

Research Article

Simulation of Charge Sensitive Preamplifier using Multisim Software

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Abstract

Simulation of the Charge Sensitive Preamplifier Circuit has been carried on Multisim Software. Multisim Software is powerful software that creates the best user friendly simulation environment for engineers, students and professors. We can simulate electronic circuits and generate prototype for Printed Circuit Boards (PCB's). In this paper we have simulated the Charge Sensitive Preamplifier Circuit with a pulsed voltage source. We have analysed the behaviour of the Charge Sensitive Preamplifier Circuit with different rise times. The output waveforms have been observed on the oscilloscope.

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

1. Introduction

Preamplifier is the interface between detector and rest of the pulse processing system. The input fed to the preamplifier can be charge or current pulse but the output of the preamplifier is the voltage pulse. Without significantly degrading the signal to noise ratio the main function of the preamplifier is to extract the signal from the detector. Thus, the preamplifier is located close to the detector. The output pulse of the preamplifier is linear tail pulse. Two important factors that are considered for the preamplifier are as follows:

- The cable length between the detector and the preamplifier is maintained at the minimum so as to terminate the capacitance quickly to maximize the signal to noise ratio.
- To have low output impedance source to the preamplifier.

There are different types of Preamplifiers such as Voltage Sensitive, Current Sensitive and Charge Sensitive. Voltage Sensitive Preamplifier is preferred for scintillator detector. Since the output of the Photo Multiplier Tube is a voltage pulse thus the preamplifier selected is Voltage type. Current Sensitive preamplifier are basically designed for timing application and is chosen when rise time is similar to the rise time of the detector. Charge Sensitive Preamplifier is preferred for semiconductor detector. In Nuclear spectroscopy applications, Charge sensitive preamplifier is much preferred.

The output of semiconductor detector is usually a current pulse lasting from 10^{-9} to 10^{-5} sec which is fed to the Charge sensitive preamplifier. A Charge sensitive

preamplifier can deliver a voltage pulse and in an ideal case, the rise time of the output voltage pulse is equal to detector current pulse. In this paper we have analysed the behaviour of the Charge sensitive preamplifier using Multisim Software. This Software gives the best SPICE simulation environment and provides practical application in prototyping and testing the PCB Designs.

2. Literature Survey

A model of the SiC Radiation Detector was constructed based on TRIM calculation to study the damage by tritons for a given diode package. For predicting the count rate the results were obtained in TC irradiation field of OSURR using a charge sensitive preamplifier. The performance of the detector was analysed using the standard pulse height analysis along with the charge sensitive preamplifier [Thomas E. Blue *et al*, 2008]. The design and implementation of a low noise CMOS charge sensitive preamplifier with pole/zero compensation have been carried on neutron detector. The first prototype chip was fabricated using Taiwan Semiconductor Manufacturing Company. Here, the input MOSFET in the preamplifier needs to dominate the noise of the entire system. The input MOSFET introduces noise in the system but it can be optimized by the designer. The noise sources of the preamplifier can be optimized for each detector system. Different charge sensitive preamplifier topologies have been studied in this paper and design is successfully implemented and even low noise performance can be achieved [Steven Curtis Bunch *et al*, 2006]. A low noise high performance charge preamp was designed and tested for Super collider. The amplifier provides an

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improved performance in bandwidth and noise performance. This amplifier was fabricated and tested in a new high frequency, radiation hardened BIFET Technology from Harris Corporation. In addition to that, a shaper circuit is designed and tested with the preamplifier circuit to produce low noise signal [K. Y. Ling, 1989], [L. T. Wurtz, and W.P. Wheless *et al*, 1993]. Two fast charge preamplifiers were developed and tested one amplifier was used for energy spectroscopy and other was used for timing application. This arrangement resulted in obtaining a signal of proper shape and proper polarity for use with timing application. One of the important use of these fast amplifiers is in timing spectroscopy application with surface barrier detectors [Neven Karlovac *et al*, 1977]. Radeka in 1968 had summarized the design consideration for wideband low noise charge preamplifiers [V. Radeka *et al*, 1968]. Work has been done by Sherman and Roddick in the field of preamplifier with a separate fast and slow channels [I.S. Sherman *et al*, 1968]. Noulis had done a detailed comparison analysis of four equivalent charge sensitive preamplifier in terms of noise performance. In this paper different topologies were presented in order to find out the performance of topology in terms of noise, with respect to technology and design specification. In all technologies consumption was kept constant only noisy device were input transistor and feedback element [T. Noulis *et al*, 2008].

3. Charge Sensitive Preamplifier Circuit

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

The Schematic Diagram of the charge sensitive preamplifier is stated as follows:

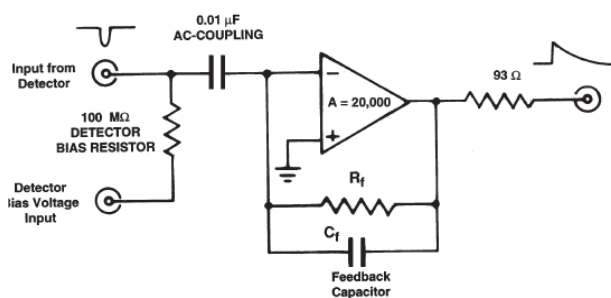


Fig 1: RC feedback Charge Sensitive Preamplifier

In Fig 1, The RC feedback circuit is shown in the above diagram. It is an ac-coupled amplifier. A coupling capacitor is connected between the input from the

detector and charge preamplifier circuit and this configuration can be eliminated when 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 [D. K. Wehe *et al*, 2006].

In Charge Preamplifier Circuit, charge is collected on the feedback capacitor, which integrates the detector current pulse [F.S.Fouling *et al*, 1982]. As collection of charge takes place on the feedback capacitor, it produces a step change in voltage. The output voltage is thus proportional to the total integrated charge on the capacitor. The output voltage pulse height is thus proportional to the energy deposited by radiation interaction. The output pulse height of the charge preamp is characterized by short rise time. The output voltage pulse V_o of the charge preamp and decay time constant T_f is given as follows:

$$V_o = Q_D / C_f \text{ and } T_f = R_f C_f$$

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: stability of feedback capacitor and preamplifier open loop gain. C_f capacitance should be selected for good temperature stability and open loop gain must be made large.

The preamp has few limitations:

- The intrinsic noise associated with the feedback resistance R_f can be eliminated by selecting higher value of R_f , but by increasing this value tends to increase the time constant.
- By reducing C_f to keep the time constant, but the disadvantage of reducing the capacitor results in affecting the linearity of the preamp.

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

4. Multisim Simulation

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

Pulsed voltage source is defined as a voltage source that repeats at a specified time interval. The symbol of the Pulsed voltage source is shown below:

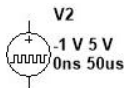


Fig 2: Symbol of Pulsed Voltage Source

Fig 2 represents the symbol of Pulsed Voltage Source. This source is coupled with the preamplifier and results are observed on two oscilloscope.

We have tested the circuit with different rise times of 200nsec, 350nsec and 500nsec. With the rise time of 200nsec, we vary the pulse height of the Pulsed voltage source keeping rest of the parameters constant. We have set the initial value to 0V, and we vary the pulsed voltage value from 20mV to 200mV and set value of the pulse width is 4nsec and time period of 50usec. In this circuit we have used OPA637 opamp which is a precision high speed opamp with a fast settling speed of 450nsec and very low noise of 4.5V/√Hz. 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:

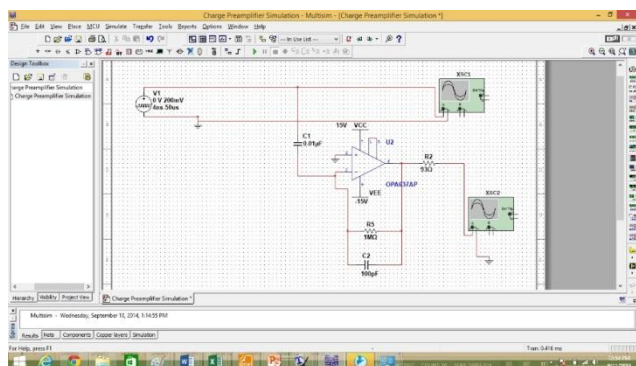


Fig 3: Circuit Diagram of Charge Sensitive Preamplifier along with Pulsed Voltage Source

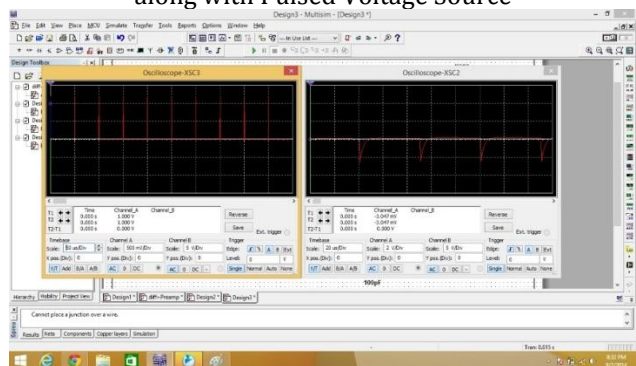


Fig 4: Output observed on Oscilloscope for Pulsed Voltage Source and Charge Sensitive Preamplifier

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

5. Result and Discussion

The Table for testing of the preamp for the rise time of 200nsec is depicted below. The Table shown below

states the reading observed on the two oscilloscopes and the ratio of input v/s output voltage is constant approximately 53. The rise time of pulsed voltage is same as that of the charge preamp which is also constant that is 189nsec.

Table 1: Testing of Charge Sensitive Preamplifier for the rise time of 200n sec

Input Pulse Amplitude (mV)	Rise time of Input pulse observed on Oscilloscope (nsec)	Output Amplitude of Input Pulse observed on the Oscilloscope(mV)	Rise time of Charge sensitive Preamplifier (nsec)	Output Amplitude of Charge Sensitive Preamplifier (mV)
20	189	19.25	189	1034
40	189	39.224	189	2130
60	189	59.459	189	3180
80	189	79.951	189	4262
100	189	98.36	189	5257
120	189	119.498	189	6347
140	189	134.097	189	7216
160	189	160	189	8483
180	189	176.815	189	9517
200	189	199.169	189	10530
220	189	214.387	189	11484
240	189	237.957	189	12562
260	189	255.93	189	12976
280	189	278.819	189	12992
300	189	292.767	189	12995

We have plotted the graph of Charge Sensitive Preamplifier v/s Voltage of Pulsed Source for the rise time of 200n sec

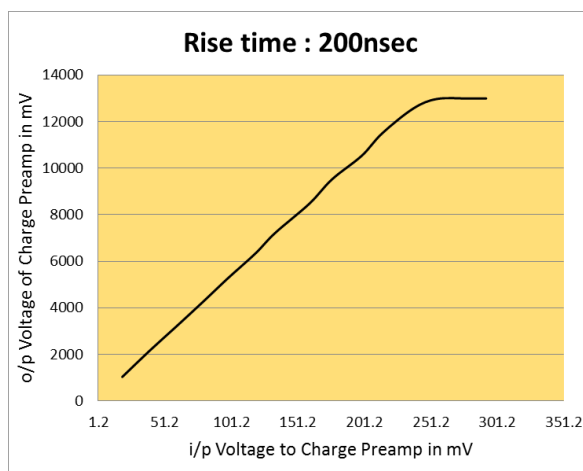


Fig 5: Graph of Charge Sensitive Preamplifier voltage v/s Voltage of Pulsed Source for the rise time of 200nsec

Fig 5 depicts the linear relationship between input and output voltage.

The Table for testing of the preamp for the rise time of 350nsec is depicted below. The Table shown below states that the reading observed on the two

oscilloscopes and the ratio of input v/s output voltage is constant approximately 65. The rise time of pulsed voltage is same as that of the charge preamp which is also constant that is 350nsec.

Table 2: Testing of Charge Sensitive Preamplifier for the rise time of 350n sec

Input Pulse Amplitude (mV)	Rise time of Input pulse observed on Oscilloscope (nsec)	Output Amplitude of Input Pulse observed on the Oscilloscope(mV)	Rise time of Charge sensitive Preamplifier (nsec)	Output Amplitude of Charge Sensitive Preamplifier (mV)
20	340	19.415	340	1264
40	340	39.761	340	2527
60	340	58.41	340	3741
80	340	78.186	340	5034
100	340	98.749	340	6305
120	340	119.285	340	7551
140	340	140	340	8823
160	340	160	340	10087
180	340	179.902	340	11335
200	340	200	340	12582

We have plotted the graph of Charge Sensitive Preamplifier v/s Voltage of Pulsed Source for the rise time of 350n sec

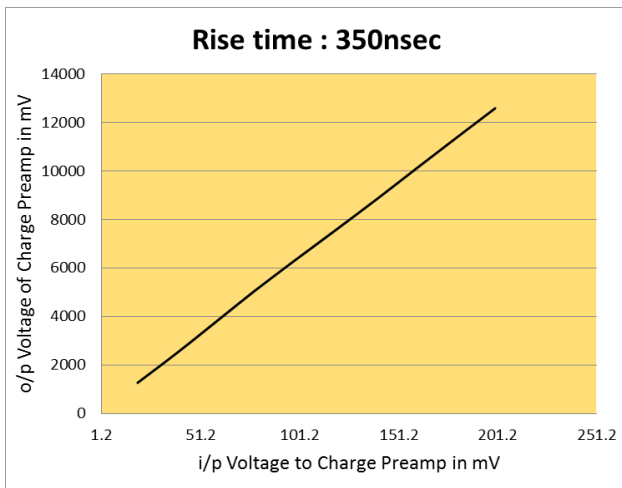


Fig 6: Graph of Charge Sensitive Preamplifier voltage v/s Voltage of Pulsed Source for the rise time of 350nsec

Fig 6 depicts the linear relationship between input and output voltage.

The Table for testing of the preamp for the rise time of 500nsec is depicted below. The Table shown below states that the reading observed on the two oscilloscopes and the ratio of input v/s output voltage is constant approximately 71. The rise time of pulsed voltage is same as that of the charge preamp which is also constant that is 492nsec.

Table 3: Testing of Charge Sensitive Preamplifier for the rise time of 500n sec

Input Pulse Amplitude (mV)	Rise time of Input pulse observed on Oscilloscope (nsec)	Output Amplitude of Input Pulse observed on the Oscilloscope(mV)	Rise time of Charge sensitive Preamplifier (nsec)	Output Amplitude of Charge Sensitive Preamplifier (mV)
20	492	19.75	492	1470
40	492	39.333	492	2801
60	492	58.99	492	4201
80	492	78.498	492	5626
100	492	96.825	492	6796
120	492	116.847	492	8394
140	492	137.328	492	9788
160	492	158.759	492	11179
180	492	177.106	492	12631
200	492	198.478	492	12988

We have plotted the graph of Charge Sensitive Preamplifier v/s Voltage of Pulsed Source for the rise time of 500n sec

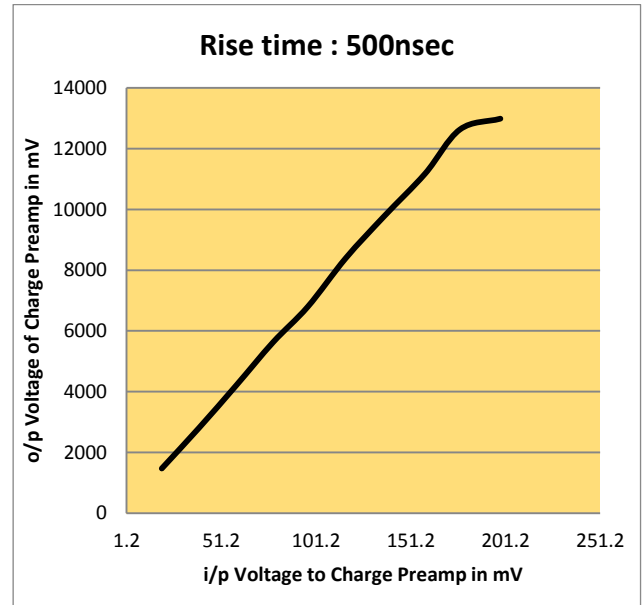


Fig 7: Graph of Charge Sensitive Preamplifier voltage v/s Voltage of Pulsed Source for the rise time of 500n sec

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

Conclusion

Thus, we have successfully tested, analysed and determined the characteristics of the Charge sensitive preamplifier circuit using Multisim simulation. A brief summary of need of Charge sensitive preamplifier is explained and stated why it is required for

semiconductor detector. Simulation have been carried in Multisim software for different rise times such as 200nsec, 350nsec and 500nsec and we observed with the help of graphs, the ratio of input v/s output voltage is constant.

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