PORTIONS OF THIS DOCUMENT ARE ILLEGIBLE

TITLE: NEW APPROACH TO FUSION-LASER OPTICAL PULSE GENERATION HAS PROVEN VERY RELIABLE

AUTHOR(S): Robert L. Carman

MASTER

SUBMITTED TO: Society for Optical and Quantum Electronics (SOQUE)

University of California

LOS ALAMOS SCIENTIFIC LABORATORY

Post Office Box 1663   Los Alamos, New Mexico 87545
An Affirmative Action/Equal Opportunity Employer

NEW APPROACH TO FUSION-LASER OPTICAL PULSE GENERATION HAS PROVEN VERY RELIABLE*

R. L. Carman, F. Wittman, and N. Clabo
Los Alamos Scientific Laboratory
Post Office Box 1663
Los Alamos, New Mexico 87545

ABSTRACT

Starting with 6 CW frequency stabilized CO_2 oscillators, we have been able to reliably generate $\sim$ 1 ns pulses with any combination of six rotational-vibrational lines selected from both the P- and R-branches, and the 9 μm and 10 μm bands. Total output power of > 100 KW has been obtained with excellent reproducibility in both the total power as well as the ratios of the powers in the six rotational-vibrational lines. This capability represents a potential starting point for temporal pulse programming of the output of a large CO_2 amplifier chain.

Pulsed CO_2 oscillators cover a broad range of types, sizes, cavity designs, and clever innovations. We discuss a different kind of CO_2 pulse generation system which is tailored to a laser fusion need. We at LASL desired a CO_2 $\sim$ 1 ns pulsed light source which would provide simultaneously any six lines chosen from the manifold of $\sim$ 100 rotational-vibrational transitions near 10 μm. Further, we wished to be able to prescribe the amplitude ratios of the six constituent lines at a total power level of approximately 1 MW, and to be able to reproducibly supply this optical pulse to a large amplifier chain. The origins of the requirement are both the target plasma physics and the potential of temporal pulse programming of the CO_2 laser output power. The conceptual design was arrived at more than 4 years ago[1] while one form of this system has been operational for nearly 2 1/2 years.

The pulse generation system is illustrated schematically in Fig. 1. Six independent CW CO_2 oscillators are housed in a single invar structure, which provides good mechanical stability. The appropriate six lines were then selected independently by proper adjustment of the Littrow mounted gratings at the rear of the cavities. All the front mirrors were aligned to assure that all the output beams were coplanar and parallel, thus simplifying the beam-combining process.
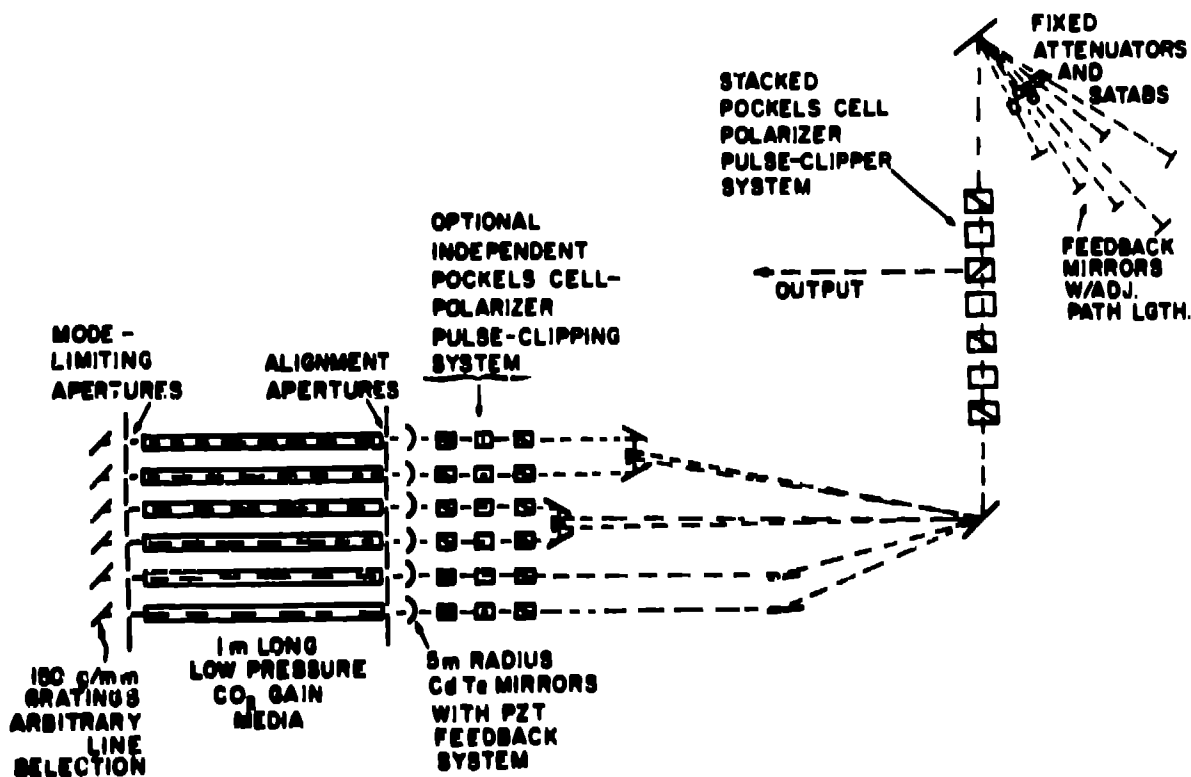
Fig. 1.
Schematic of CO_2 laser pulse generator capable of producing a pulse composed of any six lines, starting from six CW oscillators.

Adjustable diameter mode-limiting apertures were inserted toward the rear of each cavity to accomplish two objectives, namely to limit the lasing transverse modes to only TEM_{00} and to obtain the same beam divergence for each element of the composite beam at some prescribed point in the system. No transverse adjustment of these apertures was provided, thus assuring that once properly positioned they would remain in place. Intercavity nonadjustable apertures were then inserted near the output mirrors to assure that lasing could be optimized only if proper beam alignment was satisfied, namely output beam parallelism and co-planarity. Note that the output mirrors are mounted in a gimbal structure employing a piezoelectric translator (PZT), thus allowing for precision adjustment of each oscillator cavity length. When coupled to an electronic feedback system and to oscillator output power monitoring circuitry, the actual lasing frequency of each oscillator could be stabilized to < 1 MHz.

This form of CO_2 oscillator geometry provided three options for subsequently producing the desired pulse width; (1) phase all the oscillators so that when the beams are combined, the result is coherent addition and cancellation leading to a train of pulses - a method analogous to mode locking. For this to work, frequency stability of the outputs would have to be improved about 10-fold while a constant line spacing is maintained. This is achievable for some choices of six lines, (2) a series of stacked Pockels cells and polarizers are switched in a timed manner to produce the desired pulse,[2] and (3) a set of independent Pockels cells and polarizers are inserted in each beam and switched so as to produce the desired pulse after beam combining. Option 1 was ruled out because of a desire to synchronize the CO_2 output pulse with a sub-picosecond duration pulse produced by a Nd:glass laser.[3] Option 2 was elected in the work described in this report, while Option 3 is under development for use on the Antares laser facility at LASL.

The second portion of the system is essentially a ?m grating spectrograph used in reverse. A 10 μm blazed 150 g/mm grating is the heart of the system, while again a rigid invar structure was constructed to mount all the required elements, thus assuring stability. These two structures were then bolted together in such a way as to act as if they were one structure.

Figure 2 illustrates the actual oscillator system. Output mirrors mounted on piezoelectric translators coupled to a feedback system were employed to stabilize the output power of each oscillator. The nominal pressure in the oscillators was 10 torr in a flowing system, but each gain medium has independent controls of both total pressure and flow rate. While initially we anticipated a need for independent control of the gas mixes, this was found to be unnecessary. A flow rate of 1.6 SCFH N_2:3.2 SCFH He:0.6 SCFH CO_2 was finally settled upon for all of the CW oscillators. To control the output power of each oscillator,

INVAR STRUCTURE   LASER TUBE

OUTPUT MIRRORS   LINE TUNE GRATINGS

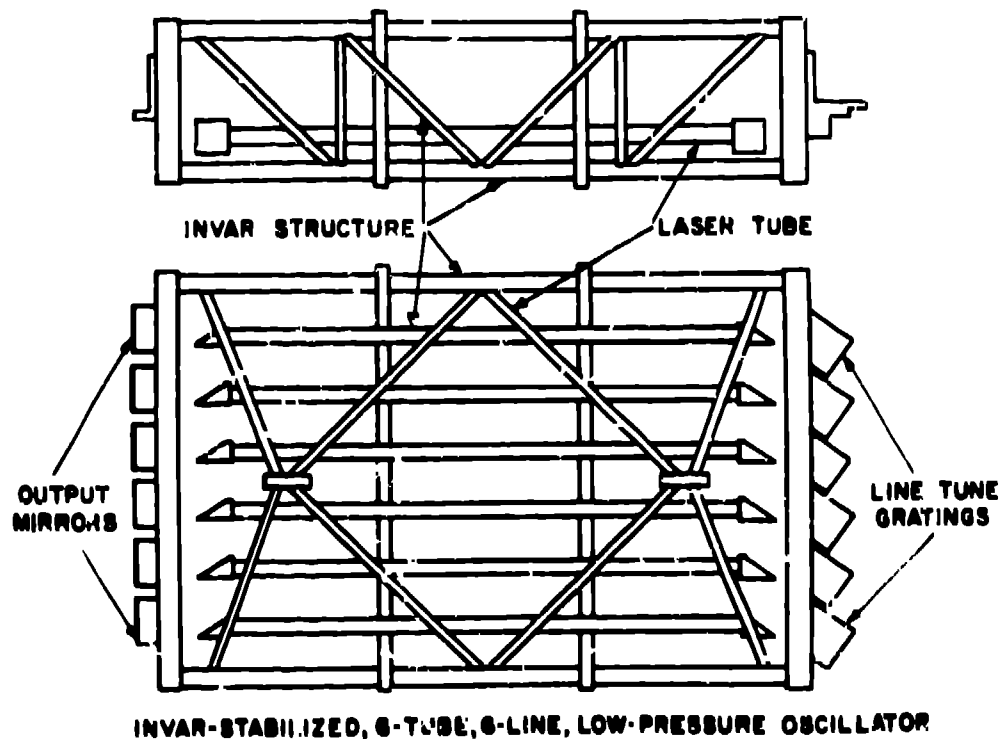INVAR-STABILIZED, 6-TUBE, 6-LINE, LOW-PRESSURE OSCILLATOR

Fig. 2.
The mechanical invar structure which houses the six independent CW oscillators.

a separate current regulated DC power supply was provided for each gain medium. Maximum output was obtained at between 35 and 40 ma and was typically 6 to 10 watts. Under normal operating conditions, the discharge currents were adjusted to achieve the desired power ratios for the six lines. While a pressure feedback system was planned for strict mainte- nance of the desired power ratios, it was also found to be unnecessary.

Figure 3 is an illustration of the beam combining optics structure. The coplanar feature of all beams implied that only the angle of incidence on the grating had to be obtained. While different combinations and locations of mirrors were required for each combination of lines chosen, we elected to make this system again nonadjustable, with every element rigidly bolted down. While initial installation is tedious, excellent long term stability has been obtained where the total beam satisfies the requirement of < 50 µrad pointing accuracy. Note that this requirement implies that each separate beam have 1/2 this pointing accuracy. The overall efficiency achieved thus far with the grating system is 75% to 80% of the total oscillator power outputs into the emerging single beam. Typical operating CW beam power after the combining system is 10-40 watts, depending on the choice of lines and desired pulsed output power spectrum at the > 100 kW level.
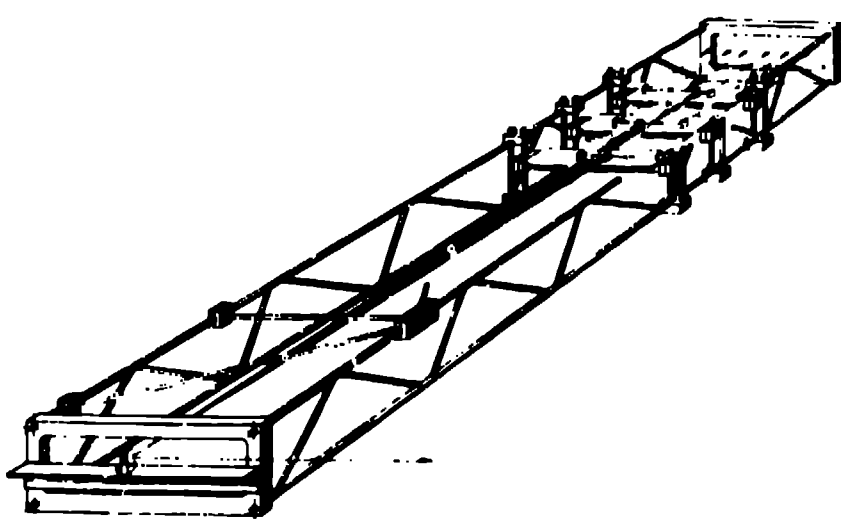

Fig. 3.

The mechanical invar structure which supports the $\sim$ 3 m inverse grating spectrograph used to combine the six beams into one.

We now turn to the 1 ns pulse generation system, schematically indicated in Fig. 4. Rather than several Pockels cells in series, producing a 1 ns pulse with $\sim$ 10-40 n.!, we first produce a 70 ns pulse. This duration is chosen because fc, a 10-15 torr total pressure in a longitudnal discharge amplifier, we observe no rotational coupling of the CO_2 lines. Thus, the gain observed on any line is independent of which other 5 lines are present, and is very reproduible. We believe that this occurs because there is effectively no competition between the six lines for the same inversion. On the other hand, a 2 ns risetime and falltime degrades only by several ns while experiencing e^5 gain. By adjusting the Pockels cell pulse timing, we obtain a nominal 70 ns pulse output from the last ampli- fier with < 5 ns risetime and $\sim$ 10-15 ns falltime.

We found, experimentally, that a CW beam in the first Pockels cell substantially reduced the achievable energy contrast ratio, presumably due to heating. We had anticipated this problem and planned to use 2 mechanical shutters prior to the first Pockels cell. The first reduced the CW power to a 1 second pulse, while the second shortened the pulse to $\sim$ 1 ms. These shutters have eliminated any thermal effects, namely, both thermal lensing and con trast degradation. By splitting up the Pockels cells we also completely control potential amplified spontaneous emission problem. Outputs from the last 1 m amplifier achieve > 100 kW total power while attaining a pulse intensity contrast ratio of > 10^5:1 and a pulse energy contrast ratio of $\sim$ 10^3:1 over the 1 ms time window. The final pair of Pockels cells then shortened the pulse to < 1 ns with a risetime of < 500 ps, and excellent pulse contrast characteristics, namely > 10^6:1 intensity contrast ratio.

To achieve the high gain coefficients in these low pressure amplifiers, a special kytron Marx bank has been developed and is shown in Fig. 5. This pulser typically applies $\sim$ 150 V/cm torr to the longitudinal discharge in a very fast rising pulse, which initiates a uniform discharge in our 12 mm bore tubes. As soon as significant current begins to flow, the voltage drops to 10-30 V/cm torr with a current of $\sim$ 10 a/cm^2. The duration of the
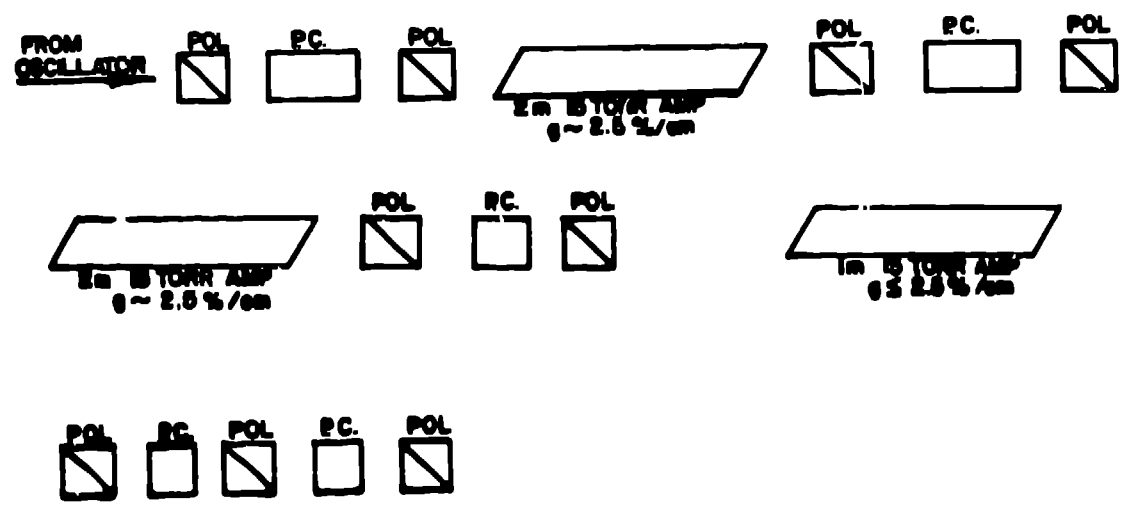
AMPLIFIER CHAIN

Fig. 4.
The present pulse generation and amplification system. After the six-line CW beam is gated down to an ~1 ms pulse using mechanical shutters, a 70 ns pulse is chopped out using GaAs Pockels cells. The pulse is further amplified using low pressure longitudinal discharge amplifiers prior to the production of the nominal 1 ns pulse using CdTe Pockels cells.
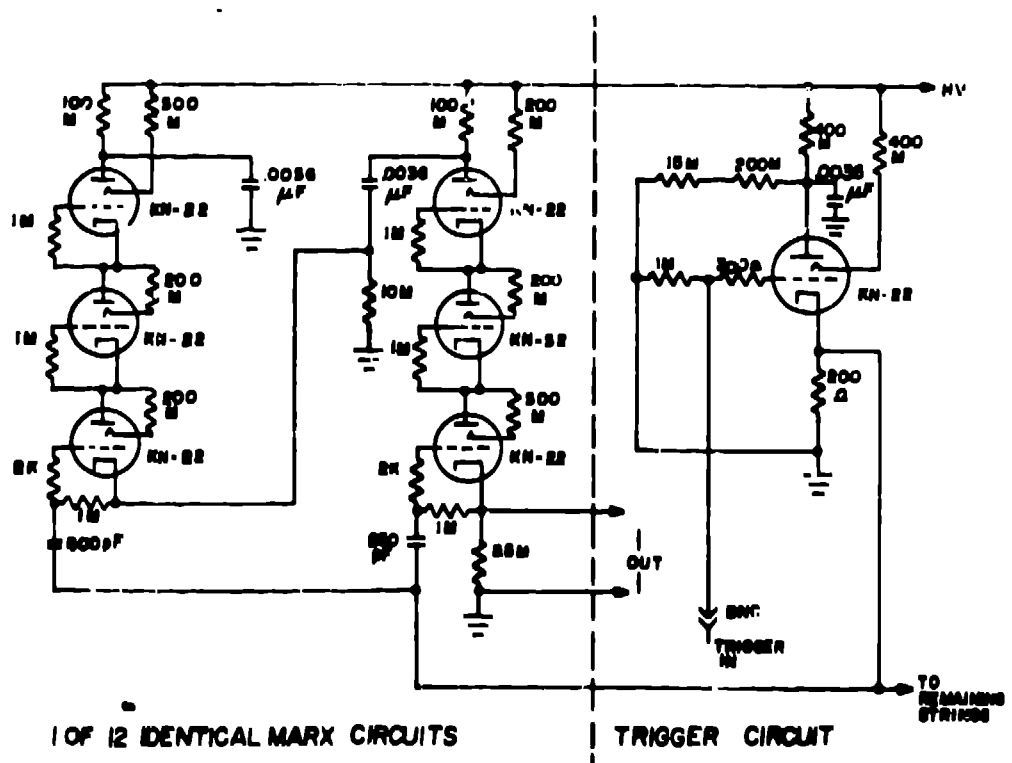

Fig. 5.
A circuit diagram of the two stage Marx banks used to apply voltage to the low pressure amplifiers. The circuit is unusual both because it is constructed from Krytron strings as well as because it produces a very fast rising voltage waveform which assures a uniform plasma discharge when combined with a small DC voltage bias across the gain medium.

current pulse is 5-10 µs. The gain appears ∿ 90 µs after initiation of the discharge. We have also found that a DC bias of 5-10 V/cm torr further improves the reproducibility of the gain obtained. The gain of the last amplifier stage is adjusted to obtain the desired power levels. This adjustment is accomplished by raising the total pressure while reducing the CO_2 concentration in the gas mix. Typically, the total gain of this amplifier chain is repeatable to ± 30%.

The physical length of this pulse generation and amplification system is > 10 m; a 1 cm diameter CO_2 beam would diffract to > 3.5 cm diameter in this distance. A complex relay Ba F_2 lens system is used to compensate for diffraction, where each lens is used as a field lens and satisfies the condition that the lens focal length f and beam divergence Θ_{div} are given by

$$f \; \Theta_{div} = D_{desired} = D_{input};$$

(1)

D is the laser beam diameter.

Because of the large number of elements, use of the CW beam for alignment seemed desirable. However, adequate input power for easy detection with standard LN cooled Au doped Ge detectors lead to thermal lensing in the many elements. To overcome this effect, we have employed a high speed mechanical chopper having an on-to-off time ratio of 10^4:1 coupled with a slow speed chopper with a synchronized window once every 100 ms. The net effect is the production of a 10 µs pulse once every 0.1 sec, thus reducing the average power by 10^4 while forcing the thermal lensing effects to be responding in the transient limit.[4] The effect of transiency is to reduce the thermal effect approximately by the ratio of the actual pulse duration to the time to achieve a steady state response. This provides another 10 to 100 fold reduction in the most significant thermal nonlinearities.

The existing system is presently under consideration as a pulse generation system for use at the Gemini laser facility. The second, more complex system employing Option 3 mentioned above is presently under development for use as the pulse generator for the new Antares laser facility currently slated to produce > 40 kJ from its final amplifiers. Figure 6 illustrates the two options for pulse shaping the output of a large CO_2 amplifier chain operated in a highly saturated gain condition. Since the observed gain is different for the different rotational-vibrational lines, we take advantage of this to allow the leading edge of the pulse to be programmed.[5] The gain will not be saturated for all transitions, which
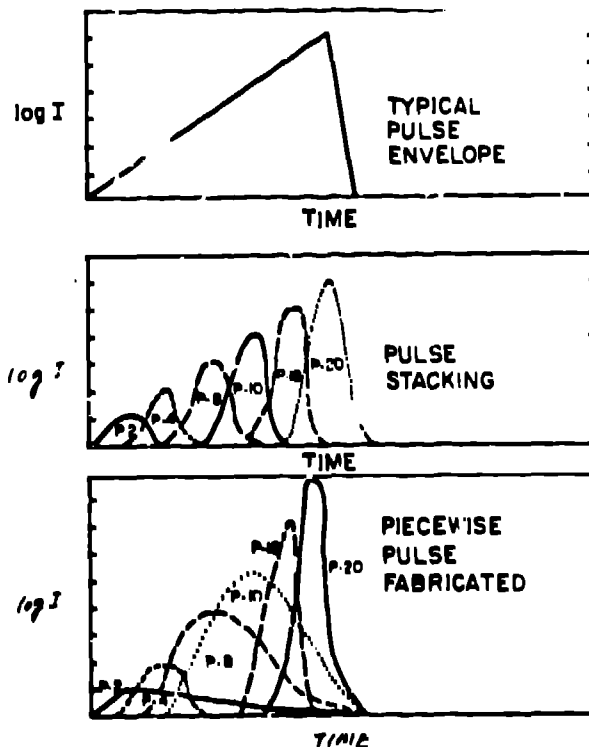

Fig. 6.

The upper frame illustrates a CO_2 laser output pulse shape which might be desired. The center and lower frames illustrate possible temporal histories for each of six rotational-vibrational transition outputs leading to the desired pulse envelope. The center temporal and spectral output could be obtained using a set of Pockels cells either in parallel or in series (Option 2 or 3). Since the six pulse shapes are all different in the lower frame, only a set of Pockels cells used in parallel and driven by different but synchronized electrical sources can be used (Option 3).

forces a tight tolerance on the ratios of the allowed input power/line. Due to reduced gain for the P(2) over that of the P(20) transition, for example, a substantial peak power ratio and temporal separation of the two lines is achievable. The pulse-stacking approach can be employed using either Option 2 or Option 3, referred to above, as the pulse generator. The piecewise pulse fabrication in principle allows all six lines to be present at the time of peak output while allowing the tailoring of the pulse leading edge, but the parallel Pockels-cell approach of Option 3 above is required. Also, each Pockels-cell chain is driven by a different electrical waveform. While a difficult electrical engineering problem, we have demonstrated that this is possible.[2]

By electing the parallel Pockels cell scheme of Option 3, both pulse shaping ideas can be tried. However, a fundamental difference exists between this approach and that of Figs. 1 and 4 discussed at length here. Because the pulses generated at the CW oscillator are now 1-10 ns in duration, we must employ TEA-type high pressure CO_2 amplifiers, in order to obtain the necessary gain-bandwidth product, instead of the low pressure longitudinal discharge amplifiers shown schematically in Fig. 4. A question then arises as to whether the desired reproducibility in the constituents of the output pulse can be obtained. If this problem is found to be serious, an additional option is to proceed, as in Fig. 4, but instead of a series of Pockels cells at the output which produces the 1 ns pulse from the amplified 70 ns pulse, we could again use the beam combining optics to first divide the 70 ns pulse into 6 beams, employ the parallel Pockels cells followed by a recombining of the beams. By choosing 3 different planes of incidence to the grating, this could all be accomplished utilizing the beam combining system illustrated in Fig. 3.

1. R. L. Carman, L. J. Garwin, N. Clabo and H. Lane, Los Alamos Scientific Laboratory, Laser Fusion Program Progress Report, LA-6982-PR, January-June 1977, pp. 27-28; R. L. Carman, N. Clabo and H. Lane, Los Alamos Scientific Laboratory, Laser Fusion Program Progress Report, LA-7328-PR, July-December 1977, pp. 62-64.
2. R. L. Carman and N. Clabo, Los Alamos Scientific Laboratory, Laser Fusion Progress Report, LA-5919-PR, July-December 1974, p. 70; R. L. Carman, Los Alamos Scientific Laboratory Laser Fusion Progress Report, LA-6050-PR, January-June 1975, pp. 16-17; R. L. Carman, "Temporal Laser Pulse Shaping for Laser Fusion Research," Los Alamos Scientific Laboratory Report, LA-UR-75-1755 (1975); R. L. Carman, Bull. Am. Phys. Soc. 20, 1286 (1975) and Los Alamos Scientific Laboratory Report LA-UR-75-1945 (1975); R. L. Carman, "Optical Pulse Programming for Laser Fusion," Los Alamos Scientific Laboratory Report LA-UR-76-1613 (1976).
3. R. L. Carman, A. G. Engelhardt and N. Clabo, Laser Interaction and Related Plasma Phenomena, Vol. 4B, ed. H. J. Schwartz and H. Hora (Plenum Publishing Corp., New York, 1977) pp. 619-638.
4. See, for example, R. L. Carman and P. L. Kelley, Appl. Phys. Lett. 12, 241 (1968); R. L. Carman, A. Mooradian, P. L. Kelley and A. Tufts, Appl. Phys. Lett. 14, 136 (1969).
5. R. L. Carman, Bull. Am. Phys. Soc. 22, 1212 (1977) and Los Alamos Scientific Laboratory Report, LA-UR-77-2520 (1977).