UFSD Test with Proton Beam and Signal Analysis by Using CFD Method

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Abstract

Detecting the charge particles a t Giga hertz rate is one of the applications of UFSD (Ultra- Fast Silicon Detectors). The UFSD test in front of the proton beam to count the beam particles and use it for more precise in Dose Delivery System for treatment the cancerous tumor by charge particles can become an effective step for development of cancer treatment. After choosing the best time measurement method which was constant fraction discriminato r (CFD) method, by our previous experience, we used MATLAB software to analyze the UFSD signals. The results of many different runs of programs in MATLAB for many registered signals shows: 1- These sensors are reliable to count the proton particles in giga hertz rate. 2-The CFD devices could be used to record the UFSD output signals.

Key words: Ultra-Fast Silicon Detectors (UFSD), Dose Delivery System (DDS), Time Measurement, MATLAB, Proton Therapy.

Introduction

When a detector encounters a small amount of charge, it has high safety and high efficiency in collecting charges, which itself is a key to having a good time resolution power, and detectors with this feature are Ultra-Fast Silicon Detectors in which the time resolution power is less than 30 ps. Ultra-Fast Silicon Detectors promise new silicon detectors with a higher signal-to-noise ratio than the older sensors.

The internal gain makes them ideal for precise time resolution and particle counting at GHz. [1,2] By our previous experiences that UFSD signals simulated with signal generator and Weightfield2 software and also obtained from UFSD test against pico-laser beam, UFSD signals had been analyzed with three time measurements method included cross-correlation (CC) ; time over threshold (TOT) and constant fraction discriminator (CFD) and finally CFD method was known as the best method.

Then at the first step CFD method will be explained and in second step we will explain how to obtain experiment data from UFSD test at CNAO (European Council for Nuclear Research) in Italy and finally four sets of data obtained in 2015; 2016 and 2017 will be analyzed by CFD method with MATLAB software.

Constant Fraction Discriminator (CFD)

We consider a triangular wave, $v_t = t * \tan\alpha$, $\tan\alpha = \frac{v_m}{t_m}$ .Now we shift it a little bit along axis time and also attenuate amplitude, formula 1, then send new signal with main signal to a comparator device. It is visible that zero crossing point from comparator output signal will happen when two signals are the same, formula 2. By equating two formulas it will be seen that the time of zero crossing point does not depend on the wave amplitude:

$$v_t1 = (t - t_d).\frac{v_m}{t_m} \quad , \quad v_t2 = k.t.\frac{v_m}{t_m} \tag{1}$$

$$(t - t_d).\frac{v_m}{t_m} = k.t.\frac{v_m}{t_m} \quad => \; t = \frac{t_d}{1-k} \tag{2}$$

Of course that is what we need; finding a time point which does not depend on amplitude or energy.[3,4] Also we be able to catch signals passing from this point with standard deviation less than 100ps for credibility.

Four different data to analyze

1- Data Obtained by Ultra-Fast Silicon Detectors (UFSD) Test with the Proton Beam at CERN[1] (European Council for Nuclear Research)

We studied a set of real similar experimental data in terms of signals actuality to be ready for analysis of real data would be obtained from the CNAO (National Center of Oncological Hadron Therapy in Italy) experiment that was in progress.

These data included the Ultra-Fast Silicon Detectors signals obtained from Ultra-Fast Silicon Detectors test with the proton beam, which was about 8 GB and were registered at the CERN (European Council for Nuclear Research) laboratory in 2015, and was provided to the Medical Physics Group in Turin University. Of course, we did not have the exact information on how to do the experiment and its purpose. We were only partially aware of the energy of the proton beam.

After applying CFD method to the intended data (Figure 1), the results are sorted in Table 1. As can be seen, in different data sets, various but close values are obtained for the standard deviation. Generally, with a total data of 10000 or 20000, and different data sets with names RUN100 or RUN200, it could be said that the standard deviation would be about 100ps and even goes to 57ps to 65ps by changing the threshold voltage and increasing the number of signals, which is an acceptable figure. Although each set of data was completely different from the other.

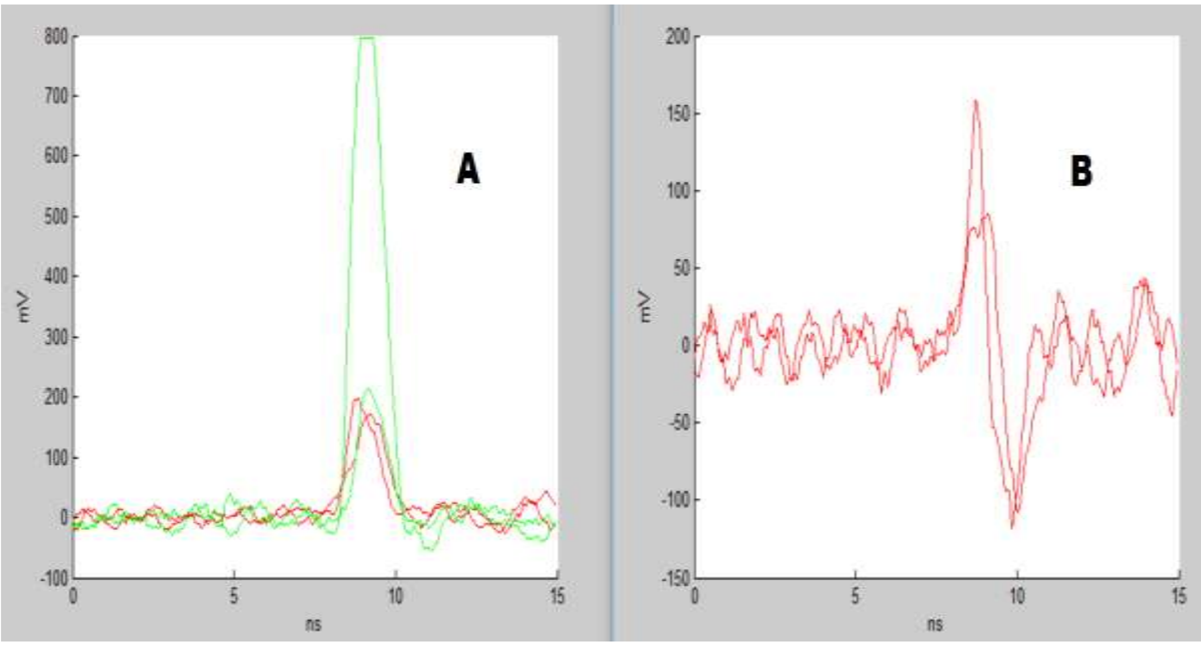

Figure (1): The sample of the analyzed paired signals (A) (recorded from the CERN (European Council for Nuclear Research) experiment) and the curve resulted from implementing the Constant Fraction Discriminator method on these signals (B).

Test name	Total events	Real events	Threshold Voltage	tandard Deviation (ps)
RUN100	10000	2381	130	148
RUN100	10000	2215	140	93
RUN100	20000	4500	135	92
RUN200	10000	3754	160	57
RUN240	10000	2626	120	95
RUN240	10000	2583	160	89

Table (1): Standard deviation results in the Constant Fraction Discriminator method for different data obtained from CERN (European Council for Nuclear Research) experiments conducted by changing the threshold voltage level to select acceptable signals.

2-Ultra-Fast Silicon Detectors (UFSD) Test with the Proton Beam at CNAO (National Center of Oncological Hadron Therapy in Italy)

CNAO (National Center of Oncological Hadron Therapy in Italy), the scientific center for cancer treatment, is located in the town of Pavia in northern Italy, and currently is equipped with synchrotron in the world, with the capability to produce proton beam and carbon ion. The center is located next to a hospital and has three treatment rooms for cancerous tumors.

Its Dose Delivery System is based on active scattering after the proton beam is directed by gantry to the treatment room, it coming out of the vacuum and enters the patient's body with a distance about 30 cm. By directing and controlling the spot scanning devices, it scans the tumor and destroys the cancerous cells in a few phases.[5] To minimize noise, we put two sensors together with their initial amplifiers into an aluminum box, which should be made and prepared according to the dimensions of the sensors. We connect and screw the board of two sensors (1 mm^2 × 50 µm) back-to-back so that the beam exactly passes through both of them (Figure 2).

Figure (2): A pair of sensor board, Ultra-Fast Silicon Detectors (1 mm^2 × 50 µm).

After all, packing and transferring devices and appliances to the treatment room at CNAO (National Center of Oncological Hadron Therapy in Italy), a circuit is finally closed in accordance with Figure 3. [6,7,8,9,10,11,12,13,14,15] The sensors were placed on the patient's bed in front of the beam by a mechanical arm and, by controlling the device until the two sensors were exactly exposed to the direct proton beam ($10^9 p/s$, FWHM 1 cm). Sample of recorded signals from the UFSD tests and implementing CFD method to analyze them have been shown in figures 4 and 5.

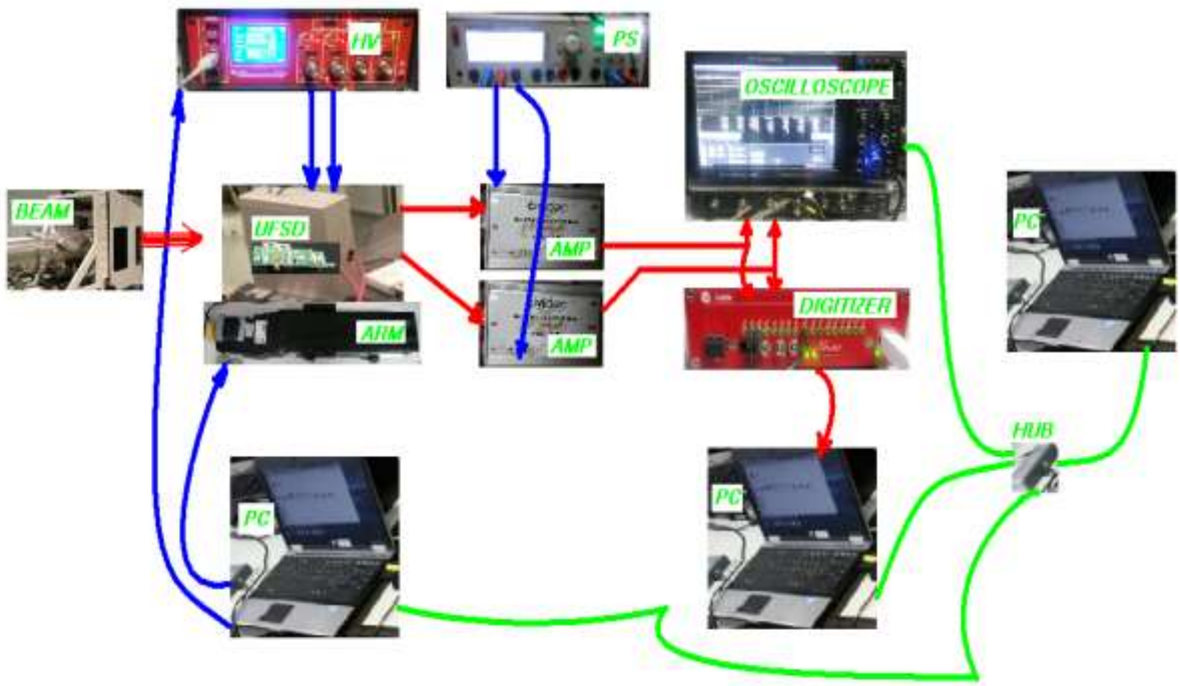

Figure (3): Connections at CNAO (National Center of Oncological Hadron Therapy in Italy) experiment.

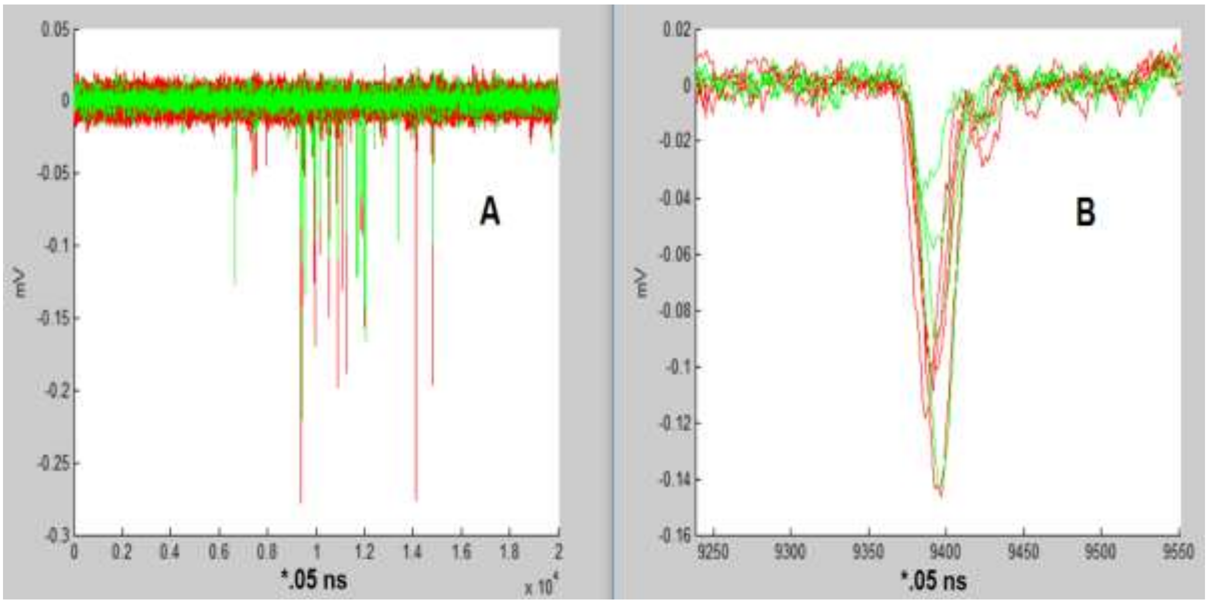

Figure (4): Sample of the existing signals in the data set obtained from the CNAO (National Center of Oncological Hadron Therapy in Italy) experiment.

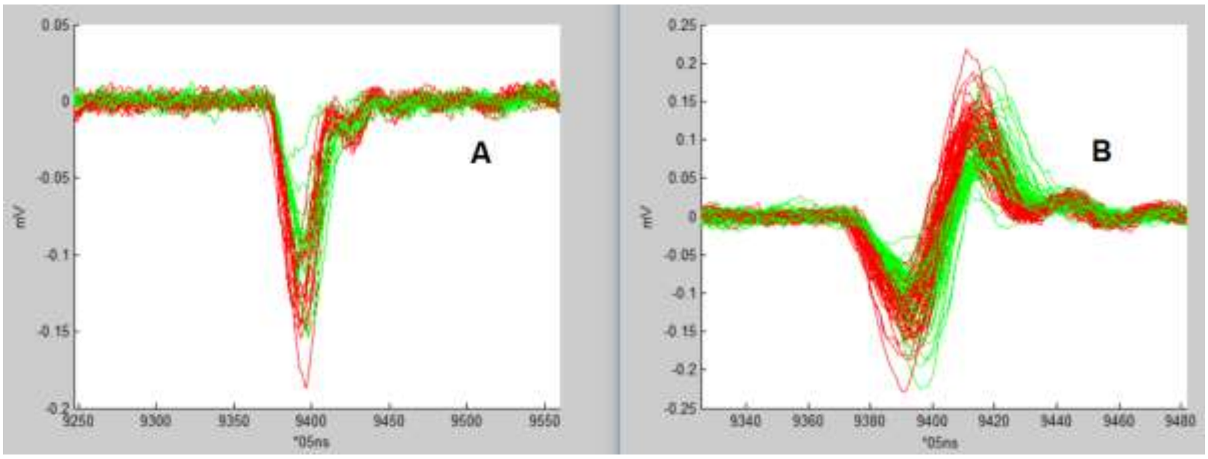

Figure (5): Sample of the analyzed signals (A) (recorded from the CNAO (National Center of Oncological Hadron Therapy in Italy) experiment) and the obtained curve by implementing the Constant Fraction Discriminator method to these signals (B).

Given the shape of the received signals, the analysis became much more difficult. Because the issue of filtering of the signals was raised, and the fact that many signals did not have the amplitude while triggering, and they are similar to noise and should not be considered.

In table 2, the type of radiation and its energy level and the simultaneous trigger or separate tragic are specified for signal recording, while the standard deviation at the zero-crossing point of generated signals in the Constant Fraction Discriminator method, and the number of signals fully record and the acceptable signal are also presented. Although many of the signals have been lost, the results indicate that the implementation of this method is reliable and promising for the remainder. For about 30 categories of recorded data, this should be done carefully so that the maximum acceptable signal for processing was obtained. This issue was just determined after the Constant Fraction Discriminator program was implemented.

Particle	Energy(MeV)	HV	Triger	Total events	Real events	Standard deviation
Proton	60	150	CH1+CH2	70	57	97ps
P	60	150	CH1 only	300	46	89ps
P	60	150	CH1+CH2	68	36	89ps
P	60	150	CH1 only	590	27	127ps
P	227	150	CH1+CH2	48	12	83ps

Table (2): Implementation of the Constant Fraction Discriminator method for all data taken from the CNAO (National Center of Oncological Hadron Therapy in Italy) experiment

We can say that Constant Fraction Discriminator method is the best time measurement method for Ultra-Fast Silicon Detectors signals because it shows good results by giving standard deviation around 90ps to 120ps for one type of Ultra-Fast Silicon Detectors and 145ps to 168ps for another type of Ultra-Fast Silicon Detectors named St. Cruz.

3- Other Two Similar Experiments in CNAO

Biased on our previous experiments, we made two other similar experiments on April 2017 and November 2017. of course, by some changes like using different kind of sensors contained:

SENSOR, April 2017

A.Mignone board W8 Boron(2 short sensors 1strip gain +1strip no gain)

B.Mignone board W8 Boron(2 long sensors 1strip gain +1strip no gain)

SENSOR, November 2017

A = Hamamatsu 50 um circle 1 mm diameter (det.8)

B = CNM 50 um 1,2x1,2 mm^2 (det.6)

C = Hamamatsu 80 um 3x3 mm^2 (det 14)

D = Hamamatsu 80 um 3x3 mm^2 (det 15)

20 spill 10^9 p/spill TOT=2*10^10 p

Mignone board + Cividec BB 40 dB circa 3 mV noise nd also different energies in proton beam and different high-voltage level compare to previous test. Although many signals were different in case of shape and many different programs were written to analyze in MATLAB, but finally obtained results were similar to before and standard deviations obtained about 110ps in CFD method shown in table 3.

Run time	Particle	Energy(MeV)	HV	Total events	Real events	Standard deviation
April	Proton	197	250	450	110	113ps
April	P	214	250	450	105	110ps
November	P	62	150	350	90	98ps
November	P	227	250	350	82	105ps

Table (3): Brief results of Implementation of the CFD method for all data taken from CNAO experiment on April 2017 and November 2017.

Results

According to tests with different sensors and different condition also analyze obtained signals by using CFD method, it can be said:1-UFSD are proper to use counting proton particles in Giga hertz rate for precise treatment system of cancerous tumor in Dose Delivery System. 2Using the CFD method to analyze the UFSD output signals obtained 100ps, has been given hopeful results that we can use CFD devices to record the UFSD signals in front of proton beam by the very confidence.

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