Modelling of picosecond timing signals from fast vacuum photodiodes

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Abstract

Very high bandwidth vacuum photodiodes with 10s of picoseconds rise time are utilised in Cherenkov detectors for inertial confinement fusion diagnostics. Experimental measurements of the pulse shape and time resolution of a fast Photek PD010 photodiode tube, undertaken using very fast pulsed laser illumination at the ORION facility, Atomic Weapons Establishment, Aldermaston UK, were compared with a computer model to understand detector performance with the aim of improving the time resolution. The physical processes defining the performance of the photodiode detector were modelled using CST Studio Suite software. This package combines very high frequency electromagnetic field modelling, particle tracking, space charge effects and secondary electron emission simulation, and has enabled a realistic simulation of detector behaviour and performance predictions to be made. We present a comparison between experimental measurements of time resolution and pulse shape over a range of device operating voltages, with simulations obtained with CST particle tracking software using the device CAD design file to accurately model the PD010 device. These results demonstrate the remarkable correlation that can be achieved between experiment and simulation, even at picosecond time-scales.

Keywords: Detector, Simulation, Particle tracking, Picosecond timing

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1. Introduction

Vacuum photodiodes should offer even faster time resolution and higher signal bandwidth than microchannel plate based photomultipliers, albeit with lower sensitivity due to their lack of electron gain. The absence of the microchannel plate removes the additional pulse broadening associated with the electron amplification, a cascade process along the length of the microchannel pore.

In a photodiode the fundamental signal bandwidth depends on the following factors:

- The variation in the delay of the photoelectron emission from the photocathode. This is an insignificant effect.
- The variation of the photoelectron flight time due to variations in emission angle and energy, also insignificant due to the magnitude of the accelerating voltage.

Figure 1: A plot of measured PD010 pulse responses of the same detector with differing illumination and electronics showing the effect of varying laser pulse width, electronic interfacing and oscilloscope bandwidth.

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Figure 2: The Photek PD010 photodiode was modelled with CST Studio Suite software using particle tracking with the particle-in-cell solver. This figure shows a CST model cross-section of a simplified Photek PD010 photodiode detector (left) and a photo of the actual detector in its housing (right).

- Secondary electron production: Further pulse broadening can be caused by elastically or inelastically scattered primary electrons, or secondary electron emission from the anode.
- Charge coupling: The transient anode signal is developed by the motion of primary and secondary electrons between photocathode and anode. These moving charges induce a signal on the anode which depends on the coupling between the charge and the anode.

The detector geometry has a major influence on the signal pulse characteristics. In practice, impedance matching of the output is a crucial factor in minimising pulse rise time, width and ringing. Realistic modelling of these physical processes requires a combination of electromagnetic field simulation at very high frequencies together with particle tracking, space charge effects and secondary electron emission. CST Studio Suite software was used simulate all aspects of photodiode performance.

2. Modelling using CST Studio Suite

The Photek PD010 photodiode was modelled with CST Studio Suite software [1] using the particle-in-cell solver with particle tracking. A cut-away drawing of a simplified photodiode detector is shown in figure 2. The model used for simulation results in figure 3 was significantly more detailed and was developed using the 3D CAD STEP file used for actual device manufacture. It was straightforwardly imported into the CST Studio Suite software to create an accurate geometrical model. The results show that the simulation can accurately predict photodiode performance even at very high bandwidths, allowing accurate evaluation of new designs prior to their manufacture.

3. Comparison of simulation with fast photodiode measurements

Experimental measurements of the Photek PD010 at varying operating voltages were undertaken in February 2015 using a

fast, picosecond pulse width laser at the AWE ORION laser facility. Comparisons between experimental data and simulation are shown in figure 3. These used a 50 GHz simulation bandwidth at three tube operating voltages: 5 kV (upper), 2.5 kV (centre) and 0.625 kV (lower). Each plot shows the experimental data obtained using a fast oscilloscope (17 GHz bandwidth) in comparison with simulated results. The latter were filtered using a 2nd Order Butterworth low pass filter to emulate the oscilloscope bandwidth.

Figure 3: Plots showing the comparison between simulated pulses and measured PD010 pulse response over a range of operating voltages. The simulations accurately model both the arrival time and shape of the output pulse.

4. Conclusion

The fit of simulation data to experimental results is remarkably good, especially given that the full design with SMA connector coupled to a 600 mm coaxial cable was not included in the model. This suggests that the major effects resulting from impedance mismatch occur in the large scale end of the waveguide where non-ideal geometrical features represent larger phase errors (the simulation bandwidth is 50 GHz = 6 mm wavelength).

References

- [1] CST Studio Suite, Comput. Simul. Technol. (2014), Available from: URL: www.cst.com
- [2] Proceedings of the 1st EPS conference on Plasma Diagnostics (2015), PoS(ECPD2015)005