A bipolar shaping amplifier for low background alpha/beta counters with silicon detectors.

Sam Thys,[1] **Olivier Evrard, Sofie Put**

Mirion Technolgies

Lammerdries-oost 25 - 2250 Olen, Belgium

E-mail: `sthys@mirion.com`

Paul Leroux

KU Leuven, Dept. Electrical Engineering (ESAT), ADVISE lab

Kleinhoefstraat 4 - 2440 Geel, Belgium

E-mail: `paul.leroux@kuleuven.be`

This work focuses on the design of a 4 complex pole, bipolar shaping amplifier for use with Si (PIPS®) detectors in alpha/beta counters and presents calculations and measurement results. This design allows for the compensation of the preamplifier pole.

---

[1]Speaker

A bipolar shaping amplifier for low background alpha/beta counters with silicon detectors.

1. Introduction

Current existing alpha/beta counters use gas-flow detectors becasue of their low energy detection threshold compared to Passivated, Implanted, Planar Silicon (PIPS®) detectors. However, gas based systems suffer drawbacks with respect to safety and required infrastructure for the gas. The latest evolutions of the characteristics of PIPS® detectors allow to reach a lower energy threshold, that is comparable to gas-flow detectors. For these new alpha/beta counting systems, redesign of the front-end electronics is necessary which includes a shaping amplifier. These systems prefer the use of a bipolar shaping amplifier to simplify the complexity of the system. But more importantly, unlike unipolar shaping amplifiers, bipolar shaping amplifiers don't have baseline shifting issues. Thus they don't require baseline resorers which simplifies the system. The use of a baseline restorer could introduce switching noise that could be seen as background radation, which is unwanted. Sine^n based shaping amplifiers are preffered over RC-CR^n shaping amplifiers due to their lower resolving time [1]. A sine^n based bipolar shaping amplifier is presented in [2]. This design is limited to one complex pole pair. This work presents the design of a sine^4 bipolar shaping amplifier with adjustable pole-zero compensation and present the calculations, simulations and validation.

1. Calculations

The shaper is based on a sine^n shaping amplifier [3]. These systems have a shorter resolving time than CR-RC^n based shaping amplifiers. The step response of the bipolar sine^n shaping amplifier is the mathematical derivative of the unipolar sine^n shaping amplifier.

$$\frac{d}{dt} e^{-3t} \sin(t) = e^{-3t} \sin^{n-1}(t) \left[n \cos(t) - 3 \sin(t) \right] \qquad (1)$$
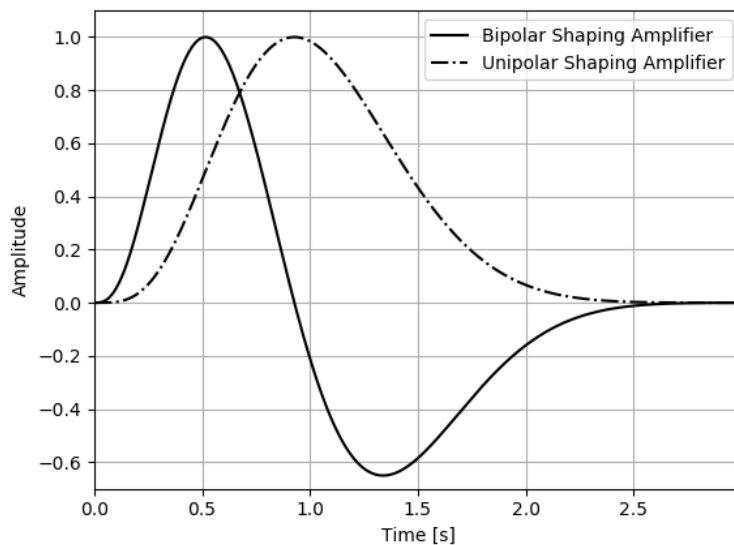

Figure 1: The unipolar shaped pulse and it's mathematical derivative, the bipolar shaped pulse

Translating this to the Laplace domain gives the transfer function of the required shaping amplifier. The transfer function contains one real pole and n complex poles. For the bipolar shaping amplifier also two zeros in the origin are required. This shaping amplifier has poles all lying on a vertical line at -3 in the complex plane.

$$L\left\{\frac{df(t)}{dt}\right\} = \frac{s^2}{(s+3)} * \prod_{k=1}^{\frac{n}{2}} \frac{1}{(s+3-2kj)*(s+3+2kj)} \qquad (2)$$

2. Circuit description

The circuit for implementing a sine[4] bipolar shaping amplifier consists of two Bridged-T feedback networks that both implement a complex pole pair of the shaping amplifier. The input network of both Bridged-T feedback networks generate the zero's required for the bipolar response. The real pole is generated with an RC filter. The input networks of the Bridged-T feedback network also generate both an additional real pole which is unwanted for our system response. The Bridged-T feedback networks also generate unwanted zeros. By carefully choosing the component values, the system can be designed such that the internal unwanted zeros and internal unwanted poles cancel out. Only the poles and zeros nessesary for the required pulse shape remain.

$$F(s) = \frac{s + \frac{1}{(R_{pz}+R_1)C_1}}{s+\frac{1}{R_1C_1}} \quad \frac{s+\frac{1}{(R_2||R_3)C_3}}{s^2+\frac{1}{(R_2||R_3)C_3}s+\frac{1}{R_2R_3C_2C_3}} \quad \frac{R_7}{R_8} \quad \frac{s}{s+\frac{1}{R_0C_0}} \quad \frac{1}{s+\frac{1}{R_4C_4}} \quad \frac{s+\frac{1}{(R_5||R_6)C_6}}{s^2+\frac{1}{(R_5||R_6)C_6}s+\frac{1}{R_5R_6C_5C_6}} \qquad (3)$$
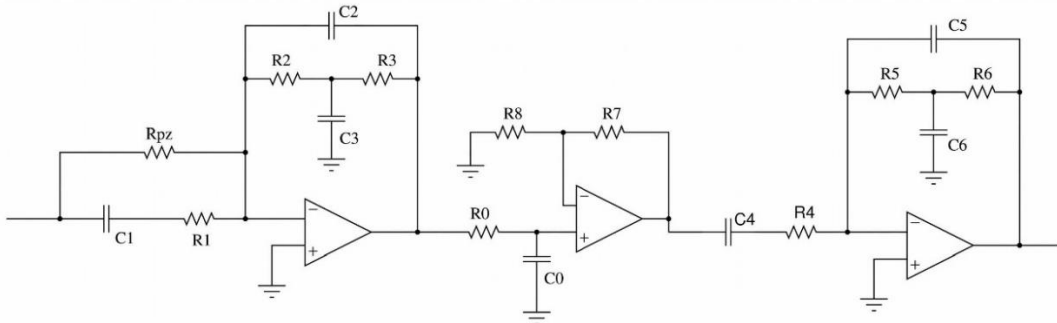

Figure 2: Circuit of the sine[4] Bipolar shaping amplifier with two Bridged-T feedback networks and an RC-filter.

By connecting a preamplifier to the bipolar shaping amplifier, an additional pole is introduced in the system. The pole can be compensated by adding the resistor R_{pz} parallel to C_1 and R_1. The resistor R_{pz} moves the zero introduced by C1 and R1 away from the origin to compensate for the external the pole of the preamplifier. By designing the system such that the poles that are closest to the real axis in the complex plane are implemented by the first Bridged-T feedback network, a unipolar pulse response is obtained after the center stage. This node can be used to more easily check the pole-zero compensation. The undershoot that exist with non-optimal preamplifier pole-zero compensation is much larger at this point than the overshoot at the output. This way the pole-zero cancelation can be set more accurately.
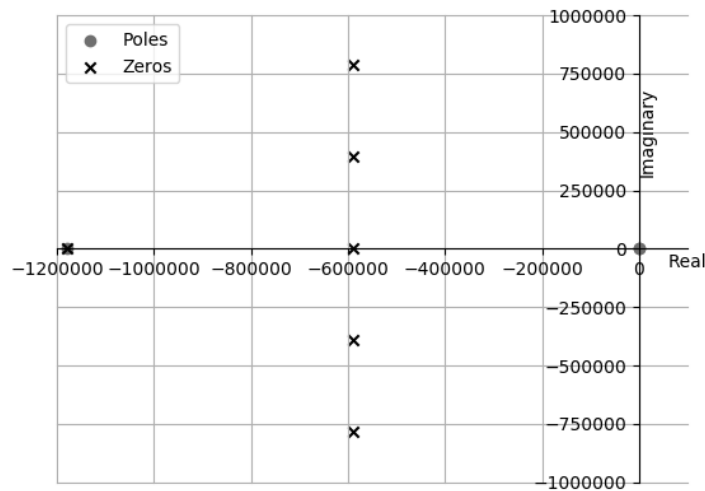
A bipolar shaping amplifier for low background alpha/beta counters with silicon detectors.

Figure 3: Pole-zero polot of the sine[4] bipolar shaping amplifier.

3. Measurements and results

The shaping amplifier is realized on a PCB and is measured by replacing an existing shaping amplifier in a spectroscopy measurement chain with the designed shaping amplifier. A square wave is injected into a Canberra 2003BT preamplifier which is connected to a silicon PIPS® detector. The preamplifier is connected to the designed bipolar shaping amplifier that shapes and filters the pulse. A Canberra Multiport II MCA detects the peak amplitude of the generated pulse and creates a spectrum that can be analyzed with GENIE-2000. Calibration of the measurement system is done with a radioactive source containing PU-239, AM-2541 and CM-244. The FWHM of the energy peak created by the square wave is measured to get the resolution.
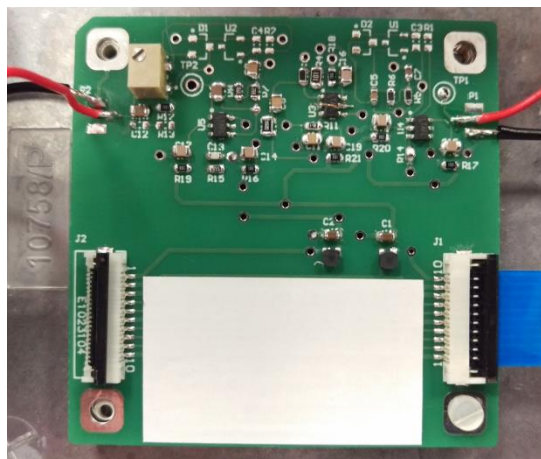

Figure 4: PCB realisation of the sine[4] bipolar shaping amplifier.

An oscilloscope is used to adjust the pole-zero compensation and record the shaped pulse. The theoretical and measured signal shapes are displayed in Figure *5*. There is a very good match between both shapes. Some mismatch exists due to component tolerances.

A bipolar shaping amplifier for low background alpha/beta counters with silicon detectors.
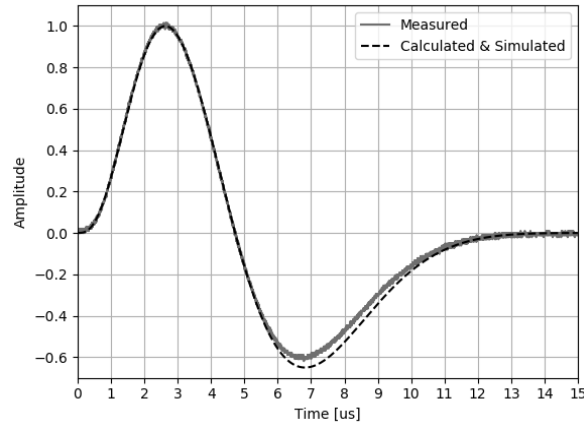

Figure 5: Calculated and measured step response of the designed bipolar shaping amplifier.

Table *1* displays the measured and estimated resolutions with three different silicon Si detectors together with the resolution measured with a Canberra 2024 shaping amplifier set for a unipolar pulse with a shaping time of 2μs. Each detector has a different size and thereby a different detector capacitance. Due to the unipolar pulse shape of the 2024 shaping amplifier, the resolution is better than the designed bipolar shaping amplifier.

Table 1: Estimated and measured resolutions of different sizes of Si detectors with the designed bipolar shaping amplifier and the measured resolution with a Canberra 2024 shaping amplifier set for a unipolar pulse with a shaping time of 2μs.

Detector Area [mm²]	Detector capacitance [pF]	Serial resistance [Ω]	Leakage Current [nA]	Estimated Resolution FWHM [KeV]	Measured Resolution FWHM [KeV]	FWHM resolution with a 2024 amplifier [KeV]
300	155	30	1,0	6.8	6,9	6.0
600	270	31	1,5	11.7	11,5	7.8
900	415	22	3,5	16.6	20,6	12.2

4. Conclusion

This work presented the developed and testing of a sine^n bipolar shaping amplifiers with 4 complex poles. The presented circuit makes it easier to more accurately adjust the pole-zero compensation.

References

[1] E. Fairstein, *Linear unipolar pulse-shaping networks: current technology*, in IEEE Transactions on Nuclear Science, vol. 37, no. 2, pp. 382-397, April 1990

[2] E. Fairstein, *Bipolar pulse shaping revisited,* IEEE Transactions on Nuclear Science, vol. 44, no. 3, pp. 424-428, June 1997.

[3] C. H. Mosher, *Pseudo-Gaussian Transfer Functions with Superlative Baseline Recovery*, IEEE Transactions on Nuclear Science, vol. 23, no. 1, pp. 226-228, Feb. 1976.