Contribution ID: **53** Type: **Poster**

Analysis of Time of Arrival Measurement with Low-Gain-Avalanche-Diode Sensor

Thursday, 5 September 2019 16:55 (20 minutes)

Results of analyzes of Time-of-Arrival measurements with Low-Gain-Avalanche-Diode sensors were carried out for the amplitude or time-over-threshold corrected leading edge measurements and for practical realization of Constant-Fraction-Discrimination based on ideal delay and RC-type low-pass filtering delay. The Expected current waveforms, resulting from modeling of a sensor and application of varied conditioning of a signal in the front-end circuit, including varied transfer functions and their parameters were considered together with practically achievable signal-to-noise ratio. The work has been done to estimate the levels of variations of time-of-arrival measurements that are achievable in the practically built systems.

Summary

Low-Gain-Avalanche-Diode (LGAD) sensors are young devices that possess attractive features for building timing layers in the experiments on the HL-LHC. A program allowing modeling current waveforms, originating from ionization due to the traversing particles through LGADs and consequent multiplication of the generated charge have been developed by Nicolo Cartiglia. To learn what performances can be expected from readout electronics coupled to LGADS, analyzes of Time-of-Arrival (ToA) measurements were carried out for the amplitude or time-over-threshold (ToT) corrected Leading Edge (LE) measurements and for practical realizations of Constant-Fraction-Discrimination (CFD) based on ideal delay and additional RC-type low pass filtering. The time-domain simulation environment, allowing representing the entire signal processing chain from the LGAD current waveforms, through amplification and conditioning of signals in filtering, addition of noise based on equivalence of frequency and time domain representations and discrimination was developed in the Mathematica package.
The purpose of this work was to be able to enter any transfer function of an amplifier-shaper block in s-domain, including cut-off frequency and degree of additional delay in case of realistic realization of CFD, noise assuming signal-to-noise ratio, define time binning of ToA, ToT and binning for amplitude measurements, select family of current waveforms of LGAD signals for designated bias voltage and neutron fluence and obtain results for typical ToA measurement methods. The methods included in the analyzes are: the amplitude or time-over-threshold corrected LE measurements and practical realization of CFD based on subtraction of delayed by either ideal delay or by RC-type low pass filtering waveform from the scaled original one.
As an illustration of the obtained results are given those for the CR-RC3 amplifier-shaper transfer function with the peaking-time varied from 1 to 4 ns and signal-to-noise ratios varying from 30 to 100 for LGAD responses simulated for a 50 µm-thick sensors for neutron fluences 0, 5e14 and 1e15 n1MeV/cm2. Studies of time binning from 20 to 100 ps, from 80 to 1200 ps and amplitude binning from 3 to 8 bits equivalent were done for ToA, ToT and amplitude measurements, respectively, to answer the question about foreseeable level of the time measurement precision.
Assuming a signal-to-noise ratio of 60 and peaking time of impulse response equal to 2 ns (as reasonable values due to power consumption), ToA variation ranging from 30.5 ps and 35.0 ps for ideal CFD and CFD with RC delay to 37.5 and 35 ps for LE with ToT and amplitude correction, were obtained for non-irradiated sensors. These values change correspondingly to 31.5 ps and 35.0 ps for CFDs and 35.0 and 44.0 ps for LEs for 5e14 n1MeV/cm2 and 36.5 ps and 49.0 ps for CFDs and 50.0 ps and 53 ps for LEs for 1e15 n1MeV/cm2. Decreasing

peaking time to 1 ns leads to noticeable improvements in LE results by 5 to 7 ps, while improvements in the CFD results is about 1 ps for the ideal delay and 5 to 7 ps as well for the RC delay. The review of the results is given.

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Session Classification: Posters

Track Classification: ASIC