Analyzing an Array of Diamond Photodetector Detectors

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Summer High School Research Program
2003

Abstract:

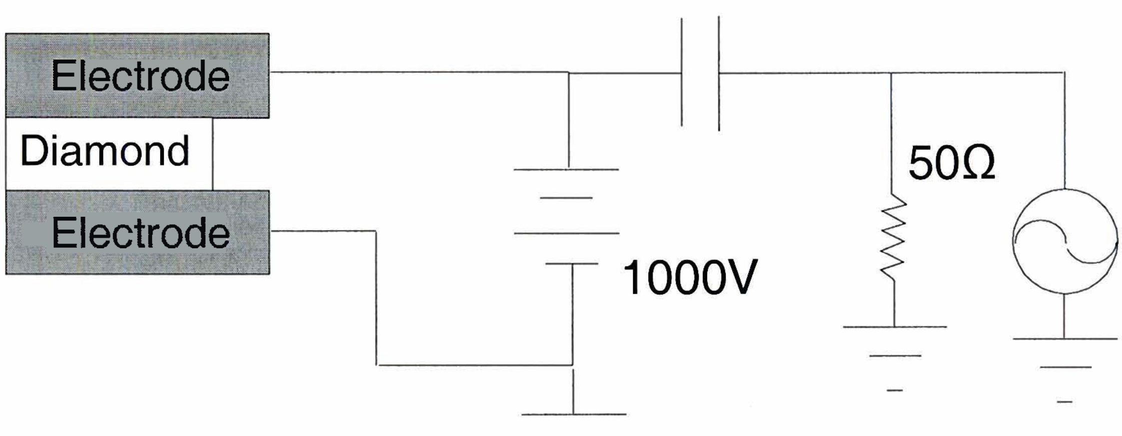
Diamond photoconductor device (PCD) detectors are used to measure X rays emitted by the implosion of a target within the target chamber. The temporal profile of the X-ray emission is encoded in the voltage signal from a PCD by the response function of this detector. Recovering the time dependence of the x rays requires deconvolving the diagnostic response from the measured signal using mathematical transforms. Before this process can occur, the noise from the signals must be reduced. Two methods of function approximation have provided the best results. One method uses the Hermite series of orthogonal polynomials, and the other method uses a Gaussian function that has been convolved with two separate exponential functions. In addition to the deconvolution problem, other tasks involving the PCD detectors were carried out. A backup array holder had to be fashioned with slight modifications added, and the apertures inside the PCD detector were all verified to be in their proper position. With those measurements, calculations were made to find the field of view of the photo array.

Introduction to Inertial Confinement Fusion:

Inertial confinement fusion is a study that hopes to efficiently carry out fusion reactions using extreme forces. By compressing a small target of deuterium and tritium with many laser beams, the pellet will reach the high pressures and temperatures required for fusion. The outer portion of the target expands outward, while the core of the target pushes inward . Both of these processes emit X rays outward from the pellet. Various X-ray detectors mounted on the target chamber receive the signal from the shot. The X rays then are used to analyze the dynamics of the shot.

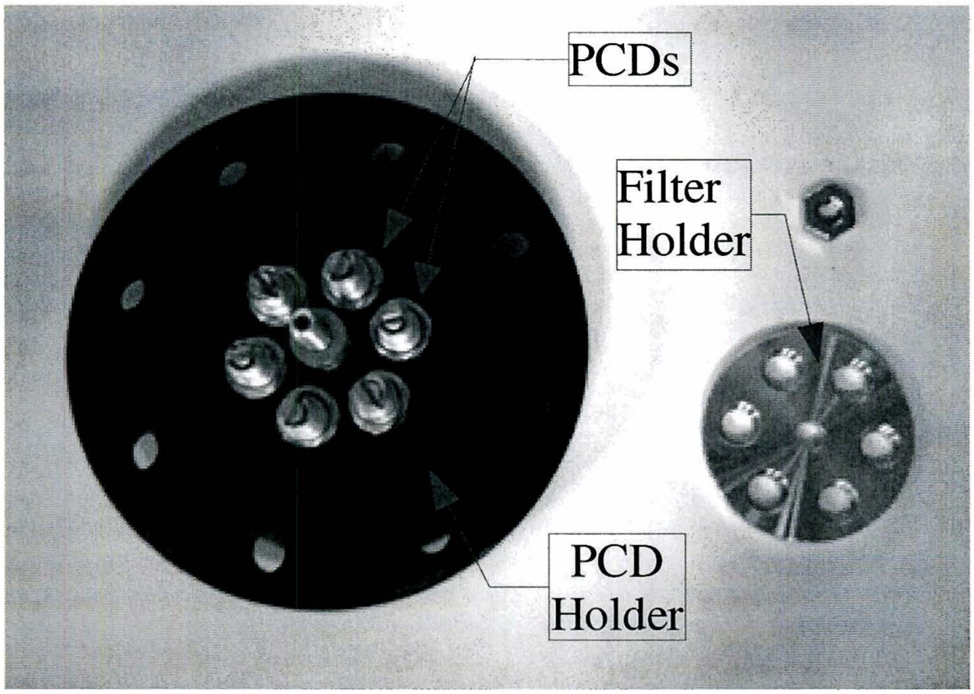
Introduction to Diamond Photoconductor Devices:

Diamond Photoconductor Devices (also referred to as Diamond PCDs) are used to measure the intensity of X rays. Diamond has a unique photoelectric property that it responds to X rays but not the ultraviolet rays used by the Omega laser. This characteristic works to eliminate a lot of the interference that other X-ray detectors have. The diamond, that receives the radiation, is located between two electrodes. This makes the PCD behave like a capacitor. Below is a diagram of the Diamond PCDs in circuit.



A photocalorimeter on the Omega laser uses six PCDs to record information about the emission of X rays from the target. This instrument uses a series of apertures to block the stray X rays and focus on the X rays that were emitted by the target.

Building a PCD holder:



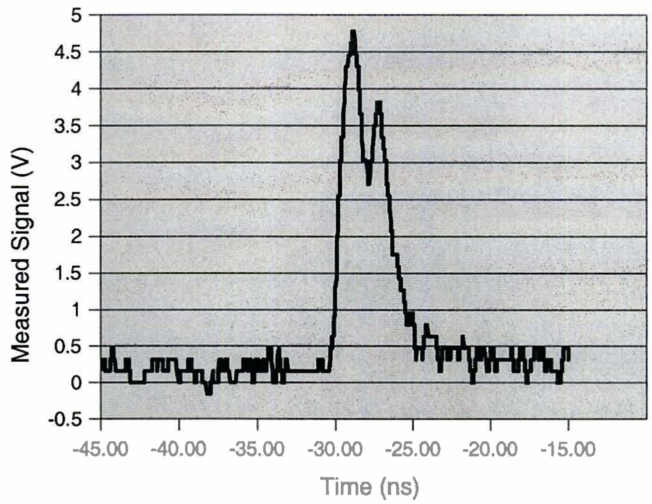
New PCDs are going to be used on the photocalorimeter. These new detectors are significantly smaller than their predecessors. To adapt to this change, a new PCD holder and PCD filter holder needed to be fashioned. With the PCD holder and filter holder closer together than before, a way of mounting one onto the other had to be developed. To solve this problem a small screw tapped post was placed at the center of the holder. The filter holder was modified as well. The old radius to the center of the holes was half of an inch and was enlarged to a full inch.

Calculating a Field of View:

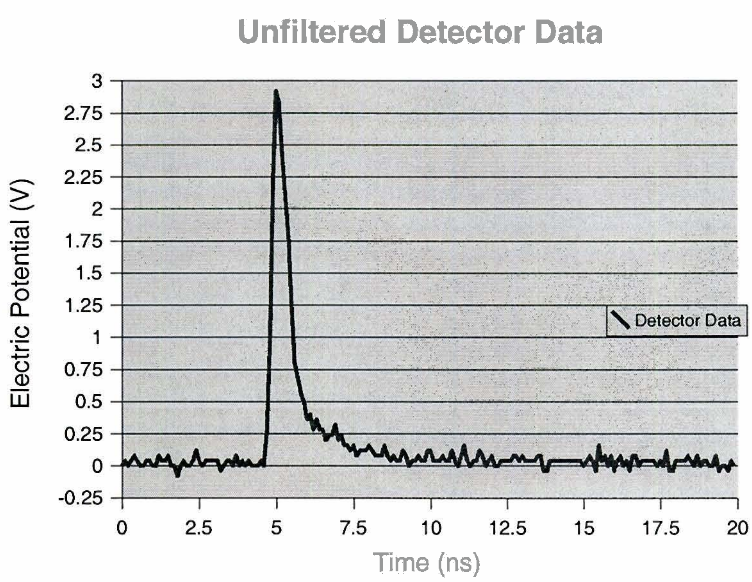
The photocalorimeter's set of four apertures (including the filter holder) is uniquely designed for the current PCD arrangement. However, new PCDs and other possible modifications could cause the apertures to block out some of the X-ray signal, thus decreasing the accuracy of the instrument. Solving this problem requires precise measurements of the position of the apertures as well as verification of the aperture sizes. Using the measurements, it has been calculated that the current arrangement allows for an infinitesimally small object to be seen 20.3cm behind and 54.6cm in front of the actual target position. It was also found that the new, smaller PCD would be able to view the entire target and still have ample leeway for future modifications.

Analyzing Data from a PCD:

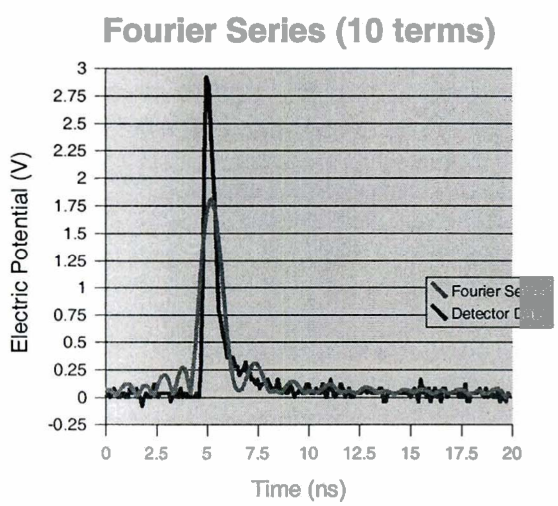
PCDs do not measure the X-ray signals perfectly. The devices behave similar to a capacitor in its circuit, and have two separated metal diodes. Theoretically, a capacitor will discharge its voltage in an exponential fashion. When looking at a graph of the response from a diamond PCD, there should be two separate pulses (the first pulse from the outer shell emission and the second pulse from the implosion of the core of the target), one convolved pulse is produced, as in the graph below from PCD 2 on shot 21578.

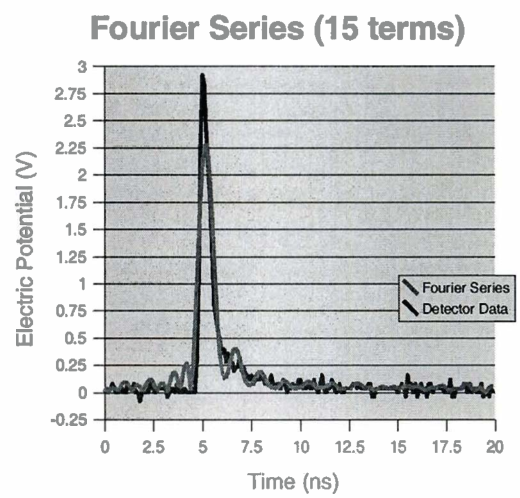


Shots 27260 and 27261 were used to measure the response function of the diamond PCDs. This response function will enable us to deconvolve the signals received from the detectors. These shots used a 100 ps pulse directed at a solid gold sphere, where there was no implosion. The readings from these shots show how an X-ray signal, similar to a delta function, is distorted. Below is the raw data from PCD 2 on shot 27261.



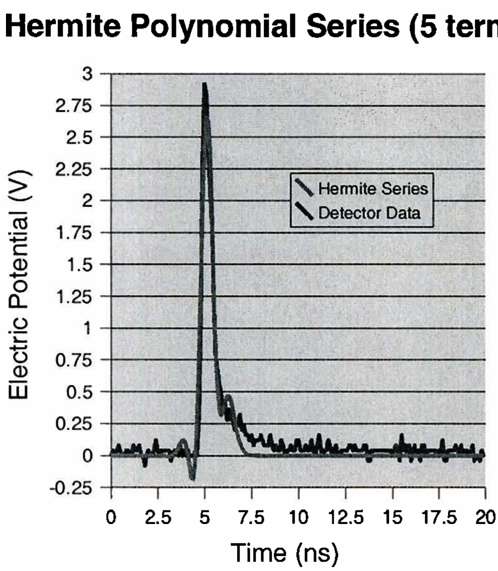
The first step in returning the PCD data back to the actual X-ray signal is to eliminate the noise in the response function, which would be amplified in the deconvolution process. To do this, a model of the response function was needed. The first method to accomplish this was using a Fourier series. A Fourier transform was taken on the data for the response function, and only the lower frequencies were kept. Those frequencies were then inverse Fourier transformed into a smoothed response function. This process yielded very poor results.

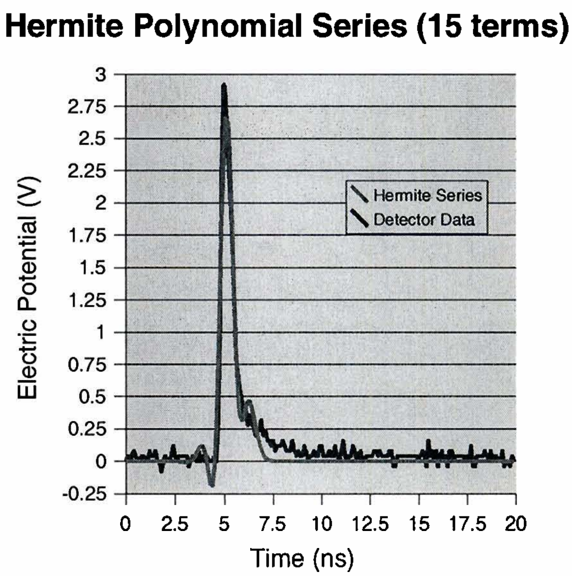




As the number of terms in the Fourier series increases the peaks are more closely approximated. However, the peaks of the data set were not closely modeled at any of the different term levels. The modeled functions also oscillated heavily at either side of the pulses.

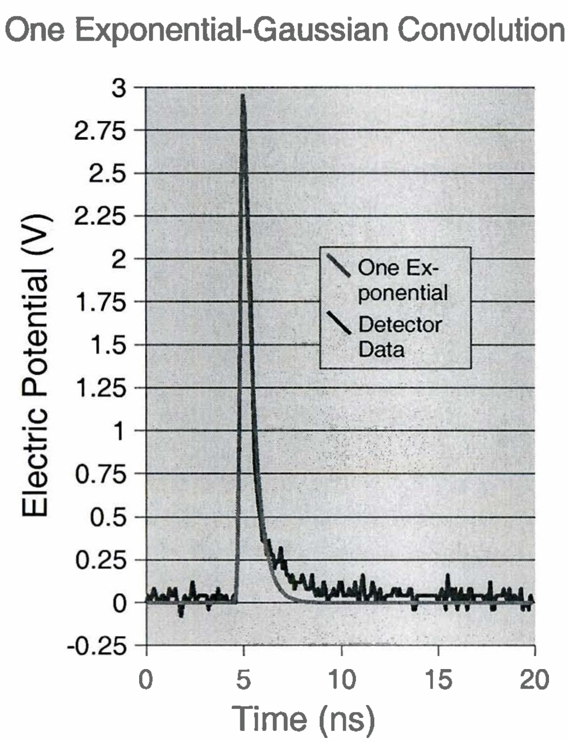
The second model for the function was derived using the Hermite series of orthogonal polynomials. This series was chosen for this process because it had the weighting function of a Gaussian (in this case $e^{-(x^2)/2}$). The noise of the function in relation to the functional value of true response is lowest at the peak of the data and highest at the ends. Because the Hermite series has a built in weighting function, the values at the peak will be closely followed and the noise at the base will be ignored. The Fourier series is lacking a weighting function of this kind. The results from this decomposition were vastly better than those of the Fourier series.

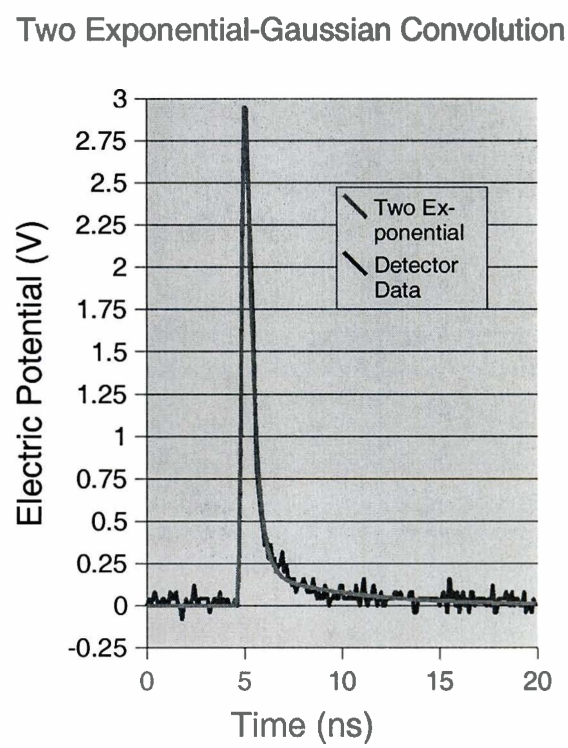




These graphs show that as the term number increases the precision of the approximation on the pulse increases. With too many terms, the area of the curve to the right of the pulse does not follow the nature of the curve.

The best representation of the data was created by using a model for the detector that fits an exponential function convolved with a Gaussian function. The PCDs work like capacitors in circuits, which discharge energy in an exponential fashion. The convolution integral was solved for the Gaussian and the exponential, and fitted to the data using the nonlinear least squares (NLINLSQ) function in PV Wave. The NLINLSQ function evaluates a number of permutations of the function with slight changes made to the different input variable. The function returns the model that creates the smallest value for the sum of the squared differences between the representation and the data. For further accuracy, instead of using a single exponential in the function, a double exponential was used. This provided the best results of any model.

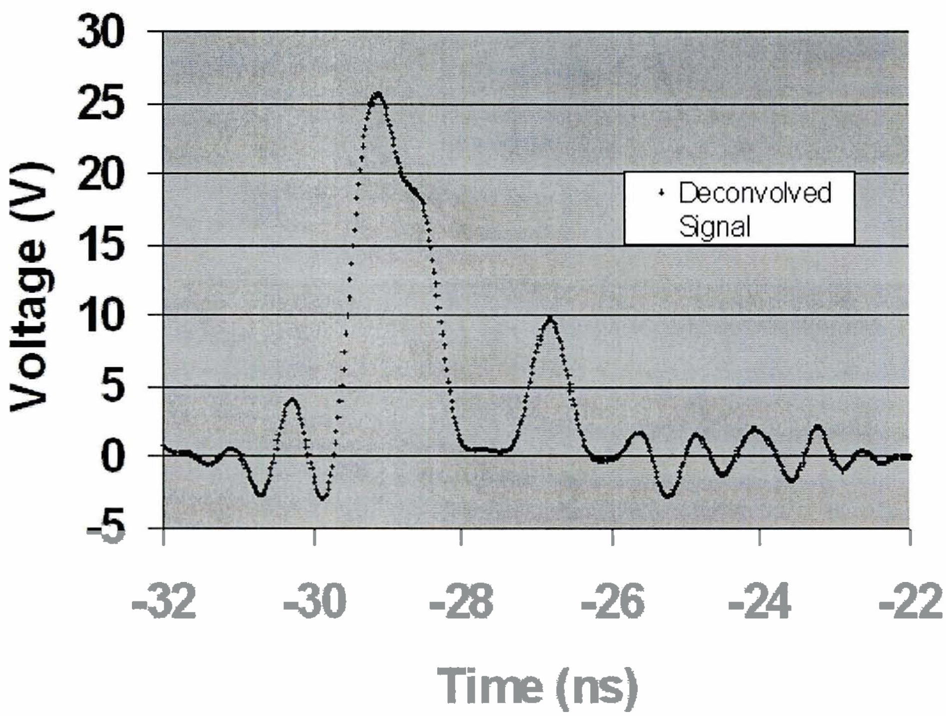




Both of these graphs approximate the peaks of the data with good precision. The single exponential does not follow the tail of the data, while the double exponential is a close approximation at almost every point.

Deconvolution:

The response function has been modeled to a high degree of accuracy and can now be used to determine the X-ray signal from a PCD. First, the quotient of the Fourier transform of the data from the detector and the Fourier transform of the response function is found. If the response function had not been modeled, the noise from that data would have been amplified by the Fourier transforms, leaving little useful data. Even so, the new data's noise will cause the high frequencies of the Fourier transform to distort the result. To deal with this problem a Weiner filter is used to eliminate the high frequencies. After the filter is employed the product is inverse Fourier transformed into the final signal seen below.



The result differs from the input data because it contains two distinct pulses, which is what really happens in the target chamber. Oscillations are seen at either side of these pulses. The oscillations are caused by the filter used in the process, which eliminates all of the high frequencies of the Fourier transform.

Conclusion:

The x-ray emission of the target explosion and implosion is hidden in the response function of the PCD device. To lower the noise in the response function, different processes of function approximation were tested. In the end, a double exponential convolved with a Gaussian yielded the best results. With this function the x-ray emission can be lifted from the voltages recorded from the detector. The photocalorimeter has a new PCD holder and filter holder to adapt itself to the new style PCD.

Acknowledgments:

I would first like to thank Dr. James Knauer for all of the time and effort he has devoted towards this project. I would also like to thank Dr. R. Stephen Craxton and the Laboratory for Laser Energetics for allowing me to participate in this unique and exciting program. The summer research program has been an invaluable learning experience that I would recommend to any student interested in the sciences.