International Journal of Systems Signal Control and Engineering Application

MEDWELL PUBLICATIONS SINCE 2000

Design and Development of 20 Channels Shaping Amplifiers and Discriminators using Eagle

M. Nazrul Islam, Kh. Asaduzzaman and Mahbubul Hoq

Nuclear Electronics Division, Institute of Electronics, Atomic Energy Research Establishment, Bangladesh Atomic Energy Commission, G.P.O Box 3787, Savar, Dhaka, Bangladesh

Key words: Shaping Amplifier, Discriminator, time constant, Threshold, SMD, ERC, DRC, CAM

Corresponding Author:
M. Nazrul Islam
Nuclear Electronics Division, Institute of Electronics, Atomic Energy Research Establishment, Bangladesh Atomic Energy Commission, G.P.O Box 3787, Savar, Dhaka, Bangladesh

Page No.: 99-104
Volume: 13, Issue 4, 2020
ISSN: 1997-5422
International Journal of Systems Signal Control and Engineering Application

Abstract: A study on 20 channels consisting of shaping amplifiers and discriminators has been described in this paper. This module has been designed, fabricated and tested using CAD tool EAGLE. A comprehensive study of the module like basic constituent, operating principle, mathematical derivation and testing results have been presented. The board has been designed with SMD components with 1 µsec shaping time constant and an integral discriminator of few mV to supply span (5V). Therefore, the simplest concept for pulse shaping is proposed that was used of a CR high-pass filter followed by an RC low-pass filter. Thereafter, 100% finished 2-layer board has been created by Autorouter with desired track size and layer. Finally, adding the ground and mounting holes manufacturing data have been created by using CAM processor and sent to board house for fabrication. After fabrication, the board has been assembled and tested successfully.

INTRODUCTION

In dealing with signal pulses from radiation detectors, it is often desirable to change the shape of the pulse in predetermined fashion[1]. By far the most common application 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 µsec). Pulse shaping affects both the total noise and peak signal amplitude at the output of the shaping Amplifier[2]. The preamplifier output is too small to directly measure its amplitude. Therefore amplification is necessary. In order to increase the signal to noise ratio the preamplifier output is filtered (in other words it is shaped) using special shaping circuits. Shaping serves an additional purpose: it diminishes the duration of the preamplifier pulse in order to reduce the pile-up effect. It can be shown that disregarding the flicker noise an optimum shaping exists. This shaping is the so-called cusp pulse (Fig. 1). Unfortunately the cusp pulse has an infinite length, so such a system can never be realised in practice. Actually, shaping performs two key functions: It optimizes the energy resolution and minimizes the risk of overlap between successive pulses (Fig. 1).

After designing the schematic Electrical Rule Check (ERC) has been performed for electrical errors and consistency check between schematic and board. Likewise, Digital Rule Check (DRC) has been operated for reporting any errors in the Board like clearance errors under set of design rules[3].

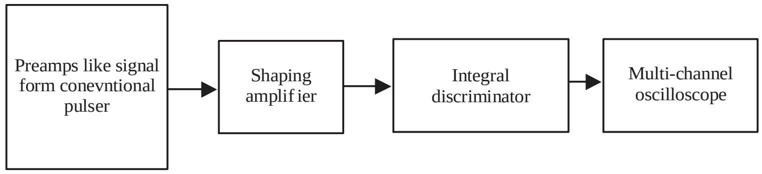

Fig. 1: Block diagram shows the experimental setup for the proposed module

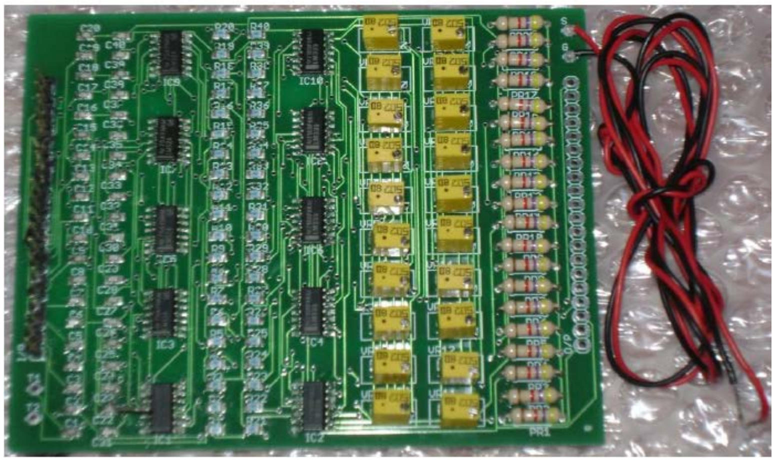

Fig. 2: The board of the proposed module created by EAGLE

MATERIALS AND METHODS

Principle of operation: The preamplifier signal first passes through the CR filter. It attenuates the low frequencies which contain a lot of noise and very little signal. The decay time is shortened by this filter, diminishing the probability of pile-up[4]. Just before the pulse reaches the output of the amplifier it passes through an RC low pass filter. This improves the signal to noise ratio by attenuating high frequencies. The CR and RC filters have the same time constant: τ (1 µsec). The step response of the CR-RC filter reaches its maximum at t = τ and the maximum value is 0.37. The noise contribution can be minimised by choosing an appropriate shaping time constant. At short time constants the series noise, thermal noise in the channel of the input FET, is dominant. At long shaping time constants the parallel noise viz. leakage currents, resistor thermal noise component dominates and removes DC offsets and baseline fluctuation. In order to determine whether this will be a problem for any application, there is a equation (valid for small base line shifts) (Fig. 2):

$$\frac{S}{H} = R * \tau * 2.5\times10^{-6} \tag{1}$$

Where:

S = The negative baseline shift
H = The pulse height
R = The count rate (counts/sec)
τ = The shaping time of the shaping amplifier (µsec)[5]

The discriminator circuit selects the minimum pulse height. When the input pulse exceeds the discriminator preset level, the discriminator generates an output pulse. The discriminator input is normally an amplified and shaped detector signal. This signal an analog signal because the amplitude is proportional to the energy of the incident particle[8].

Circuit analysis

Shaping amplifier: The output of a single differentiating network is not a very attractive waveform for pulse analysis systems. The sharply pointed top makes subsequent pulse height analysis difficult because the maximum pulse amplitude maintain only for a very short time period. Furthermore because the differentiation allows all high-frequency components of any noise mixed with the signal to be passed by the network, signal-to-noise characteristics of the network in practical applications are usually very poor. If a stage of RC integration is added following the differentiation, however, both of these drawbacks are considerably

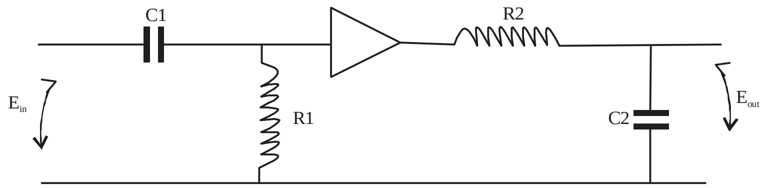

Fig. 3: A shaping network consisting of sequential differentiating and integrating stages sometimes denoted a CR-RC network

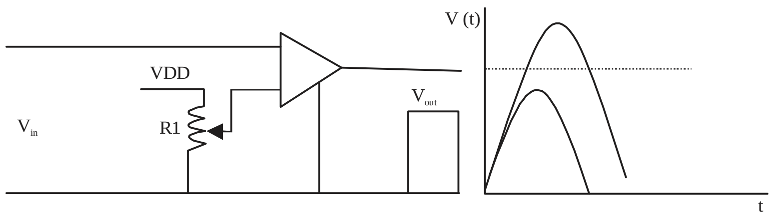

Fig. 4: The function of an integral discriminator. The two input pulses shown, only the larger one crosses the discrimination level and produces a logic pulse output

improved. The combination of a single stage of differentiation followed by a single stage of integration is in fact a common method of shaping preamplifier pulses (Fig. 3).

The proper choice for the time constant of the shaping circuits depends primarily on the charge collection time in the detector being used. In the interest of reducing pileup, one would like to keep these time constants short, so that, the shaped waveform can return to the baseline as quickly as possible. In both types of network, the time constant given by the product of resistance and capacitance plays a critical role. In the analysis that follows, we represent this time constant as τ, or $\tau = RC$. The unit of τ is second, if R is in ohms and C is in farads[6]. From the circuit equations, the input voltage E_{in} and output voltage E_{out} are related by:

$$E_{in} = \frac{Q}{C+E_{out}} \tag{2}$$

$$E_{out}+\tau\frac{de_{out}}{dt} = \tau\frac{dE_{in}}{dt} \tag{3}$$

where, Q represents the charge stored across the capacitor. Now, if we make RC sufficiently small, wecan neglect the second term on the left and:

$$E_{out} \cong \tau\frac{dE_{in}}{dt} \tag{4}$$

In order to meet these conditions, the time constant should be small compared with the duration of the pulse to be differentiated. In the opposite extreme of large time constant, the first term on the left of (Eq. 5) can be neglected and we have:

$$E_{out} \cong E_{in} \tag{5}$$

The passive RC network can serve as an integrator. The circuit equation is now:

$$E_{out} = iR+E_{out} \tag{6}$$

The current, i also represent the rate of charging or discharging of the capacitor:

$$E_{out} \cong \frac{1}{\tau}\int E_{in}dt \tag{7}$$

The network will integrate provided the time constant τ is large compared with the time duration of the input pulse. In the opposite extreme of small time constant the circuit equation becomes:

$$E_{out} \cong E_{in} \tag{8}$$

Thus, if the conditions for integration are not met, the network tends to pass the waveform without change. An ideal unity-gain operational amplifier separates the two individual networks for impedance isolation, so that, neither network influences the operation of the other. The general solution of the response of the combined network to a step voltage of amplitude E at t = 0 is:

$$E_{out} = \frac{E\tau_1}{\tau_1-\tau_2}\left(e^{-\frac{1}{\tau_1}}-e^{-\frac{1}{\tau_2}}\right) \tag{9}$$

Where, τ_1 and τ_2 are time constants of the differentiating and integrating networks, respectively. In nuclear pulse amplifiers, CR-RC shaping is most often carried out using equal differentiating and integration time constants. In that event, (Eq. 9) becomes inde determinant and a particular solution for this case is:

$$E_{out} = E\frac{t}{\tau}e^{-\frac{1}{\tau}} \quad (10)$$

Discriminator circuit: In order to count the pulses properly, the shaped linear pulses must be converted into logic pulses. The Integral discriminator is the simplest unit that can be used for this conversion and consists of a device that produces a logic pulse only if the linear input pulse amplitude exceeds a set discrimination level. If the input pulse amplitude is below the discrimination level, no output appears.

This selection process is illustrated in Fig. 3 unless specifically designed otherwise, the logic pulse is normally produced shortly after the leading edge of the linear pulse crosses the discrimination level. Figure 4 the function of an Integral Discriminator. The two input pulses shown, only the larger one crosses the discrimination level and produces a logic pulse output.

The discrimination level is normally adjusted by a front panel control. In many counting situations, the level is set just above the system noise so that the maximum sensitivity for counting detector pulses of all sizes is realized. Other situations may call for a higher discrimination level to count selectively only events above a set minimum size. For example, much of the background may be limited to relatively low pulse amplitudes, so that, some finite discrimination level may greatly enhance the signal-to-background counting ratio.

RESULTS AND DISCUSSION

The tail pulse output of the preamplifier typically has amplitude of a few tens or hundreds of millivolts and is too small to be counted directly. Furthermore, the pileup of these long pulses at high rates could cause stability problems. Therefore, the next step is normally to process the pulses through a linear amplifier.

Table 1 and 2 shows the characteristics data for the 20 channel shaping amplifier with 1 µsec shaping time constant. From these tables, first of all, it has been observed that for a step pulse input from a commercial pulser of amplitude 74.00 mV has output ranging from 67.0 mV, worst case, to 70.60 mV. Over all out put amplitude for all channels is quite appreciable. Then the step pulse input has very fast rise time, 192 ns, the corresponding values for the shaping amplifier output are more than 10 µsec. Thereafter, the fall time for the input signal is 15.82 µsec that of output pulse is decreasing tendency to some hundreds ns. It is seen from the table that input signal has very small rise time and large fall time on the contrary output signal has opposite nature. The pulse width of the shaping amplifier output is double ,6.32 µsec, almost all cases that of input signal 3.36 µsec .The positive and negative overshoot for both the cases has been recorded as 0.0%. Finally, the gain for the shaping amplifier has been observed as 90% except the worse cases.

Table 1: The shaping amplifier characteristics data for channel 1-10

		Output signal									
Parameters	Input signal	Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8	Ch9	Ch10
Amplitude (mV)	74.00	67.00	68.20	67.80	67.00	67.60	69.00	68.40	69.60	70.20	70.00
Rise time n/µsec	192.20	17.87	16.36	17.62	18.71	17.87	17.87	16.36	16.33	18.53	17.62
Fall time µsec	15.82	7.65	6.74	7.85	6.22	9.13	8.30	7.06	7.40	7.83	8.18
Pulse width(µsec)	3.36	6.32	5.77	5.87	5.92	6.08	6.11	5.16	4.96	5.76	5.96
Positive overshoot	0.00 (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Negative overshoot	0.00 (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gain	-	0.905	0.923	0.916	0.905	0.914	0.933	0.925	0.914	0.949	0.946

Table 2: The shaping amplifier characteristics data for channel 11-20

		Output signal									
Parameters	Input signal	Ch11	Ch12	Ch13	Ch14	Ch15	Ch16	Ch17	Ch18	Ch19	Ch20
Amplitude (mV)	74.00	68.80	69.40	68.20	67.80	67.60	69.40	70.80	68.20	70.60	67.60
Rise time n/µsec	192.20	17.43	16.46	17.30	18.71	17.12	16.79	18.71	17.43	17.30	16.18
Fall time µsec	15.82	9.17	8.78	8.23	8.43	9.21	9.13	9.16	7.67	7.32	8.58
Pulse Width (µsec)	3.36	6.17	5.86	5.96	6.14	6.11	6.02	6.05	6.01	6.12	5.86
Positive overshoot	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)
Negative overshoot	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)
Gain	-	0.930	0.938	0.922	0.916	0.914	0.938	0.957	0.922	0.954	0.914

Table 3: The discriminator characteristics data for channel 1-10

Parameters	Input signal	Output signal Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8	Ch9	Ch10
Amplitude mV(V)	74.00	4.45	4.47	4.43	4.44	4.45	4.44	4.43	4.41	4.44	4.45
Rise time (n/µsec)	192.20	1.366	1.366	1.361	1.340	1.361	1.311	1.366	1.340	1.366	1.366
Fall time (µsec)	15.82	1.366	1.366	1.361	1.340	1.361	1.311	1.366	1.340	1.366	1.366
Pulse width (µsec)	3.36	11.21	12.50	11.34	12.46	13.07	11.66	13.53	12.24	12.47	11.54
Positive overshoot	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)
Negative overshoot	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)
Threshold	-	51.00 (mV)	52.00) (mV)	51.34 (mV)	52.33 (mV)	53.95 (mV)	52.04 (mV)	54.15 (mV)	55.65 (mV)	56.21 (mV)	56.43 (mV)

Table 4: The discriminator characteristics data for channels 11-20

Parameters	Input signal	Output signal Ch 11	Ch 12	Ch 13	Ch 14	Ch 15	Ch 16	Ch 17	Ch 18	Ch 19	Ch 20
Amplitude mV	74.00 (V)	4.45	4.43	4.44	4.45	4.45	4.44	4.43	4.44	4.45	4.45
Rise time (µsec)	192.20 ns	1.28	1.29	1.26	1.28	1.26	1.26	1.29	1.27	1.28	1.27
Fall time (µsec)	15.82	1.28	1.29	1.26	1.28	1.26	1.26	1.29	1.27	1.28	1.27
Pulse width (µsec)	3.36	14.60	15.25	14.57	15.77	14.43	13.31	12.17	14.51	13.26	15.89
Positive overshoot	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)
Negative overshoot	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)	0.00 (%)
Threshold (mV)	-	55.55	57.64	56.90	59.25	55.73	54.22	53.30	53.71	54.53	52.96

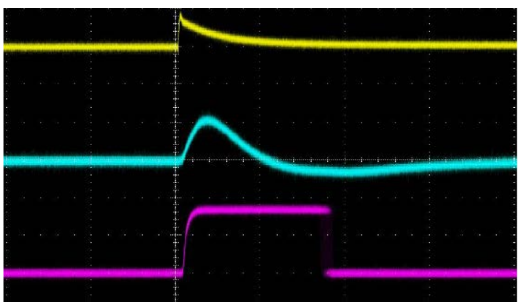

Fig. 5: The waveform of the shaping amplifier and Discriminator

Table 3 and 4 shows the functionality testing data for 20 channel discriminator fabricated with 20 channel shaping amplifier into a single board. It has been observed that discriminator output pulse amplitudes for all (Fig. 5) channel approach to supply voltage. While the supply voltage was 5.0 V, the output logic pulse amplitude has been observed as 4.36 and 4.72 V for that of 5.0 V. The discriminator outputs have large pulse width as seen from 9.66-18.07 µsec.

There were no positive or negative overshoot. At the end, Threshold or noise level can be selected from some µV to supply as the board has been designed with multi-turn potentiometers. In the present case, the threshold levels were from 50.71-57.64 mV. The selected operational amplifier LM324 is low-cost, short circuited protected outputs, single supply operation and four amplifiers per package. The LM339 consists of four independent precision voltage comparators with an offset voltage specification as low as 20 mV max for each comparator which were designed specifically to operate from a single supply over a wide range of voltages.

CONCLUSION

The board has been tested with a low signal amplitude and very fast signal (192 nsec). All the channels are functioning properly with this signal.

Therefore, the board can be used with a multi-anode detector applications successfully. This project is also helpful for understanding radiation measurement instruments like radiation survey meter, area radiation monitor, radiation spectroscopy and nuclear counting system.

ACKNOWLEDGEMENT

The resaerchers wish to express deep gratitude to Nuclear Safety Research Association (NSRA) and Prof. H. Takahashi, University of Tokyo for his valuable guidance, discussions and supervision a project regarding “Practice in Radiation Measurements and Instrumentation”.

REFERENCES

01. Jagdish, U., C.L. Britton, M.N. Ericson, W.L. Bryan, W.G. Schwarz, M.E. Read and R.A. Kroeger, 2000. A preamplifier-shaper-stretcher integrated circuit system for use with Germanium strip detectors. IEEE. Trans. Nuclear Sci., 47: 1868-1871.

02. Spieler, H., 2002. Pulse processing and analysis. Proceedings of the IEEE NPSS Symposium on Short Course, 1993 Nuclear Science, November 10-11, 2002, IEEE, San Francisco, California, pp: 1-199.
03. Anonymous, 2004. Tutorial version 4.1. CadSoft Computer Inc., Chicago, Illinois.
04. Knoll, G.F., 1988. Radiation Detection and Measurement. John Wiley and Sons Inc., New York, USA.,.
05. Anonymous, 2008. Gaussian shaping amplifier application guide. Cremat Inc., Newton, Massachusetts.
06. Anonymous, 1999. Datasheet LM324-on semiconductor. Semiconductor Components Industries LLC, Phoenix, Arizona.