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**OPERATING MANUAL FOR
SINGLE-SHOT AUTOCORRELATOR**

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HEALTH DIRECTORATE
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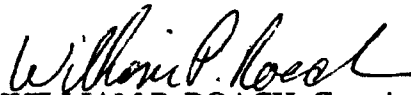
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The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.


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OPERATING MANUAL FOR SINGLE-SHOT AUTOCORRELATOR

INTRODUCTION

In Armstrong Laboratory's Directed Energy Division (AL/OED), we routinely generate laser pulses ranging from 5 picoseconds (ps) down to 50 femtoseconds (fs) in many different types of experiments. Single pulses are used in most cases; therefore, it is necessary to measure the individual pulsewidths. We cannot use the standard slow-scan autocorrelator because it averages hundreds of pulses over tens of seconds to obtain the full width at half maximum (FWHM) of the average pulse. It has become necessary to quantify the pulse-to-pulse variations in recent research efforts. Since the standard slow-scan autocorrelator could not measure other than the average pulse (1), we designed a single-shot autocorrelator based on a *background-free Michelson interferometer*. The single-shot autocorrelator can measure the time behavior of single events from pulsed lasers producing pulsewidths from 5 ps to 50 fs (2,3).

THEORY OF OPERATION

This single-shot autocorrelator design, based on a method first presented by Jansky et al. (4), has been utilized by several researchers in the picosecond (5) and subpicosecond (2) time domains. The basic concept is to transform the temporal shape of the pulse into a spatial profile which can be analyzed by a linear diode array or charge-coupled device (CCD) camera.

The design of this noncolinear, background-free autocorrelator is based on a spatio-temporal transformation; this system provides the spatial profile of the recorded pulse proportional to the second-order autocorrelation function of the incident pulse. The system generates a spatial profile of the second-harmonic signal which contains the same information as measured by a classical autocorrelator and calculates the fundamental pulsewidth using a calibration factor (CF) and a form factor (FF). A detector (CCD camera) integrates the second-harmonic signal over a time longer than the pulsewidth and records a spatial shape $S(x)$ proportional to the second-order autocorrelation function $G_2(\tau)$ of the incident pulse:

$$S(x) \propto \int_{-\infty}^{+\infty} I(t + \tau)I(t - \tau)dt = G_2(2\tau)$$

Remember, however, that the second-harmonic beam shape $S(x)$ is not exactly the second-order intensity autocorrelation function $G_2(\tau)$, but is the related function $G_2(2\tau)$. It can be shown that the FWHM δ_0 of the spatial function $S(x)$ is related to the temporal incident pulse FWHM η_0 by:

$$\eta_0 = K\delta_0(\Delta t_0/\Delta x_0)$$

where Δt_0 and Δx_0 are defined as above, and K is an FF (Equation 7 from reference 3) depending on the incident pulse shape ($K = 0.65$ for Sech^2 pulse, $K = 0.707$ for a Gaussian pulse, and $K = 1$ for a square pulse). Thus, the calibration of this single-shot autocorrelator is shown to be obtained in exactly the same way as in the classical slow-scan or fast-scan

autocorrelator and leads to a simple measurement method. A beam diagnostic instrument records the image and performs the calculations. The optical layout of the beams, paths, and hardware is shown in Figure 1.

As shown in the figure, a noncolinear beam arrangement is used to obtain a background-free signal (i.e., zero signal from the fundamental); the two beams cross in the potassium-titanyl-phosphate (KDP) crystal. The angle between the two beams has been reduced to a minimum because the frequency-doubling mechanism in the KDP crystal is nearly the same for the bisector as for the two incident beams when the angle is very small. Thus, three light beams are produced at the second-harmonic frequency, each propagating in a different direction. Only the beam produced in the bisector contains autocorrelation information; consequently, both beams must overlap each other inside the crystal in space and in time.

In a classical slow-scan autocorrelator, the two beams are usually focused on the nonlinear crystal, and the combined second-harmonic signal is recorded only at the bisector because spatial information is not required. In the single-shot autocorrelator, the beams are defocused by inserting a bi-concave lens with a focal length (f) of -500 mm before the beamsplitter, which expands the beams to cover the entire surface area of the nonlinear crystal and to produce the spatially distributed second-harmonic signal. The shape of the spatially distributed second harmonic contains information relative to the temporal shape of the original pulse profile. The CCD camera records the spatial image by integrating the time history of the second harmonic generated in the KDP crystal.

This autocorrelator was designed to operate with wavelengths between 532 and 580 nm and with pulsewidths as short as 50 fs. The KDP crystal was designed for efficient second-harmonic conversion for wavelengths between 532 nm and 580 nm with "phase matching" (i.e., the wavevector mismatch between the polarization wave and the generated wave must be zero). Zero mismatch was made possible by fabricating the crystal such that the propagation and polarization of the fundamental was along a direction different from a principal axis of the birefringent crystal. This design element, also known as "critical phase matching," can be achieved over a range of wavelengths by rotating the crystal for each wavelength. A chart showing the phase matching angle for KDP as a function of the fundamental wavelength is given in the *Handbook of Laser Science and Technology* (6). The second-harmonic power undergoes periodic oscillations as a function of thickness and creates a limiting circumstance known as the "coherence length." Coherence length is the limiting factor in the measurement of ultrashort pulses; thus, a 300- μ thickness will limit time measurement to greater than 50 fs. The 30-mm diameter, 300- μ -thick KDP crystal was cut at an angle between 68 and 82 deg (actual angle = 72 deg). The actual usable diameter is 28 mm. The crystal is mounted between two 1-mm-thick sapphire windows in an air-tight, moisture-proof, nitrogen-filled holder. An ultraviolet filter (UG11) is mounted in front of the CCD camera to block all visible light and transmit only the second harmonic between 290 nm and 266 nm. As shown in the diagram, an $f = 50$ mm lens images the three beams on the CCD detector in the camera. The Model 4800 Cohu camera is the detector of the BeamGrabber Model 6100 laser diagnostic instrument manufactured by Photon, Inc. This instrument analyzes the images recorded from a single pulse and presents the data as the spatial width in microns of the half-intensity points of the

autocorrelation signal. This width is then multiplied by the CF and the FF to obtain the FWHM temporal pulsewidth.

SET-UP PROCEDURE

The autocorrelator should be mounted on an optical table near the experimental setup to insure that the pulses are not degraded by long transmission paths. Dispersion is more critical than beam divergence; there is a negative lens inside the autocorrelator which expands the beam to cover the maximum usable area of the KDP crystal. By rotating the KDP crystal, it is possible to optimize the second-harmonic generation from pulses that are polarized in a specific configuration; consequently, we have designed the single-shot autocorrelator to measure only vertically polarized pulses.

The single-input beam, as shown by the arrowhead in Figure 1, must be directed through the adjustable iris to the center of mirror M1 and through the second iris through the center of the -500-mm-f lens to the beamsplitter. This beamsplitter provides a 50/50 split of the input beam in the visible wavelength range for vertical polarization. All mirrors are front surface, planar, and rated at L/20. The part of the pulse transmitted through the beamsplitter (the stationary pulse) is reflected by mirror M2 first, to mirrors M4 and M5, and then to the center of the KDP crystal. Mirror M2 will not normally be adjusted after the beam is positioned onto the KDP crystal. The pulse reflected from the beamsplitter is directed first to mirror M3, then to mirrors M4 and M5, and finally to the center of the KDP crystal where it overlays the transmitted pulse in space and time, since the path lengths are equal. Mirror M3 will not normally be adjusted again after the beam is positioned on the KDP crystal; the separation of the two pulses immediately past the beamsplitter is between 1.25 - 2.50 cm (0.5 - 1 in). After the two pulses are observed to strike the center of the KDP crystal, all beam-position adjustments are then made using the rotation and translation of the beamsplitter with the two micrometers. The rotation required to position the beam correctly is so small that the beamsplitter still provides a 50/50 split. No other adjustments are required.

By rotating the beamsplitter which translates the reflected beam in a horizontal direction only, we can position the beam on the KDP crystal while observing our progress on the BeamGrabber monitor. Translating the beamsplitter provides only minimal positional changes, but does adjust the length of the path between the beamsplitter and the KDP crystal and makes very fine time-delay adjustments possible. Since the two pulses must overlap within the KDP crystal in both space and time, these two adjustments are used to align the autocorrelation signal and fine-tune the patterns on the monitor.

After the BeamGrabber is turned on, the following procedure must be used to configure the instrument before trying to align an autocorrelation signal. Figure 2 shows the front panel and control switches and lights for the Model 6100. Figure 3 shows a display of vertical and horizontal measures with an explanation of the displayed information, while Figure 4 provides an explanation of the display for the ellipticity measures.

SET-UP PROCEDURE FOR BEAMGRABBER--MODEL 6100

Definitions for Main Menu

To access the Main Menu, depress the Main Menu key on the front panel of the BeamGrabber. The Main Menu simply lists the submenus.

A. Measurement Menu

From the Measurement Menu, the user can select the types of measurements to be performed. The following selections are possible:

1. Width - X and Y Ellipse

Width set to X and Y indicates calculations from a horizontal raster (X) and a vertical raster (Y). If Ellipse is chosen, then the calculated diameters are derived from the Major and Minor axes of the beam.

Diameter Display Indicators -- The BeamGrabber will produce four types of indicators for diameters. The first is a valid number. The others are listed below.

- a. ---- Indicates insufficient intensity at the cursor location to make a valid beam measure.
- b. +++++ Indicates that the A/D converter has detected a saturated condition location; thus, a distorted profile is displayed.
- c. ***** Indicates "too much noise." Noise (interference) may be caused by stray ambient light falling on the detector, by multiple reflections striking the detectors, possibly on the edges, or by placing the beam itself too close to the edge of the detector.

2. Fit - GAUSS OFF

If fit is turned on, the system compares the best fit Gaussian to the horizontal and vertical cross-sections. With the Display On option activated, the fitted Gaussian is drawn along with the cross-sectional plots. With the Text On option activated, goodness of fit numbers are calculated and displayed for the two axes (denoted as Gx and Gy). If fit is turned off, no fitting takes place.

The following equation is used to compute the goodness of fit:

For all points i:

$$\frac{\sqrt{\sum_{i=1}^N [\text{raw}(i) - \text{fit}(i)]^2}}{P}$$

where N = Number of points

P = Peak raw value

3. Energy - On Off Lock %

If the Energy option is on, a relative energy percentage for the beam is displayed. If the Energy option is turned off, this number is not displayed. If lock % is selected, the number is displayed; the Set Ref button will not affect this display. The E will be displayed in inverse video to indicate that the Set Ref button will have no effect.

4. Irradiance - @Cursor Peak Off

Irradiance @cursor means that the irradiance values displayed will be those at the intersection of the cursors. The position numbers displayed along with the irradiance will also track the center of the crosshairs. If the Autocenter function is enabled and Irradiance @cursor is chosen, the irradiance and position displayed are at the energy center.

If Peak is chosen, the irradiance displayed is the peak value on the screen. The position number displayed is the position of the first pixel found with that peak irradiance. Pixels are searched sequentially from the upper-left-hand corner of the screen, horizontally to the lower-right-hand corner.

5. Vid - VCR TV Contour Normal

Video sets the mapping of the camera data to output data. VCR mode indicates that data is mapped one to one (i.e., 0 in equals 0 out, 1 in equals 1 out, etc.). This mode is useful to record the laser data in a raw mode on a VCR for later analysis.

TV mode indicates that the data is mapped with a gamma less than 1. In TV mode, the low-level signals are highlighted and the high-level signals are deactivated. TV mode is very useful in order to see low-level scattering or other beam aberrations.

Contour mode separates the grey scales into eight distinct levels. These levels present a clear picture of the contour of the laser energy.

Grey Scale Percentages:

87.5 to 100% of full scale is in red.
75 to 87.5% of full scale is in orange.
62.5 to 75% of full scale is in brown.
50 to 62.5% of full scale is in green.
37.5 to 50% of full scale is in blue.
25 to 37.5% of full scale is in pink.
12.5 to 25% of full scale is in purple.
0 to 12.5% of full scale is in grey.

Normal mode provides "normalized" display of the contour plot. In this mode, the color levels are adjusted as a percentage of peak.

90 to 100% of peak is in red (0% black).
50 to 90% of peak is in orange (20% black).
37.5 to 50% of peak is in brown (40% black).
13.5 to 37.5% of peak is in green (60% black).
10 to 13.5% of peak is in blue (80% black).
0 to 10% of peak is in grey (100% black).

B. Calibration Menu

The Calibration Menu offers three different selections to calibrate the BeamGrabber to operate with any camera.

1. Black Level Calibration

Black Level Calibration calculates an offset for each gain stage. The calculated offsets are used when changing gains from the front panel to insure the integrity and accuracy of our numbers.

For the most accurate results, the camera black level should be calibrated anytime after the experimental setup has changed the ambient light levels reaching the camera face. A neutral density (ND) filter (of value 2 or greater) completely covering the front of the camera helps to minimize errors due to background light.

2. Camera Selection

The user selects the camera type that is used with this system. If the camera is not listed, the user can select "other" and set default pixel sizes for the camera type.

Selecting other cameras brings up a submenu from which the user sets pixel sizes via the arrow keys.

3. Restore System Setup

Restore System Setup reinitializes the system to the factory default parameters. Factory default settings on BeamGrabber are as follows:

- a. Reference Numbers are used while displaying delta. Notice that X & Y positions are never displayed as delta values.

Wx	-	5000 μ
Xy	-	5000 μ
Wmin	-	5000 μ
Wmaj	-	5000 μ
Ratio	-	0.5
Angle	-	-45
Gx	-	0.5
Gy	-	0.5
E	-	14622720 (224*256*255)
Ixy/lpk	-	128

- b. General purpose instrumentation buss (GPIB) address - 3

- c. RS232 baud rate - 9600

- d. Camera type - COHU (x-33.60 μ , Y-25.75 μ)

- e. Limit screen settings:

1. Position Limits:

X Pos.	Min.	-	-8600u
	Max.	-	8600u
Y Pos.	Min.	-	-6600u
	Max.	-	6600u
Limit Check		-	OFF

2. Width Limits:

X(Minor)	Min.	-	0u
	Max.	-	6600u
X(Major)	Min.	-	0u
	Max.		8600u
Limit Check		-	OFF

3. Elliptical Limits:

Ratio	Min.	-	0.00
	Max.	-	1.00
Angle	Min.	-	-90
	Max.	-	90
Limit Check		-	OFF

4. Energy Limits:

Energy	Min.	-	0%
	Max.	-	300%
Irrad.	Min.	-	0
	Max.	-	255
Limit Check		-	OFF

5. Fit Limits:

X(Minor)	Min.	-	0.000
	Max.	-	1.000
Y(Major)	Min.	-	0.000
	Max.	-	1.000
Limit Check		-	OFF

f. Gain - 0

g. Clip - 13.5%

h. Avg. - 5

i. X Reference - 0

j. Y Reference - 0

k. Measurement Menu Selections:

Widths	-	X&i
Fit	-	Gauss
Energy	-	OFF
Irrad.	-	@Cursor
Vid.	-	Contour

1. Triggering Screen Setup:
 - Signal - Internal
 - Slope - Positive
 - Max rate - 60.00

C. Limit Set Menu

The Limit Set Menu has five submenus. Each submenu provides for setting minimum and maximum bounds on real time values calculated by the machine. The submenu selections are:

1. Position
2. Width
3. Elliptical Ratio and Angle
4. Energy and Irradiance
5. Goodness of Fit

From each submenu the user can select a minimum and a maximum bound for each of two parameters. This submenu will also show the user the current value for the parameter. Finally, each submenu provides a switch to view (check) the limits set on that particular submenu.

While the plotting screen is being displayed, each numerical value is compared to the minimum and maximum bounds set in this table. If checking is enabled and the calculated parameter is outside of the bounds set by the minimum and maximum bounds on this submenu, the parameter is displayed in inverse video. If the parameter is in bounds or if limit checking is turned off, the parameter is displayed in standard video.

D. Trigger Menu

The Trigger Menu lists three parameters:

1. Signal - Internal or External

Selecting Internal Signal indicates that the BeamGrabber will collect data from the camera at max rate times per second. The Trigger Out Signal will change levels to indicate the field of data to be collected. This change of state can be used to trigger lasers or synchronize external events.

If an External signal is selected, the BeamGrabber will wait for a valid trigger on the Trigger In BNC before data will be collected.

2. Slope - Negative or Positive

If slope is set to Negative, a high-to-low transition is used as a valid trigger. If the slope is positive, a low-to-high transition is used as the valid trigger. When a valid trigger occurs, the next full field of data is collected.

3. Max Rate - 60 Hz, 30 Hz, 15 Hz, 10 Hz, 7.5 Hz, 6.0 Hz, 5.0 Hz, 4.3 Hz, 3.0 Hz, 2.0 Hz, 1.0 Hz, 0.5 Hz, 0.1 Hz, 0.05 Hz, 0.01 Hz.

When the BeamGrabber is in Internal Signal mode, the max trigger rate becomes the rate at which the BeamGrabber collects video information from the camera. In External Signal mode, the max rate becomes the maximum rate at which the BeamGrabber will allow data to be collected from the camera. If the laser is causing an External trigger at a rate faster than the max trigger rate, the BeamGrabber will not update video information any faster than the maximum rate. If the laser is causing an External trigger at a rate slower than the max trigger rate, the BeamGrabber will update video at the laser trigger's rate.

E. RS232 Menu

The RS232 Menu lists baud rate options at which the RS232 transmits and receives data.

- The selections are: 300, 1200, 2400, 4800, 9600 baud. The factory default RS232 baud rate is 9600.

F. GPIB Menu

The user selects a GPIB address from the GPIB Menu. Addresses can range from 1 to 31. The factory default address is 3.

Configuration

**** NOTE **** Connect BeamGrabber to the camera, and turn the camera on before turning on the BeamGrabber.

1. a. Press "Main Menu."
- b. Use the up and down arrow keys to move the "*" to select "Trigger" and press "Enter Save."
- c. Use the up and down arrow keys again to select "Signal."
- d. Use the left and right arrow keys to highlight "External."
- e. Press "Enter Save."

2.
 - a. Press "Main Menu."
 - b. Use the up and down arrow keys to select "Measurements Menu" and press "Enter Save".
 - c. Use the up and down, left and right arrow keys to highlight the following:

Widths : "X and Y"
Fit : "Off"
Energy : "Off"
Irrad. : "@Cursor"
Vid. : "Contour"
 - d. Then press "Enter Save."
3. With a BNC cable connect "Trigger In" to a transistor-transistor logical (TTL) level sync from the laser.* The Trigger input to the BeamGrabber should be at least 1 μ s long. The input which can accept any trigger signal between 4.0 and 4.8 V is triggerable from TTL or complementary metal-oxide-silicon (CMOS). A low-level signal must be between -0.6 and +0.8 V.
4. Turn on autocentering ("Autocenter" light).
5. Turn on graph function ("Graph On" light).
6. Turn on text function ("Text On" light).
7. Turn on the continuous capture function ("Continuous" light).
8. Use the left and right arrow keys to select "Gain" indicator on the screen. Use the up and down arrow keys to set it to "11."
9. Use the left and right arrow keys to select the clip level indicator on the screen. Use the up and down arrow keys to set it to "50.0%."
10. Use the left and right arrow keys to select the "AVG" indicator on the screen. Use the up and down arrow keys to select the desired number of pulses to be averaged.

*When used with the SpectraPhysics ultrashort-pulse system, the trigger pulse may be obtained from the SM-1 sync module, sync out. When using this sync pulse, the BeamGrabber will be updated each time the laser fires.

--NOTE: This description was adapted from the Model 6100 BeamGrabber's Manual.

OPERATING PROCEDURE

Measurement of a pulsewidth is a simple procedure once the BeamGrabber is able to record a pulse and display it on the monitor. With the pulse repetition rate of 10 pulses per second from the laser, confirm that the image from the transmitted beam is observed on the left side of the monitor and is being captured by the BeamGrabber. The reflected beam is then adjusted back and forth with the beamsplitter rotator to observe the image on the right side of the monitor. The two images from the split pulses should be close to each other but should not overlap. Adjust the beamsplitter rotation until the two images almost touch each other while searching for the autocorrelation image between the two primary beams. If no autocorrelation signal can be found, the beamsplitter translation stage must be adjusted to vary the time delay between the two images until the autocorrelation signal is visible. The micrometer setting on the translation stage will be close to 3.90 mm for the correct time delay between the two pulses. For very fine time-delay adjustments (up to 20 μ), the piezo-electric voltage may be adjusted between 0 and 100 volts.

The BeamGrabber will capture a new autocorrelational signal each time the laser fires when the BeamGrabber is set up as described in Step 7 of the Set-Up Procedure for continuous capture. The BeamGrabber monitor shows a two-dimensional picture, but the autocorrelation information is only contained in the x-dimension. The y-dimension shows how the autocorrelation signal varies across the beam as the two pulses coincide in time and in space across the KDP crystal. The true autocorrelation signal should be taken in the x-direction corresponding to the peak in the y-direction.

PRINTING PROCEDURES

Parallel Printer

BeamGrabber Model 6100 supports most LX/FX Series Epson and compatible 9-pin printers which have ESC* graphics mode. A partial list of printers which may be used follows. The print facility of the Model 6100 enables the user to print all text and graphics information displayed on the plotting screen. A print command may be issued by pressing the PRINT button on the front panel or by issuing the PRNT command from an RS232 or GPIB source. If a print command is issued and the Model 6100 does not find the printer connected, it will abort its search for the printer and issue a screen message.

If the Text On LED is not illuminated, no text information is printed; and if the Graph On LED is not illuminated, no graphics information is printed. No printing is performed if the BeamGrabber is displaying any menus screen (i.e., when the Main Menu LED is illuminated).

Graphics

To print graphics, the Graph On LED should be illuminated. If normal video is selected, only five contour rings are printed; otherwise, seven contour rings are printed. See "Video" section for more details on video selections.

Text

To print text, the Text On LED should be illuminated. Since only displayed text is printed, the user should select the desired text from the Measurement Menu screen. See "Measurement Menu" section for details.

Compatible Printers

The following printers are compatible with the BeamGrabber.

Apex 80	420i	DFX-5000	EX-800	EX-1000	FX-80
FX-85	FX-86e	FX-100	FX-185	FX-286	FX-286e
FX-850	FX-1050	HS-80	LX-80	LX-86	LX-800
LX-810	RX-80	RX-80F/T+	RX-100	RX-100+	T750
T-1000					

Procedure

The procedure for obtaining a printout of the autocorrelation signal is simple and straightforward. Connect an Epson FX-compatible printer to the "PARALLEL PRINTER" connector on the rear of the BeamGrabber. Pressing the "PRINT" button on the front of the BeamGrabber initiates automatic printing.

CALIBRATION

The calibration of this instrument is carried out using exactly the same procedure as for the classical autocorrelator. The procedure introduces a known calibrated delay in one beampath and records the translation of the autocorrelation image on the camera x-axis. The BeamGrabber performs all calculations for this calibration. The introduction of the delay Δt_0 into one of the two incident beams shifts the autocorrelation pattern second harmonic along the x-axis. This shift Δx_0 is related to the delay Δt_0 by the equation (3):

$$\Delta x_0 = c\Delta t_0/2n\sin(\phi/2)$$

where:

- Δx_0 = change in x direction
- Δt_0 = change in time-induced delay
- n = linear index of the nonlinear crystal
- ϕ = angle between 2 incident beams

A calibrated etalon may be used to introduce a known time delay in one beampath or both. For instance, an ultrathin etalon supplied by Spectra-Physics can be used in the calibration for certain pulsewidths. This 200- μ -thick etalon introduces a time delay of 307 fs for a wavelength of 580 nm as measured by the slow-scan autocorrelator when it is placed in one beampath during an autocorrelation. If this etalon is placed in one path of the single-shot autocorrelator, a delay of 307 fs for 580 nm is introduced, and a corresponding displacement on the x-axis of the monitor can be measured providing the pulsewidth being measured is much greater than the 307 fs. It must be remembered that the single-shot autocorrelator only works when the two pulses overlap in both time and space inside the KDP crystal. Obviously if one pulse is shorter than 300 fs, with the 307-fs delay, the two pulses will not overlay in time. Therefore, no autocorrelation signal can be observed. The only way to observe an autocorrelation signal in this case is to translate the beamsplitter to reposition the pulses in time. However, the method used to calibrate this unit was to place the 307-fs delay in one beampath and a 265-fs delay etalon in the other beampath with a net delay between the two pulses of 42 fs. For this 42-fs delay, the spatial profile of the autocorrelation signal was shifted along the x-axis from -291 μ to -89 μ as shown in Figures 5 and 6. Whenever the two etalons were reversed, the x-axis shift was in the other direction from -291 μ to -492 μ as shown in Figure 7. For this 42-fs calibration, pulses of 100 fs can be measured as shown in Figure 8. Clearly, the spatial profile can be shifted along the x-axis, and a time-to-space conversion has taken place and, therefore, the single-shot autocorrelator does indeed perform according to theory.

PULSEWIDTH MEASUREMENTS

This single-shot autocorrelator measures individual pulsewidths between 5 ps and 50 fs from a laser in the visible wavelengths between 532 and 580 nm and has a calibration factor (CF) as a function of the positioning of the 50-mm-f lens and the CCD camera. The CF, as just discussed, was determined for positioning the lens and camera at the time of setup; before any new measurement is made a new CF must be determined. The CF is calculated using the following equation:

$$CF = (\text{x-axis displacement/introduced delay})$$

$$CF = (-89+492)/(42+42) = 4.8$$

A form factor (FF) of $K = 0.65$ is used in the calculations for the assumed $(\text{Sech})^2$ pulse shape. The actual pulsewidths for measurements by the BeamGrabber for individual pulses will be:

$$\text{Pulsewidth} = K(W_x/CF) = (.65W_x/4.80)$$

where:

$K = FF$

$W_x = x\text{-axis FWHM measured by BeamGrabber}$

$CF = CF \text{ as above}$

As shown in Figure 8, the pulsewidth calculated using the FWHM $W_x = 734 \mu$ is 99 fs. The pulsewidth measured using the slow-scan autocorrelator was 117 fs for a 50-s scan using 100 fs/s scan rate.

SPECIFICATIONS

The following specifications are for the Model 6100 and COHU camera.

INPUT SIGNALS

VIDEO IN

input beam detector signal
RS170 format
via BNC connectors (2)

EXTERNAL TRIGGER

coordinate capture with pulsing
TTL & CMOS compatible
min. 2.5Vdc transition
max. 24Vdc relay
positive or negative polarity
> 1- μ s duration
via BNC connector

OUTPUT SIGNALS

VIDEO OUT

support external monitors,
VCRs, video printers, etc.
NTSC (color) & RS170 (B&W)
via BNC connectors (1 each)

INTERNAL TRIGGER

control source pulsing
TTL & CMOS compatible
0-5Vdc transition
positive or negative polarity
50- μ s duration
0.01-60Hz adjustable rate
via BNC connector

PARALLEL PRINTER PORT

support IBM-compatible
9-pin dot matrix
DB25-pin female connector

RS232 SERIAL COMM PORT

download & full remote control
DB9-pin female connector
DCE configuration
baud rate up to 9600
data in ASCII/binary format

GBIB PARALLEL COMM PORT

download & full remote control
IEEE488 connector
IEEE488.1 compatible

programmable address (0-30)
std talker/listener interface
with SRQ support
data in ASCII/binary format

ELECTRICAL

IMAGER

Single CCD using frame transfer
method

IMAGE AREA

8.8 by 6.6 mm (corresponding to
2/3-inch tube)

ACTIVE PICTURE ELEMENTS

754 (H) by 488 (V)

NUMBER OF PICTURE CELLS

780 (h) by 244 (V)

CELL SIZE

11.5 μ m (H) by 270 μ m (V)

RESOLUTION

Horizontal: 565 tv lines
Vertical: >350 tv lines

CONTRAST VARIATION

25 $^{\circ}$ C < 5% overall

SCANNING SYSTEM

RS170, 2:1 interlaced

VIDEO OUTPUT

1.0 V p-p, 75 ohm unbalanced

GAMMA

0.5 or 1.0, jumper selectable

GRAY SCALE

Renders all shades of gray on
EIA tv resolution chart, 1956

AGC

6 dB variable gain (peak-average
adjustable)
Jumper selectable on/off

AUTO LENS

Peak/average adjustable

SIGNAL-TO-NOISE RATIO, 25 °C

50 dB (gamma 1, gain 0 dB),
unweighted 8-MHz bandwidth

AUTOMATIC BLACK LEVEL

Maintains setup level at 7.5 ± 0.5
IRE units if picture contains at
least 10% black

SYNCHRONIZATION

EIA RS-170 crystal, 14.31818 MHz
clock output standard
Genlock, with crystal or line lock
backup (jumper selectable)
External H and V drive

POWER OPTIONS

12V dc/ac $\pm 10\%$, 60 Hz ac
24V dc/ac $\pm 10\%$, 60 Hz ac
115 V ac 60 Hz, $\pm 10\%$ (with
optional wall transformer)

POWER CONSUMPTION

4.2 Watts

REFERENCES

1. Van Stryland, E.W. (1979). The effect of pulse to pulse variation on ultrashort pulsewidth measurements. Optics Comm., 31, (1), 93-96.
2. Ishida, Y., Yajima, T., and Watanabe, A. (1985). A simple monitoring system for single subpicosecond laser pulses using an SH spatial autocorrelation method and a CCD image sensor. Optics Comm., 56 (1), 57-60.
3. Brun, A., Georges, P., LeSaux, G., and Salin, F. (1991). Single-shot characterization of ultrashort light pulses. J. Phys. D, 24, 1225-1233.
4. Jansky, J., Corradi, G., & Gyuzalian, R.N. (1984). Tilted-pulse second-harmonic beam analysis for femtosecond to subnanosecond laser pulse-duration measurements. Appl.Phys., 33, 79-82.
5. Gyuzalian, R.N., Sogomonian, S.B., & Horvath, Z. (1979). Background-free measurement of time behaviour of an individual picosecond laser pulse. Optics Comm., 29(2), 239-242.
6. Weber, Marvin J. (Ed.). (1986). Handbook of laser science and technology, vol. III, Optical materials: Part 1. Boca Raton, FL: CRC Press, p.115, 1986.

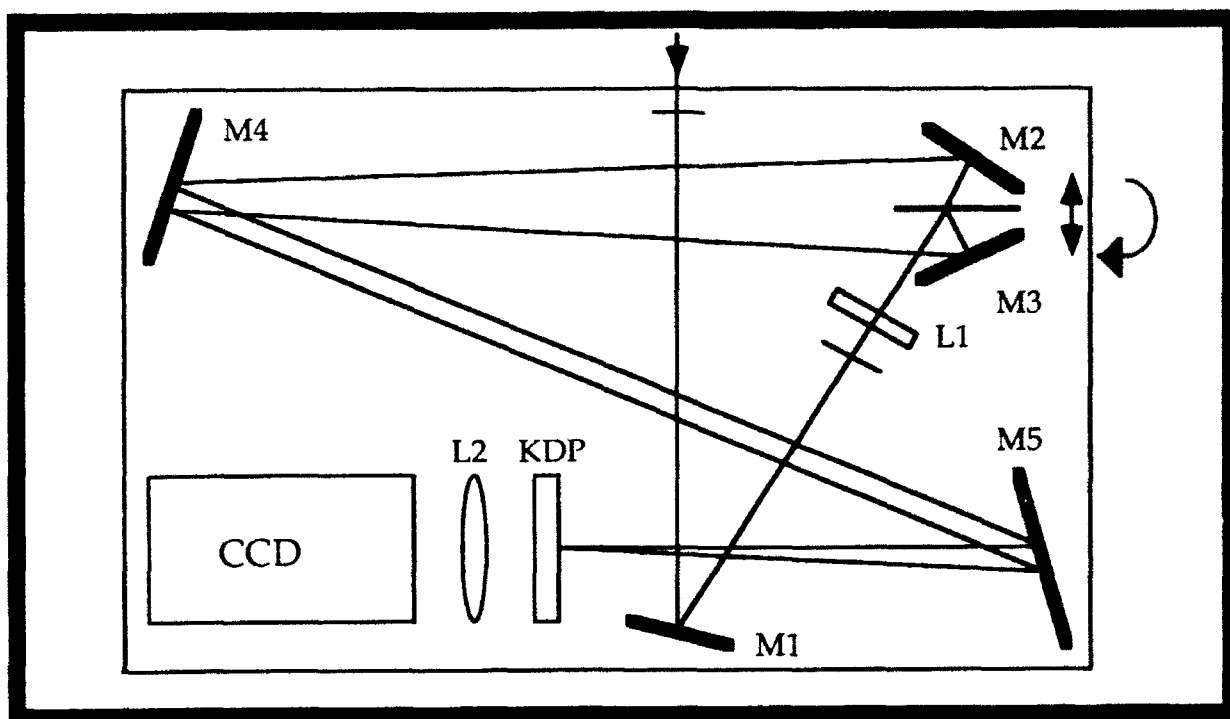


Figure 1. Single-shot autocorrelator.

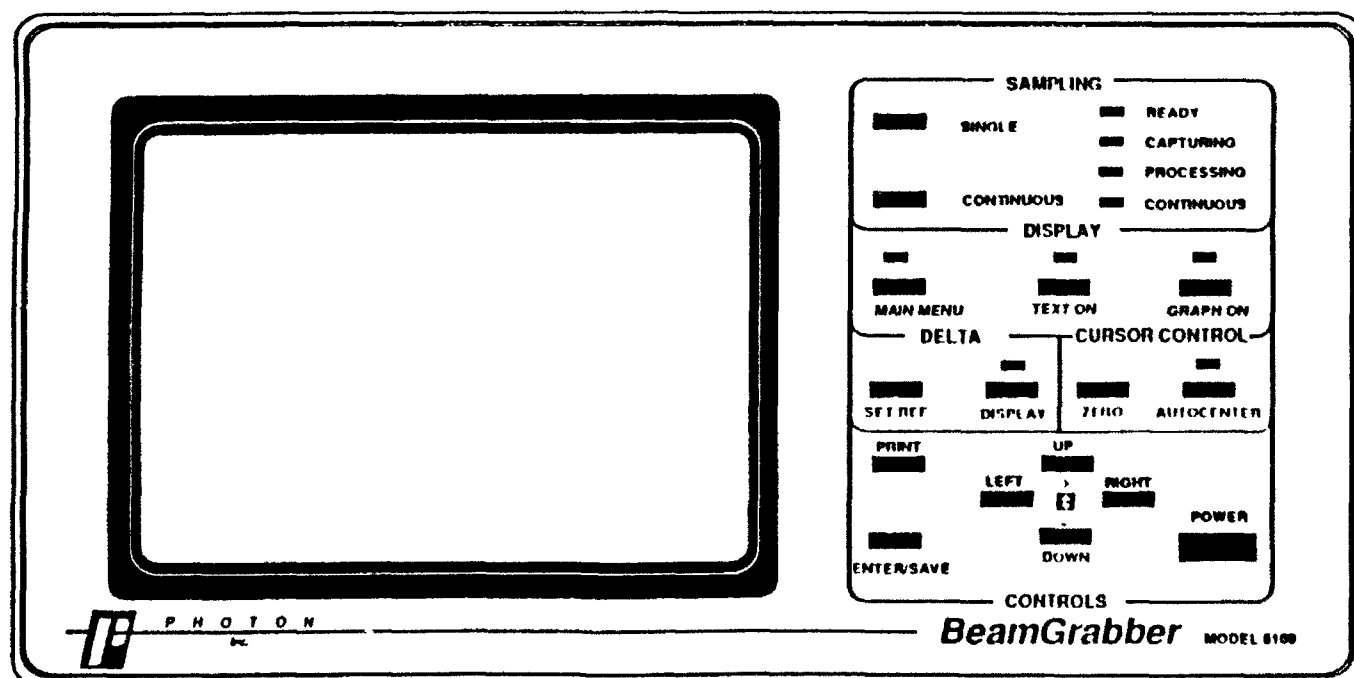


Figure 2. Front panel.

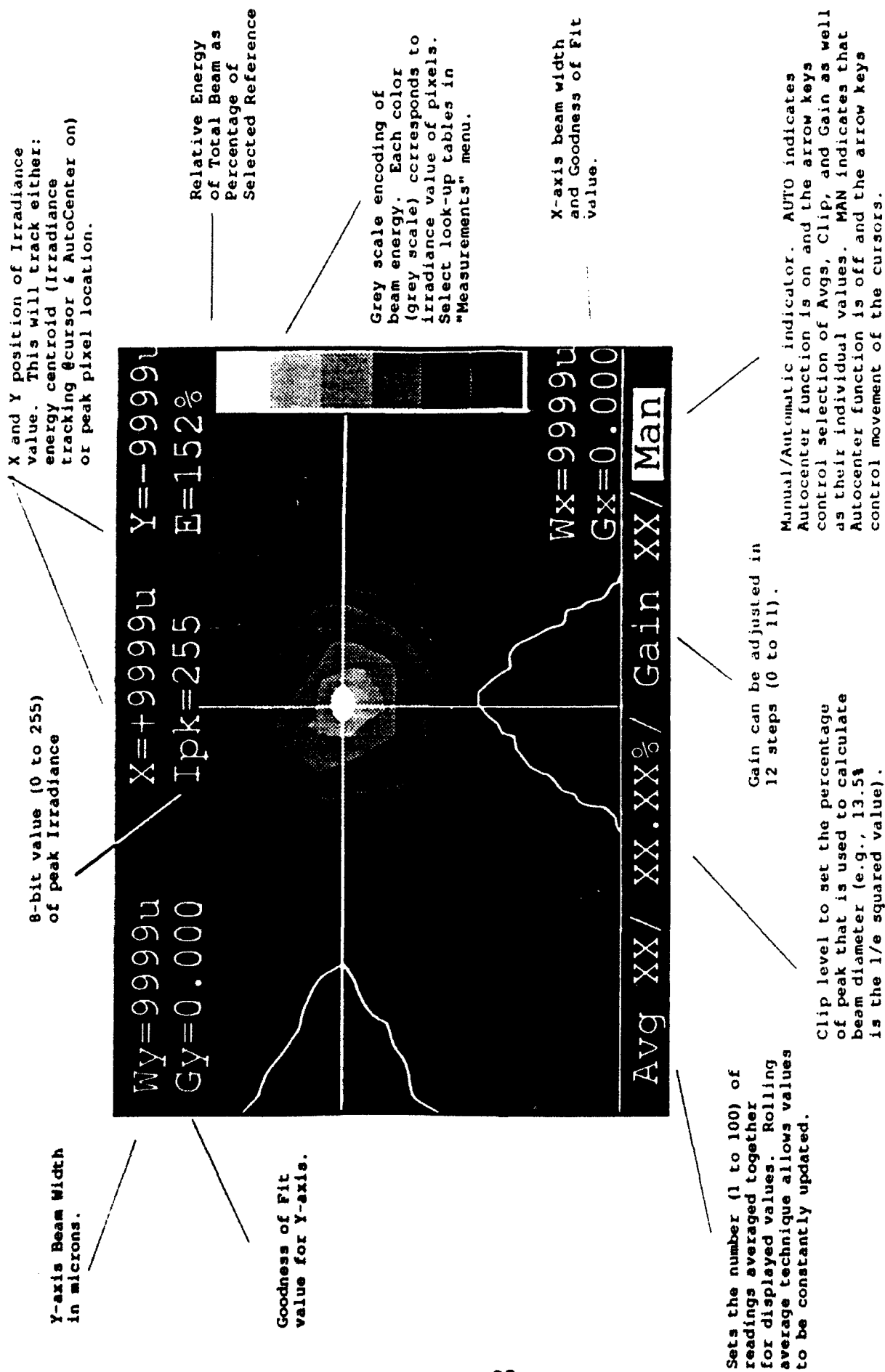


Figure 3. Display of vertical and horizontal measures.

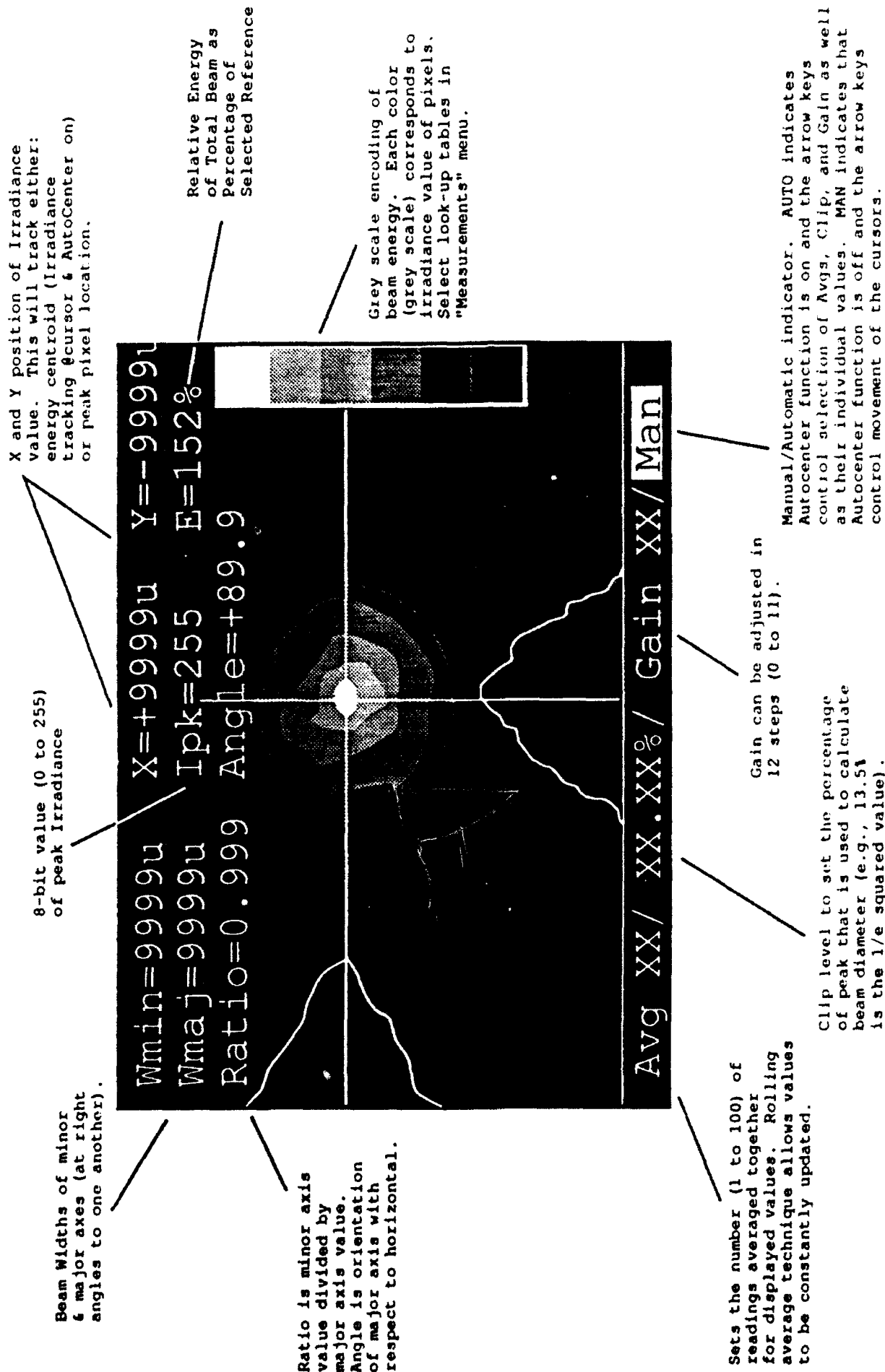
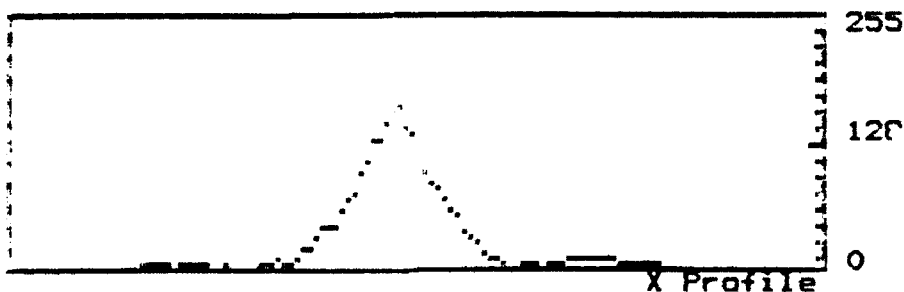
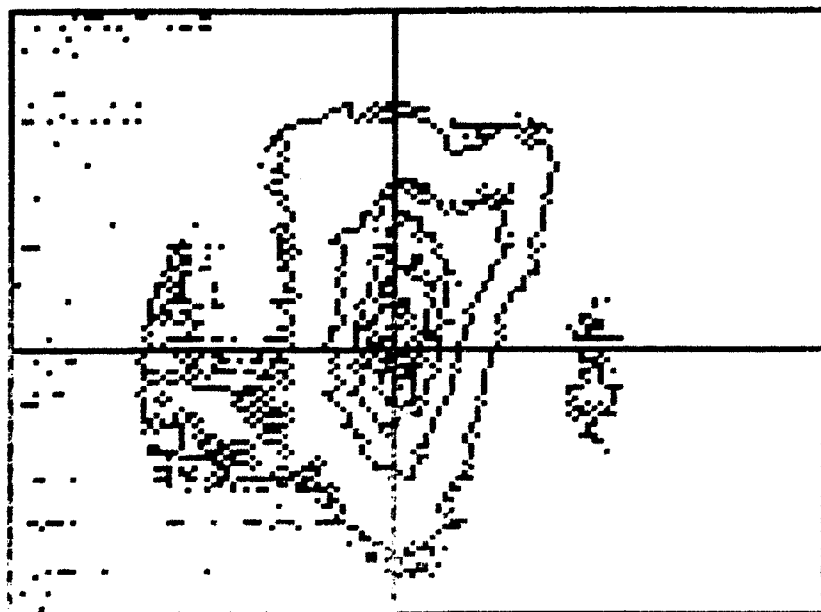
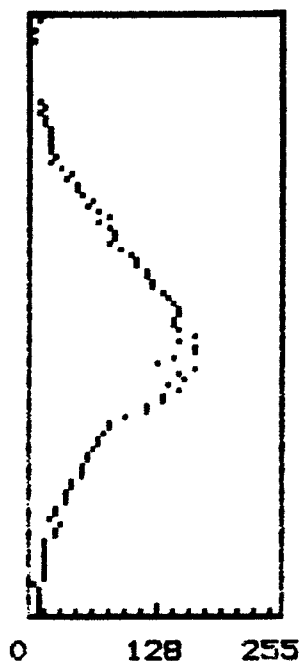


Figure 4. Display of ellipticity measures.

Y Profile



X Profile

Current Settings:

Display Delta = Off

Autocenter = Off

X Reference = 4397 u

Gain = 11

Clip Level = 50.0%

Sample Averaging = 9

Y Reference = 3658 u

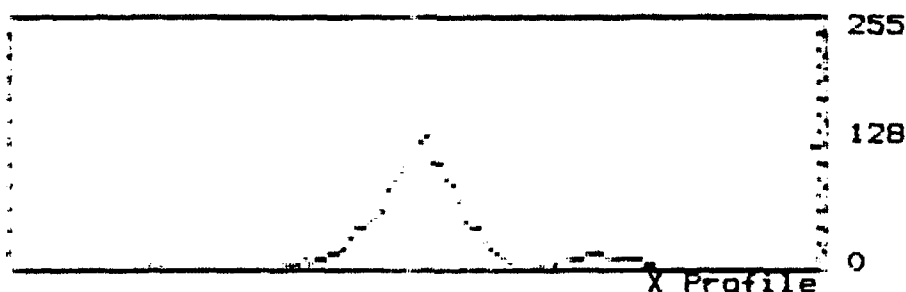
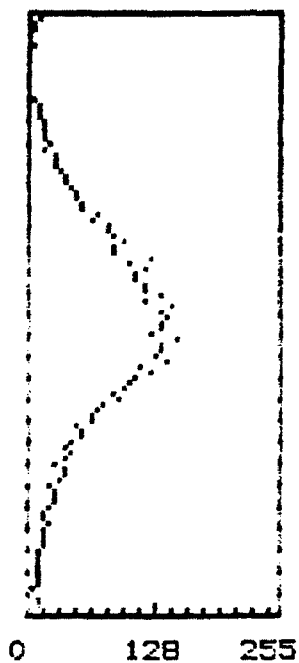
Results:

****System not calibrated. Calibrate system for accurate results****

	Value	Limit Check (Pass/Fail/Off)	Limit Settings	
			Min.	Max.
Wx	895 u	Off	0 u	6600u
Wy	1772u	Off	0 u	8600u
Ixy	144	Pass	0	255
X	-291 u	Off	-8600u	8600 u
Y	474 u	Off	-6600u	6600 u

Figure 5. Single-shot autocorrelation with zero delay.

Y Profile



Current Settings:

Display Delta = Off
Autocenter = Off
X Reference = 4397 u
Gain = 11

Clip Level = 50.0%
Sample Averaging = 9
Y Reference = 3658 u

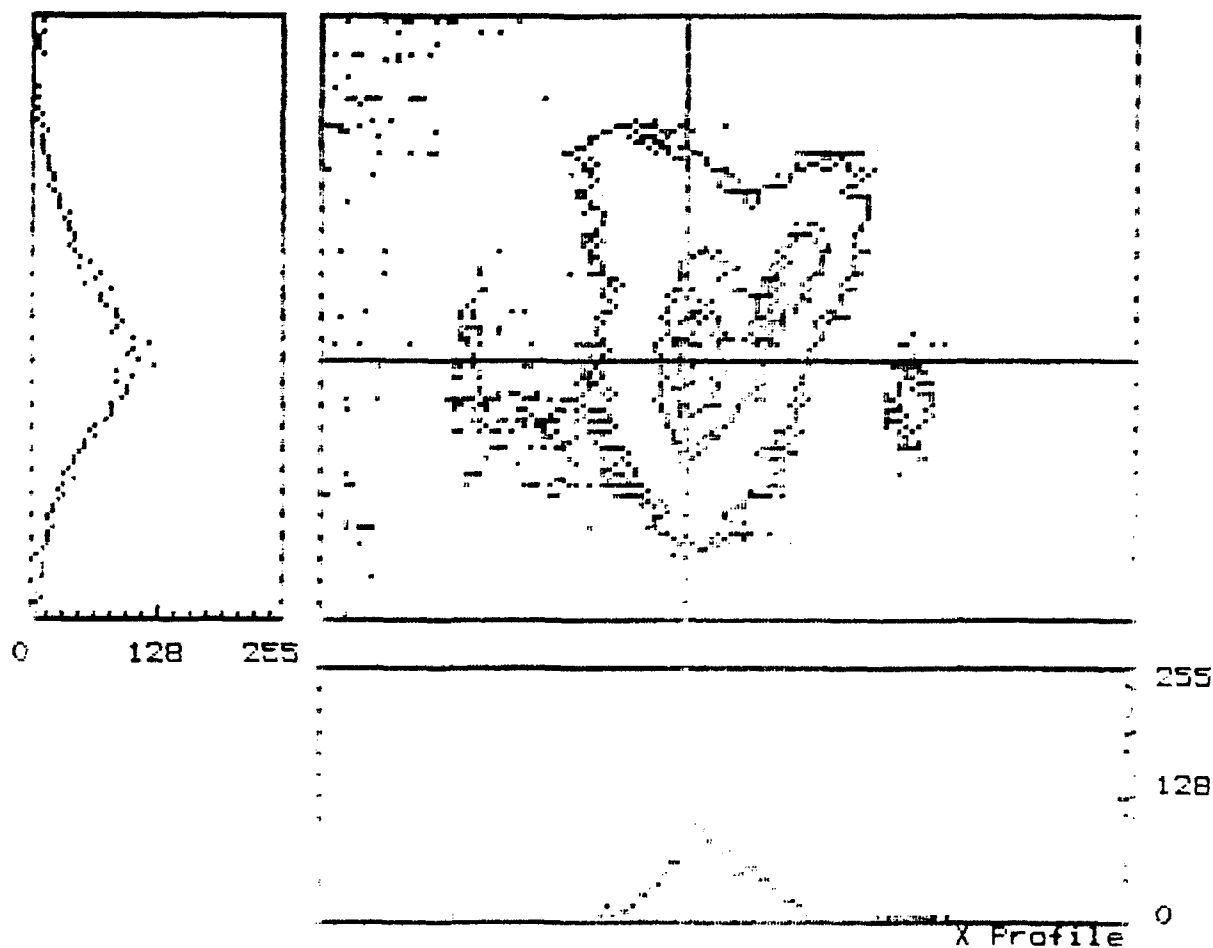
Results:

****System not calibrated. Calibrate system for accurate results****

	Value	Limit Check (Pass/Fail/Off)	Limit Settings	
			Min.	Max.
Wx	682 u	Off	0 u	6600u
Wy	1763u	Off	0 u	8600u
Ixy	97	Pass	0	255
X	-89 u	Off	-8600u	8600 u
Y	680 u	Off	-6600u	6600 u

Figure 6. Single-shot autocorrelation with +42-fs delay.

Y Profile



Current Settings:

Display Delta = Off
Autocenter = Off
X Reference = 4397 u
Gain = 11

Clip Level = 50.0%
Sample Averaging = 9
Y Reference = 3658 u

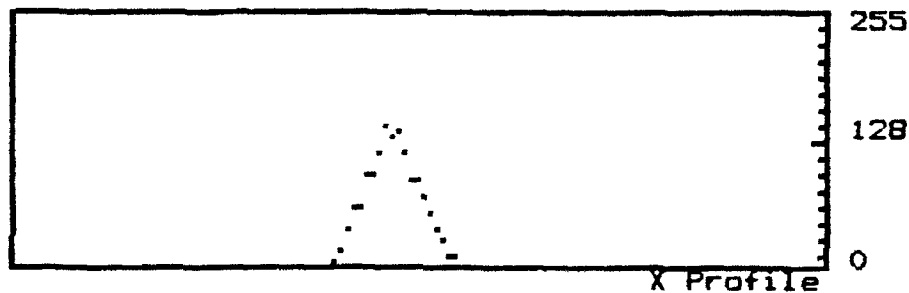
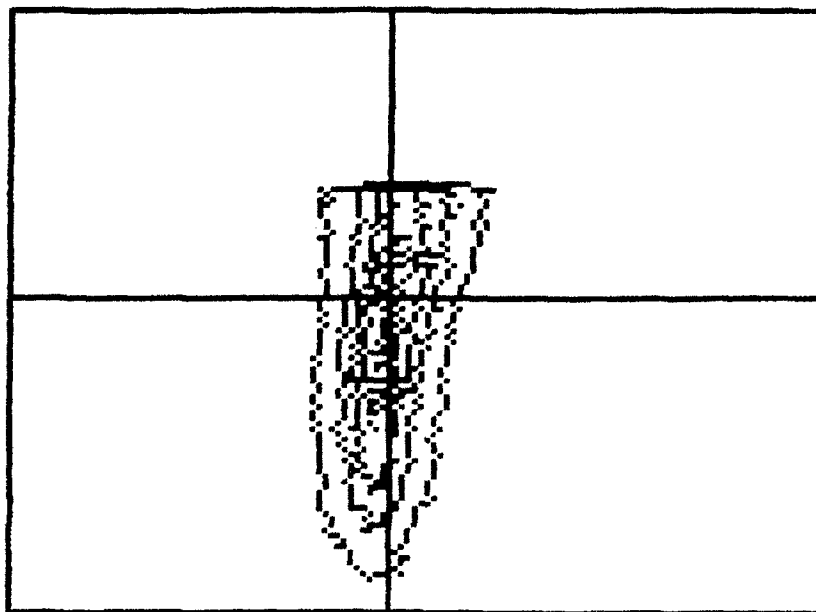
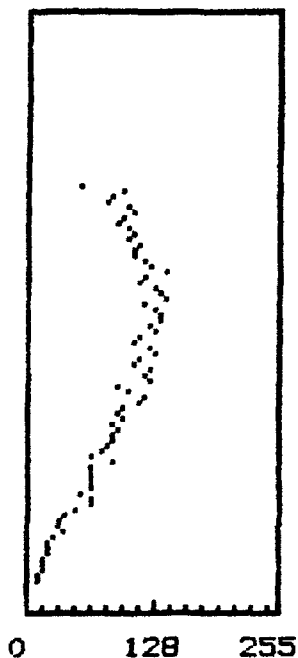
Results:

****System not calibrated. Calibrate system for accurate results****

	Value	Limit Check (Pass/Fail/Off)	Limit Settings	
			Min.	Max.
Wx	1073u	Off	0 u	6600u
Wy	1573u	Off	0 u	8600u
Ixy	97	Pass	0	255
X	-492 u	Off	-8600u	8600 u
Y	423 u	Off	-6600u	6600 u

Figure 7. Single-shot autocorrelation with -42-fs delay.

Y Profile



Current Settings:

Display Delta = Off
Autocenter = Off
X Reference = 4397 u
Gain = 11

Clip Level = 50.0%
Sample Averaging = 9
Y Reference = 3658 u

Results:

****System not calibrated. Calibrate system for accurate results****

	Value	Limit Check (Pass/Fail/Off)	Limit Settings	
			Min.	Max.
Wx	734 u	Off	0 u	6600u
Wy	2589u	Off	0 u	8600u
Ixy	128	Pass	0	255
X	-836 u	Off	-8600u	8600 u
Y	1240 u	Off	-6600u	6600 u

Figure 8. Single-shot autocorrelation measurement.