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ELECTRONIC MODULE FOR 6-BAF$_2$-DETECTORS POSITIONING CONTROL

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ABSTRACT

A new electronic module to control the positioning of six conical BaF_2 detectors is presented. The BaF_2 detectors are built in a cubic structure as part of a PAC (Perturbed Angular Correlation) spectrometer. Basically it consists of an electronic circuit that controls the velocity of a six step motors according to the γ–γ coincidence rate. Each of the stepper motors is coupled to a BaF_2 detector attached to a photomultiplier and a voltage divider. The distance between each detector is proportional to the activity of a short-life radioactive sample positioned in the center of cubic structure. The detectors are brought closer to the sample periodically and automatically according to the decreased activity, eliminating the need for human presence. This module was designed and constructed in the IPEN-CNEN/SP by employing national components.

1. INTRODUCTION

Measurement of Perturbed Angular Correlation (PAC) of gamma rays is a microscopic technique to determine the hyperfine fields or electric field gradients at the site of probe nucleus generated by neighboring ions and electrons. The method can also provide information on dynamic properties of the local environment. The radioactive nuclei are introduced into a host material where they eventually decay to an excited state of the daughter nucleus which subsequently decays to the ground state by emission of two successive gamma rays γ_1 and γ_2. The interaction between nuclear moments and extra nuclear electromagnetic fields perturbs the angular correlation between the emitted gamma rays in a way which can be used to determine the properties of the host material on a microscopic scale. A detailed analysis of these perturbations reveals the electronic properties of the host material such as: crystalline and magnetic structure, structural defects, phase transitions, etc. Further details about the PAC technique and experimental procedure can be found elsewhere [1]. In general the PAC experiments are made in gamma spectrometers typically consisting of four or six BaF_2 scintillator detectors and an electronic system to measure the time differential delayed γ–γ coincidences [2, 3]. In these arrangements the time distribution of coincidence events for combination of γ_1 (start) and γ_2 (stop) detected in each pair of detectors are measured. A “slow-fast” coincidence circuit validates the signals from each detector and the pair of detectors responsible for the coincidences is identified a routing module. For an accepted coincidence the time to amplitude converter provides an amplitude signal proportional to the time difference between arrival of γ_1 and γ_2. A multichannel analyzer stores the digital information in each memory block and generates real time spectra.

Currently the PAC experiments are performed at the Laboratory of Hyperfine Interactions (LIH) at IPEN in two spectrometers consisting of four or six detectors, respectively. The 4-detectors spectrometer (fig. 1a), in use since 1999, has a planar structure with 90° between the detectors and provides 12 valid spectra of γ_1-γ_2 coincidences. In the 6-detectors spectrometer (fig. 1b), recently built, the detectors are positioned in a cubic structure providing 30 valid spectra. The larger number of spectra of this 6-detectors spectrometer provides experiments to be performed in a shorter time (approximately by a factor of 1.8). In addition, the rate of coincidences is higher compared to the 4-detectors spectrometer, enabling measurements with short half-life nuclear probes. However, these types of measurements need the continuous adjust of the detectors position to maintain the coincidence rate at a relatively constant value. Thus, the human presence is required during the entire experiment.

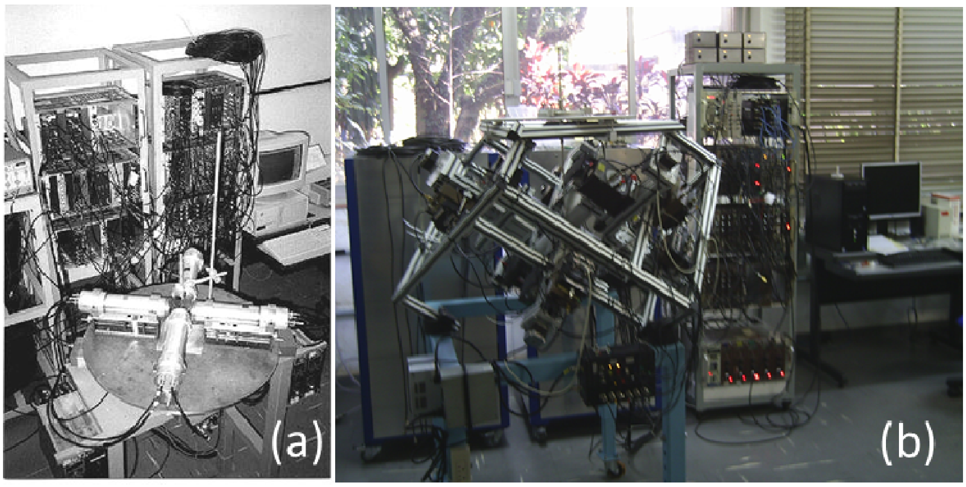

Figure 1. PAC spectrometers of LIH: 4-detectors (a) and 6-detectors (b).

In order to avoid the need for human presence throughout the experiment, was developed an electronic module that must maintain constant the coincidence rate independent the half-live of the radioisotope used as probe. Therefore, this present work shows the development of the prototype of the electronic module for 6-BaF_2-detectors positioning control and the results obtained after its installation in the PAC spectrometer.

2. GENERAL DESCRIPTION OF THE 6-DETECTOR SPECTROMETER

A block diagram of the 6-detector spectrometer is illustrated in figure 2. The most practical set up is obtained when the cube is positioned with one of its main diagonals is in the z-axis (fig. 3) and the detectors are positioned on each of the six faces of the cube. Necessary space for introducing the auxiliary systems such as cryostat for cooling the samples and small furnace for heating is from top or under the detectors.

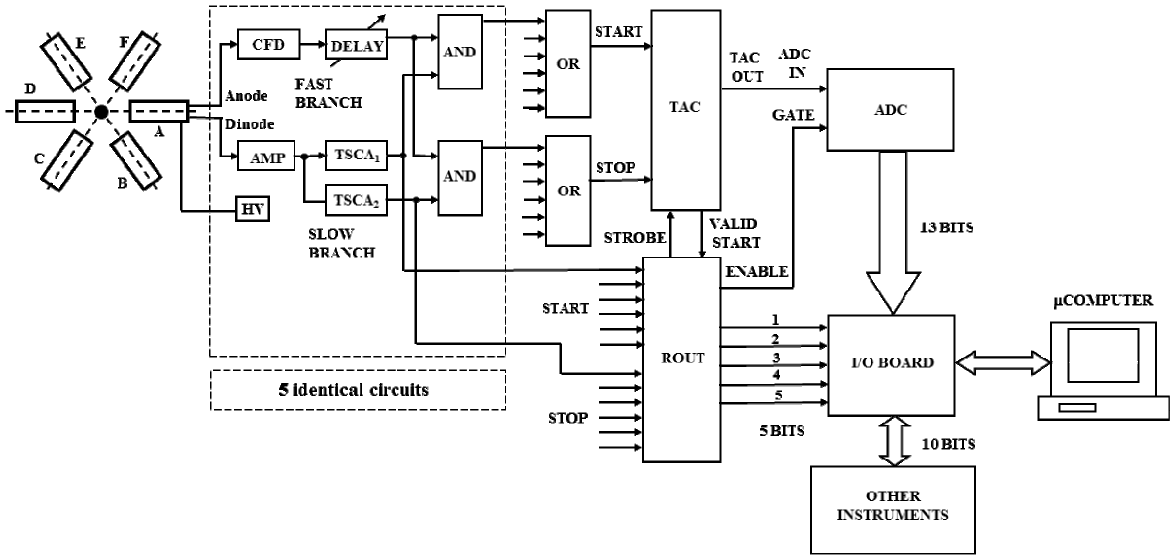

Figure 2. Block diagram of the 6-detectors spectrometer (A – F: BaF_2 detectors; HV: high voltage power supply Ortec 456; CFD: constant fraction discriminator Canberra 2126 e fast amplifier AN201/N o equivalent; DELAY: delay with coaxial cable RGC213; AMP: spectroscopy amplifier Ortec 572; TSCA: time single channel analyzer Ortec 551; AND, OR: logic units LeCroy 429A e 622; TAC: time to amplitude converter Canberra 2145; ROUT: router IPEN; ADC: analog to digital converter Canberra 8715; I/O board: 32 digital input/output board National Instruments PCI-6534; μCOMPUTER: PC computer).

Each BaF_2 detector yields two types of signals. Two distinct signals from the detectors carry information about the gamma radiation energy and the detection timing respectively. The energy signal (from dynode photomultiplier tube) is amplified (AMP) and the energy selection is performed by the timing single channel analyzers (TSCA), defining the windows on γ_1 or γ_2 of the gamma cascade ("slow branch"). The amplified signal energy is also applied to the circuit of detector positioning, providing a sampling of the activity of the radioactive probe. The circuit for detector positioning provides power to the stepper motor coupled to each detector and three digital signals that communicates with an input-output (I/O) board. The timing signal (from anode of photomultiplier tube) goes to a constant fraction discriminator (CFD) and is delayed by about 2.5 μs ("fast branch"). The coincidence between the slow and fast signals is established by a coincidence circuitry (AND). The output of AND circuitry is a pulse that provides information about the photon energy and the instant of its detection. This signal goes to a time to pulse height converter (TAC) and it is connected to "start" or "stop" depending on γ_1 or γ_2. The linear output pulse from TAC goes to an analog to digital converter (ADC) circuitry. The "router" provides a 5 bits output going to the I/O board which addresses the digital data to a PC. The experimental data obtained in this way corresponds to 1 of the 30 possible combinations of the detectors and can be stored in the computer in a file mode as well as for constructing histograms in real time. The I/O board has additional 14 digital inputs for connections to other instruments that may be used in the experiment, as for example, controller of sample temperature in the cryostat and furnace, and step motors for programmed positioning of the detectors as the radioactive source decays, which is the purpose of this work.

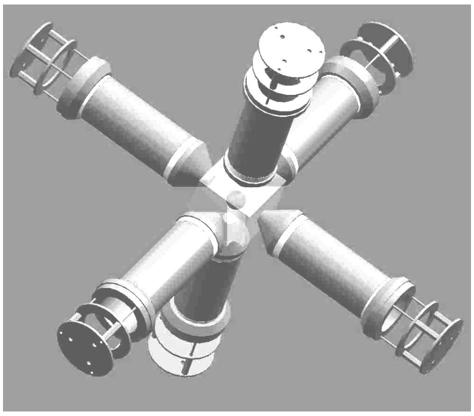

Figure 3. Cubic arrangement of the 6-BaF_2-detectors.

3. THE ELECTRONIC MODULE FOR DETECTORS POSITIONING

A block diagram of the electronic circuit for detector positioning control is illustrated in fig. 4. The entire electronic module consists of six identical circuits. Each detector cart contains the stepper motor coupled to the detector and the control board (fig. 5). The detector cart can move forward and back ward about 105 mm. The BaF_2 detector, in turn, is coupled to the voltage divider and the photomultiplier.

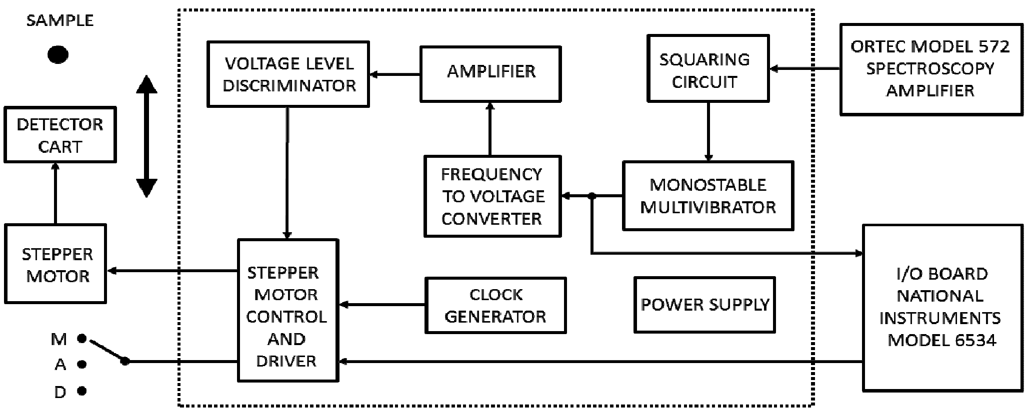

Figure 4. Block diagram of the electronic module for 6-BaF_2 detectors positioning.

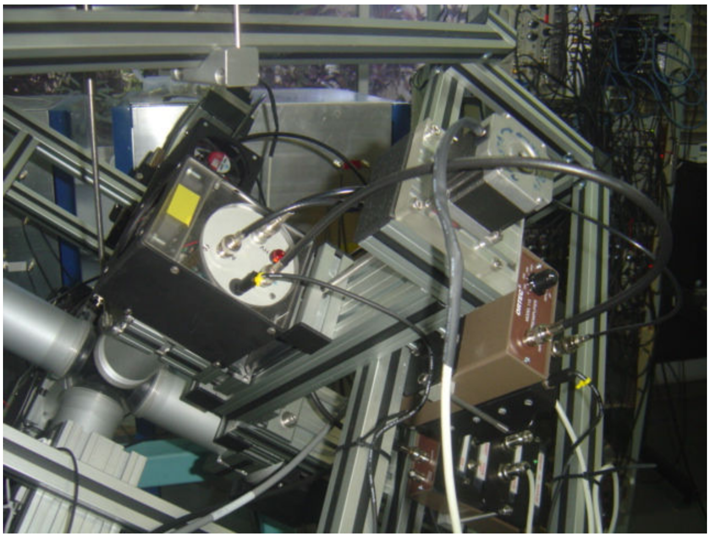

Figure 5. The detector cart.

The control positioning of the detectors can operate in three different ways, manual (M), automatic (A) and digital (D). In manual mode (M) the operator manually controls the movement and direction, forward and backward, of the BaF_2 detector. In automatic mode (A) an analog electronic circuit controls the movement of the detector and maintains a constant rate of coincidences within an adjustable range through a potentiometer (2000 to 20000 counts/s). In digital mode (D) a square wave that corresponds to the count rate is applied to a card input. In this case the square pulses are counted and compared with a preset value using LABVIEW software. When both values are the same, and at one time, an output digital signal stops the stepper motor. So the count rate is constant.

Each control board controls the movement of one of the six detectors. The operation of this circuit is described below. The output Gaussian pulse from the model 572 spectroscopy amplifier is applied to the input of the squaring circuit. The resulting square pulse is enlarged by monostable multivibrator and converted in voltage. This voltage is amplified and is made a levels discrimination. The output is V_1. If V_1 is below a V_{min} value, the detector will move forward, increasing the coincidences rate. If V_1 is above a V_{max} value (where $V_{max}>V_1>V_{min}$), the detector will move backward, decreasing the coincidences rate. If V_1 is between V_{min} and V_{max} will stop the movement of the detector, stabilizing the coincidences rate. The power supply provides +5V e +12V for the internal circuits.

4. APPLICATIONS

Several applications of this spectrometer with the automatic detectors positioning control in the near future are expected. The use of ^{111m}Cd with a relatively short half-life ($T_{1/2}$ = 49 min.) in the study of insulator compounds where the use of ^{111}In is not recommended due to strong "after affects", which often appear due to electronic sub-shell rearrangement following the electron capture decay process of ^{111}In.

Another example ^{199m}Hg ($T_{1/2}$ = 43 min.) as a nuclear probe in the in-situ study of corrosion in metallic monocrystals at high temperatures, study of coordination compounds of mercury with important applications in biology and bioinorganic chemistry. The isotope ^{187}W ($T_{1/2}$ = 24h) has been used in several studies of chemical compounds of tungsten and presents a typical example where the use of six-detector spectrometer is very useful.

5. CONCLUSIONS

A new electronic module to control the positioning of six conical BaF_2 detectors has been designed and constructed at IPEN. This module is not available commercially and has been constructed in our electronic workshop. This new module will enable PAC experiments using radioisotopes with short half-live, decreasing the human constant presence. This new electronic module is functioning adequately.

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