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SCIENCE DIRECT

Nuclear Instruments and Methods in Physics Research A 540 (2005) 180–187

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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A low-noise current-mode preamplifier for gamma asymmetry measurements

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Received 30 June 2004; received in revised form 28 October 2004; accepted 30 October 2004
Available online 8 December 2004

Abstract

The NPDGamma experiment will measure with high accuracy a very small parity-violating directional asymmetry A_γ in the emission of gamma rays from the capture of polarized cold neutrons by protons. High event rates and systematic error considerations require the use of current mode detection with vacuum photo-diodes and low-noise solid-state preamplifiers. The preamplifier requirements, design, and measured properties are described.

PACS: 84.30.Le; 24.80.+y; 13.75.Cs

Keywords: Amplifiers; Symmetries; Nucleon–nucleon

1. Introduction

The NPDGamma experiment that is under commissioning at the Los Alamos Neutron Science Center (LANSCE) plans to measure the parity-violating directional asymmetry A_γ in the emission of gamma rays from the capture of polarized cold neutrons by protons [1,2]. The polarization of the pulsed neutrons is reversed periodically by turning on and off a radio frequency magnetic field in a spin flipper. The polarized cold neutron beam is incident on a liquid para-hydrogen target where most of the neutrons are captured by protons. The 2.2 MeV gammas from the capture reaction are detected by an array of 48 CsI scintillators, measuring approximately $15 \times 15 \times 15\,\mathrm{cm}^3$ [3]. A_γ is expected to be very small, 5×10^{-8}, requiring both collection of a large number of gammas and suppression of systematic effects to below 10% of the expected asymmetry. Meeting these conditions requires that the detector is operated in current mode, its electronic noise is small, and the dynamic range

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doi:10.1016/j.nima.2004.10.036

of the signal processing electronics is large. We have designed and built a detector system that meets all these requirements. In this paper, we describe a low-noise current-to-voltage preamplifier that is the heart of the detector and discuss its performance.

A current-mode detector system is a prerequisite for successful operation at very high rates. Radiation (2.2 MeV gamma quanta) interacts with a detection medium (CsI) and produces light pulses having a long decay time with components up to 2 μs. The peak rate in each of the 48 detectors is of order 100 MHz and thus the pulses from different events overlap. The overlapping nature of the pulses requires current-mode rather than pulse-mode signal processing. The light signals are converted to current signals by a photo-cathode. The currents are then amplified. The amplification is most often accomplished using a photo-multiplier tube, which has the advantages of providing a large, low-noise gain of up to 10^7.

For the NPDGamma experiment the use of photo-multipliers is precluded by their high sensitivity to magnetic fields. The trajectories of slowly moving electrons that are emitted from the photo-cathode can be deflected by fields of order 1 G to such an extent that they fail to strike the first dynode, causing the gain of the photo-multiplier to be a strong function of the applied magnetic field; a 1 G applied field can change the gain of a photo-multiplier by 100%. In the NPDGamma experiment, a 30 kHz radio-frequency (RF) magnetic field having a strength of a few Gauss is used to rotate the neutron spin by 180°. The purpose of the spin reversal is to effectively interchange the role of top and bottom detectors, so that the detector efficiencies do not have to be precisely matched. The physics asymmetry changes sign with neutron spin reversal while the differences in efficiency between detectors do not. In addition, since the spin is reversed at a rate of 20 Hz by turning the RF magnetic field on and off, the effects of detector efficiency drifts with time are suppressed.

In order to reduce the field from the RF spin flipper at the position of the detectors, the spin flipper is enclosed in an aluminum cavity to contain the RF magnetic field. The spin flipper, however, can affect the detectors in two ways. First, the field can induce a signal directly into the detector or associated electronics through magnetic pickup. We refer to this as an additive effect, since it is observed whether or not a signal is present. Second, the field can change the gain of the detector. We refer to this as a multiplicative effect, since it is only observed when a signal is present. These effects are potentially the most dangerous systematic effects because they are correlated with the neutron spin direction. A 1 μG field could change the gain of a photo-multiplier by 10^{-6}, 200 times larger than the goal statistical error of the experiment. For this reason, the scintillation light from the CsI detectors is converted to current by vacuum photo-diodes, and the photo-currents are converted to voltages and amplified by solid-state electronics. The photo-diodes used for NPDGamma have a gain sensitivity to changes in magnetic field of less than $1 \times 10^{-4}\,G^{-1}$, and a second-order sensitivity of less than $1 \times 10^{-5}\,G^{-2}$ [4].

Because the gain of the vacuum photo-diode is unity, a preamplifier is needed. Low-noise signal processing is required for two reasons. First, we require that the electronic noise (dominated by the preamplifier) is small compared to shot noise arising from the detection of gamma quanta. A second and more stringent requirement is that imposed by the need to demonstrate by in situ measurement that any false asymmetry of instrumental origin is significantly smaller than the statistical error goal, 10% of the expected physics asymmetry of 5×10^{-8}, on a time scale that is small compared to the experiment running time, a few times 10^7 s. We consider both additive electronic pickup of the reversal signal and possible gain shifts from magnetic fields. The preamplifier that we have designed, built, and tested meets all of these requirements.

2. Concept

The function of the NPDGamma preamplifier is to convert the current from the anode of the vacuum photo-diode to a voltage. The electronic noise of the preamp should be small enough to