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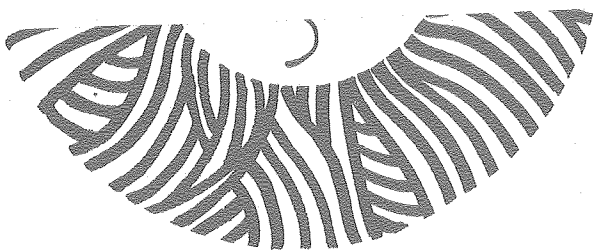
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## DISCLAIMER

# A RAPID-SCANNING AUTOCORRELATION SCHEME FOR CONTINUOUS MONITORING OF PICOSECOND LASER PULSES

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## ABSTRACT

We describe a scheme for rapidly introducing a periodic linear time delay to a train of picosecond laser pulses.  By incorporating this scheme in one arm  of the Michelson interferometer of a conventional autocorrelator, the second order intensity autocorrelation function of a cw train of picosecond pulses is continuously displayed on an oscilloscope.

## Introduction

With the advent of synchronous pumping, mode-locked cw dye lasers have become an important tool for performing time-resolved spectroscopy. The standard method for measuring the width of the pulses produced by these laser systems is the well known second harmonic (SHG) auto-correlation technique[1-3]; however, useful autocorrelation traces require minutes to obtain. Hence, it is desirable to devise methods which enable the continuous monitoring of the temporal characteristics of these pulses in "real time". One approach involves the rapid introduction of a periodically varying time delay in one arm of the Michelson interferometer (MI) used in conventional second harmonic generation autocorrelators. Previously reported methods for imple-menting this approach employ nonlinear[4, 5] or stepwise linear[6] variable time delays. However, they have a limited scanning range[4-6] and are not dispersion-free[6].

In this communication we describe a simple, yet precise, method for the introduction of a periodic time delay to a train of picosecond laser pulses. It enables the high resolution display of the auto-correlation function of picosecond pulses continuously on an oscilloscope. It is highly linear over a wide scanning range ($\geq$ 150 psec), and is dispersion-free.

## The Rapid-Scan Autocorrelation Scheme

The rapid introduction of a <u>linear</u> periodic time delay is achieved by incorporating in one arm of the Michelson interferometer a pair of parallel mirrors mounted on the two ends of a shaft rotating at a constant angular frequency f (see Fig. 1). Thus, after being equally split by the beam splitter, one half of the incoming train of pico-

second pulses is incident on mirror $M_1$ and is reflected to mirror $M_2$ from which it is transmitted in a direction parallel to that of the original direction. Following a rotation of the shaft by an angle $\theta$, this beam will traverse a different path (i.e., is delayed) and is transmitted with a certain displacement while remaining parallel to the direction of incidence. The transmitted beam is normally incident on a stationary mirror $M_3$, from which it is retroreflected, retracing the incident beam in the opposite direction.

In the other arm of the MI, a stationary mirror $M_4$ (mounted on a translation stage) retroreflects the other half of the incoming train of pulses, and the two reflected beams (from mirrors $M_3$ and $M_4$) are then recombined collinearly at the beam splitter. The combined beam is focused onto an angle-phase-matched nonlinear crystal and the generated second harmonic is detected by a photomultiplier as in conventional autocorrelators. In our scheme, however, the photomultiplier output is the input to a high impedance oscilloscope. The time-base of the oscilloscope is triggered by the output of the photodiode PD which is placed between $M_2$ and $M_3$ such that it intercepts a portion of the beam before it is incident on $M_2$. As shall be seen in the next section, the rotation of the parallel pair of mirrors $M_1$ and $M_2$ results in a linear variation of delay with time. Hence, the oscilloscope directly displays the second order intensity autocorrelation (with background) of the incoming train of pulses. To properly position the autocorrelation trace, one translates mirror $M_4$ such that the peak occurs at the center of the scan range on the oscilloscope screen. The calibration of the oscilloscope in terms of delay is done by measuring the displacement of the autocorrelation peak on the screen for a given translation of $M_4$.

We note that in order to obtain a background-free SHG, one simply replaces $M_4$ with a corner cube. Furthermore, by keeping $M_1$ and $M_2$ fixed (no rotation) and translating $M_4$ with a stepping motor, a conventional slow autocorrelation scan can be obtained.

Geometrical Considerations

From the geometry given in Fig. (1), it can be shown that the optical path difference ($\Delta\ell(\theta)$) of the back reflected beam as a function of the rotation angle $\theta$ is given by

$$\Delta\ell(\theta) = 4R \left[\sin 2\psi \sin\theta - (1 - \cos 2\psi)(1 - \cos\theta)\right] \quad (1)$$

where R is the shaft radius and $\psi$ is orientation angle of the mirror. For $\theta \ll \pi/2$

$$\Delta\ell(\theta) \simeq 4R\theta \left[\sin 2\psi - \frac{\theta}{2}(1 - \cos 2\psi)\right] \quad (2a)$$

Since the second term within the square bracket in Eq. 2a is small, then

$$\Delta\ell(\theta) \simeq 4R\theta \sin 2\psi \quad (2b)$$

From Eq. 2b it is seen that, for small values of $\theta$, $\Delta\ell(\theta)$ is a linear function of the rotation angle $\theta$. This implies that, at a fixed rotation frequency f, the delay introduced to a train of ultrashort pulses will vary linearly with time.

When $d \ll R$ (where d is the diameter of mirrors $M_1$ or $M_2$), mirror $M_2$ intercepts the beam over a small range of rotation angles $0 \leq \theta \leq \theta_{max}$, where $\theta_{max}$ is given by

$$\theta_{max} \simeq \frac{d}{R} \frac{\sin\psi}{(2 - \cos 2\psi)} \quad (3)$$

Substituting Eq. 3 into Eq. 2b, we obtain the range optical path differences

$$\Delta\ell \simeq \frac{4 d \sin 2\psi \sin\psi}{(2 - \cos 2\psi)} \quad (4)$$

which is maximized when $\psi = \pi/4$. At this angle

$$\Delta\ell \simeq \sqrt{2}\, d \tag{5}$$

The non-linearity (NL) over the total scan range can be determined by comparing the second term in the square bracket in Eq. 2a with the first. For $\theta_{max}$, this yields

$$NL \simeq \frac{d}{4R} \tan \psi \frac{(1 - \cos 2\psi)}{(2 - \cos 2\psi)} \tag{6}$$

which, for $\psi = \pi/4$, is

$$NL \simeq \frac{d}{8R} \tag{7}$$

As a numerical example, for $d = 2.5$ cm, $R = 7.5$ cm, and $\psi = \pi/4$ the scan range $\tau = \Delta\ell/c = \sqrt{2}\, d/c = 117$ psec., where $c$ is the speed of light. The nonlinearity is 4% over that entire range. Increasing R improves the linearity of the scan.

## Experimental Results and Discussion

In Fig. (2) we show the intensity autocorrelation trace (with background) for a cw train of incompletely mode-locked R6G dye laser pulses as displayed on an oscilloscope using the above described method. As can be seen from the figure, the coherence spike and the contrast ratio of 3:2:1 are clearly observed. The input average power to the autocorrelator was only $\sim$ 4 mW. With the 0.1 mm KDP crystal we used, the filtered SH background level was $\sim$ 100 mV.

Given Eq. 2b and since $\theta = 2\pi f t$, where $t$ is time, a delay of $\Delta\tau$ is related to a time increment $\Delta t$ as follows:

$$\frac{\Delta\tau}{\Delta t} \cong \frac{8\pi R f}{c} \tag{9}$$

In our experimental setup:    R = 12.25 cm, d = 3.5 cm, and f = 5 Hz.  The experimentally determined calibration factor $\Delta\tau/\Delta t$ is 50 psec/msec, which is in excellent agreement with Eq. 9.  From Fig. (2) we determine the total scan range $\tau$ ($=[\Delta\tau/\Delta t]$ x 3.3 msec) to be 165 psec, which agrees very well with the prediction of Eq. 5.  Given the experimental calibration factor of 50 psec/msec and assuming a $\text{sech}^2$ shape, the width of the pulse shown in Fig. (2) is 15 psec.

In principle, the time resolution of this autocorrelator is set by the second harmonic generation process itself.  This is true as long as the rise time of the detection and display parts of the auto-correlator are sufficiently fast such that $\Delta t_r = \Delta \tau_r c/8 \pi R f$, where $\Delta t_r$ is the width of the autocorrelation trace on the oscilloscope corresponding to the fastest resolvable pulsewidth $\Delta \tau_r$.  Assuming $\Delta \tau_r \sim 0.1$ psec, it follows that typical values of $\Delta t_r$ are on the order of one microsecond which is easily reached in practice.  We estimate our experimental resolution to be 0.1 psec.

We should like to point out that the parallel mirrors configuration is insensitive to vibration; in addition, the alignment process is straightforward.  We also note that the small feedback to the laser cavity did not have any observable effect on the picosecond pulse operation of the dye laser.

## Conclusions

We have presented a simple fast-scanning autocorrelation scheme for "real-time" display of ultrashort pulses.  This scheme has wide scanning range, high resolution, and is dispersion-free.  This auto-correlator should prove useful for optimizing the performance of cw mode-locked dye lasers.  It enables one to monitor pulse duration and characteristics while concurrently performing the experiment of interest.

REFERENCES

1.  H. P. Weber, J. Appl. Phys. 38 (1967) 2231.

2.  M. Maier, W. Kaiser, and J. A. Giordmaine, Phys. Rev. Lett. 17 (1966) 1275.

3.  J. A. Armstrong, Appl. Phys. Lett. 10 (1967) 16.

4.  R. L. Fork and F. A. Beisser, Appl. Opt. 17 (1978) 3534.

5.  K. L. Sala, G. A. Kenney-Wallace, and G. E. Hall, IEEE J. Quantum Electron. QE-16 (1980) 990.

6.  Y. Ishida, T. Yajima, and Y. Tanaka, Jap. J. Appl. Phys. 19 (1980) L289.

## FIGURE CAPTIONS

Fig. (1)  The Rapid-Scanning Michelson Interferometer Part of the
SHG Autocorrelator.  R is the radius of the rotating shaft,
d is the mirror diameter, and $\psi$ is the angle of mirror
orientation with respect to the incident beam.  Dashed
lines represent the shaft and mirrors after a rotation by
an angle $\theta$.  PD is the photodiode used to trigger the
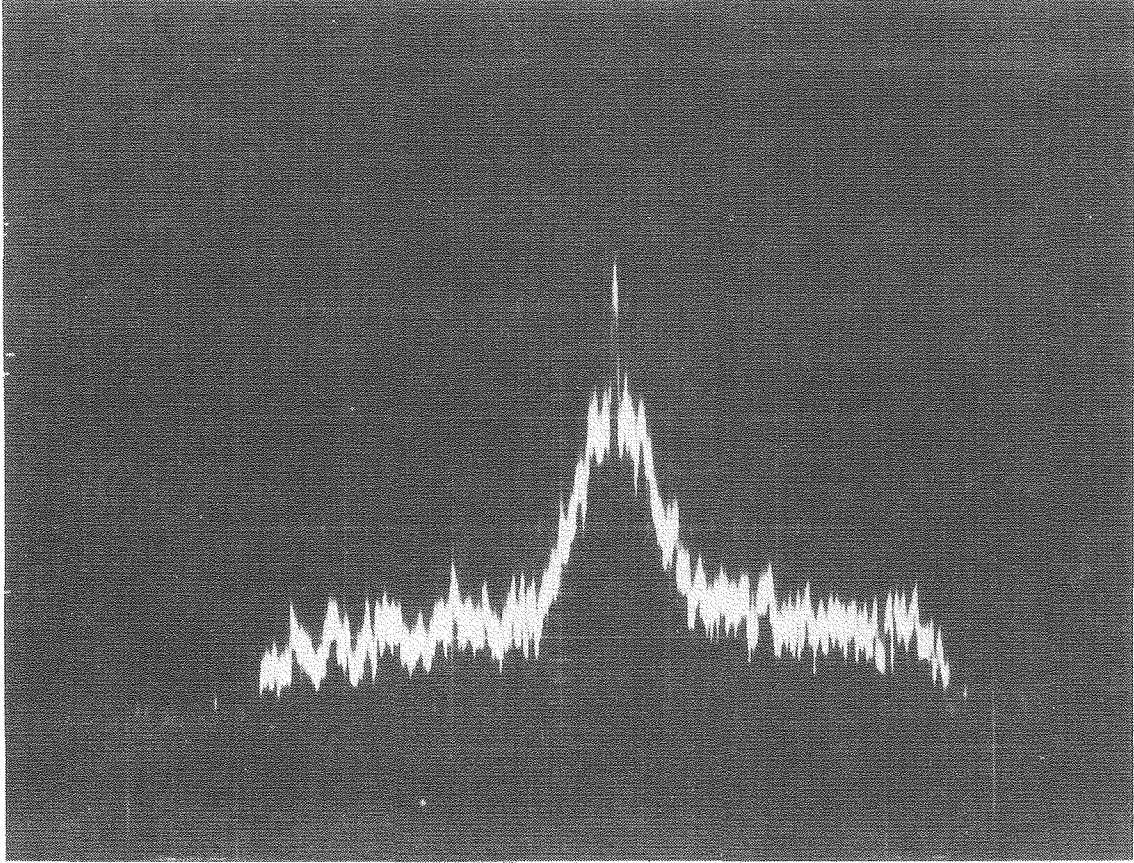oscilloscope.

Fig. (2)  Rapidly-scanned 2nd order intensity autocorrelation trace
of a cw train of ultrashort dye laser pulses.  Horizontal
scale is 500 $\mu$ sec/division.  Vertical scale is 50 mV/division.
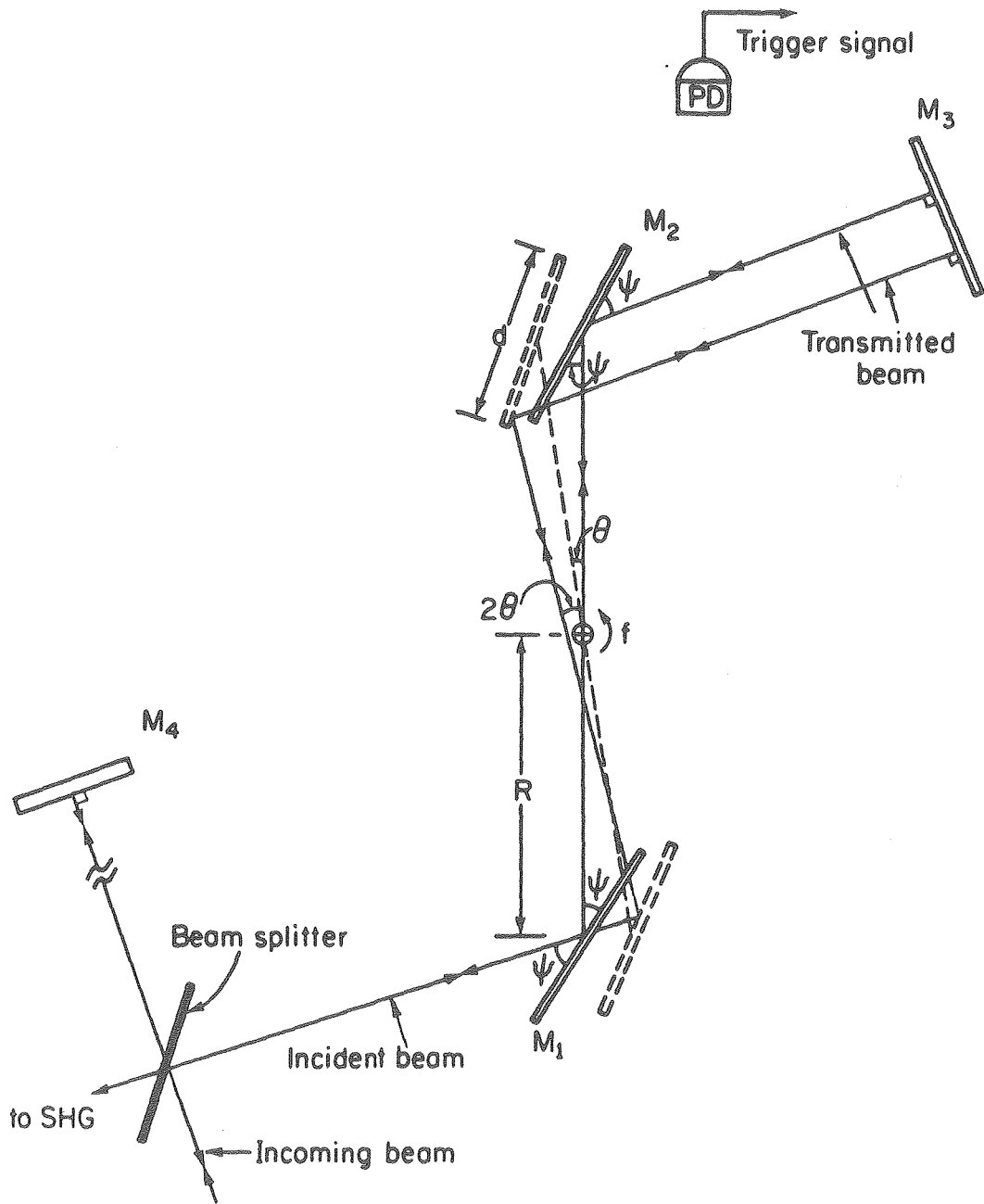
XBL 8010-2270

FIG. (1)

XBB 800 12725

Fig. (2)