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Correcting raw diagnostic data for oscilloscope recording system distortions at the National Ignition Facility

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ABSTRACT

The National Ignition Facility (NIF) is now producing experimental results for the study of inertial confinement fusion (ICF). These results are captured by complex diagnostic systems and are key to achieving NIF's goal to demonstrate thermonuclear burn of deuterium and tritium fuel in a laboratory setting. High bandwidth gamma-ray fusion-burn measurements and soft X-ray indirect and direct drive energetic measurements are both captured with oscilloscope recording systems that distort or modulate the raw data. The Shot Data Analysis team has developed signal processing corrections for these oscilloscope recording systems through an automated engine. Once these corrections are applied, accurate fundamental quantities can be discerned.

1. Introduction

The NIF, a 192-beam pulsed laser system for studying inertial confinement fusion (ICF) [1], was completed in May 2009 and is currently producing experimental data and results. Data is collected with specialized diagnostic instruments that measure optical, X-ray, and nuclear phenomena. Interpreting the data from these diagnostics is key to fulfilling NIF's goals of demonstrating ignition of deuterium and tritium fuel in a laboratory setting. These important data, collected after each NIF laser shot, is uniquely distorted by the custom hardware used to collect the data. These distortions must be carefully removed from the data, without increasing the noise or decreasing the bandwidth or dynamic range, before the NIF experimental results can be further studied.

The NIF Shot Data Analysis team (SDA) has built algorithms to remove distortions and further process and quantify results from diagnostic data. After a shot, all diagnostic data are automatically transferred to an Oracle database from which the NIF Shot Data Analysis Engine is triggered. The engine runs the signal and image processing algorithms on a Linux cluster and stores results back into the Oracle database where they can be viewed by scientists [2]. The Shot Data Analysis flow is shown in Fig. 1.

Oscilloscope recording systems are used to record raw outputs from the Dante soft X-ray flux diagnostic and the Gamma Reaction History (GRH) diagnostic. This paper will review the signal processing algorithms used to remove the oscilloscope recording system distortions from these two diagnostics. Section 2 will cover the demodulation and stitching scheme used to unfold and combine high dynamic range GRH signals sent through a Mach–Zehnder optical link. Section 3 will review the methods employed to correct the non-uniform timebase distortion of the raw Dante data introduced by equivalent time sampling oscilloscopes as well as the corrections for the cable induced signal dispersion and attenuation.

2. Gamma Reaction History diagnostic (GRH)

2.1. GRH hardware overview

The GRH diagnostic measures nuclear bang time and burn width, which are fundamental to diagnosing ICF implosions and steering NIF toward ignition. Fusion gamma-rays provide a direct measure of the nuclear reaction and are not affected by Doppler spreading like neutrons [3].

The gamma ray signals are detected by Gas Cherenkov Detectors that convert high energy gamma-rays to visible or UV light. The visible photons are then collected by fast optical recording systems that include an ultrafast photo-multiplier tube (PMT). The electrical PMT output signal is split and sent to two Mach–Zehnder modulators for transmission through a fiber optic cable with minimal loss

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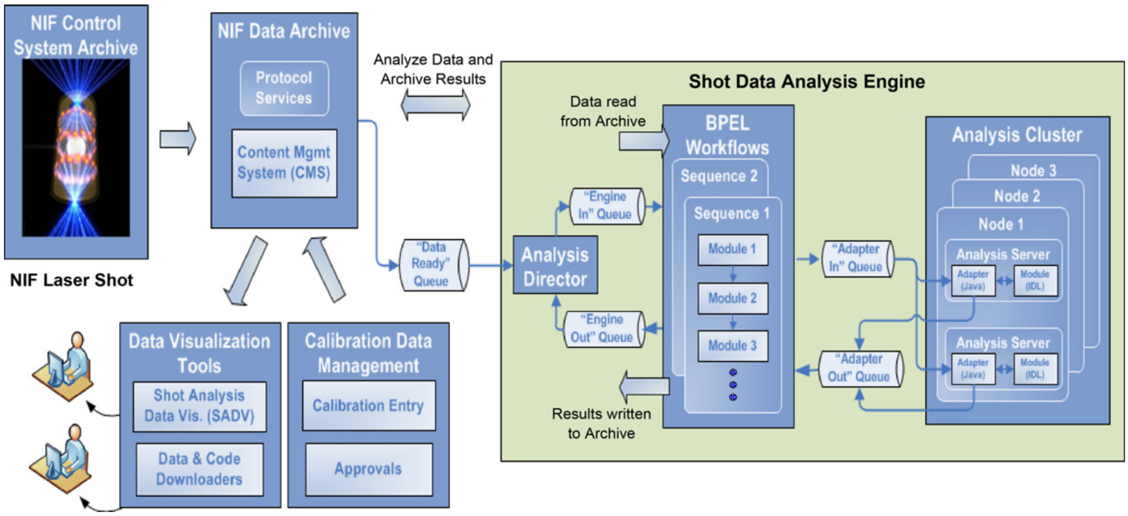

Fig. 1. Shot Data Analysis automated engine workflow.

of bandwidth. Finally, both signals are split again and detected with four photodetectors before being acquired by a four channel scope [3]. The diagnostic flow is shown in Fig. 2.

2.2. *GRH recording system distortions*

The fiber links at NIF are based on Mach–Zehnder (M–Z) modulators because they are well suited to analog signal transmission and recording of pulsed power diagnostics. They preserve bandwidth over arbitrarily long fibers (as opposed to co-axial cables), they can tolerate large voltage pulses without damage, and they have high-gain input amplifiers. The default configuration for NIF uses two M–Z modulators per GRH detector and a 10× difference in attenuation to provide a dynamic range of 1000:1 at full system bandwidth. Each M–Z signal is then split and sent into two photoreceivers. To achieve the highest dynamic range and minimize the signal to noise ratio, one channel is AC coupled and records the signal at the level of the laser noise and the other channel is DC coupled to record the full amplitude from the M–Z. The digitizer channel coverage is shown in Fig. 3 [4].

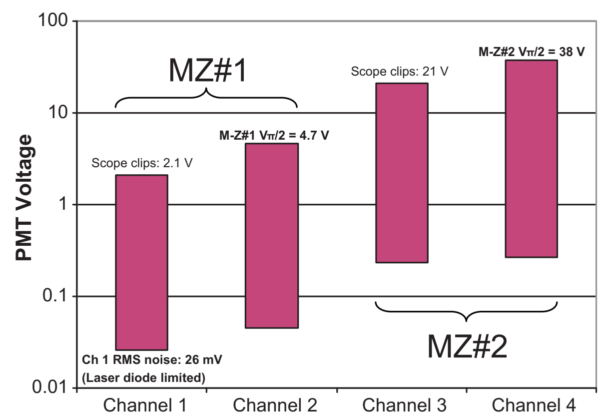

Fig. 3. GRH system dynamic range.

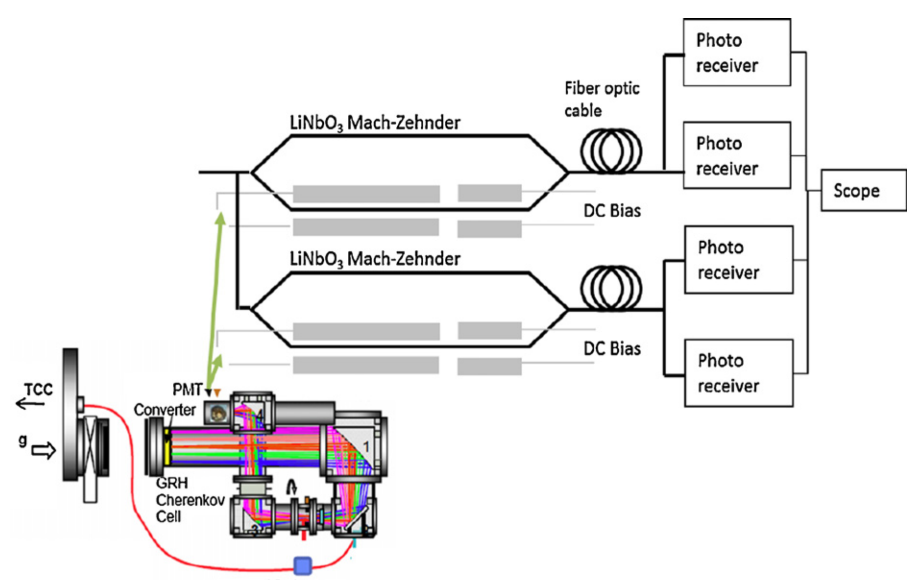

Fig. 2. GRH diagnostic hardware layout.