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LOW-COST AMPLIFIER FOR ALPHA DETECTION WITH PHOTODIODE

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ABSTRACT

A low-cost amplifier for Hamamatsu S3590-09 PIN photodiode to be used in alfa detection is presented. This amplifier consists basically of two circuits: a pulse preamplifier and a shaper-driver. The PIN photodiode is reverse-biased and connected to a charge preamplifier input. Incident alpha particles generate a small current pulse in the photodiode. The integrating circuit of the low noise preamplifier transforms current pulse into a voltage pulse with amplitude proportional to the charge carried by the current pulse. The shaper-driver consists of a differentiator and an integrator and is responsible for filtering and further amplifying the preamplifier signal, generating a NIM-compatible energy pulse. The performance of the set photodiode-amplifier was successively tested through the use of a ^{243}Am radioactive source. The low-cost photodiode amplifier was designed and constructed at IPEN - CNEN/SP using national components and expertise.

1. INTRODUCTION

Silicon PIN photodiodes provide a reliable and compact solution for radiation monitoring. Alpha, beta, gamma, and X-ray radiation can be detected either directly via the absorption in the crystal lattice [1] or indirectly via the measurement of the luminescence radiation of a scintillation crystal [2].

There are several papers that report the application of PIN photodiodes for direct detection of radiation using an expensive low-noise charge preamplifier [3–6]. In some cases, the entrance windows on some unencapsulated PIN photodiodes is thin enough to allow alpha particles to penetrate into the depletion region and some low leakage models exhibited good energy resolution, enough to be coupled to low-cost preamplifiers for alpha radiation or neutron radiation (using a boron converter).

During the development of a neutron detector using a boron converter and a PIN photodiode [7], we came across the need for a low-cost portable and versatile amplifier that could be easily incorporated into the detector. As in such an application the detector will be used as a particle counter, the most important feature of the amplifier is not the energy resolution but the noise discrimination – the ability to perform as a spectrometer will be useful only during the development stage, or for fine-tuning the device gain and discrimination.

The acquisition system built in-house presented in this work consists of a large active area Si PIN photodiode, a charge preamplifier and a shaper-driver. This circuit can work as alpha spectrometer or as alpha counter, depending on the electronic setting based in the energy window of the alpha radiation.

2. PIN PHOTODIODES

A typical PIN photodiode structure is shown in Figure 1. It consists of a highly-doped transparent p-type contact layer on the top and the n-type layer on the bottom. The most important issue of the PIN photodiode for the application of this paper is the thick intrinsic (undoped) layer between the n and p layers. This structure is necessary for one basic requirement. When charged particles, such as alpha-rays, strike the absorption layer of the PIN photodiode, their energy dissipates along a linear track whose length is determined by the type and energy of the incident charged particles and electron-hole pairs are generated by means of Coulomb interaction of a charged particle with electrons. The number of generated electron-hole pairs does not depend on the type of charged particle but rather on the energy loss (at 300 K, one electron-hole pair is generated on average per each 3.62 eV). The energy loss can therefore be estimated by detecting the amount of this charge.

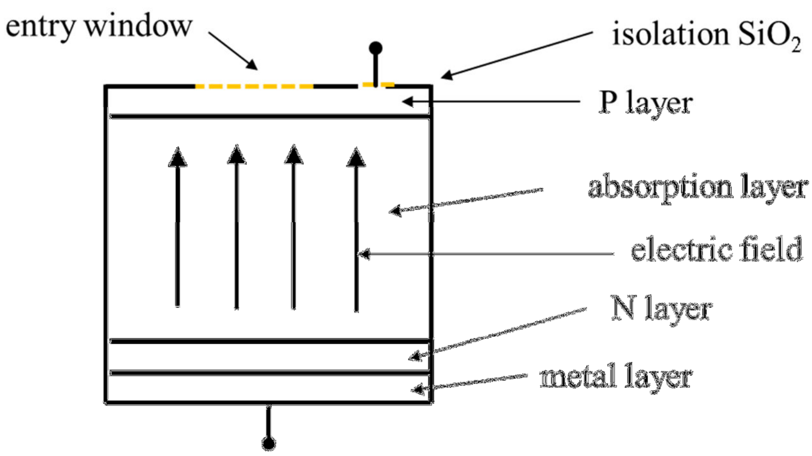

Figure 1: Basic scheme of PIN photodiode structure.

Electron-hole pairs drift apart, and when the minority carriers reach the junction between the two layers, they are accelerated by the electric field. If the two sides are electrically connected, an external current flows through the connection. If the created minority carriers of that region recombine with the bulk carriers of that region before reaching the junction field, the carriers are lost and no external current flows.

One of the most important aspects in detection applications is related to the noise characteristics of the photodiode. Two parameters have major contribution to the noise level: leakage current and capacitance of the photodiode. Existence of the intrinsic layer lowers both the leakage current and the capacitance of junction, so it is possible to achieve good energetic resolution even at room temperature. So, the main characteristics of the PIN used in this work are: large active area (10 mm x 10 mm), low capacitance, usability with scintillators and radiation detection by itself.

3. THE PIN PHOTODIODE AMPLIFIER

The circuit of the PIN Photodiode amplifier can be divided into two main parts: the preamplifier circuit and the shaper (Figure 2). The preamplifier is the first stage of the photodiode amplifier which is the most critical. An integrating circuit has been used, which transforms a current pulse from the Hamamatsu S3590-09 PIN photodiode [8] into a voltage pulse with amplitude proportional to the charge carried by the current pulse. This pulse is amplified by two very common BJT-NPN transistors (BC547) in cascade. These transistors, however, have good frequency response, signal-to-noise ratio and linearity.

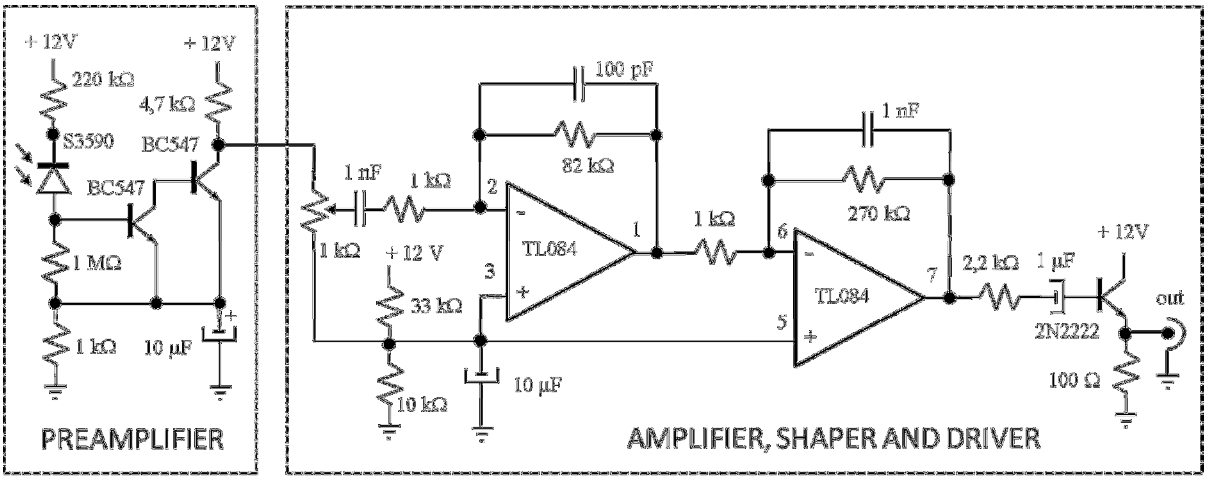

Figure 2: Scheme of the photodiode amplifier developed.

The amplitude of the voltage signal in the preamplifier output is only about few dozen mV, so additional amplification and noise-filtering is a must. This is performed by a circuit called "shaper". Every signal has its natural spectrum in the frequency domain and a noise spectrum is added to it. When one uses filters, it is possible to improve the signal-to-noise level. A differentiator and an integrator (CR-RC filters) with equal shaping time constants (≈ 0.1 s) were used for each stage. A 2N2222 transistor (current driver) lowers the output impedance of the circuit. To achieve the optimum noise performance of the system we have investigated experimentally the shaping time constant dependence. The output signals (A and B) obtained after each stage can be seen in Figure 3, where it is possible to infer that the total gain of the shaping amplifier stage is of about 80x. The output signal (B) can be applied directly to a multichannel analyzer making the system operate as a spectrometer. In order to use the system as a pulse counter, purpose of this work¸ the discrimination level of the output signal must be set in the 1 kΩ potentiometer before being applied to a pulse counting module.

The whole prototype (including the photodiode) was assembled inside a black metal casing, in order to avoid the influence of ambient light and shield the system from both electrical interferences and environmental alpha particles.

With the exception of the photodiode, all the electronic components used in this circuit were easily purchased at national stores. The total price of the prototype, except the photodiode, was less than US$15.

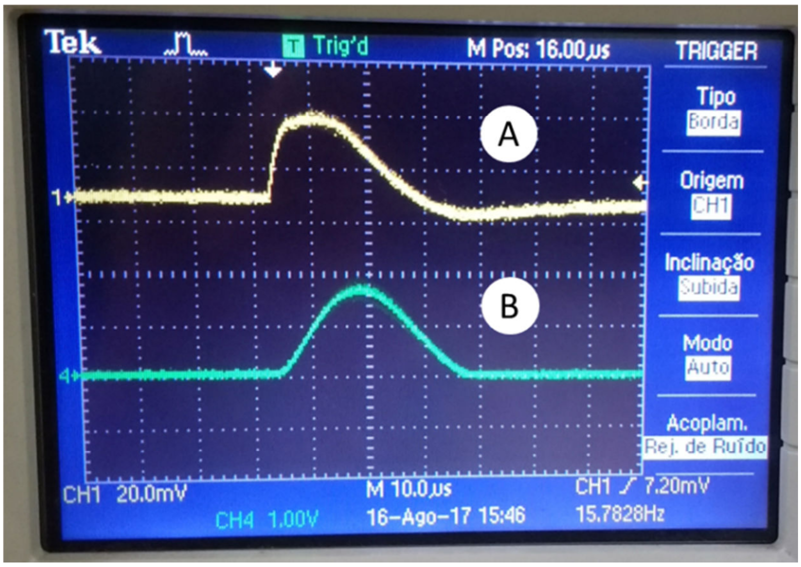

Figure 3: Preamplifier output pulse (A) and correlated output pulse (B) from the photodiode amplifier circuit.

4. EXPERIMENTAL VERIFICATION

An uncalibrated ~1kBq alpha source of ^{243}Am (most intense alpha particle energies: 5.32 MeV - 11% - and 5.36 MeV – 87% [9]) deposited on a stainless steel disk was placed 5.0 mm from the photodiode, inside the system's casing, at room pressure and temperature. The output pulse from the amplifier described in this paper was fed directly to an ORTEC Spectrum Ace multichannel analyzer, without any further amplification or processing.

In order to check the amplifier's performance, an acquisition of 54000 seconds (live time) was carried out, with the resulting spectrum presented in Figure 4. The system's observed dead time was 0.07%. The resulting spectrum was analyzed using the IDEFIX software [10], which uses a gaussian model with an exponential tail and an error function to fit each peak; a group of two peaks was fitted, referring to the most intense alpha emissions from ^{243}Am, and the resulting Full Width at Half Maximum (FWHM) of each of the peaks was less than 6%, whereas in more expensive systems it may be as low as 1-2%. The results obtained, however, are perfectly good for the requirements of a neutron counter based on the detection of alpha particles from the ^{10}B(n,α)^{7}Li nuclear reaction [7], as in this case the PIN photodiode will work essentially as an alpha particle counter – it may also be useful for other less-demanding alpha particle detection applications, too. As the proposed application doesn't require energy response, the energy calibration was not performed – if necessary, it shall be performed at a future stage.

In order to verify the noise discrimination of the system, a second acquisition was performed, without the presence of the radioactive source, for 72000s (live time). The resulting spectrum didn't present any counts, indicating excellent discrimination of alpha particles from the background β particles and X and γ rays. This also suggests that the noise threshold of the system could, if required by some other application, be reduced without prejudice to the performance.

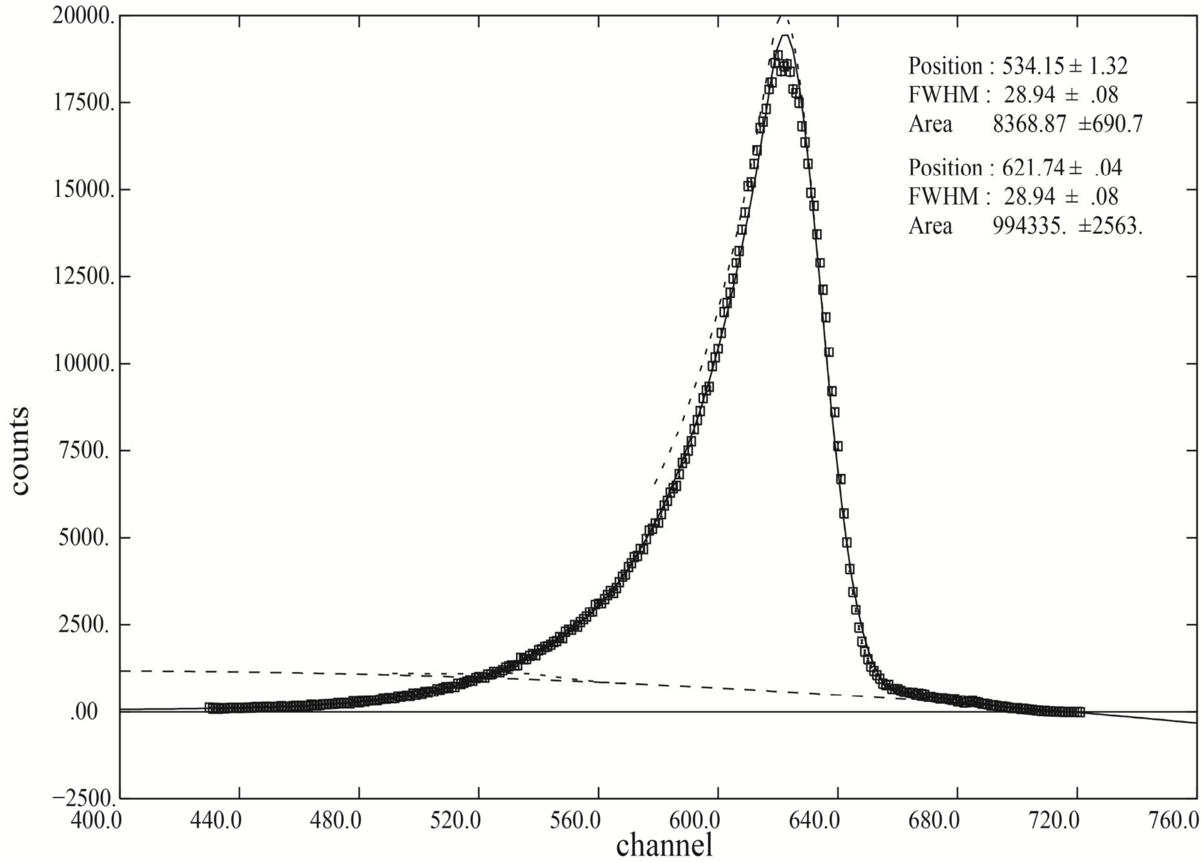

Figure 4: Experimental ^{243}Am alpha-ray spectrum obtained using the S3590-09 photodiode coupled to the proposed amplification system – dots represent the experimental data and the lines represent the fit to a pair of Gaussian peaks.

5. CONCLUSIONS

A system comprised of a preamplifier and a shaping amplifier for use with a S3590-09 PIN photodiode was developed aiming at producing a low-cost system that can be applied in an alpha or neutron detection system (using an appropriate boron converter). The performance of the system for the detection of alpha particles was determined using a ^{243}Am alpha source, resulting in an energy resolution that is less than 6%. Also, a measurement of the background didn't result in any counts, showing that the discrimination of the system is excellent for the intended application as a particle counter. The whole alpha spectrometer (excluding the photodiode) was assembled for less than US$15, using only over-the-counter commercial components.

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