PREPRINT UCRL- 80781

CONF-780519--3

Lawrence Livermore Laboratory

THE REGENERATIVE AMPLIFIER: A SOURCE FOR SYNCHRONIZED, VARIABLE-DURATION PULSES

by

J. E. Murray and W. H. Lowdermilk

May 1978

This paper was prepared for Proceedings of the Conference on Picosecond Phenomena, Hilton Head, South Carolina (May 24-26, 1978).

THE REGENERATIVE AMPLIFIER:
A SOURCE FOR SYNCHRONIZED, VARIABLE-DURATION PULSES*

J. E. Murray and W. H. Lowdermilk

Lawrence Livermore Laboratory
University of California
Livermore, California 94550

Regenerative amplifiers (RA) are flexible and stable devices for amplifying and varying the pulsewidth of picosecond pulses. With a Nd:YAG - RA we have demonstrated amplifications up to 14 orders of magnitude with a stability of ± 2%. We have also demonstrated variable pulsewidths over the range 10^{-11} to 10^{-9} sec for a fixed injection pulsewidth. With these capabilities, the RA can be used in a dual-pulse system to provide stable, accurately synchronized pulses of widely different duration. Such a system greatly extends the range of pulse-probe experiments for studies of relaxation phenomena, photochemistry, and laser-generated plasmas.

An example of a RA dual-pulse system is illustrated in Fig. 1.

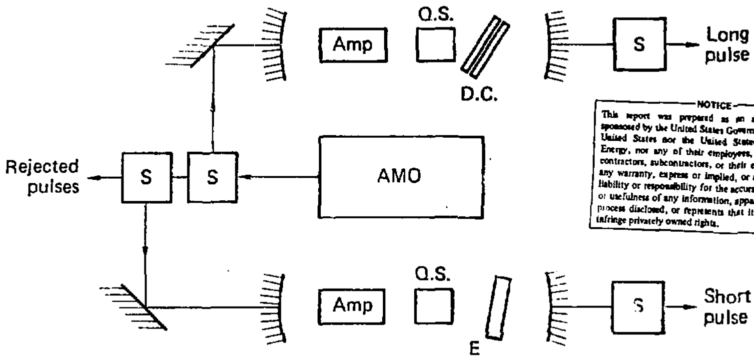

Fig. 1 Regenerative amplifier dual-pulse system: AMO — actively mode-locked oscillator, S — avalanche transistor switchout, QS — Q-switch, DC — dye cell, E — etalon.

Avalanche transistor switchouts [1] select single pulses from the actively mode-locked oscillator for injection into two RA's. The oscillator must be actively mode-locked to provide the necessary amplitude and pulsewidth stability for the injected pulses.

*Work performed by the Lawrence Livermore Laboratory under the auspices of the U. S. Department of Energy under contract W-7405-eng-48.

In one RA, the pulsewidth is stretched during amplification with an intracavity etalon; in the other, it is compressed with a saturable dye. Single pulses are selected from the RA pulse trains with two additional switchouts to obtain the synchronized output pulses.

Pulsewidth expansion is easily characterized analytically, and experiments have proven that pulsewidth and amplitude stability are independent of expansion. Pulsewidth compression, however, is much more complex and sensitive to initial conditions. Therefore, numerical analysis was used to optimize the compression process for minimum pulsewidth and maximum stability within the constraint that pulse fluence not exceed component damage levels.

Simultaneous pulse amplification and compression were modeled by numerical solution of three coupled equations. In the limit of small changes with each pass k, and assuming constant Gaussian pulse shape [2], these have the form:

$$\frac{dP}{dk} = P\left[G - \ell - \frac{d}{1+P} - 2\,\frac{G}{T^2}\right]$$

$$\frac{dT}{dk} = T\left[\frac{G}{T^2} - \frac{d}{2\ln 2}\,\frac{P}{(1+P)(2+P)}\right]$$

$$\frac{dG}{dk} = -\,s\,GTP,$$

where $P = I/I_S$, $T = \tau\Delta\omega_a/\sqrt{8\ln 2}$, $s = p\sqrt{2\pi}\,I_S\,R/(\Delta\omega_a J_S)$. Variables and parameters associated with the pulse are: FWHM pulsewidth τ and peak pulse intensity I measured at the dye cell; with the dye: unsaturated transmission $\exp(-d)$ and saturation intensity I_S; with the amplifier rod: gain $\exp(G)$, bandwidth $\Delta\omega_a$, saturation fluence J_S and the constant $p \leq 1$ whose value depends on level degeneracies; and with the resonator: loss $\exp(-\ell)$ and the ratio R of the beam area in the dye cell divided by the beam area in the gain medium.

In Fig. 2 are plotted the values of T and $\ln P$ at maximum pulse amplitude and the number of passes N required to reach the maximum. The two cases illustrate predicted behavior for two different dye concentrations. For large concentration (Fig. 2a), the variable values are found to be much more sensitive to the initial gain coefficient G_i than for small concentration (Fig. 2b). The transition between these two types of behavior occurs at a critical dye concentration d_c, whose value depends on ℓ, $\Delta\omega_a$, s, and the initial pulse parameters. The best predicted performance was found for minimum loss, dye concentration just below d_c and, with Nd:YAG and Eastman 9860 dye, the maximum value of R. An upper limit on R is dictated by damage at the Nd:YAG amplifier.

A Nd:YAG dual-pulse system has been developed for diagnosing laser-generated plasmas. It utilizes a pulse compression RA whose design is based on these results. An electro-optic cavity dump was used to maximize pulse extraction efficiency while holding ℓ to 0.10. A Brewster-angle dye cell, normal YAG rod and focusing cavity geometry gave R = 6.7. With the amplifier gain stabilized to ± 0.1% [3,4], a pulsewidth compression from 120 ps to 15 ps was achieved with ± 5% amplitude stability. Predicted and measured output characteristics were in good agreement. Streak-camera photographs such as Fig. 3 verified synchronization of the long and short pulses within ± 5 ps.

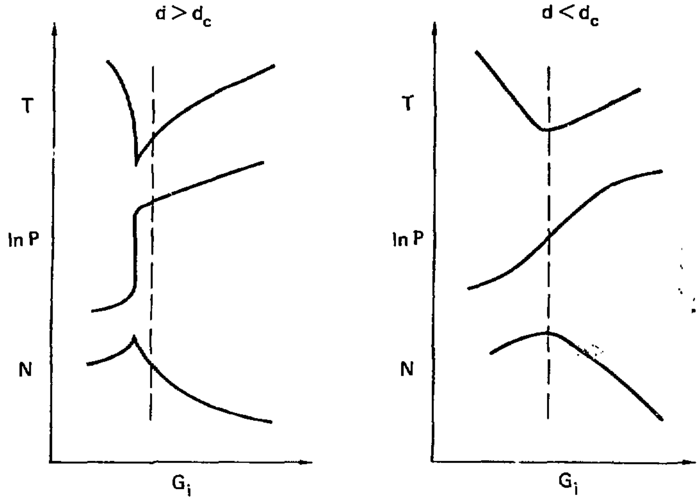

Fig. 2 RA variable values at the maximum pulse amplitude versus initial gain coefficient for dye concentration (a) above and (b) below the critical value d_c.

Fig. 4 Streak-camera photograph of 150-ps and 30-ps pulses synchronized within ± 5 ps.

References

[1] S. J. Davis, J. E. Murray, D. C. Downs, and W. H. Lowdermilk, Applied Optics (October 1, 1978).

[2] V. S. Letokhov, JEPT Lett. 7, 25 (1968).

[3] D. J. Kuizenga, Opt. Commun. 22, 156 (1977).

[4] D. C. Downs, J. E. Murray, and W. H. Lowdermilk, IEEE J. Quant. Electron. (August 1978).