Research Migration Project

https://esim.fossee.in/research-migration-project

Name of the participant: Anik Jain

Affiliation / Institution: Department of Electronics and Communication Engineering, NIT Delhi, Delhi, India

Title of the circuit: eSim Migration of an X-ray Detector Charge-Sensitive Preamplifier for Noise Reduction

Theory/Description: Solid-state radiation detectors, such as PIN photodiodes used in X-ray detection, generate micro-ampere current pulses that require immediate, low-noise amplification. A Charge-Sensitive Preamplifier (CSP) is the critical analog front-end for this task. It integrates the microscopic charge burst into a measurable voltage step. This circuit utilizes a low-noise operational amplifier (acting as the core of the CSP) combined with a precise RC feedback network. The feedback capacitor performs the charge integration, while the parallel feedback resistor acts as a pole-zero cancellation mechanism, discharging the capacitor to prevent baseline wandering and saturation at high radiation counting rates. The input is modeled as an equivalent PIN photodiode circuit consisting of a pulsed current source, junction capacitance, and shunt resistance.

Reason to reproduce with eSim: The original circuit and its noise optimizations were validated using a proprietary commercial tool (LTSpice). Reproducing this highly sensitive, physical-layer instrumentation circuit in eSim validates the capabilities of open-source EDA tools for advanced applied physics applications. It provides significant educational value by demonstrating how to model sensor equivalents and perform complex AC noise and transient analyses using open-source workflows (KiCad and ngspice). This makes verified, low-noise front-end designs accessible to researchers and students in the field of high-energy physics without requiring commercial licenses.

Expected Outcome/outputs: The simulation is expected to demonstrate the conversion of a simulated sub-microsecond current pulse (mimicking an X-ray strike) into a distinct, measurable voltage step with an exponential decay. The transient analysis will validate the pole-zero cancellation mechanism by showing the baseline voltage returning to zero. Furthermore, an AC noise analysis using ngspice will validate the circuit's noise immunity by plotting the Equivalent Noise Charge (ENC) or noise spectral density ($V/\sqrt{Hz}$), corresponding to the baseline results of the reference paper.

Circuit Diagram:

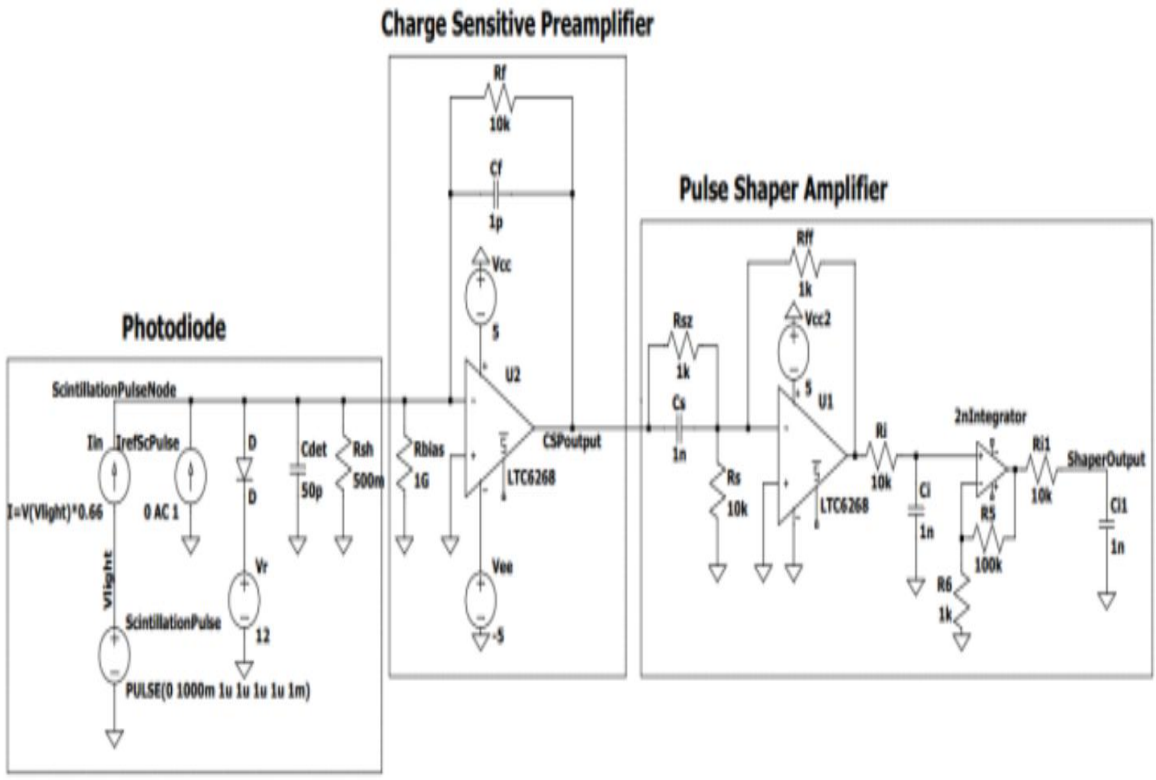

Figure 1: Reference schematic of the X-ray detector front-end circuit to be migrated to eSim. (Source: Dimković).

Block Diagram:

[X-ray Photon / Pulse Current Source] ➔ [PIN Photodiode Equivalent Model] ➔ [Low-Noise Op-Amp Integrator] ➔ [Pole-Zero Cancellation Feedback] ➔ [Measurable Voltage Step Output]

Description: The circuit models an X-ray detection chain starting with a PIN photodiode equivalent model, which consists of a pulsed current source, junction capacitance, and shunt resistance. The generated charge is integrated by a Charge Sensitive Preamplifier (CSP) utilizing a low-noise operational amplifier with an RC feedback network to produce a voltage step. Finally, the signal passes through a CR-RC-RC Pulse Shaper Amplifier. This shaper controls the rise and decay times to prevent pulse overlap, producing a rounded pulse that optimizes the Signal-to-Noise Ratio (SNR).

Expected Results (Input, Output waveforms and/or Multimeter readings) :

- **AC Noise Analysis Plot:** A frequency-domain plot showing the input-referred noise spectrum, demonstrating the preamplifier's ability to maintain a high Signal-to-Noise Ratio (SNR) across the bandwidth of interest.
- **Transient Analysis Plot:** Time-domain graphs showing the fast, microsecond current pulse at the input, and the resulting integrated voltage step at the output, complete with the controlled exponential decay back to the baseline.

Research Paper:

Title: Simulation and Machine Learning-Assisted Optimization of X-ray Detector Circuit for Noise Reduction

Author: Aleksandra Dimković

Page No.: 01-05

Link:
https://ssss.elfak.rs/pdfs/RADOVI%20I%20ABSTRACTI/24.%20Aleksandra%20Dimkovic/24.pdf

Source/Reference(s):

- **Dimković, A., "Simulation and Machine Learning-Assisted Optimization of X-ray Detector Circuit for Noise Reduction." University of Nis, Faculty of Electronic Engineering, Serbia.**
- **Ngspice User Manual (for configuring .noise and transient simulation directives in eSim).**
