Master Thesis

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The conceptual design and development of Novel low cost sensors for measuring the relative light emission in the pre-millisecond stages detonating explosive charges

Olivier M

CSIR. Defence, Peace, Safety and Security. CSIR, PO Box 395, Pretoria, 0001

Abstract

During the course of the CSIR's research into the characterisation of explosive sources to devise methods of active intervention against threats, the need has arisen to research a particular means of early identification of the threat, which is the intense light flash during the threat detonation. For this purpose, a low cost rugged fast optical sensor was sought, since the application thereof would imply possible destruction, especially if integrated into an active intervention system later on. Given the average time of about 1ms available for intervention, it is clear that the active intervention system needs to operate within that period, hence the interest in the characteristic light emission of detonations in the pre-millisecond time frame. It was thought that by characterising this emitted light in terms of wavelength (temperature) and amplitude (and maybe other unique phenomena), the size of the threat could be determined and logic decisions derived therefrom. Needless to say, the environment in which the detonation light emission sensor is to operate, is extremely hostile in terms of shock, dust, flying debris, fast rise time of the explosive event, and Electro-magnetic Interference (EMI) caused by the detonation itself. It must be noted that the light sensor research was driven by the outcome of research tests performed in aid of the development of an active intervention system. During this research the possibility of using commercially available low cost optical detectors at room temperature in combination with cost effective narrow band pass op- tical filters for the relative measurement of the light emission at discrete wavelengths during explosive detonation events were investigated. In 2006, not much applicable lit- erature could be found on this subject, hence the educated "shot-in-the-dark" approach then, which, by a systematic approach of explosive tests and continuous evaluation up to 2011, led to a surprisingly simple and robust low cost optical sensor. The research commenced with a range of optical detector elements selected for their responsivity and bandwidth in the optical spectrum of interest; the optical filtering by means of the recording of the emitted light signal during scaled down explosive tests at the Blast Impact Survivability Research Unit (BISRU) at the University of Cape Town. These tests were followed by full-scale tests at DBEL, and confirmed the findings at BISRU that the light emissions at the longer wavelengths (>2 m) manifest themselves too late for use within the intervention time frame. It was therefore decided to concentrate on the ultra-violet (UV) to near infra-red (NIR) spectrum of the emitted light for further full scale tests, since these discrete spectra showed the most promise for characterisa- tion of the emitted light. During this period a robust sensor housing with detector and filter mounts was designed for protection against blast shock and EMI. During the following years, certain types of optical detectors that were used during previous tests were eliminated according to results obtained, and more discrete narrow band pass filters added in the visible to NIR spectrum. A dedicated fast instrumen- tation amplifier (bandwidth > 1MHz and selectable gain up to 40dB) was developed to amplify weak signals (mainly caused by the heavy load in the detector circuit to improve rise times). However, the emission of light per wavelength in this region was measured to be relatively strong, and actually not as fast as was anticipated. This meant that the load resistor value of the detector element could be increased without affecting the signal

negatively (bandwidth sufficient), thus adding to the amplitude of the signal to such a point that amplification in a 10m to 30 meter stand-off scenario was no longer needed. This culminated in an unamplified universal detector element being used with various narrow band pass filters up to 1 m, integrated as a very robust analog sensor at a discrete wavelength, and facilitating the direct comparison of light amplitude/relative intensity of the detonation at discrete spectral points. The sensor was employed in the field at various full scale explosive tests at DBEL, which led to the capture of a vast amount of light emitted data for different types of explosives, at various distances from the detonation, and of varying mass. Analysis of this data showed that the broadband light intensity of the emitted light scales to the explosive mass1/3 (as published by FJ Mostert and M Olivier in the Journal for Applied Physics, October 2011). Further analysis also confirmed the attenuation of the emitted light intensity by the square of the distance. Besides the aforesaid, various other key inputs to a possible active intervention algorithm have been identified. These findings are inputs to the determination of i.a. the detonation threat size, a vital component in the active intervention algorithm. The results of these experiments confirmed that the final low cost analog sensor can measure relative light emission at discrete wavelengths from detonation of explosives in the very early stages of development, and that the sensor has many other applications in the detonics research fields as well.