steady-state limit. Comparisons with existing transient and steady-state theories show close agreement in the limits where those theories are valid, and predictions are made in the short-pulse regime where the photon rate equation is invalid. These predictions indicate that the pulse duration is dominated by the transit time along the pumped region. Also, a careful evaluation of the field evolution shows that in some cases the laser is overcoupled at early times and, as the pulse is emitted, becomes undercoupled; in other cases the operation remains undercoupled throughout the buildup and pulse emission process. This provides new insight into the mechanisms involved in the DFL. Further refinements of this theory which may have an effect on the output characteristics will include excited state absorption, reabsorption of the lasing light in the case of dye lasers, molecular rotation and diffusion, and the addition of a saturable absorber to the medium.

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3.B Pulse Shaping with Dispersive Microstriplines

Laser-driven inertial-fusion targets require carefully controlled temporal shaping of the driver pulse to achieve high performance. Saturation during propagation of the beam through many stages of amplification results in the need to shape the input pulse in order to attain the required output temporal shape. A particularly effective method of shaping the input optical pulse involves the production of specific electrical waveforms which can be synchronized with a square optical pulse, in an electro-optic crystal, to create a shaped optical pulse. These electrical transients have been generated using a frozen wave generator developed at LLE[1] and a tapered-line pulse shaper proposed at LLNL.[2] These methods rely on multiple reflections within transmission-line elements to create the desired waveforms, and, thus, are more complicated to use than a method which employs the dispersive properties of a transmission line near its cut-off frequency. These dispersive properties have been predicted by G. Hasnain *et al.*[3] and observed by Valdmanis, Mourou, and Gabel[4] in the picosecond and subpicosecond range. We have developed a technique that uses dispersion to generate monotonically increasing high-voltage waveforms in the nanosecond and subnanosecond timescales which are required for laser fusion. The result of the design, construction, and operation of a dispersive two-conductor transmission line is compared with calculations which simulate the evolution of the actual input pulses along this line.

Experimental Investigations

Our investigation of pulse shaping utilizes the intrinsically dispersive microstrip transmission line, which demonstrates frequency-dependent propagation velocities due to the conveyance of non-TEM modes. The dielectric substrate and the air superstrate create an inhomogeneous dielectric geometry, and the microstrip exhibits a discontinuity in the field lines between its strip and ground plane. This field configuration can be shown, through simple arguments based on Maxwell's equations, to contain the longitudinal components producing dispersion. Since we wish to create rather than avoid dispersed waveforms, it is convenient to maximize the effect of those parameters which most influence the field discontinuities. This indicates that the high-frequency relative dielectric constant and thickness of the substrate should both be made large. Characteristic impedance limitations require that a thick substrate be matched with a wide stripline, and, thus, our microstrip is designed with a large geometry, restricted mainly by the availability of thick substrates of substantial high-frequency dielectric constant.

The complete pulse shaping system is shown in Fig. 18.27. The input electrical pulse is generated with the use of a semiconductor photoconductive switch, which acts as a gate to a dc-biased charge line. This switch is closed when driven by a single, high-intensity, 100-ps optical pulse (1064 or 532 nm) from a cw-pumped, q-switched, mode-locked Nd:YAG oscillator. The output pulse from the switch follows the laser pulse and exhibits a rise time of about 100 ps; the pulse duration is determined by the natural recombination of the semiconductor or the length of the charge line. The most important characteristic of this pulse is its rising edge, which contains high-frequency components up to 3.5 GHz. As long as the cut-off frequency of a microstrip is below this frequency, dispersion will occur and the original shape of the pulse will change.

The microstrip, to which the switch output pulse is coupled, consists of a thick piece of acrylic, situated between two copper foil electrodes. In this instance, the copper electrodes are placed in the configuration used for previous work,[5] that of a balanced microstrip. This geometry utilizes two electrodes of equal width, rather than having one as a ground plane with the dimensions of the substrate; it also serves to reduce the effective substrate height to half the value of a conventional

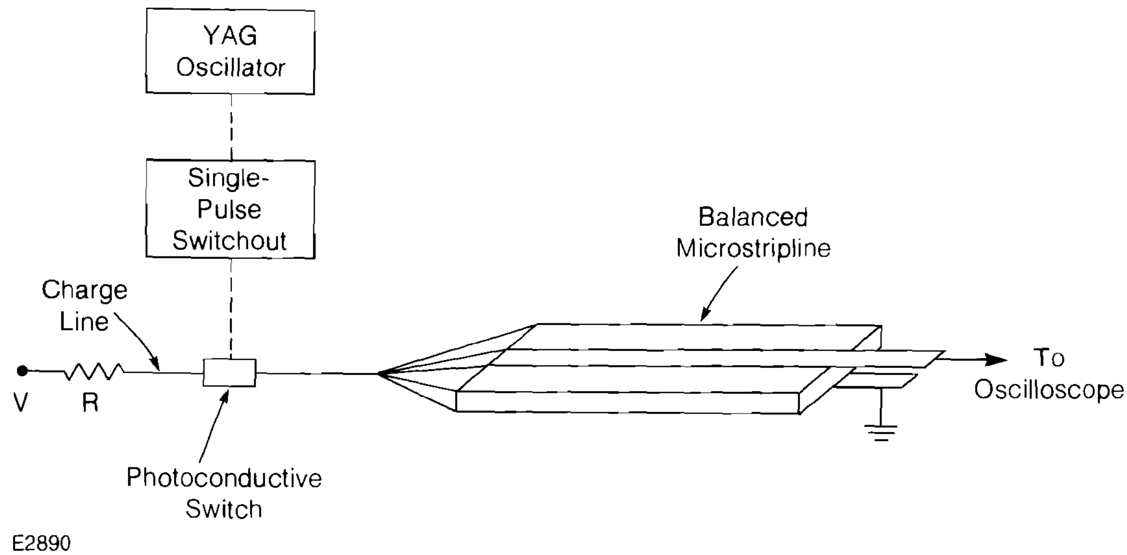

Fig. 18.27
Schematic diagram of the dispersive transmission line pulse shaper. A section of cable is discharged through a semiconductor photoconductive switch driven by a single 100-ps pulse from a q-switched, mode-locked Nd:YAG oscillator. The switch output is coupled to a balanced microstrip which has a cut-off frequency below that corresponding to the input-pulse rise time. The pulse shape at the output of the line is reconstructed with a sampling oscilloscope.

microstrip. However, reducing the height, as mentioned earlier, also reduces the dispersion, so that all follow-up experiments have been conducted using a stripline with a ground plane.

The substrate is cut into several segments, each of different length, so that the dispersion can be observed as a function of propagation distance along the line. The dispersed output pulse is reconstructed using a Tektronix S-6 sampling head mounted in a 7834 mainframe. The dispersion is evidenced in the sampled waveforms through the delay of high-frequency information with respect to that of low frequency. As the waveform is sampled at greater propagation distances, the high frequencies are delayed by greater amounts. Therefore, the rise time consists of lower frequencies and becomes longer. In addition, as the high-frequency components are delayed through the rest of the pulse, a pulse-sharpening effect attributed to energy conservation becomes apparent, and a secondary pulse which grows with propagation distance is formed. The progress of the dispersed pulse is outlined in Fig. 18.28.

Theoretical Calculations

These observations are supported by the results of calculations which simulate the evolution of the experimental input pulse along a microstrip (see Fig. 18.28). The rise times and FWHM durations are compared with the estimated values from the observed waveforms. The rise times of the experimental and calculated pulses consistently agree to within the resolution on our sampling oscilloscope. The simulation also predicts the formation of the secondary pulse and the increase in the pulse width with propagation distance. Some of the discrepancies in waveform shapes may be attributed to reflections due to characteristic impedance mismatches when coupling signals between a switch, coaxial cable, and the microstrip.

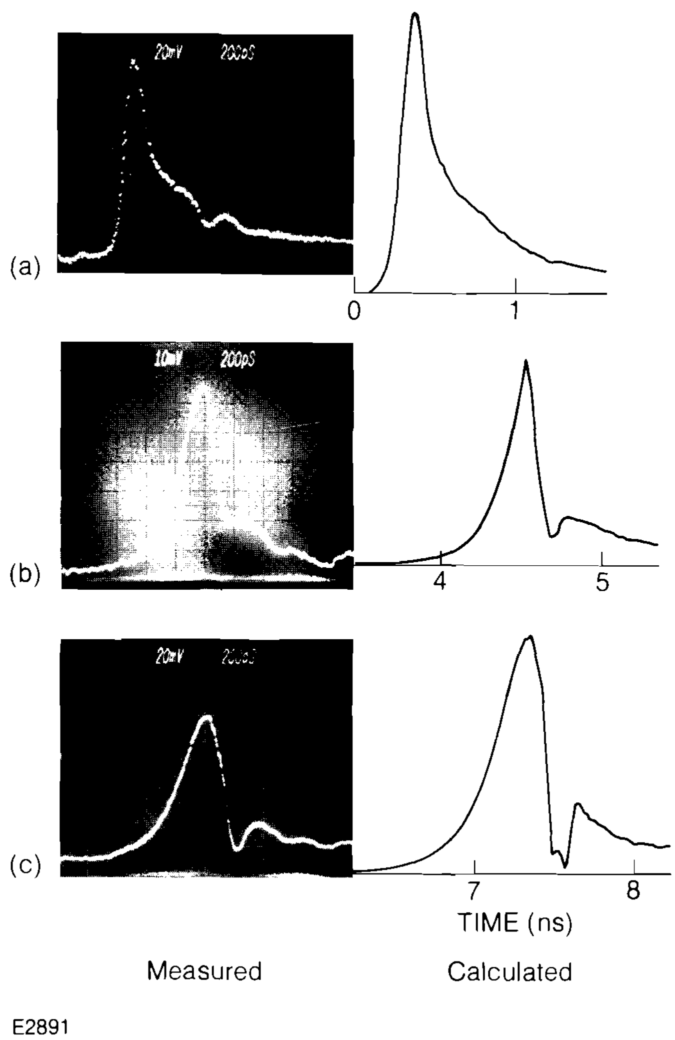

Fig. 18.28.
Comparison of experimental and calculated pulses propagating on a microstripline.
(a) The real and digitized switch output/ microstrip input pulse.
(b) Dispersed pulse after 82.1 cm of travel on microstrip. Experimentally, the 10-90% rise time is 320 ps. Theoretically, it is 350 ps.
(c) Dispersed pulse after 137.7 cm of propagation. Experimentally, the rise time is 400 ps. Theoretically, it is 415 ps.

The simulation of this dispersion is accomplished by first reading into the computer the normalized values corresponding to the experimental input pulse, along with the relevant parameters of the substrate: geometry, conductivity, and high- and low-frequency dielectric constants; and the parameters of the strip-conductor: geometry and resistivity. The spectrum of the input pulse is then multiplied by the complex propagation factor of the striplines with frequency-dependent phase and attenuation terms, before a final transformation is made to return the pulse to the time domain. It should be noted that the theory employed here is by no means exact. Both the functions used to determine the frequency-dependent relative and effective dielectric constants of the substrate (the latter is derived by curve-fitting to the exact analysis[6]) are simple approximate formulae, so that, depending on the properties of the substrate involved, the accuracy will vary.

The dependability with which predictions of pulse shapes can be made indicates that stripline materials and geometries may be designed to yield specific waveforms for fusion applications. Typically, these waveforms consist of monotonically rising ramps with front-to-back contrast ratios of the order of 10:1 (see Fig. 18.29). This ramp is synchronized, in an electro-optic crystal, with a square optical pulse so that the resultant optical pulse has the same shape as the front ramp of the electrical pulse. Thus, the microstrip can be designed to exhibit its maximum dispersive capabilities; then the propagation length, input electrical transient duration, and synchronization between electrical and optical pulses are adjusted until the appropriate optical waveform is created.

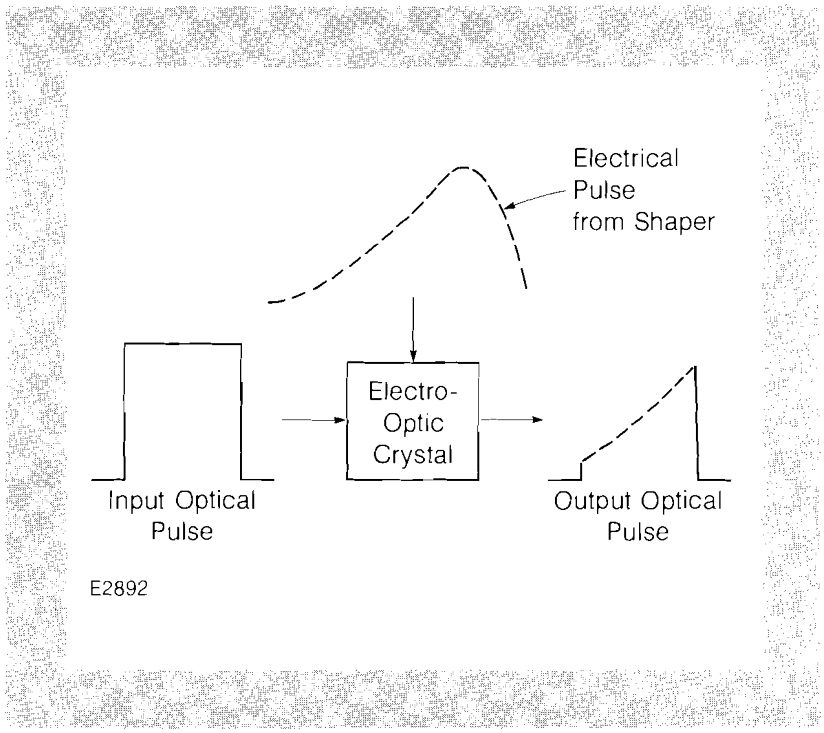

Fig. 18.29
Synchronization of a flat optical pulse with the rising edge of an electrical "shaper" pulse. The output optical pulse will exhibit the same gradual rise which is produced by dispersion of a fast pulse on a microstripline.

Conclusion

We have demonstrated that the concepts developed for the dispersion of picosecond pulses on microstrips apply also for longer pulses which are useful for laser fusion experiments. We also have a simple theory by means of which the shape of dispersed waveforms on microstrips can be accurately predicted. Finally, we have discussed a technique which exists for generating electrical pulses suitable for use in optical pulse-shaping projects.

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