Pulse Shaper for a Particle Detector

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Certificate

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Prof. Pradeep Sarin

October 27, 2014

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Introduction

Importance of Particle detectors

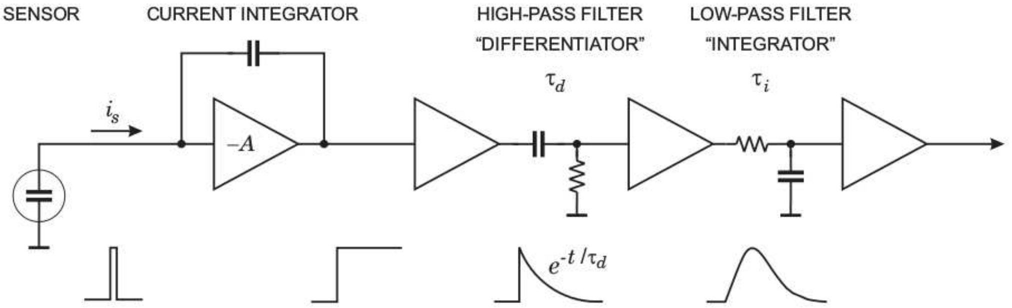
Measurement of various properties of high-energy particles produced in accelerators, nuclear decay processes and cosmic radiation is of primary importance in several fields such as experimental particle physics and nuclear physics. The variety of existing particle detector designs represents the experimentalist's varied requirements; energy, momentum, charge etc. are quantities that are used to identify the reaction products amongst several possible different particle species.

Integrating a detector with an electronic circuit is absolutely essential; the data, in any application of reasonable size, can then be processed, used and stored in a methodical fashion given the vast literature on instrumentation and electronic circuit design. This circuit (or multitudes of them) may then be interfaced with a computer which would provide sophisticated tools for data analysis.

What is a Pulse Shaper?

An ideal pulse shaping circuit would convert a narrow pulse (from a sensor) to a broader output with a rounded maximum, whose maximum height is directly related to the peak height of the input funciton. A realistic pulse shaper has to balance the following factors:

- Ensure that the shape of the output is not affected by changing the characteristics of the input within a certain pre-specification.
- Ensure that the output returns to zero before another pulse is received. Otherwise pulses would pile-up in amplitude, leading to incorrect readings.
- Ensure that the output pulse is wide enough to match the measurement time
- Ensure that noise is kept to a minimum by (ideally) not increasing the bandwith too much.

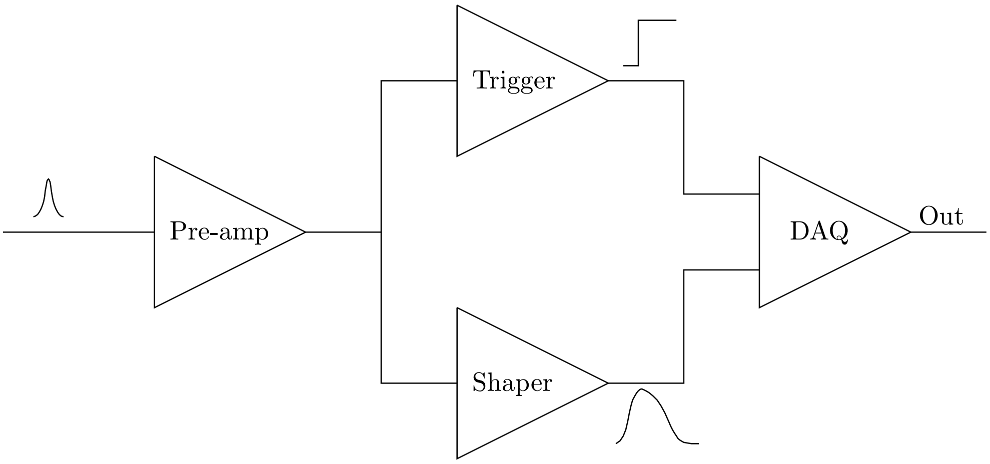


(Image source: Spieler H., *Analog and Digital Electronics for Detectors*)

Thus, the **problem statement** can be framed as: to design a semi-gaussian pulse shaper which satisfies the criteria of low noise, no amplitude pile-up, with an overall time constant of $\sim 10\mu s$ (for the given DAQ).

Necessity for a separate Pulse Shaping circuit

A typical detector consists of the the following setup



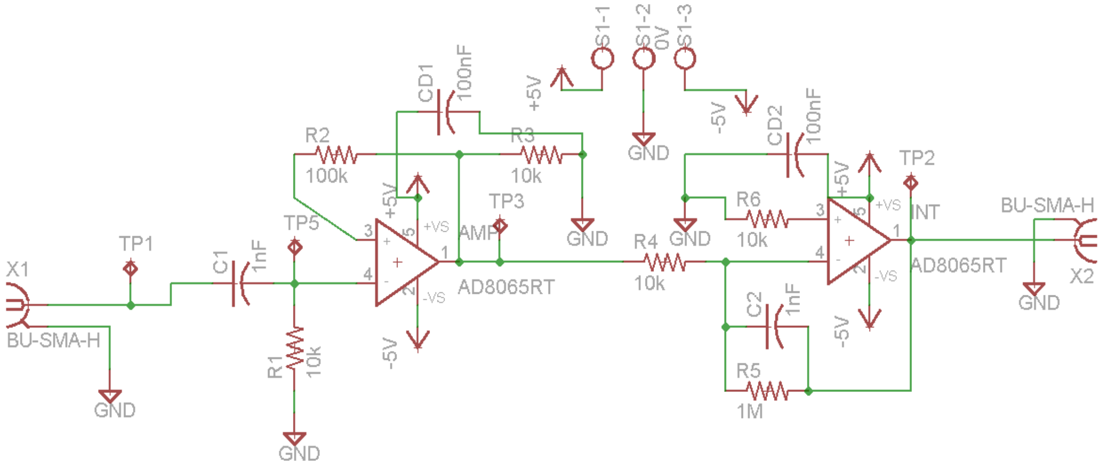
The task of the pre-amplifier circuit is to simply increase the order of magnitude of the signal while retaining its shape without distortion; reducing noise in the pre-amplifier design is important. The shaper makes the shape of the input pulse to be nearly Gaussian (in case of semi-Gaussian pulse-shaping). The trigger is supposed to send a signal to the Data Acquisition system (DAQ) so that it “knows” when to sample the shaper’s output. The DAQ’s task is to correctly sample the shaper’s output at the appropriate time (determined by the trigger output and pulse shaper’s time constant(s)) and then process the signals digitally.

While it is possible to simply use a pre-amp connected to a Data Acquisition system (DAQ) directly, there are many advantages to using an additional step with a pulse shaper:

- The shaper’s time constant now determines the rate at which the DAQ should sample its input. In the case that the time constant of the signal received by the pre-amplifier is very short, one would require a very fast DAQ to directly read the signal. This can be avoided when a shaper is used.

- The pulse shaper can also add in additional stages of amplification in the process of shaping. This reduces the gain requirement on the pre-amplifier design, permitting larger bandwidth.

Circuit design



The basic idea of the circuit is to have three components

1. A passive differentiator : Creates an exponential curve from a rising edge

2. An inverting amplifier : Allows resistors to be changed for adjustable gain factor. The gain ratio should be set according to the expected input size and required output size. In the above example it is just set to 11.

3. An inverting active integrator : Integrates the exponential, which later decays (with a much larger time constant) and slowly returns to zero.

It is well known that the time constants of the differentiator and integrator should be matched so that the output is semi-gaussian.

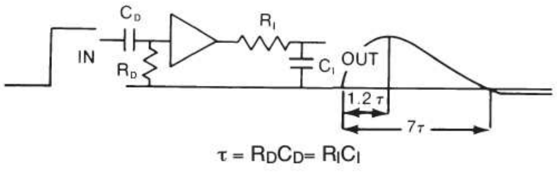
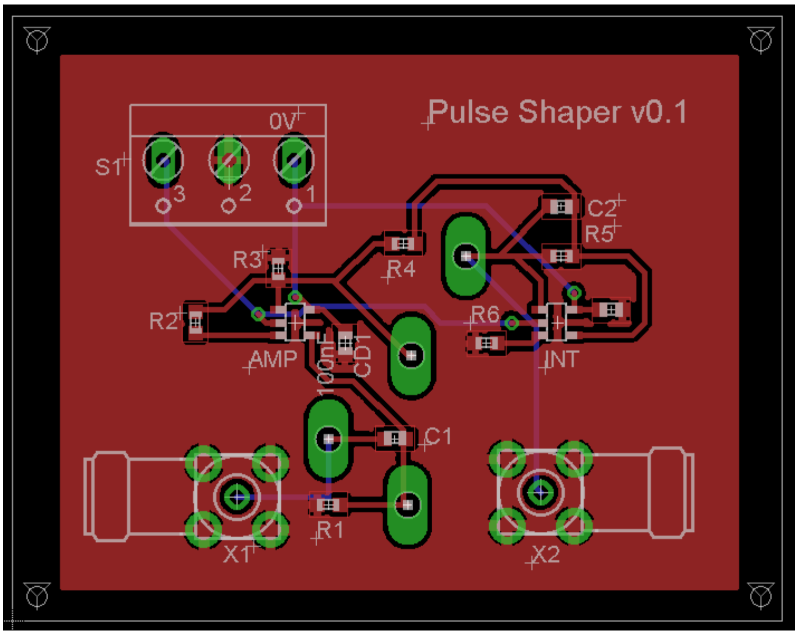


Fig. 9. CR-RC Pulse Shaping.

(Image source: ORTEC® - Introduction to Amplifiers)

Additional components include decoupling capacitors for both the op-amps. There are multiple test points marked TP for easily checking voltages at important points.

Implementation



The above PCB (and previous circuit schematic) was designed using CaDSoft Eagle software. The PCB measures roughly 2.35 cm x 1.84 cm. By mistake, the SMA connectors have not been placed on the periphery. 0603 resistors and capacitors have been used. Also there was a slight error in the actual printing of the board; the pads have been printed on the back instead of the front, rendering them nearly useless.

Since the board made by chemical etching, the vias are just holes with no copper walls so they were connected with thin silver wires.

Results and Conclusions

The circuit was tested by giving 10kHz square pulses of varying amplitudes. At this frequency the expected final output would be a sequence of semi-gaussians which decay well before the next rising or falling edge is encountered. At the differentiator stage, an output of decaying exponential curves is expected.

The current circuit I've made is not functioning as expected, even at somewhat low frequencies of 10kHz with low Pk-Pk input voltages (∼0.1V). Except for the output of the first stage (passive differentiator), the rest of the circuit's voltages are not correct; when tested with different supply voltages (±8V,±5V) although the op-amp was not in saturation (output voltage $< V_{\mathrm{cc}}$), the waveforms observed at the two op-amp terminals were significantly different.

I have double-checked the connections but I have not yet been able to debug the circuit completely to pinpoint the exact source of the problem but I suspect that either (or both) of the op-amps have stopped functioning correctly, perhaps due to improper handling on my part and/or poor soldering technique.

A simpler and better approach would have been to first make the circuit on a breadboard as a proof-of-concept using easily available components, which would function for relatively low frequencies. This can also be done with more complicated shapers including two or more integration steps (with appropriate time constants); a breadboard implementation would have enabled much faster iteration and debugging. After demonstrating its functioning, making an actual circuit on a PCB would have been more sensible.