HEP FRONT-END ELECTRONICS: Pulse shaping and filtering circuits*

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Aim of the HEP FRONT-END ELECTRONICS experiment is to get oneself familiar with some of the most crucial components of the linear signal processing in High Energy Physics experiments: preamplifiers, pulse shaping circuits and time-to-voltage converter. While a charge sensitive type amplifier has been chosen to illustrate the operation of the preamplifiers, a simple circuit employing a capacitor as charging element demonstrates the principle of time-to-voltage conversion. A set of simple circuits have been designed to demonstrate different types of pulse shaping and filtering techniques. Whereas separate notes describe the operation and experimental procedure on the charge sensitive preamplifier and time-to-voltage converter, schematic details on the individual pulse shaper circuits which are used in the experiment as well as the suggested studies on them are briefly given in this note.

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1 Need for pulse shaping

In dealing with signal pulses from radiation detectors, it is often desirable to change the shape of the pulse in some predetermined fashion. The most common application for this is in processing a train of pulses produced by a preamplifier.

In order to assure that complete charge collection occurs, preamplifiers are normally adjusted to provide a decay time for the pulse which is quite long (typically $50\mu s$). If a second signal should now arrive within this period, it will ride on the tail of the first and its amplitude will be distorted. Because it is the amplitude that carries the basic information (the charge deposited in the detector), the *pile-up* of pulses on the tails of preceding pulses which have not fully decayed to zero can be a serious problem. The ideal solution is to *shape* the pulses in such a way to shorten the pulse tail, but preserving the information carried by the maximum amplitude of the pulse.

A second reason for pulse-shaping is the optimisation of the signal-to-noise ratio. For a given noise spectrum, there usually exists an optimum pulse shape in which the signal is least disturbed by noise. In fact, tail pulses in the presence of typical noise spectra are not ideal. Thus, even at low counting rates where pile-up is not a problem, pulse-shaping remains important.

Lastly, pulse shaping is also carried out in some situations to meet the requirements of some of the data acquisition components such as a peak sensing ADC and so on. It is ideal to have a pulse with a rather *flat* peak for particular case.

Two categories of pulse shaping methods: employing resistor-capacitor networks or transmission lines are commonly used in nuclear pulse amplifiers. The latter method has the advantage that the rise time of the pulse is left unaltered so that this method becomes ideal for fast amplifiers. The signal-to-noise ratio, however, is much poorer than that obtained in RC shaping.

Please refer to the references listed under section 5 for a complete description of various circuits discussed in the following sections.

2 General description of the circuit boards

Five different circuits have been compiled for the experiment which are wired on two separate boards: *Board A* and *Board B*. Board A contains a CR-RC shaper, a Pole-Zero Cancellation circuit and a Base Line Restorer while Board B contains a semi-Gaussian shaper and a Delay Line shaping circuit. Both the boards are provided with a simple on-board pulser of variable pulse width and the pulse frequency built around a TTL IC and a few passive components. The pulser produces a TTL pulse of about 5 volts in amplitude.

A provision is also made to feed an external signal to the circuit boards. Selection of internal or external pulse input is made using a toggle switch. The pulser input may be fed as input to one of the shaper circuits using the board's input DIP switch. However, in case of Pole-Zero Cancellation, output from the differentiator stage of the CR-RC circuit (*Diff. out*) is hard-wired to be fed as input. Each pin on the input DIP switch corresponds to one of the circuits. For the same reason mentioned above, while testing Pole-Zero Cancellation, apart from its designated input switch pin, CR-RC shaper's input switch pin should also be selected. Output signals from these circuits can also be routed to the LEMO00 connector (marked *CRO*), using the output DIP switch so that they may be viewed on an oscilloscope. Following table gives details on this.

Circuit	Board	I/P DIP SW-Pin	O/P DIP SW-Pin
RC-CR shaper	A	1-1	4-1
Pole-Zero Cancellation	A	1-1 & 1-2	4-2
Base Line Restorer	A	1-1	4-3
Semi-Gaussian shaper	B	1-1	2-1
Delay Line shaper	B	1-2	2-2

Where ever necessary, a bank of resistors are provided through DIP switches for studying the response of the circuit for different time constants. Except in the case of Delay Line shaping circuit, operational amplifiers LM310 or UA741 have been used to isolate different stages of pulse shaping as well as for driving the circuit output. Operational amplifiers LM318 were used in the Delay Line shaping circuit.

The circuit boards require ± 12volts supply for their operation, which is fed in through the *green* connector. VCC for the TTL IC 74HC132 (Quadruple postive-NAND Schmitt triggers) is derived from the +12 volts power rail by using two rectifier diodes and a three terminal regulator. Please refer Figures 1 to 7 for complete schematics of the circuits.

3 Circuits on Board A

3.1 CR-RC shaper circuit

This circuit is essentially a differentiator or a high-pass filter followed by an integrator or a low-pass filter (Fig. 3). Time constants for both the stages may be chosen using the resistor bank mounted on DIP switches 2 and 3 respectively, while the capacitor is fixed at 1000 pF for the both stages. The resistor values provided are 10KΩ, 20KΩ, 51KΩ and 100KΩ.

Experimental procedure

1. Choose different combinations of resistors for CR and RC stages, calculate the time constants in each case.

2. Note the ratio of output to input pulse heights in all the cases. Expected values for differentiator+integrator time constants are 0.50 for 2+1, 0.37 for 1+1 or 2+2 and 0.25 for 1+2.

3. While selecting equal time constants for both stages, observe how many time constants does the circuit take to produce the output pulse peak(expected value is 1.2) as well as to reach the base line(expected value is 7).

3.2 Pole-Zero Cancellation circuit

This circuit is similar to the CR-RC shaper except for the resistance bank added in parallel with the capacitor of the CR network (Fig. 4). Again, the time constants for CR-RC stages may be chosen using the resistor bank mounted on DIP switches 6 and 7 respectively, while the capacitor is fixed at 1000 pF for the both stages. Resistor bank for the Pole-Zero Cancellator is mounted on DIP switch 5. The resistor values provided are 100KΩ(pot), 20KΩ, 51KΩ and 100KΩ. Please remember that a differentiated pulse derived from CR-RC shaper circuit is fed as input to this circuit. Keep all the resistors correspond to the time constant of the integrator of the CR-RC shaper circuit (DIP Switch 3) open. You may also keep the time constant of RC stage of the Pole-Zero circuit at 10μsecs.

Experimental procedure

1. By choosing same resistor values for the input CR circuit as well as the Pole-Zero circuit's CR stage , observe the undershoot in the output of the circuit. Keep all resistors of the Pole-Zero Cancellator open at this time.

2. Now, select an appropriate resistor or their combinations from the Pole-Zero Cancellator so as to cancel the undershoot in the output. You may select the trim pot by appropriate DIP SW and fine adjust the resistor value which will accurately eliminate the undershoot. Switch off power to the module and measure the R_z between test points 1 & 2 with multi meter.

3. Repeat this experiment for all four values of resistors of the CR stage.

4. Values expected for R_z are approximately the same as that of the resistor selected in the input CR circuit.

3.3 Base Line Restorer circuit

Apart from restoring the shifted baseline, these circuits also reduces low frequency disturbances such as power-line hum and vibrational microphonics. There are many complicated circuits employed for restoring baseline in real life experiments. The simple *classic* circuit[8] chosen here (Fig. 5) has certain disadvantages but nevertheless demonstrates the technique.

The CR network of the circuits described above is also used in this experiment as the first stage, time constant for which may be chosen using the resistor bank mounted on DIP switch 8, while the capacitor is 1000 pF. The resistor values provided are 10KΩ, 20KΩ, 51KΩ and 100KΩ. Alternately one can also use an external tail pulse generator and feed the signal at the EXT input LEMO00 socket provided and keeping the input selection switch in EXT position.

Experimental procedure

1. Study the effect of input pulse frequency on the base line shifting and hence the average output pulse amplitude. Vary the input pulse frequency using the appropriate trim pot of the on board pulser or that of external tail pulse generator as the case may be.

2. Now, observe the effect of the Base Line Restorer circuit by pressing and holding the push button switch which connects the back-to-back diodes into the circuit and hence cancels the baseline shift.

4 Circuits on Board B

4.1 Semi-Gaussian shaper circuit

Semi-Gaussian shaper is the best choice in terms of signal-to-noise considerations, but results in pulse pileup problems due to wide pulses.

This circuit consists of one stage of CR, followed by four stages of RC networks, time constants of each stage of which is fixed at $10\mu s$ (Fig. 6). Test pins are provided at each stage on the circuit to view the pulse.

Experimental procedure

1. Note the peak pulse height at each stage.
2. Note the left half width at half maximum and right half width at half maximum for each case. Does successive stages make the pulse more symmetrical and also improve time taken by the pulse to return to baseline?

4.2 Delay Line shaping circuit

Rise time of the input pulse is unaltered in Delay line shaping and so ideal for using with a fast amplifier. Delay generated by the transmission cable should be large enough compared to the rise time of the input pulse, else ballistic deficit takes place.

This is an example circuit which uses a signal transmission cable for pulse shaping. In this circuit, the input signal is passed through two paths - one in which the signal is inverted and amplified(to a maximum gain of 5) and another in which it is delayed (in the transmission cable), attenuated (by 2 due to cable terminators) and passed through a non-inverting amplifier of gain 2. The signal in the two paths is summed up with appropriate weights before it is passed through another inverted I-V amplifier of gain $10K\Omega$ (Fig. 7). Two LEMO00 connectors are provided for inserting transmission cable.

Experimental procedure

1. Measure the input pulse width of the on board pulser at test point 6.

2. Insert a transmission cable of known length into the LEMO00 connectors provided.
3. Observe width of the output signal.
4. What is transmission delay of the cable used per metre?

5 Further reading

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