FPGA Signal Processing for Real-Time Dust Detection

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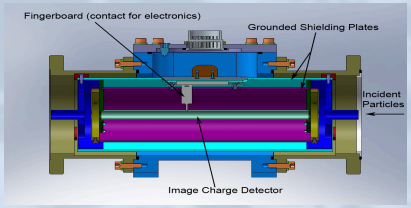
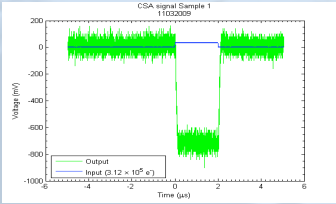
Introduction

The lunar atmosphere is a surface bound exosphere (SBE) and is maintained by a dynamic equilibrium between solar wind electrons and ions, photoelectrons emitted from the surface, and ejecta from micrometeroid impacts (impacts typically ~20km/s). Due to the diffuse nature of the exosphere, the ejecta travel in ballistic trajectories and either escape the lunar environment or fall back to the surface (potentially creating secondary ejecta). A 3MV lunar dust accelerator has been built at the University of Colorado to simulate those impacts at <100km/s, which will increase understanding of the exosphere as well as provide calibration services for future in situ measurement instruments. To be useful as a scientific instrument, the accelerator must be able to detect the particles in-flight so as to select particles valuable to the particular experiment as well as provide knowledge of particle properties (i.e. charge and velocity).

Detectors

The detectors function through image charge amplification as an incident particle enters the innermost conducting cylinder. Electronics, which include a CSA, output a signal with an amplitude proportional to the dust grain's charge.





The figure to the left is an example of an ideal detector signal. The fastest, and most interesting, particles also tend to be the least massive and lowest charged. This low charge presents difficulties in analog triggering as the signal is often embedded in noise.

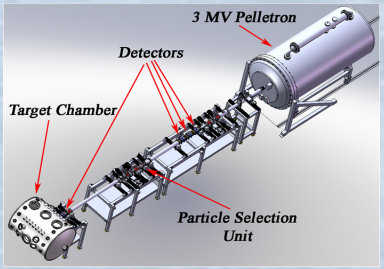
FPGA

Field Programmable Gate Arrays (FPGAs) offer a hardware platform to place complex digital logic. They are useful when the design calls for:

- Speed
- Parallelism
- Reconfigurability

LabVIEW FPGA module is a good option for developers as it allows for FPGA programming with hardware integration built into a development environment that is already commonly used in science and engineering.

Accelerator



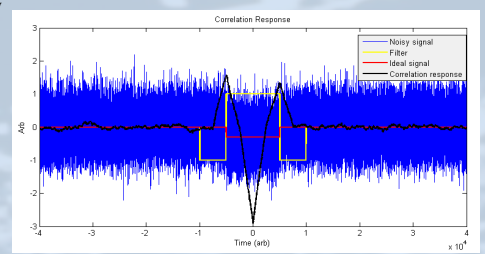
The 3MV accelerator allows for impact studies and calibration services. Its use as a scientific tool rests on its ability to detect and select in-flight dust grains for the target chamber. An FPGA based system is being developed to detect charge and velocity of signals with SNRs as low as 0.25.

Real-Time Cross-Correlation

A cross-correlation is an effective way to extract a triggerable response from a noisy signal. The equation below describes the technique: f(t) is the filter function, g(t) is the signal, and h(t) is the correlation response.

$$h(t) = \sum f(t)g(t-\tau)$$

This implementation has 7 filters of the shape shown in yellow to the right, with widths a factor of 2 apart, spanning 1-128 km/s. The filters threshold at certain correlation response levels, and start a counter at the correlation zero crossing. Timing the zero crossings from the 1st and 3rd detector gives velocity. The charge is measured by first running the signal through a boxcar filter, measuring RMS noise of the smoothed signal, and then taking a sample and hold of the smoothed signal.



The figure shown here is a simulation showing the effectiveness of cross-correlation. The real-time nature of this implementation (μs time scales) means a software implementation isn't possible.

Discussion

- Simulations of the FPGA code show an ability to detect signals with an SNR as low as 0.25.
- Methods described here can be used for any low SNR signal processing task where signal shapes are known.
- LabVIEW FPGA module offers advantages to VHDL and Verilog because of its inherent hardware integration and use of a language that is commonly used in the community.

Acknowledgements

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