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Design and Simulation of Fast Pulse Processing Unit for PET Medical Imaging System

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Abstract: In positron emission tomography, gamma ray photons produce electronic pulses at the output of scintillation detectors. In the present work OrCAD Capture software is used to design and simulate various pulse shaper circuits in electronic modules provided in PET imaging system. Both fall-time and rise-time 5ns have been simulated. The designed pulse shaping circuit could response to pulse rate of up to 50MHz. It is concluded that the simulated pulse shaper reproduces detector and amplifier pulse shapes satisfactory.

Key words:

INTRODUCTION

Over past decade, improvements in medical imaging with PET (Positron Emission Tomography) have been a challenge for research engineers [1]. One important part is achieving shorter imaging time to reduce patient motion artifacts and enable the clinic to visit more patients per day [2]. For this purpose, higher efficiency in pulse counting system of a PET is required. This implies a better distribution of radiation activity in patients' body plus faster pulse processing electronics. There has been recent interest to find a practical model for scintillation detectors. Such a model is needed to find optimal estimators and fundamental performance limits of coincidence timing in Positron Emission Tomography (PET) Time of Flight (TOF) detection systems. The model must be able to describe the gamma ray interaction in the scintillation detectors along with the gain associated with the photo-detector but be simple enough for efficient implementation [2].

Two general types of scintillation detectors might be recognized namely slow such as NaI (Tl), BGO, etc. or fast such as LSO, GSO, etc.) [3]. Detector blocks made of fast crystals leads to short decay time of about 40 ns while slow crystals have a long decay time of about 230 ns, which can be shortened to 200 ns [4]. With a 10-pF capacitor at the input, a rise time of 13 and18 ns was measured respectively [5].

For energy spectra acquisitions with the single LSO crystal, a 3700-kBq ^{22}Na source was used [6]. The analog signals from the detector were amplified by the preamplifier and shaped (500-ns integration time) before being digitized with a multichannel analyzer. The integration applied by a spectroscopy amplifier board was 200ns.

However it is extremely demanding, in terms of power consumption, to process signals from detectors with low noise using very short amplifier shaping times. In addition, pulse shapes employed in most amplifiers have tails which have durations several times longer than the rise time. These contribute to pileup so that the presence of a pulse height above a given threshold may not alone constitute evidence of a detected particle [5]. A shaping amplifier with 10–20 ns peaking time has been designed and produced [7].

In the present work, we report the design and simulation of two circuits. One emulates the pulses of a scintillation detector. The other is a fast shaping amplifier. In our research, a circuit has been designed and simulated which reproduces the output pulses from a scintillation detector. Besides, the pulse processing circuit was designed in a manner to produce semi-Gaussian pulses eligible to be processed by ADC.

A circuit is designed that can emulate the pulse shapes of the output of a scintillating detector. Such pulses must possess a short rise time and a long fall time.

The shaper has two major applications in the front-end signal processing. Firstly, it is required to improve the signal-to-noise ratio at the constant fraction discriminator (CFD) input. Secondly, it is essential to avoid pulse pileup at very high count rates.

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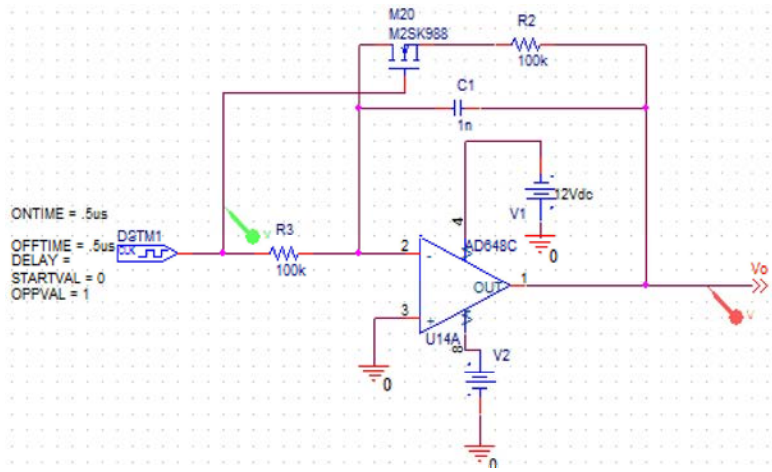

Fig. 1: Circuit emulating the output pulses of a scintillating detector.

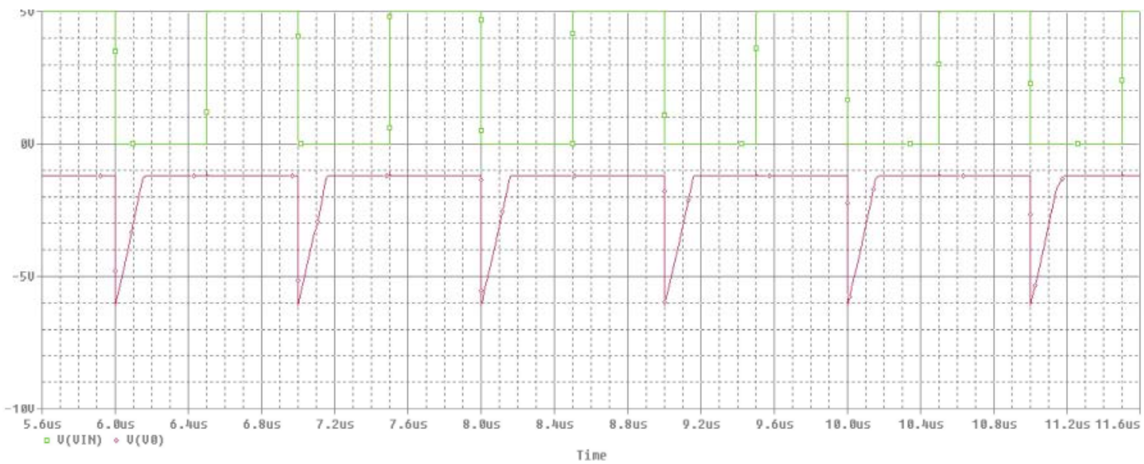

Fig. 2: Pulse shape at the output of circuit in figure one.

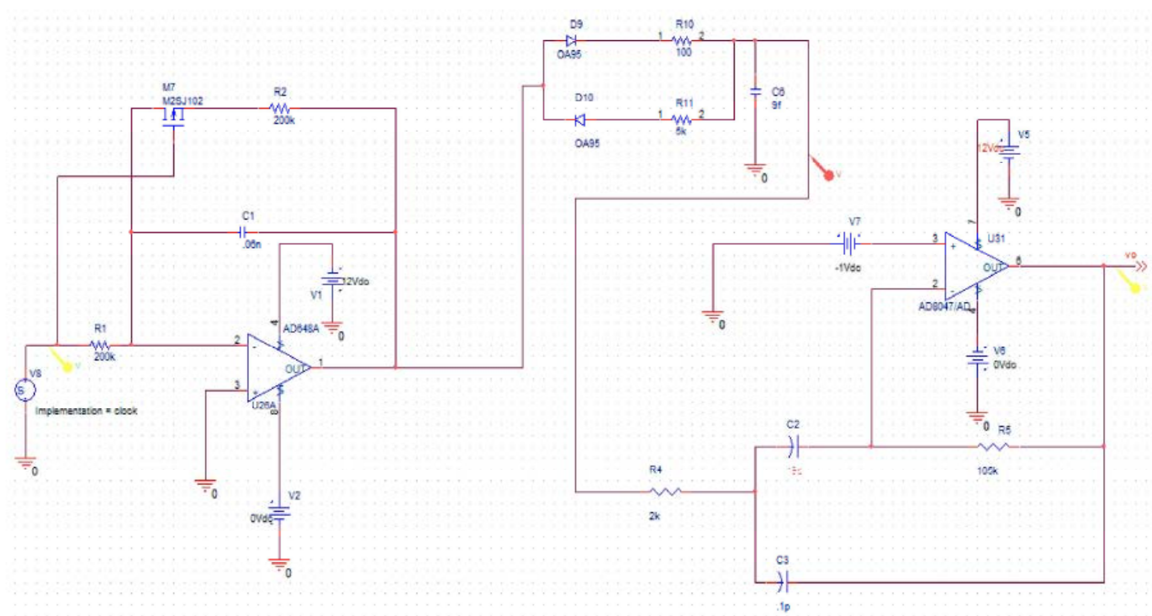

Fig. 3: A circuit to emulate output pulses of a resistive feedback preamplifier and output of fast shaping amplifier.

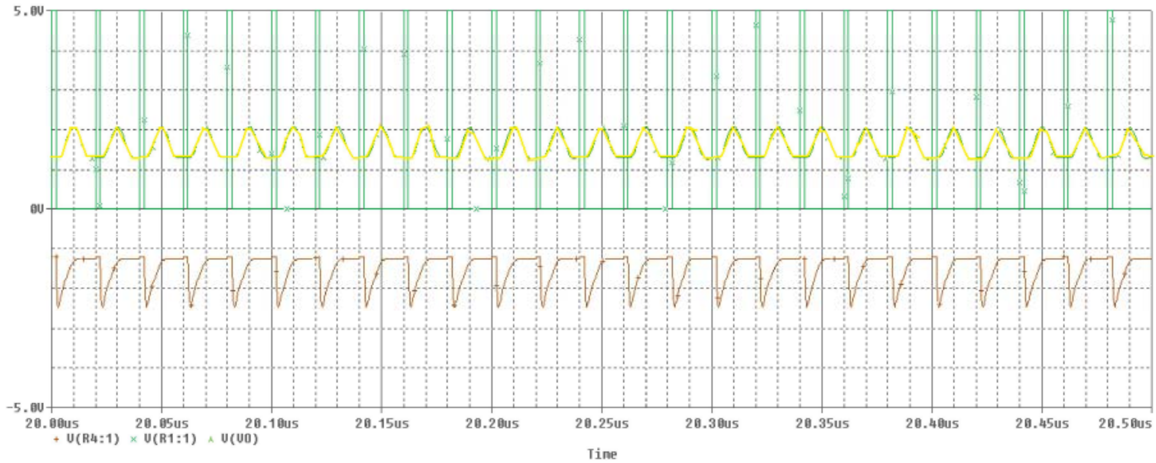

Fig. 4: The pulse shapes produced by the circuit of figure three. Upper part is output of FSA and the lower is output of preamplifier.

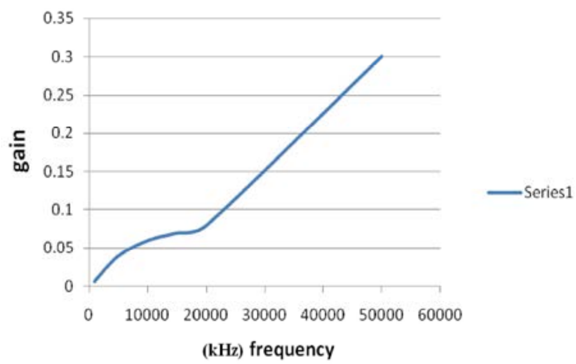

Fig. 5: Approximate frequency response of the circuit of figure 3.

The simulated time response of the CR-RC filter for a V_{max} of 0.4V has been studied. The shaper output signal has a peaking time of 50.3ns with a peaking amplitude of 768mV [8].

Circuit Description

Pulse Emulator Circuit: Figure 1 shows a circuit which reproduce the pulses generated by scintillation detector. This circuit is comprised of an Op-amp (AD648C), a M2SK988 MOSFET working as a switch. This switch controls the charge and discharge cycle of capacitor C1. The Op-amp possesses a proper response up to the required frequency and is supplied with 12 volts DC. The output pulses are depicted in figure 2.

FSA Emulator Circuit: Figure 3 shows the circuit which reproduce the pulses generated by FSA (Fast Shaping Amplifier) in the detector electronics. This circuit is comprised of an Op-amp (AD8047/AD), 2 germanium diodes, two resistors and a capacitance to produce pulse with short rise time and longer fall time. The Op-amp, possess a proper response up to the required frequency and is supplied with 12 volts DC.

The output pulses are depicted in figure 4.

CONCLUSION

A circuit has been designed that can reproduce pulses with shapes similar to the output pulses from a scintillating detector. The rise time is 1 – 5ns and fall time is 180-200ns. The simulated pulse was fed to a simple circuit to emulate pulse shape appearing at the output of spectroscopy amplifier (fig. 2, lower curve). This pulse train was processed by a RC-CR active filter-pulse shaper to reproduce semi-Gaussian pulses suitable for ADC input (fig. 2 upper curve). In our design, the op-amp slew rate distortions at short shaping times are also minimized. The approximate frequency response of the circuit of figure 3 is shown in figure 5. It is obtained by computing the amplitude ratio of a sinusoidal input.

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