Pulse Shaping on the OMEGA Laser System

Current target designs for laser-driven inertially confined fusion experiments require that the laser drive pulse be tailored to the target, i.e., that the pulse have some temporal shape other than Gaussian. On the 60-beam OMEGA[1] laser system this is accomplished by placing an electro-optic modulator at the input of the system, which is driven by an electrical pulse from a shaped microstrip line. This modulator shapes a 10-ns square optical pulse from a single-mode Nd:YLF laser, which is preamplified in a regenerative amplifier (regen) and then sent through the subsequent OMEGA amplifier chains. Gain saturation in the amplifiers and the presence of the frequency-tripling cells cause a significant distortion of the input pulse at the output; however, by modeling these effects we can generally construct a microstrip line that produces a desired output in one pass.

Pulse-Shaping System

The pulse-shaping system, shown schematically in Fig. 72.16, has been described in detail in Ref. 2 and will be described only briefly here.

1. Optical System

The initial pulse is generated from a 10-ns pulse sliced from a 100-ns single-longitudinal-mode Nd:YLF laser pulse using conventional Pockels cells. This pulse is input to the dual-amplitude, fiber-coupled waveguide integrated-optic modulator. In our system, one of the two modulators is used as a gate and the other for shaping. The gate and shaped waveforms are applied to the modulator radio frequency inputs, while the dc inputs are used to adjust the modulator dc offset. The gate pulse is used to suppress possible pre- and post-pulses from the shaped-pulse–generation process and can aid in the production of pulse shapes with very steep rise or fall times.

2. Electrical Waveform Generation

The electrical waveforms are generated using a system modeled after a design developed at Lawrence Livermore National Laboratory (LLNL).[3] The gate pulse is generated using a 50-Ω microstrip with a single Si photoconductive (PC) switch at one end. The microstrip is charged to the half-wave voltage of the modulator. When the Si PC switch is triggered using a short optical pulse, a square pulse of twice the electrical length of the microstrip line is generated.

The shaped pulse is generated using a 50-Ω microstrip charge line with an Si PC switch at each end. One end of the line is connected to a shaped microstrip line, while the other end is connected to the modulator. The switch nearest the shaped microstrip is triggered first, using a short optical pulse. The square pulse from the charge line propagates down the shaped microstrip, generating a shaped reflected pulse. The second switch is triggered after the initial pulse has left but before the

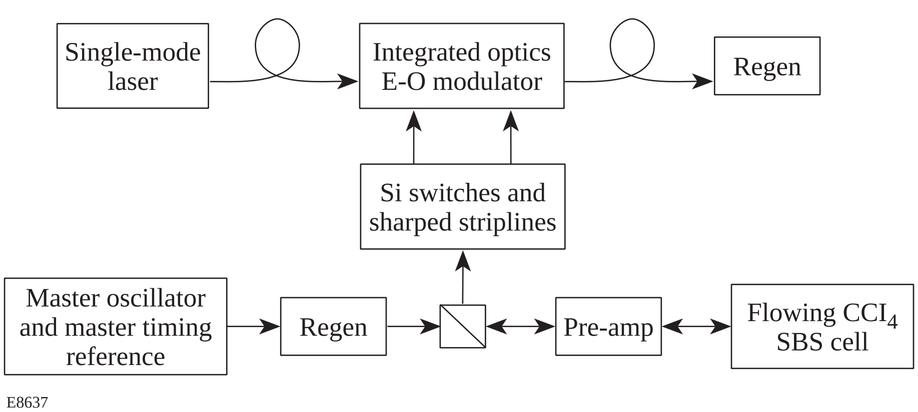

Figure 72.16
The pulse-shaping system consists of the optical modulators, electrical-pulse–generation system, and the SBS pulse-generation system used to trigger the Si photoconductive switches.

reflected pulse has returned, allowing the reflected pulse to propagate to the modulator. Recently, the separation between the charge line and shaped line has been increased by connecting a cable between them. This allows transients caused by the switches to die out before the reflected pulse propagates back through the charge line.

The reflection coefficient required to produce the desired electrical pulse is calculated using a layer-peeling technique.[3] From this technique, the width of the shaped microstrip can be calculated using the formulas of Ref. 4. The microstrip is machined to the required profile using a computer-controlled precision milling machine.

3. Trigger-Pulse Generation

The fast-rise-time pulses required to trigger the Si PC switches are provided by focusing the regen-amplified, 1- to 3-ns pulse from a Nd:YLF oscillator into a liquid cell containing carbon tetrachloride (CCl_4). This produces a backward-propagating SBS pulse with a rise time of less than 100 ps. The timing of the leading edge of the SBS pulse depends on the amplitude of the incident pulse; hence, the input pulse is actively amplitude stabilized. Using this system, an absolute timing jitter of less than 30 ps is obtained.

Pulse-Shape Calculation

Generating the input pulse required for a desired UV output pulse involves backward propagating the pulse through an accurate model of the frequency-conversion cells and the laser system. Originally this was done by using the laser-propagation code *RAINBOW*[5] combined with the *MIXER*[6] model of the frequency converters. The presence of the frequency converters and the system's nonuniform radial gain cause the result obtained by this procedure to be inaccurate. This occurs because backward propagating the desired output pulse through the system produces as many input pulse shapes as radial zones used in the calculation, and forward propagating the average of the computed input pulses does not reproduce the desired output pulse. Iteration was used to improve the results, but the resulting procedure was slow and unwieldy.

By recognizing that the laser provides energy gain, rather than power gain, arbitrary pulse shapes can be forward or backward propagated through the system based on a table lookup of the output of a single *RAINBOW* run. Forward propagation through the system then requires 11 table lookups, one for the laser and ten (one for each radial zone) for the frequency converters. Backward propagation still requires iteration, but since the required calculations are now simply table lookups, quick, accurate solutions can be obtained by standard root-finding routines.

By incorporating the laser-gain tables, frequency-conversion tables, regen gain model, and the $\sin^2$ modulator transfer function into a spreadsheet, we can now rapidly compute the electrical input pulse required to produce a specified output pulse. The layer-peeling synthesis and microstrip line impedance to width formulas have also been incorporated, allowing direct generation of the Gerber plot file required by the mill used to machine the microstrip line. Thus, microstrip generation is reduced almost to a one-step process. Bandwidth limitations in the system in general require the introduction of one extra step because our output pulses typically require an electrical input pulse with a sharp cusp at the end. The bandwidth of the shaping system is insufficient to produce this cusp, so the pulse is distorted. This problem is avoided by extending the electrical pulse beyond the desired end of the pulse and rounding it off, thereby reducing the required bandwidth. This extra portion is gated off optically using the gate provided by the second modulator and, hence, does not contribute to the resulting optical pulse. Presently, the rounding process is not automated, resulting in a two-stage microstrip generation process. It should be noted that microstrips must be designed for a particular UV output energy. In general, even small deviations from the design energy will result in significant pulse-shape variations.

Early in the development of the pulse-shaping system, it was determined that the modulator should not be driven too close to full transmission since the nonlinearity of the modulator's $\sin^2$ transmission function near peak transmission increases the electrical bandwidth requirement in this region. For this reason, we limit the shaped electrical pulse to 75% of the modulator half-wave voltage. The same bandwidth effect also occurs near minimum transmission, but many of our initial pulse shapes were not particularly sensitive to the limitation.

Pulse shapes that incorporate a lower-intensity lead-in, or "foot," place additional demands on the system. Although the intensity of typical foot pulses is not generally low, the very high initial gain of the system means that the foot is formed by an input intensity where the nonlinearity of the modulator is significant. This makes the pulse shape sensitive to offset voltages. One source of offset is caused by impedance mismatches in the electrical lines of the electrical-pulse–generation system, which introduces an effective baseline offset to the electrical pulse. This offset can be corrected by adjusting the modulator's dc bias-offset voltage. The original modulator control system, which could automatically adjust the bias offset to zero, did not allow further adjustment of the offset. We have recently added provision to set the dc bias offset and have found that it effectively allows cancellation of baseline offsets in the electrical pulse.

Another source of offset, the importance of which was only recently realized, is the finite contrast of the modulator used for shaping. This introduces a small, but for some pulse shapes, significant optical offset, which cannot be compensated for with a modulator bias adjustment. If the modulator's contrast is known, the offset can be partially compensated for during microstrip design. However, there will be no shape control in the modulator leakage region other than that provided by the gate. For this reason, for demanding pulse shapes, we find it desirable to use the high-contrast modulator, normally used for the gate, for shaping and the lower-contrast modulator as the gate. In this case, it is important to ensure that sufficient prepulse suppression is provided by other optical gates in the system.

The overall transfer function of the pulse-shaping system, laser, and frequency converters places extraordinary demands on accurately producing the input shape. Figure 72.17 shows the calculated output obtained by placing a sinusoidal variation on the input electrical waveform with an amplitude of 0.5% of the peak. Early in the pulse this results in an output error of about 12% (relative to design).

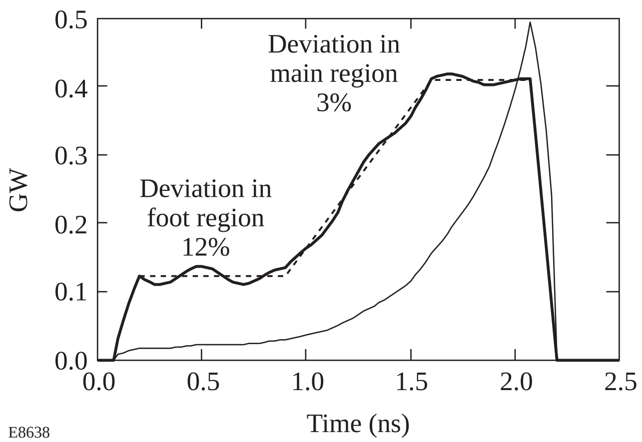

Figure 72.17
A very small sinusoidal variation (0.5% of peak) in the input electrical waveform results in a significant variation in the output pulse shape (heavy line). The effect is most severe early in the pulse. The perturbation is barely noticeable in the optical input (light line).

Pulse-Shaping Measurements

Figure 72.18 shows the measured regen output and the measured and calculated UV output from a nominal 3-ns square pulse. While the integrated energy must be adjusted by about 10%, the calculated and measured UV output shapes are in exceedingly good agreement, indicating that the models of the laser and frequency converters are highly accurate. We have found that apparent disagreements in shape between input and output measurements are invariably due to measurement problems.

While the measured output does not perfectly reproduce the design, taking the transfer function into account, we are producing input shapes within a few percent of design. The remaining errors are largely understood. Some deviations in the output are the result of dielectric variations in the stock used to produce the shaped microstrip. These can be seen in time domain reflectometer (TDR) measurements of the microstrips. We are investigating other materials to try to improve microstrip quality. Other deviations are caused by the Si PC switches and can be reduced by inserting delay between the switches and the shaped microstrip line. Still other deviations occur when the output energy does not match the design energy. Differences between measured output and output predicted from measured input result from bandwidth limitations and the finite resolution of the measurement of the initial portion of the input pulse.

The pulse-shaping system has produced a variety of shapes, some of which are shown in Fig. 72.19. Some of the data were taken prior to recent improvements in the pulse-shaping system and thus show varying levels of quality.

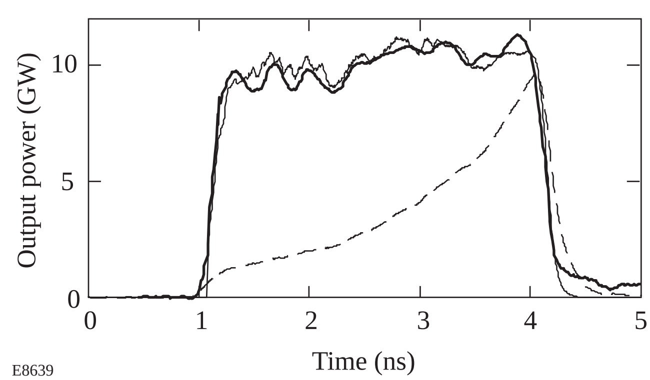

Figure 72.18
Measured regen output (dashed line) and measured (heavy line) and calculated (light line) UV output for beam 19 on shot 8559, a nominal 3-ns square pulse. The measured output was scaled down about 10% to show the matching of the shape.

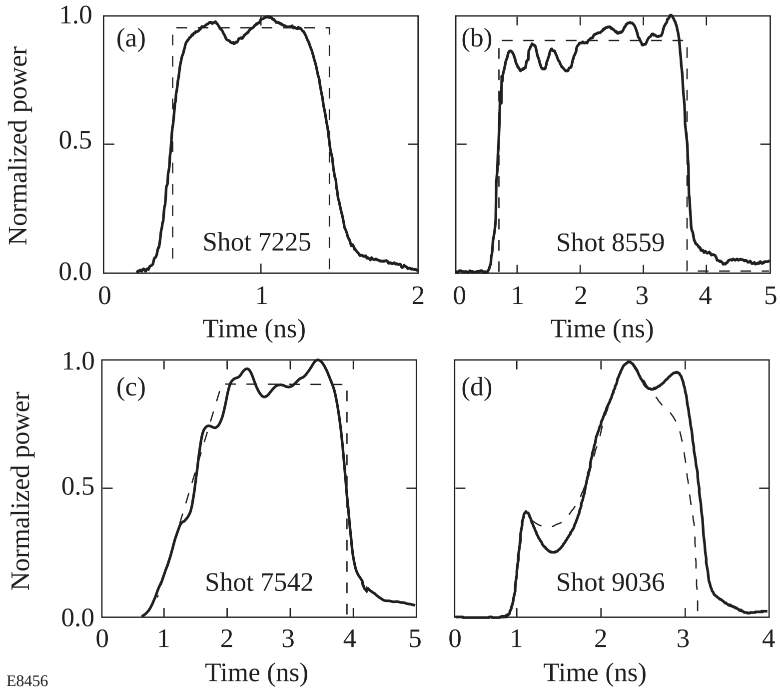

Figure 72.19
The pulse-shaping system has produced a variety of shapes including [(a) and (b)] 1- and 3-ns flat tops, (c) 1-ns ramp to 2-ns flat, and (d) a ramped pulse with a "foot".

Summary

Although we continue to make refinements, the OMEGA pulse-shaping system can be considered fully operational. We have produced a variety of pulse shapes and have demonstrated that we can accurately model the performance of the laser, conversion crystals, and other transfer functions involved in pulse-shape generation. Although measured outputs do not yet perfectly reproduce the designs, the errors are understood and should be reduced in the near future.

ACKNOWLEDGMENT

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460, the University of Rochester, and the New York State Energy Research and Development Authority. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article.

REFERENCES

1. T. R. Boehly, R. S. Craxton, T. H. Hinterman, J. H. Kelly, T. J. Kessler, S. A. Kumpan, S. A. Letzring, R. L. McCrory, S. F. B. Morse, W. Seka, S. Skupsky, J. M. Soures, and C. P. Verdon, Rev. Sci. Instrum. **66**, 508 (1995).

2. A. Okishev, M. D. Skeldon, S. A. Letzring, W. R. Donaldson, A. Babushkin, and W. Seka, in *Superintense Laser Fields*, edited by A. A. Andreev and V. M. Gordienko (SPIE, Bellingham, WA, 1996), Vol. 2770, pp. 10–17.

3. S. C. Burkhart and R. B. Wilcox, IEEE Trans. Microwave Theory Tech. **38**, 1514 (1990).

4. Rogers Technote RT 3.1.2 (Rogers Corporation, Chandler, AZ, 1994).

5. D. C. Brown, in *High-Peak-Power Nd:Glass Laser Systems* (Springer-Verlag, Berlin, 1981), Sec. 7.7, pp. 229–235.

6. R. S. Craxton, IEEE J. Quantum Electron. **QE-17**, 1771 (1981).