Temporal pulse shaping of a nanosecond laser for tissue ablation.

Degree programme: Master of Science in Engineering | Specialisation: Photonics
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Tissue ablation can be performed by pulsed, high-power laser systems such as the Master Oscillator Power Amplifier. The subsequent amplifier chain exhibits highly nonlinear characteristics, which distorts the temporal pulse shape. In an iterative optimization process, the temporal pulse shape is corrected by modulating the current of the master oscillator.

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Introduction

Laser systems are widely used in material processing, industrial applications and medical procedures such as ablating tissue. It is known from material processing that ablation efficiency depends not only on the pulse energy but also on the time-resolved pulse shape. Therefore, controlling the temporal pulse shape would be desirable to optimize ablation processes.

Theory

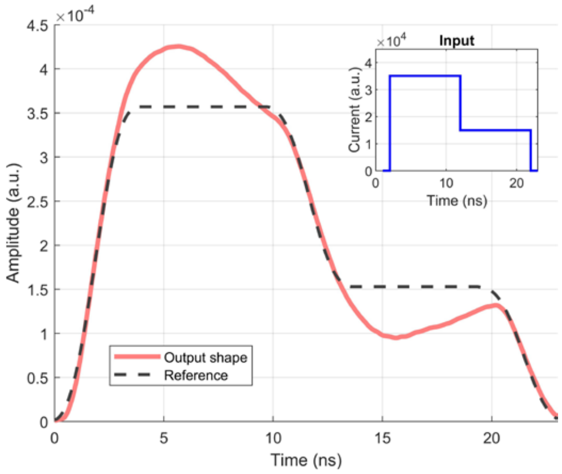
Active fibers are used in the Master Oscillator Power Amplifier (MOPA) laser for optical amplification.
The dopant atoms are optically excited into a higher energy level, creating a population inversion. A pulse travelling through the fiber can stimulate those excited atoms to release their energy as a photon, amplifying the pulse. The gain provided by the amplifier depends on the population inversion.
However, a strong pulse can deplete the population inversion, resulting in a time-dependent, nonlinear gain that distorts the pulse‘s temporal shape.

Method

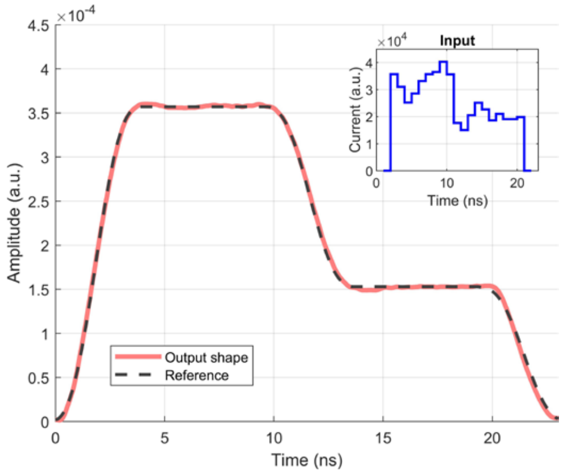
The current of the master oscillator is controlled by the computing system allowing arbitrary nanosecond pulse shapes. Two active fibers amplify these pulses, including one operating in the nonlinear regime. Typically, these nonlinearities are corrected by the Frantz-Nodvik equation with prior knowledge of the amplifiers. However, the initial pulse is already distorted due to the electro-optical response of the master oscillator resulting in inaccuracies in the equation. Hence, a pulse shaping technique is implemented using a modified particle swarm optimization (PSO). The PSO uses stochastic methods to optimize the output pulse to a desired reference shape.

Result

The implemented pulse shaping technique successfully adapts the input current to shape different output shapes. The algorithm exhibits stable convergence, typically converging to a satisfactory solution within approximately 30 iterations. In this example, the algorithm was employed on the stair pulse (see figure). The algorithm reduces the root mean square error (RMSE) by a factor of ten.



Before optimization, the RMSE is 3.3e-05 between the reference and the output shape.



After optimization, the RMSE is improved to 2.6e-06 with the optimized input shape.