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Development of Low Cost γ - Ray Energy Spectrometer

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ABSTRACT: A cost effective γ-energy spectrometer has been developedusing NaI crystal and a photomultiplier tube coupled with charge sensitive preamplifier and shaping amplifier. The USB based power supply with Phoenix Multi Channel Analyser (MCA) is made ease to record the energy of γ-ray emitted by natural radioactive source. The energy spectrometer is calibrated with the standard radioactive source. Thus recorded energy resolution is around 65KeV (-6% in 1173KeV) with radiation sources ^{60}Co and ^{137}Cs. The results indicate excellent energy resolution and in good agreement with the value of standard spectrometer. This paper describes the details of the design of the detector with specifications, associated electronic modules and the spectrum recording softwareand explains the procedure of recording the γ-ray energy spectrum.

Key words: NaI crystal, energy spectrometer, γ-ray and energy resolution

I. INTRODUCTION

Energy spectrometry is an analytical method that allows the identification and quantification of γ-emitting isotopes in a variety of matrices. In one single measurement and with little sample preparation, γ- ray spectrometry allows you to detect several γ- emitting radio-nuclei in the sample. The measurement gives a spectrum of lines, the amplitude of which is proportional to the activity of the radionuclide and its position on the horizontal axis gives an idea on its energy. Applications of γ- ray spectrometry include: monitoring in nuclear facilities, health physics, nuclear medicine, research in materials, bioscience, environmental science, and industrial uses of radioisotopes. A conservative estimate is that over 200,000 γ-ray spectrometers are in use in academic and industrial labs and facilities throughout the world. Because of the highly technical nature of this technique, the development of cost effective energy spectrometer is challenge. The conventional spectrometer consist of many parts, such as, detector, electronic modules high voltage power supply, software that interface the modules and the PC to record and store the energy spectrometer. An attempt has been made to minimize the parts of the spectrometer and powered by USB of the PC to record and store the energy spectrum.

Description of Detector (NaI) + PMT γ-Ray Spectrometer system

The Detector (NaI of 2” x 2”) + PMT γ-Ray spectroscopy system contains various components such as Integrated scintillation and PMT assembly, charge sensitive preamplifier, shaping amplifier and multiple power supplies as shown in block diagram (Figure 1). The entire setup is assembled in a die-cast aluminium box. The system optimised for Inter University Accelerator Centre (IUAC), New Delhi developed ExpEyes, multi-channel analyser (MCA) and compatible with any other MCA too. This assembly is tested for its functionality and test report is attached with representative screen capture.

Detector (NaI) + PMT Radiation detector and Assembly

The integrated assembly of Radiation detector assembly contains a NaI (Tl) scintillator of size 2” x 2” is optically coupled to a 10 stage photomultiplier tube (PMT) and shielded with ‘μ’ metal as shown in the Figure 2 and 3. Such detector is used for converting incident γ-ray radiation energy into proportional electrical pulses of decaying type. This is a commercially available unit from M/S. Saint-Gobain Crystals, Bangalore [1], These type of detectors are commonly used for γ-ray spectroscopy, thyroid measurements and health physicists applications. All the required electronics are placed with in the die-cast aluminium box with opening for radiation to enter the scintillation crystal as shown here below. The circuits are interlinked with PTFE wires, and double shielded PTFE coaxial cables (2mm).

The 10 stage PMT electrodes are based through PMT high voltage bias network. The PMT anode is supplied with +600V through load resistor of 2.2 MΩ (R2). The potential across each dynode is approximately 40 – 50 Volts as recommended in the voltage distribution ratio table for the PMT R980 [2, 3].

The divider network is fabricated on a PCB with SMD components and the socket mounted for easy installation. Optical voltage monitor across the cathode can be used to monitor the PMT bias voltage supplied.

The current pulse from anode is dropped across 2.2 MΩ load resistor and DC coupled. The decay time constant selected to be around 100mSec (C1 x R1).

Specification: Detector + PMT **γ**-ray spectroscopy system

Scintillation	:	NaI + PMT **γ**-ray spectroscopy system M/s'. Saint-Gobain crystals, IMI/I,S (NaI 2" X 2") or 2M2/2 (2"x2" x2") Integrated detection assembly
Input DC supply	:	+12V to 15V -0.2A [12V 0.5A Wall mount adopter is use]
Dimension	:	188 x 120 x 82 (mm) die-cast Aluminium enclosure (1590E)
Output	:	BNC connector, Unipolar Semi-Gaussian ~ 0-5V / 0-10V
Bias Power Supply		
HV Power supply	:	+650 KV/ ~1mA (Adjustable on PCB) factory set at +600V
Regulation Load	:	better than 0.1% at full load
Ripple	:	better than 0.0057% at full load
Dimension	:	90 x 36x 30 (mm) die-cast aluminium enclosure (G102)
PMT Bias Network		
PMT Detector	:	10 stage, ETI-9266 2" PMT
Socket type	:	14 pin JEDEC B-14-38
Total resistance	:	~ 6 M Ω
Power Dissipation	:	~ 0.1W at +600V.
Application	:	Energy spectroscopy
Signal output	:	Energy (2.2Mohms), with 100ms decay time.
Preamplifier		
Type	:	Charge sensitive preamplifier operational amplifier type
Conversion factor	:	~lmV /MeV (Si. Equ)
Decay time	:	~50 µS (±10%)
Output	:	DC blocked and 100Ω capable
Protection	:	Input is over voltage protected against spikes
Power	:	± 9V, 5mA
Dual voltage supply		
Type	:	Charge pump ICL7660
Output	:	± 9V, 20mA each
Shaping amplifier		
Output	:	P/Z, Baseline conected unipolar, with overload recovery, Semi-Gaussian type output pulse
Gain	:	2.5MeV, 5MeV respectively (Jumper select on board) for 0-5V

Signal processing electronics

The signal from the anode of PMT is buffered with on board charge sensitive preamplifier (U5) having charge sensitivity of -1mv/ Mev (47pF, 1M) (si. Equ), and decay time constant of 50µs. the preamplifier signal is DC blocked and fed to a pole-zero correction network for smooth baseline recovery of amplified signal. The block diagram of signal processing electronics is shown in Figure 4.

The signal from preamplifier is further amplified with a low noise, broadband operational amplifier (U1) and desired gain selection (COARSE gain) is done in this stage. Further amplification (FINE gain) as well as over load recovery (OVL) takes place in the next stage (U2, D2). The signal level in this stage is clamped to a desired level, so that the over all amplified signal does not exceed the desired level in order to protect the following stages. This circuit also helps to recover the amplifier quickly from pileup of events at the input due to increased radiation intensity. The signal is shaped for a desired time constant (2µs) with 2 stages of 2^{nd} order low pass filters in cascade (U3A & B).

The slow varying baseline or DC offset is corrected in the following stage with twin diode Robinson baseline recovery circuit (BLR) (Q1,D4,Q4). Further the signal is amplified and buffered for an optimum load in the last stage (U4, Q2,Q3). The required DC (±9V) supply is tapped from power supply unit through 3 pin CFU connector. The signal processing PCB is mounted on the die- cast aluminium box, and the output is made available on the BNC connector for further digitisation. Typical shaped energy output signal is tested on CRO.

Power supply Unit

The high voltage power supply is an independent unit, as shown int the Figure 5: and is enclosed ina die-cast aluminium box. The high voltage PCB also contains a dual DC voltage supply (charge pump) circuit, required for the signal processing electronics circuits. The incoming supply is zener regulated to +9.0 volts and fed to a switched capacitor type charge pump circuits (U3, U4) to generate ±9V supplies. Whereas the high voltage DC generator works on Cock craft-Walton principle. The step up transformer (T1) is fed with pulses of 50% duty cycle at 25KHz, from a pulse width modulator (PWM) circuit (U1). The primary voltage of transformer is controlled through the voltage regulator circuit (U2), to set the required output voltage through a feedback mechanism. A 6-stage Cock craft-Walton half bridge high voltage multiplier circuit generates required high output voltage (~550-600V). The output voltage is sampled through a high ohmic resistor chain to generate negative feedback voltage for a on board regulator (LM723). The CRC filter (C10, R4, C12) is used as a low pass filter, as well current limiter. The high voltage supply circuit can be shut down with jumper (JP1) selection. The output voltage is set to +550volts, for this application, and can be adjusted within ±5% with control provided on PCB. The ripple voltage at the output is measured when it is fully loaded and is measured to be 14 mV_{max} (<0.003%).

Setting up procedure

Items required:

+12-15V/-0.5A wall mount adopter	: 1no.
NaI + PMT γ- ray spectroscopy system	: 1 no.
Cathode ray oscilloscope (CRO)	:1 no. (optional)
Radioactive source (laboratory grade) ^{137}Cs / ^{60}Co	:1no.
Multichannel Analyser (511/2IV4IVBM6K), 0-5V	:1 no.
BNC-BNC coaxial cable 1M	:1no.

Procedure:

1) Power the unit with wall mount adopter. LED must glow
2) Connect the output (Energy) to CRO through BNC cable. Set +ve edge '"Trigger' threshold above +50mV DC.
3) Set the horizontal (time) scale in lμs/div, vertical scale in 0.5v/div, observe randomly occurring Gaussian shape signal with low count rate (~100Hz).
4) When the radiation source is brought closer to the scintillation side of the detector, the signal intensity increases. The amplitude of the observed signal is entirely depended on the incident energy as shown in Figure 8.
5) Ensure that the Energy output should not have any DC offset, and maximum amplitude shall not exceed +5V.
6) Setup the MCA. (Phoenix/any commercial MCA can be used)
7) Now the BNC cable can be connected to the MCA i/p for further data collection and interpretation as suggested in the MCA manual.

The internal circuit is capable of delivering the output across dynamic range of 0 - 10V, with 50 ohm load. Present circuit is wired for +5V with suggested DC power source,

CALIBRATION AND RESULTS

The γ-ray spectroscopy system is repeatedly tested with standard radiation sources at IUAC New Delhi, and pulse height distributions have been studied using different multichannel analyser (MCA). The energy resolution recorded is around 65KeV (-6% in 1173KeV) with radiation sources ^{60}Co and ^{137}Cs as shown in figure 6 and 7, which were obtained with 511 channels (Phoenix, MCA).

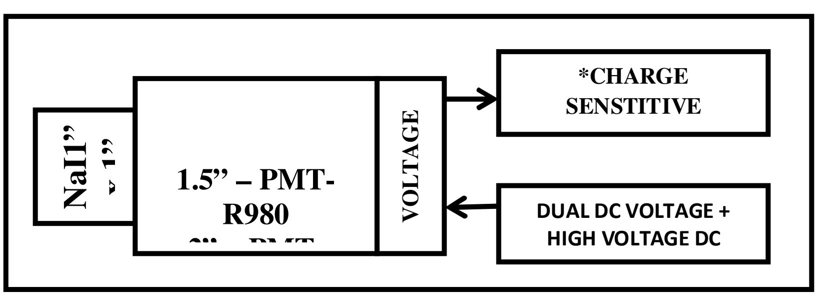

Fig. 1. Block Diagram.

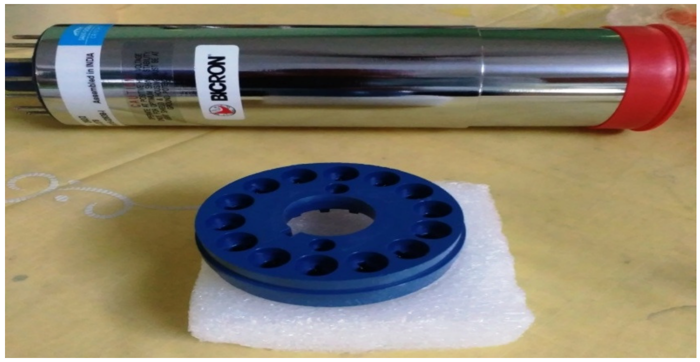

Fig. 2. Detector and 14 pin PMT socket view.

Fig. 3. Assembled view of spectroscopy unit.

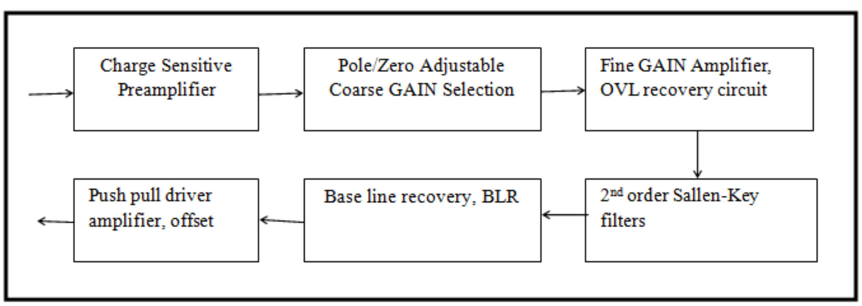

Fig. 4. Block diagram of signal processing electronics.

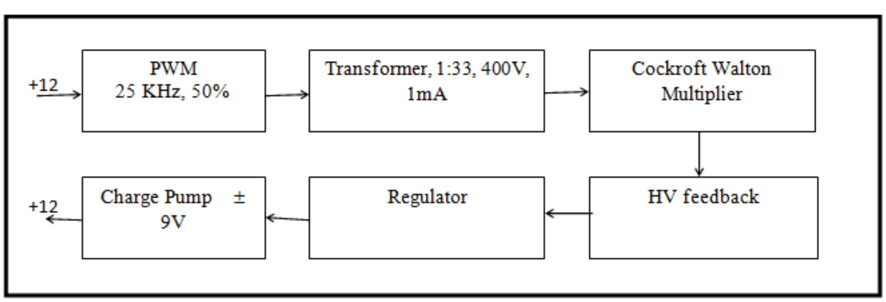

Fig. 5. Block diagram of power supply unit.

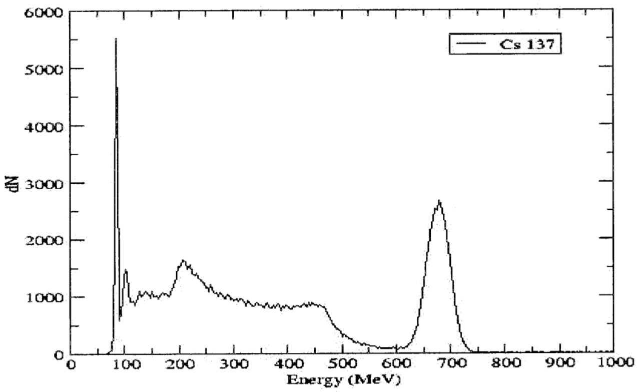

Fig. 6. Energy distribution for Cs-137 source obtained with "PHOENIX" – MCA.

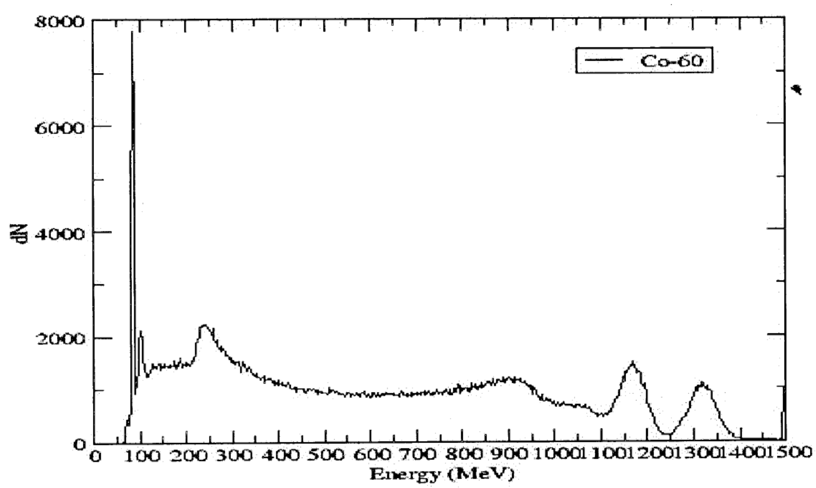

Fig. 7. Energy distribution for Co-60 source obtained with "PHOENIX"- MCA.

CONCLUSION

The spectrometer setup is designed and assembled in-house with the help of Dr. B P Ajithkumar, Senior Scientist, IUAC New Delhi. The spectrometer testing was carried at IUAC New Delhi using the radioactive sources and found excellent resolution of 6%. The calibration setup at BKIT would require the low strength radioactive sources. These sources is to be procured after getting permission from AERB regulatory board.

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REFERENCES

[1]. Scintillation materials & assemblies, M/s. Saint-Gobain crystals. http://www.crystals.saint-gobain.com
[2]. Photomultiplier tubes R98O Hamamatsu data sheet
[3]. Bases, Voltage Dividers, and Pre-amplifiers Accessories for Scintillation Detectors. http://www.crystals.saint-gobain.com