Description of an electronic controller used with an autocorrelator to measure a femtosecond pulse duration in real time

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An electronic circuit controller is described which is used with an autocorrelator and an oscilloscope to measure the duration of femtosecond laser pulses in real time. The controller drives both the autocorrelator and the oscilloscope to produce a linear trace display of a pulse autocorrelation function on an oscilloscope. The apparatus has been found very useful for monitoring, aligning, and characterizing the output from cw mode-locked dye lasers.

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INTRODUCTION

The development of the ultrafast lasers have created the need for pulse measurements in the subpicosecond time regime. Since the fastest photodiodes and oscilloscopes have a resolution of >50 ps and streak cameras are limited in resolution to 2 ps, correlation techniques must be used at present to measure the pulse duration of laser pulses below 1 ps.[1,2] In this article we describe the design of an electronic device controller which allows for real-time pulse measurements, using a standard autocorrelation technique. This apparatus has femtosecond resolution and is particularly useful in monitoring and aligning the cw dye lasers.

DESCRIPTION OF THE APPARATUS

The schematic of the autocorrelator is shown in Fig. 1. The laser beam is divided by a 50% beam splitter in a modified Michelson interferometer. One beam is reflected from a prism (retroreflector), the other from a plane mirror. The reflected beams are aligned parallel to each other but not collinear. The prism is attached to a shaker (Mini shaker 4810, B&K instruments) which is placed on a translational stage (ATS 302, Aerotech). The two reflected beams are focused by a lens inside a 1-cm long KDP crystal to generate SHG signal. The SHG signal passes through two filters (Hoya U-330) and is detected by a photomultiplier. When the paths traveled by the two beams are equal, the SHG signal increases by at least two orders of magnitude over the background. The shaker is driven by a sine wave generator at 25 Hz to oscillate the prism. This introduces a variable delay in one of the beams. The SHG signal is proportional to the autocorrelation of the pulses as a function of the delay and can be displayed directly on the oscilloscope. When the oscilloscope is being driven internally by a linear ramp voltage the displacement of the prism is not linearly related to the trace shown on the oscilloscope. Therefore, the duration of the pulse cannot be directly measured from the autocorrelation function. In order to compensate for this problem, an electronic device controller described here drives both the prism oscillator and the time base of the oscilloscope with the same frequency sine waves, appropriately phase shifted, in order to bring them in phase. In addition, a square wave voltage is applied to the z axis which blanks the oscilloscope so that only one autocorrelation trace in each period is produced.

The schematic of the electronic circuit and the timing diagram are shown in Figs. 2 and 3, respectively. A low-pass filter determined by R_1 and C_5 introduces a phase shift to the sine wave produced by the generator. The

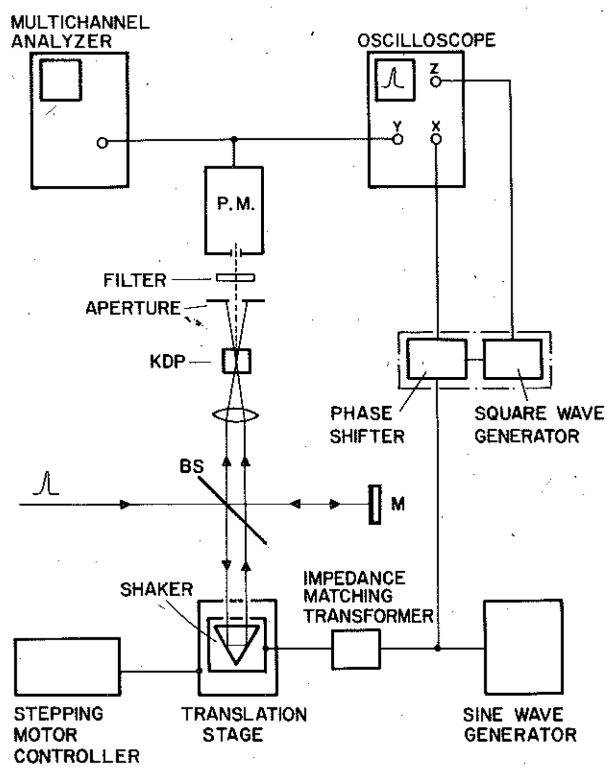

FIG. 1. Schematic of the autocorrelator.

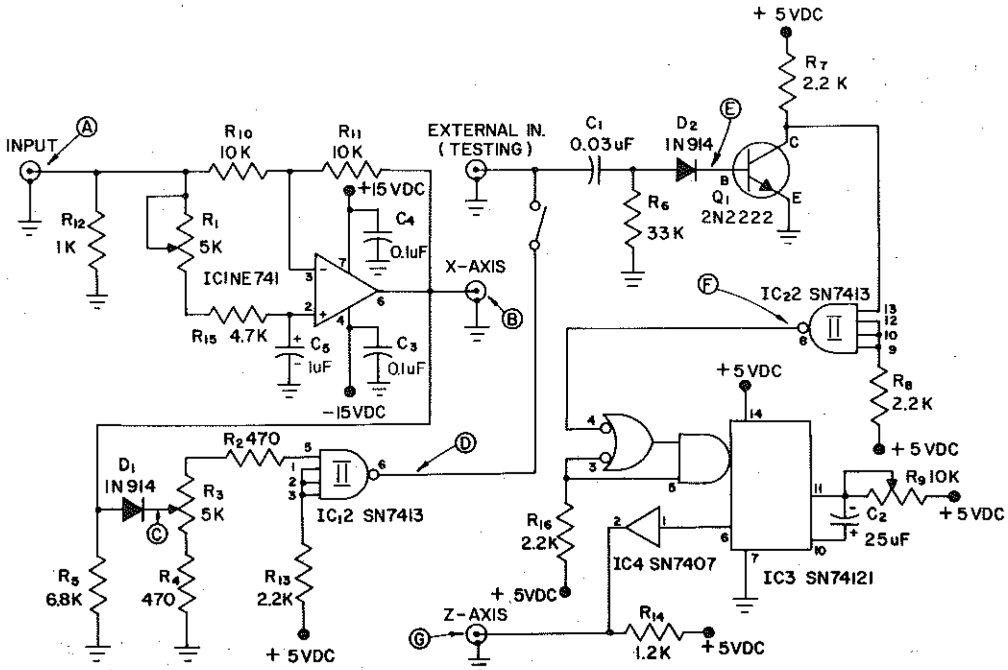

FIG. 2. Schematic of the electronic device. All resistors are 5%, ¼ W, unless specified.

amount of the phase shift (ϕ_1) is controlled by the variable resistor R_1. This sine wave is subsequently amplified by the operational amplifier IC1 and applied to the time base (x axis) of the oscilloscope. The gain of the operational amplifier is controlled by resistors R_{10} and R_{11}. The output from the IC1 also triggers the square wave pulse generator, which is applied to the z axis of the oscilloscope in order to blank part of the trace. The requirements for the square wave generator are: low jitter, adjustable delay, and pulse duration. To accomplish the first two requirements, the sine wave is shaped into a fast-rising rectangular pulse. The sine wave is rectified by the diode D_1 and shaped by the Schmidt trigger IC2. Resistor R_3 determines the phase delay (ϕ_2) of the generated pulse by adjusting the zero-crossing trigger point. The output from IC_12, a slow-rising rectangular pulse, is further modified by C_1, R_6, and D_2. The signal is differentiated by C_1 and R_6 and the negative transition is removed by D_2. The result is a pulse with a fast rise time and an exponential decay [see Fig. 3E]. Transistor Q_1 further restores the pulse and IC2 makes the output TTL

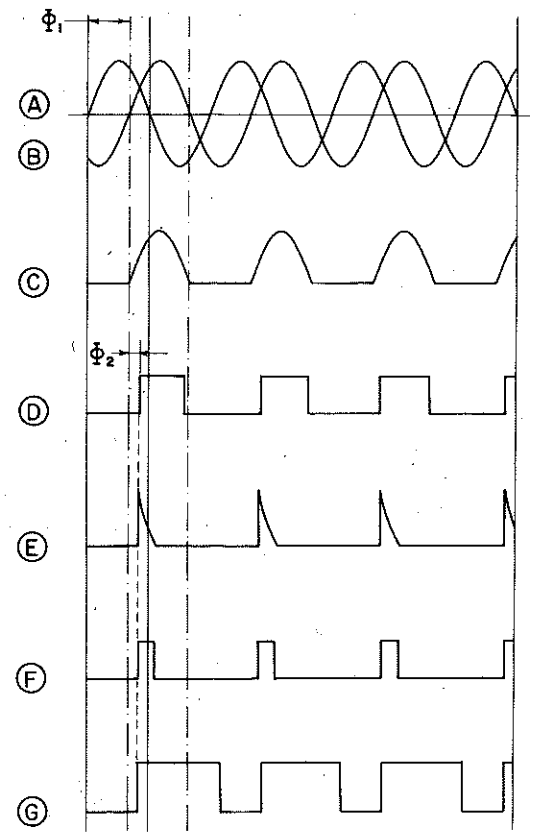

FIG. 3. Waveforms at the points indicated in Fig. 2, as explained in the text.

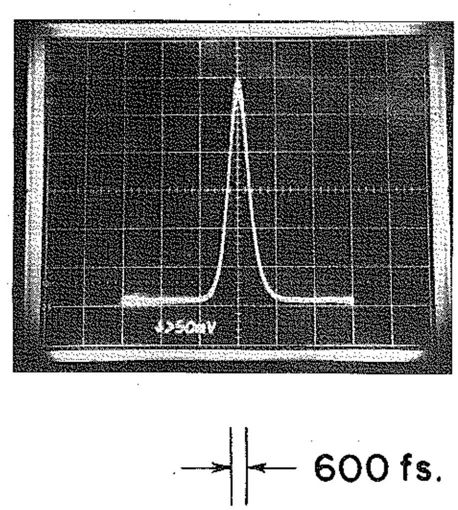

FIG. 4. A typical autocorrelation profile of the pulses generated from a cw passively mode-locked dye laser. The frequency of the shaker was set at 25 Hz. Assuming a sech^2 pulse shape, the duration of the pulses is 390 fs.

compatible [see Fig. 3F]. The output from $IC_2 2$ is used to trigger the monostable IC3. The pulse duration of the square wave is adjusted by the variable resistor R_9. The output of IC3 is buffered by open collector IC4 and applied to the z axis of the oscilloscope.

A photograph of an autocorrelation profile produced from the output of a cw passively mode-locked dye laser[3] is shown in Fig. 4. Calibration of the oscilloscope is accomplished by moving the prism by a known distance. The displacement of the autocorrelation on the scope is twice the distance divided by the speed of light. The half-width of the autocorrelation in the picture is 600 fs. The pulse duration is given by; $\Delta t/\gamma$, where Δt is the half-width of the autocorrelation and γ a constant which depends on the pulse shape.[1,2] For $sech^2$ pulses, the value of γ is 1.55. The duration of the pulses generated by the laser is 390 fs.

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