Fusion Engineering and Design 87 (2012) 1940–1944

Contents lists available at SciVerse ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

The shaping of a national ignition campaign pulsed waveform

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HIGHLIGHTS

- NIF pulse is generated using an electro-optic modulator to vary the intensity of light.
- Electrical impulse generators, each with a 300 ps pulse Gaussian signal are utilized.
- Adjusting the impulse amplitude for 140 impulses, produces a pulsed waveform.
- System auto shapes 48 waveforms with to 275:1 contrast ratio with 3% absolute error.

ARTICLE INFO

Article history:
Received 9 August 2011
Received in revised form 22 August 2012
Accepted 25 September 2012
Available online 16 October 2012

Keywords:
Pulse shaping
Laser controls

ABSTRACT

The National Ignition Facility (NIF) at Lawrence Livermore National Laboratory is a stadium-sized facility containing a 192 beam, 1.8 MJ, 500 TW ultraviolet laser system used for inertial confinement fusion research. For each experimental shot, NIF must deliver a precise amount of laser power on the target for successful and efficient target ignition, and these characteristics vary depending on the physics of the particular campaign. The precise temporal shape, energy and timing characteristics of a pulsed waveform target interaction are key components in meeting the experimental goals. Each NIF pulse is generated in the Master Oscillator Room (MOR) using an electro-optic modulator to vary the intensity of light in response to an electrical input. The electrical drive signal to the modulator is produced using a unique, high-performance arbitrary waveform generator (AWG). This AWG sums the output of 140 electrical impulse generators, each producing a 300 ps pulse width Gaussian signal separated in time by 250 ps. By adjusting the amplitudes and summing the 140 impulses, a pulsed waveform can be sculpted from a seed 45 ns square pulse. Using software algorithms written for NIF's Integrated Computer Control System (ICCS), the system is capable of autonomously shaping 48 unique experimental pulsed waveforms for each shot that have demonstrated up to 275:1 contrast ratio with ±3% absolute error averaged over any 2 ns interval, meeting the stringent pulse requirements needed to achieve ignition. In this paper, we provide an overview of the pulse shaping system, software algorithms and associated challenges that have been overcome throughout the evolution of the controls.

Published by Elsevier B.V.

1. Introduction

The NIF laser system [1] provides a scientific center for the study of inertial confinement fusion (ICF) and matter at extreme energy densities and pressures. One of the many tunable parameters critical to the success of ICF experiments is the laser pulse shape and timing [2]. Each NIF Quad (4 beams) can be configured, through experimental specifications, with distinct temporal pulse shapes. Once configured, controlling the pulse shape and energy within tight tolerances is critical to meeting these experimental goals [3]. NIF's Integrated Computer Control System (ICCS) [4] software algorithms have been developed to autonomously create and regulate each of these pulse shapes using a high bandwidth, programmable arbitrary waveform generator (AWG) to sculpt the required waveform from a seed optical square pulse.

Since the pulse shaping systems' inception the software algorithms have evolved considerably to meet the increasingly challenging pulse shape characteristics. In this paper we describe an overview of the pulse shaping system and the software controls used to successfully meet a wide variety of NIF experiment goals.

2. Pulse shaping system

Each of the NIFs' 48 Quads is capable of generating a unique temporal pulse shape to support the experimental goals. Each pulse shape is sculpted from a 45 ns square optical pulse using an arbitrary waveform generator (AWG). The AWG utilizes a 2-stage lithium niobate electro-optic modulator that varies the intensity of

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0920-3796/$ – see front matter. Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.fusengdes.2012.09.019

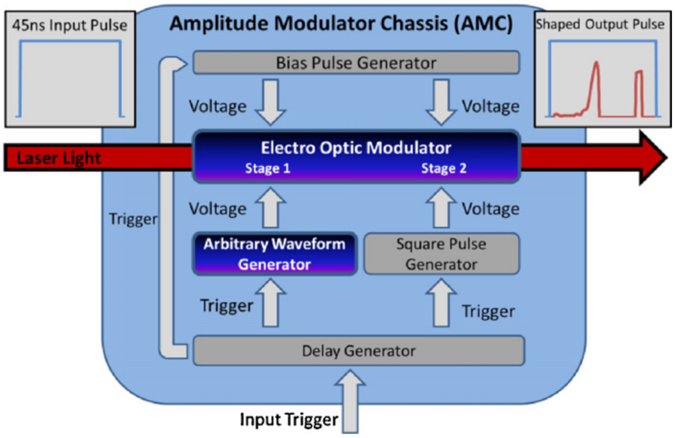

Fig. 1. Amplitude modulator chassis system components.

light in response to an electrical input. The electrical drive signal to the modulator is produced by a unique, high-performance AWG. The AWG was created by Highland Technologies, Inc. specifically for the NIF and provides programmable 16-bit amplitude modulation control over an Ethernet protocol. Each AWG is deployed in a self-contained replaceable unit named an Amplitude Modulator Chassis (AMC). All of the 48 AMCs are physically located in Master Oscillator Room (MOR) of the Injection Laser System (ILS) [5] section of the NIF. Fig. 1 shows a block diagram for the system components of an AMC.

The AWG sums the output of 140 electrical impulse generators, each having 300 ps pulse widths and temporal separation of 250 ps. By adjusting the amplitudes and summing the 140 Gaussian pulses, an arbitrary electrical pulse shape is generated. An additional phase modulator is then driven with a square pulse generator to sharpen the pulse edges and regulate the output energy of the pulse shape. Fig. 2 depicts an example of how an arbitrary waveform is generated by the system using the summation of the Gaussian impulse generators. The following sections describe the software controls developed to autonomously shape each of the experimental goal waveforms using a close loop feedback control process.

3. Pulse shaping controls

NIF pulse shaping was originally accomplished using a LabView based system requiring operator interaction to manually shape the desired experimental waveform. This process relied heavily on human interaction and judgment and took many hours to complete. It was obvious that this process would not scale to a full NIF 48 Quad system and as such led to the design and implementation of the pulse shaping control system. The deployment of the controls has resulted in a completely autonomous system capable of shaping an arbitrary goal waveform concurrently on all NIF Quads within 1 h of execution time. Fig. 3 shows a block diagram depicting the main software components involved in the autonomous shaping of a NIF pulse.

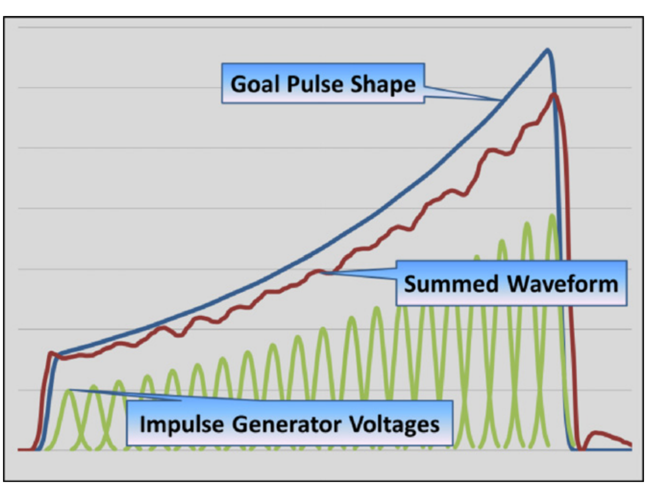

Fig. 2. Example pulse generation using impulse summation.

3.1. Shaping coordinator

Each NIF shot calls for up to 48 Quads to participate in achieving the experiment goals. The Shaping Coordinator establishes and mediates a session of Pulse Shapers corresponding to the Quads required for the shot. The coordinator initiates autonomous operations that allow concurrent execution of actions, such as shaping or energy regulation, on an established session.

3.2. Scope diagnostic mediator

The pulse shaping close loop feedback controls use scope digitizers to capture the generated optical waveform. To minimize system costs and space requirements, all 48 Quads are shaped using a total of 3 scope digitizers (16 AMC waveforms per scope). The Scope Diagnostic Mediator restricts the use of a scope to one Pulse Shaper at any particular time. The mediator allocates each Pulse Shaper a time slice in a prioritized round robin manner.

3.3. Pulse shaper

In order to achieve the experimental goals, each Quad (and thus each AMC) often require a different pulse shape specification. The Pulse Shaper control is responsible for performing the autonomous close loop feedback control to iteratively shape each Quad waveform to the goal pulse shape profile.

Each of these software components play a vital role in the waveform sculpting process however the rest of this paper focuses predominantly on the Pulse Shaper control as it provided the greatest challenges. The shaping process consists of several sequential phases starting with the calibration of the system, followed by shaping the pulse, and completing with the verification of the waveform and regulating of the pulse shape and energy over the duration of the experimental shot.

4. Impulse calibration

Calibration of each AMC, prior to pulse shaping, is critical to achieving the precision requirements required for an ICF waveform. Each AMC system is required to support waveforms from 0.1 ns to 30 ns in pulse duration, with contrast ratios of up to 275:1 and timing precision Quad to Quad of 30 ps RMS. A major factor affecting waveform variance over time is drift in the timing of each AWG impulse. The impulse calibration of each AWG originally involved an intensive 2-day procedure requiring a specialized system configuration and manual tuning of each individual impulse location.

Software controls have been developed to perform this calibration autonomously without the need for specialized system configurations. The calibration operation segments the 140 AMC impulses into four sets, each comprising of every fourth impulse. Selecting every fourth impulse in a calibration set maximizes the execution parallelism while ensuring there is no influencing overlap in signal summation. The execution of the calibration configures an equal voltage on each impulse, performs a high resolution (1 ps per point) waveform acquisition, measures the time of each peak by interpolation of the full width, half maximum Gaussian at the