

A Digital Method for the Discrimination of Neutrons and γ Rays With Organic Scintillation Detectors Using Frequency Gradient Analysis

Charles C. Lee, Michael D. Jones, Xiaoting Ma, and Richard D. Applegate

Abstract—A digital method for the discrimination of neutrons and γ rays using organic scintillation detectors is described by using frequency gradient analysis (FGA) based on the Fourier transform. Since the discrimination process and the photomultiplier tube (PMT) signals used are often very noisy, some pulse-shape discrimination methods are investigated in this system (e.g., the charge comparison (CC) method or pulse gradient analysis (PGA) using two channels). Features of the signal gradient spectra are the presence of the leading structure, the AC content, the performance of the new FGA method and the FGA method have been studied and compared with theoretical results and then verified by Monte Carlo (MC) and computer simulations. Features extracted by the FGA method related to rising time, rise to the maximum, or other features of the photomultiplier tube (PMT) and can be used for the automatic neutron and γ ray sorting by a microcontroller (MCU). It is shown that the FGA method results in an increased figure of merit (FOM) when compared to a method in the area of existing feature extraction and γ ray sorting. The FGA method has the potential to be implemented in current embedded electronic systems to provide real-time discrimination for detection instruments.

Index Terms—Digital discrimination, frequency gradient analysis, neutron, organic scintillation, pulse gradient analysis, rise of signal.

I. INTRODUCTION

ORGANIC scintillation detectors have often been used for the detection and spectroscopy of γ -rays, measurement of neutrons. But the most majority of liquid organic scintillators, the compounds used, are composed of two complementary groups—the fast and slow components of the scintillation. Therefore the structure of light that appears in the slow component often depends on the nature of the exciting particle, one can use this dependence to differentiate different kinds of radiation. Current organic scintillators including aliphatic and aromatic compounds and liquid scintillators, are particularly good examples of this phenomenon that is exploited via pulse shape discrimination (PSD). This is because of the large difference in the slow component followed by different scintillators in these media. When organic scintillators are used in neutron detectors, PSD is an essential requirement because all neutron fields contain both

an unwanted γ -ray component arising as a result of scattering reactions of the neutrons with materials in the environment, and no direct separation of the primary reaction producing the neutron field [1].

A number of techniques for PSD have been investigated with varying degrees of success. The most popular of these are the charge comparison method [2] and the zero-crossing method [3]. Both of these methods were originally implemented in analog electronics, often in dedicated instrumentation modules or service instrument modules (SIMs). More recently, both of these methods have been been implemented in the digital domain as digital electronic systems have become available with their greater speed and/or in order to make this possible. These methods have become the industrial standards for neutron sorting with other new proposed discrimination methods, such as the correlation method [4] and the current timing method [5].

In recent years, artificial neural networks (ANN) and fuzzy systems [6] have emerged as mature technologies, with several applications across many fields. They are particularly effective as pattern recognition tools, and in this sense, ANN and FS can be used to classify neutrons and γ -ray events from the measurements performed by organic liquid scintillation detectors. In particular, Li [7] and Li et al. [8] used a fuzzy logic approach to neural networks to process the shape of light pulses in an organic liquid scintillator, while D'Astous [9] proposed an approach based on fuzzy logic for pulse-shape discrimination in a single-layer scintillation detector.

In order to take advantage of capabilities offered by fast digital electronics, Bortolotto et al. [10] presented a discrimination algorithm that is computationally simple, referred to as pulse gradient analysis (PGA). This technique provides real-time digital characterization of measurements where neutrons and γ -rays coexist. The performance of the PGA method has been compared against a digital implementation of the conventional charge comparison method which demonstrated the PGA method provides an improvement in discrimination ability. Very recently, a dedicated portable neutron-to- γ -ray detector has been developed that provides real-time discrimination of mixed fields that is based on the PGA algorithm deployed on Kilobit Space 97 field-programmable gate array [11].

One of the many pulse-shape discrimination methods are two-channel features of the signal, e.g., the implementation of charge comparison method generally refers to the integration of the pulse over two different intervals and that of PGA method is based on the comparison of the relative heights of samples at the leading edge of the pulse. Since the scintillation process

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