Simulation of Charge Sensitive Preamplifier to improve Nuclear Pulse detecting using Multisim Software

Hassanein M. Atiea¹, Jabbar M. Rashid²

¹²Department of Physics, College of Science, University of Thi Qar, Iraq
hassanein_maj.ph@sci.utq.edu.iq, drjabbar.ph@utq.sci.edu.iq

Abstract: Simulation of Charge Sensitive Preamplifier (CSP) to improve Nuclear Pulse detecting Circuit has been carried on Multisim Software. Multisim Software is a great software that creates the best user-friendly simulation environment for professors, engineers, and students. We can simulate electronic circuits and build prototypes for Printed Circuit Boards (PCBs). In this paper, we have simulated CSP Circuit in two ways. Firstly, by using a pulsed voltage source. Secondly, by using a waveform generator. We have analyzed the behavior of the CSP Circuit with various rise times. The output waveforms have been observed on the oscilloscope.

Keywords: Charge Sensitive Preamplifier, Multisim software, Rise time, decay constant.

Introduction

A preamplifier is the first component in a signal processing chain of a radiation detector. The preamplifier collects the charge generated within a detector [1].

A preamplifier unit has two basic purposes, namely to provide low noise coupling of the detector to the string of amplifier and readout electronics and to produce the first stage of signal amplification. The preamplifier thus acts as a filter against objectionable line noise that may alter the input signal. Preamplifiers are designed to be either current sensitive, voltage sensitive, or charge sensitive [2], [3].

In the CSP, charge from the detector is collected on the feedback capacitor $C_f$ over a period of time, effectively integrating the detector current pulse. As the charge is collected the voltage on the feedback capacitor rises, producing a step-change in voltage. As long as the time constant $R_fC_f$ is sufficiently longer than the duration of the input pulse, the output voltage is proportional to the total integrated charge. To put it simply, the output pulse height is proportional to the quantity of energy deposited as a response to a radiation interaction. [4].

The change of $Q$ is converted to a voltage pulse using a charge sensing amplifier and the amplitude of the output voltage signal ideally is proportional to the deposited energy [5].

In a resistive feedback CSP, a feedback resistor is provided so that the charge integrated on $C_f$ could decay with a predefined time constant[6] (see Fig.1). The result is a sharply rising pulse that decays exponentially with a time constant $R_fC_f$[7].
Fig. 1. (a) a simple Charge Sensitive Preamplifier. (b) a resistive feedback Charge Sensitive Preamplifier [8].

In both cases, the amplitude of the output pulse is proportionate to the original detector pulse, which in turn is proportionate to the energy deposited in the detector. Without a feedback resistor, the feedback capacitor does not discharge, and the output voltage does not change with time after reaching the maximum value [9].

In this paper, we have analyzed the behavior of the CSP using Multisim Software. This Software gives the best SPICE simulation environment and provides practical application in prototyping and testing the PCB Designs.

CSP Circuit

When a semiconductor detector such as Silicon is used for the measurement of radiation sources such as gamma rays, X-rays the output pulse obtained from the detector is a weak charge pulse having a width of few nanoseconds. As the impedance of the detector is very high, the preamplifier is connected in close proximity to the detector to amplify the pulses. CSP handles nuclear pulses generated in the semiconductor detector.

The Schematic Diagram of the CSP is stated as follows:-
The RC feedback circuit is shown in fig 2. It is an ac-coupled amplifier. A coupling capacitor is connected between the input from the detector and the charge preamplifier circuit and this configuration can be eliminated when the dc-coupled configuration is considered.

A single cable is considered between the preamplifier and the detector which is used for the high bias and to extract the signal from the detector without degradation [11]. In Charge Preamplifier Circuit, the charge is collected on the feedback capacitor, which integrates the detector current pulse [12].

As the collection of charge takes place on the feedback capacitor, it produces a step change in voltage. The output voltage is thus proportionate to the total integrated charge on the capacitor. The output voltage pulse height is thus proportionate to the energy deposited by radiation interaction. The output pulse height of the charge preamplifier is characterized by a short rise time. The output voltage pulse $V_0$ of the charge preamplifier and decay time constant $\tau_f$ is given as follows:

$$V_0 = \frac{Q_d}{C_f}$$

$$\tau_f = R_f C_f$$

$R_f$ is the feedback resistor and $C_f$ is the feedback capacitor ranging from 0.1 to 5pF. $Q_d$ is the charge delivered by the capacitor.

As the feedback capacitance gets magnified by the open loop gain of the charge loop, so it acts as a large capacitance to the detector. Thus the input of capacitance must be greater than the other sources of capacitance. The important factors to be considered for the stability of the preamplifier are the stability of the feedback capacitor and preamplifier open loop gain. $C_f$ capacitance should be selected for better temperature stability and open loop gain must be made large.

The preamplifier has few limitations:

a) The intrinsic noise associated with $R_f$ can be eliminated by selecting the higher value of $R_f$, but increasing this value tends to increase the time constant.
b) By reducing $C_f$ to keep the time constant, but the disadvantage of reducing the capacitor results in affecting the linearity of the preamplifier.

The two limitations can be overcome by eliminating the feedback resistor, so pulses will directly be accumulated on the feedback capacitor and output voltage is grown in the staircase manner.

**Multisim Simulation**

In this scheme, we have simulated the CSP using the Pulsed voltage source and waveform generator. Instead of directly testing the detector, we have tested the preamplifier using the charge pulses which are generated by the Pulsed voltage source. Multisim Software was created by Electronics Workbench.

The pulsed voltage source is defined as a voltage source that repeats at a specified time interval. This source is coupled with the preamplifier and results are observed on oscilloscope.

We have tested the circuit with different rise times of 200 nsec, 350 nsec, and 500 nsec. With the rise time of 200 nsec, we vary the pulse height of the Pulsed voltage source keeping the rest of the parameters constant. We have set the initial value to 0V, and we vary the pulsed voltage value from 10mV to 200 mV and set the value of the pulse width as 4 nsec and the time period of 50 μsec. In this circuit, we have used LF351 Operational amplifier which these circuits are high-speed JFET input single operational amplifiers incorporating well matched, high voltage JFET and bipolar transistors in a monolithic integrated circuit. The results are observed on the oscilloscope which states that we obtain the pulses of greater height as the voltage increases. The simulation circuit diagram is stated as follows:

![Circuit Diagram of charge-sensitive-preamplifier along with Pulsed Voltage Source](image)

Fig.3: Circuit Diagram of charge-sensitive-preamplifier along with Pulsed Voltage Source.
Fig. 4: Output observed on Oscilloscope for Pulsed Voltage Source and charge-sensitive-preamplifier.

Fig. 3 and 4 presents the circuit diagram of CSP along with Pulsed Voltage Source and output were observed on oscilloscope.

The second method used to simulate the CSP in this paper is by capacitively coupling a square wave generator to the preamplifier input as shown below:

Fig. 5: Circuit Diagram of charge-sensitive-preamplifier along with signal generator.

Applying a square wave using the wave generator shown in Fig 5, a series of current spikes are applied to the CSP input of alternating polarity.
Result and Discussion

The Table for testing of the preamplifier for the rise time of 200 nsec is depicted below. Table (1) shown the reading observed on the oscilloscope.

Table (1): Testing of charge-sensitive-preamplifier for the rise time of 200 nsec.

| Input Pulse Amplitude (mV) | Output Amplitude of Charge Sensitive Preamplifier (mV) | Input Pulse Amplitude (mV) | Output Amplitude of Charge Sensitive Preamplifier (mV) |
|----------------------------|--------------------------------------------------------|----------------------------|--------------------------------------------------------|
| 10                         | 1261                                                   | 110                        | 1345                                                   |
| 20                         | 1270                                                   | 120                        | 1352                                                   |
| 30                         | 1279                                                   | 130                        | 1360                                                   |
| 40                         | 1288                                                   | 140                        | 1367                                                   |
| 50                         | 1297                                                   | 150                        | 1374                                                   |
| 60                         | 1305                                                   | 160                        | 1381                                                   |
| 70                         | 1314                                                   | 170                        | 1388                                                   |
| 80                         | 1322                                                   | 180                        | 1395                                                   |
| 90                         | 1330                                                   | 190                        | 1401                                                   |
| 100                        | 1337                                                   | 200                        | 1408                                                   |

We have plotted the graph of CSP v/s Voltage of Pulsed Source for the rise time of 200 nsec.

Fig. 6: Graph of CSP voltage v/s Voltage of Pulsed Source for the rise time of 200 nsec.

Fig 6 depicts the linear relationship between input and output voltage.
The Table for testing of the preamplifier for the rise time of 350 nsec is depicted below. Table (2) shown the reading observed on the oscilloscope.

Table (2): Testing of charge-sensitive-preamplifier for the rise time of 350 nsec.

| Input Pulse Amplitude (mV) | Output Amplitude of Charge Sensitive Preamplifier (mV) | Input Pulse Amplitude (mV) | Output Amplitude of Charge Sensitive Preamplifier (mV) |
|---------------------------|--------------------------------------------------------|---------------------------|--------------------------------------------------------|
| 10                        | 2171                                                   | 110                       | 2350                                                   |
| 20                        | 2191                                                   | 120                       | 2365                                                   |
| 30                        | 2210                                                   | 130                       | 2381                                                   |
| 40                        | 2229                                                   | 140                       | 2396                                                   |
| 50                        | 2247                                                   | 150                       | 2410                                                   |
| 60                        | 2265                                                   | 160                       | 2425                                                   |
| 70                        | 2283                                                   | 170                       | 2439                                                   |
| 80                        | 2300                                                   | 180                       | 2453                                                   |
| 90                        | 2317                                                   | 190                       | 2467                                                   |
| 100                       | 2334                                                   | 200                       | 2480                                                   |

We have plotted the graph of CSP v/s Voltage of Pulsed Source for the rise time of 350 nsec.

![Graph of charge-sensitive-preamplifier voltage v/s Voltage of Pulsed Source for the rise time of 350 nsec.](image)

Fig.7: Graph of charge-sensitive-preamplifier voltage v/s Voltage of Pulsed Source for the rise time of 350 nsec.

Fig 7 depicts the linear relationship between input and output voltage.

The Table for testing of the preamplifier for the rise time of 500 nsec is depicted below. Table (3) shown the reading observed on the oscilloscope.
Table (3): Testing of charge-sensitive-preamplifier for the rise time of 500 nsec.

| Input Pulse Amplitude (mV) | Output Amplitude of Charge Sensitive Preamplifier (mV) | Input Pulse Amplitude (mV) | Output Amplitude of Charge Sensitive Preamplifier (mV) |
|---------------------------|--------------------------------------------------------|---------------------------|--------------------------------------------------------|
| 10                        | 3112                                                   | 110                       | 3373                                                   |
| 20                        | 3141                                                   | 120                       | 3396                                                   |
| 30                        | 3169                                                   | 130                       | 3419                                                   |
| 40                        | 3197                                                   | 140                       | 3441                                                   |
| 50                        | 3224                                                   | 150                       | 3462                                                   |
| 60                        | 3250                                                   | 160                       | 3483                                                   |
| 70                        | 3276                                                   | 170                       | 3504                                                   |
| 80                        | 3301                                                   | 180                       | 3525                                                   |
| 90                        | 3326                                                   | 190                       | 3545                                                   |
| 100                       | 3350                                                   | 200                       | 3564                                                   |

We have plotted the graph of CSP v/s Voltage of Pulsed Source for the rise time of 500 nsec.

Fig. 8: Graph of charge-sensitive-preamplifier voltage v/s Voltage of Pulsed Source for the rise time of 500 nsec.

Fig 8 depicts the linear relationship between input and output voltage.

As for the results of the second method (using the signal generator), The signal generator shown in fig 9 provides a 1 kHz 1-volt peak-to-peak square wave (shown in green). The wave generator is coupled to the CSP input via a small test capacitor C_t (1 pF).
Fig. 9: Output observed on Oscilloscope for signal generator and charge-sensitive-preamplifier.

Each time the square wave changes state, a brief current pulse is injected into or out of the CSP input through the test capacitor $C_t$. The amount of charge injected into the preamplifier input is the product of the test capacitance $C_t$ and the peak to peak square wave voltage. For example, if the peak to peak square wave voltage is 1 volt and $C_t$ is 1 pF, then 1 pico coulomb is injected into the CSP with each change of state.

The gain of the CSP is 0.5 volt per pico coulomb, so the CSP output pulse is 2.3 volts (shown in yellow).

The output of the CSP exponentially decays with a time constant given by the product of the feedback components. For the CSP in this paper, which has a feedback resistor of 100 MΩ and a feedback capacitor of 0.5 pF, the decay time constant is 50 μs. This exponential decay is evident in the output waveform shown in yellow.

**Conclusion**

Thus, we have successfully tested, analyzed, and determined the characteristics of the CSP circuit using Multisim simulation. A brief summary of the need for a CSP is explained and stated why it is required for a semiconductor detector. Simulation has been carried in Multisim software for different rise times such as 200 nsec, 350 nsec, and 500 nsec and we observed with the help of graphs, that there is an increase in the output voltage of the preamplifier as the input voltage increased with a linear relationship, the output of the CSP exponentially decays with a time constant given by the product of the feedback components.
References

[1] H. Hamrita et al., “Charge and current-sensitive preamplifiers for pulse shape discrimination techniques with silicon detectors,” Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip., vol. 531, no. 3, pp. 607–615, 2004, doi: 10.1016/j.nima.2004.05.112.

[2] G. F. Knoll, Radiation detection and measurement. John Wiley & Sons, 2010.

[3] D. McGregor and J. K. Shultis, Radiation Detection: Concepts, Methods, and Devices. CRC Press, 2020.

[4] S. N. Ahmed, Physics and engineering of radiation detection. Academic Press, 2007.

[5] Z. He, “Review of the Shockley–Ramo theorem and its application in semiconductor gamma-ray detectors,” Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip., vol. 463, no. 1–2, pp. 250–267, 2001.

[6] H. Spieler, “Pulse processing and analysis,” 2002.

[7] A. Baschirotto et al., “A fast and low noise charge sensitive preamplifier in 90 nm CMOS technology,” J. Instrum., vol. 7, no. 01, p. C01003, 2012.

[8] G. Zeng et al., “Research and development of a high-performance differential-hybrid charge sensitive preamplifier,” Appl. Radiat. Isot., vol. 120, pp. 95–100, 2017.

[8] E. Potential and S. N. Ahmed, “Preamplifiers Signal processing,” 2015.

[9] A. Rogalski and Z. Bielecki, “Detection of optical radiation,” Bull. Polish Acad. Sci. Tech. Sci., vol. 52, Jan. 2006.

[11] D. K. Wehe.(June 2006), Current Trends In Ionizing Radiation Detection, Nuclear Engineering and Technology, Vol.38 No.4 .

[12] F.S.Fouling and D.A.Landis (June 1982), Signal Processing for Semiconductor Detectors,IEEE Transactions on Nuclear Science, Vol. NS-29, No. 3,