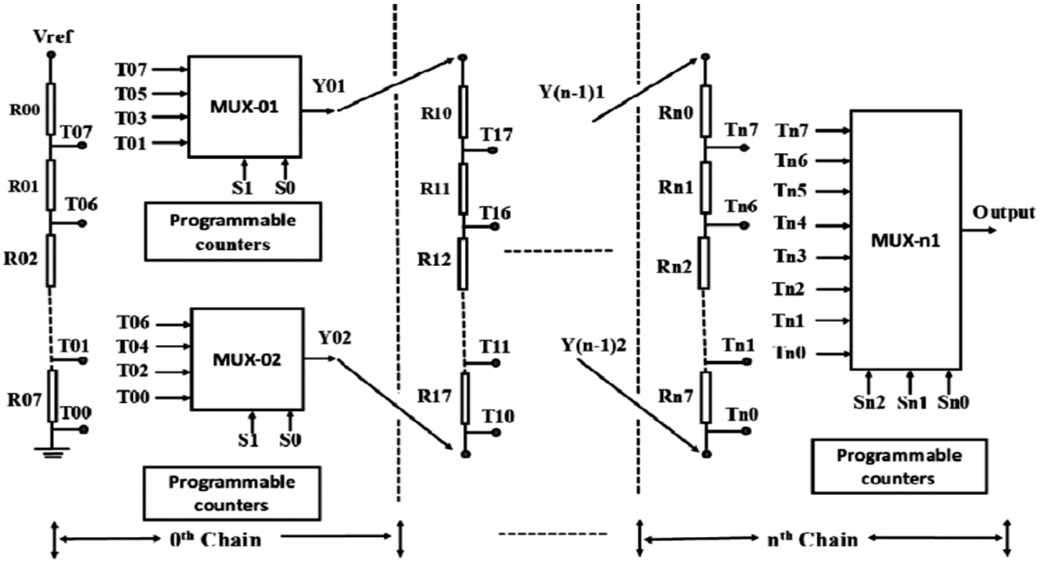
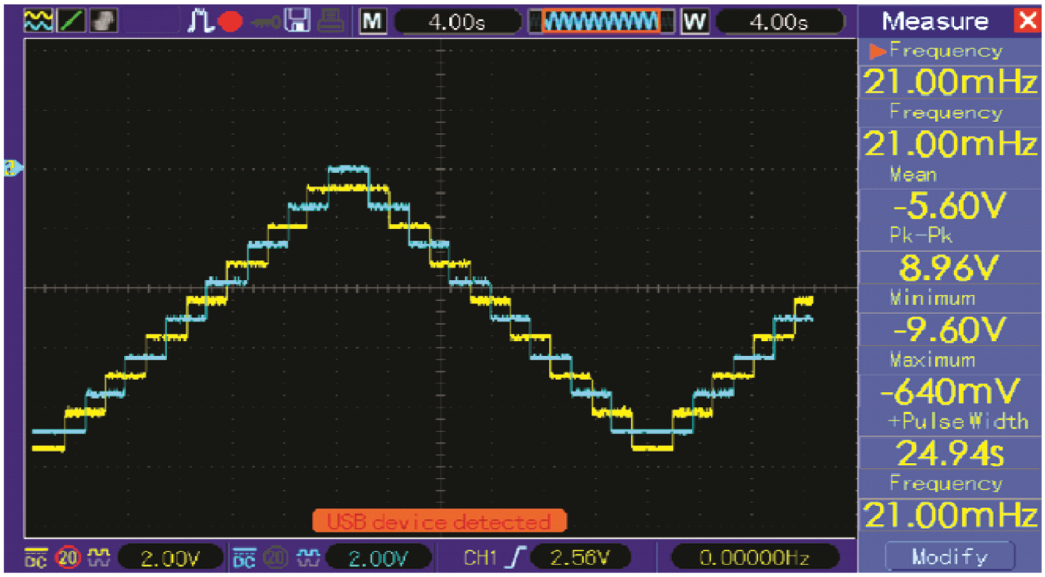


Fig. 5 — Analog multiplexers and chain of resistors based method.



USB device detected

Measure
Frequency 21.00mHz
Frequency 21.00mHz
Mean -5.60V
Pk-Pk 8.96V
Minimum -9.60V
Maximum -640mV
+Pulse Width 24.94s
Frequency 21.00mHz

Fig. 6 — Interpolated output from multiplying DACs.

(vi) The above two methods can also be used to test DNL of Analog to Digital Converters (ADCs).

3 Results

3.1 Results of DAC interpolation method

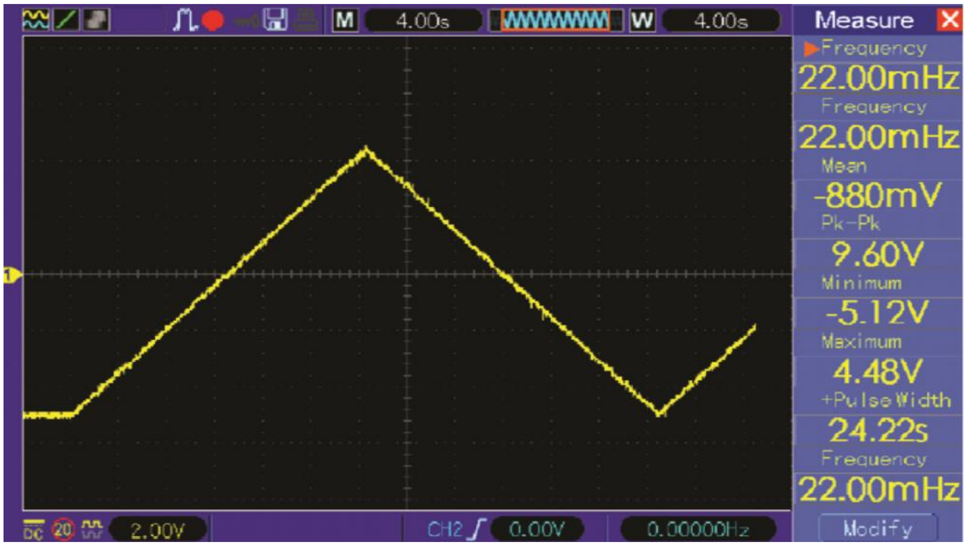
A hardware prototype of DAC Interpolation Method has been developed using two major components, Multiplying DAC and String DAC. Following Fig. 6 and Fig. 7 are the results of the hardware system.

Figure 6 shows the interpolated voltage levels in millivolts (mV) generated by two MDACs (MDAC1 and MDAC2). These two voltage levels are given to SDAC as reference voltages.

Figure 7 is the final output of SDAC resulting steps of 10 µV with sweep duration of 24.22 seconds. These sweeps of long duration are given to nuclear spectroscopy system or ADC under calibration.

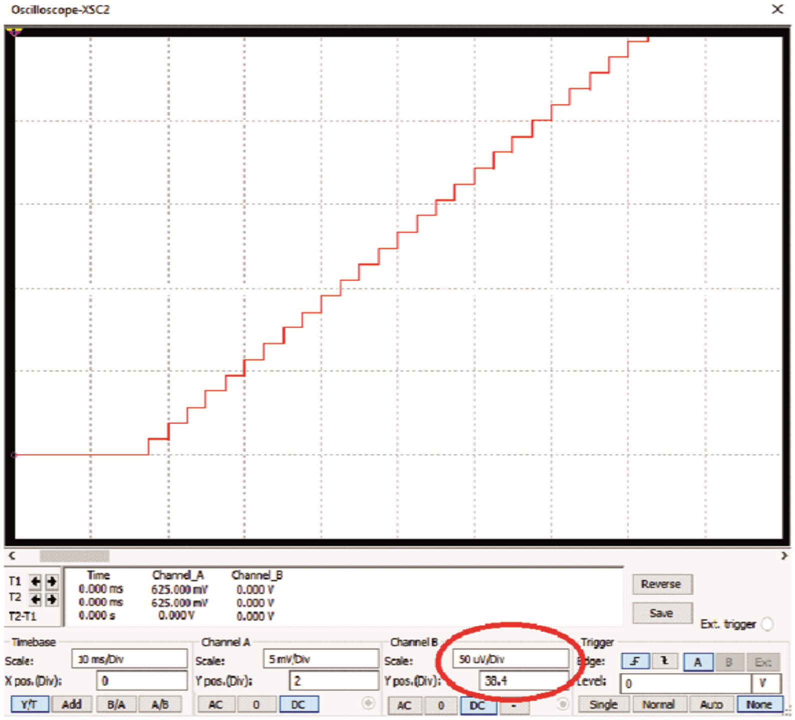
3.2 Results of analog multiplexers and chain of resistors based method

An Analog Multiplexers and Chain of Resistors based Method is simulated using Multisim Software v14.0. The simulated output with resolution of 10 µV is shown in Fig. 8.



Frequency 22.00mHz
Frequency 22.00mHz
Mean -880mV
Pk-Pk 9.60V
Minimum -5.12V
Maximum 4.48V
+Pulse Width 24.22s
Frequency 22.00mHz

Fig. 7 — Output from SDAC.



	Time	Channel_A	Channel_B
T1	0.000 ms	625.000 mV	0.000 V
T2	0.000 ms	625.000 mV	0.000 V
T2-T1	0.000 s	0.000 V	0.000 V

Timebase
Scale: 10 ms/Div
X pos.(Div): 0

Channel A
Scale: 5 mV/Div
Y pos.(Div): 2

Channel B
Scale: 50 uV/Div
Y pos.(Div): 38.4

Trigger
Edge: A
Level: 0 V

Fig. 8 — Output from chain of resistors.

4 Conclusions

The designed system using DAC Interpolation Method has resulted in generation of pulses with resolution of 10 µV step size as required for testing of 13-bit (8K) nuclear spectroscopy system. Therefore, the designed system can test the spectroscopy system with resolution as high as 16 bit (64k.) The resolution of calibration system can be decided by selecting the number of MDACs bits and SDAC bits. It is possible to vary the period of sweep from 5 seconds to 1000 seconds and above as per the requirement. An Analog Multiplexers and Chain of Resistors based Method is advantageous to use as it requires low cost electronic components and brings down the development cost of the system. It is possible to achieve long sweep duration ranging from few hundreds of milli-seconds.

Validation of both uniform amplitude pulse generation methods has been carried out using Single Channel Analyzer (SCA) type of system and it is found that the linearity error is within acceptable limits for constant SCA window. The designed system can also be used for testing Analog to Digital Converters (ADCs).

Acknowledgement

The authors would like to thank members of Research and Development Laboratory, VESIT (Vivekanand Education Society's Institute of Technology) for their help and cooperation in every stage of this work.

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