# MODEL 5-14B AUTOCORRELATOR

# OPERATING INSTRUCTIONS

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# I. Introduction

The INRAD Model 5-14 Autocorrelator is an instrument used to measure the temporal width of pulses emitted from a mode-locked laser. When used with an appropriate INRAD 530-080 mixing crystal and a high impedance oscilloscope, measurements of picosecond pulses can be made routinely to aid in monitoring laser performance.

In the autocorrelator, the pulses are split into two parts, delayed relative to one another, and then recombined non-collinearly in a mixing crystal in order to produce a second harmonic signal which is the autocorrelation function of the input pulse. This signal, which is at one half the wavelength of the incoming laser light, exists only when the beams are overlapped in time and space. Hence, the half width of the autocorrelation function is a measure of the pulsewidth. Short pulses will produce autocorrelation functions with narrow half widths because a small relative delay is sufficient to make the two pulses miss one another; long pulses will produce autocorrelation functions with broad half widths, because it takes a large relative time delay between the split pulses for them to avoid interaction in the mixing crystal. Calculation of the laser pulsewidth requires knowledge of the pulse shape which usually must be assumed (see Section IX).

## II. Description

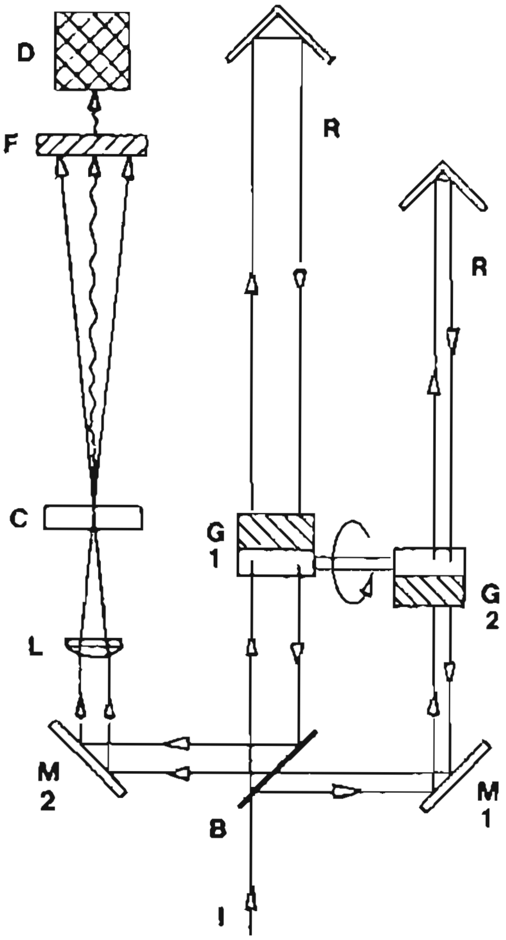
An optical schematic of the 5-14 is shown as Figure 1.

The input laser beam must be vertically polarized. One of four standard dielectric coated beamsplitters, for work in the blue (0.42 - 0.64), visible (.48-.8μm), intermediate (.75-1.5μm), or near infrared (1.1-1.6μm), has been installed at the factory. The beamsplitter has roughly equal transmittance and reflectance at the wavelength of interest. Aluminum mirrors with a SiO overcoat are used for beam turning. The limiting time resolution results from dispersion in the glass delay blocks which will lengthen short pulses. With the standard 35 mm blocks provided, time resolution is typically better than 200 fsec. With the thinner 2.9 mm blocks, time resolution is better than 50 fsec. The advantage of using the thicker blocks is the relatively large delay range of 119 psec which is displayed. For pulses on the order of 2 psec or longer, the thick blocks are generally used. For very short pulses, the thin blocks are employed. The thin blocks produce a total delay range of 10 psec. The blocks are transparent in the visible and near infrared. An untrathin (0.35mm) block option is available for resolution of faster times. The delay range of the ultrathin block option is 0.98 psec.

**Figure 1.**

OPTICAL SCHEMATIC

Model 5-14



| | |
|---|---|
| I | Input Laser Beam |
| B | 50% Beamsplitter |
| M | Mirror |
| G | Glass Delay Block |
| R | Retro Miror Assembly |
| L | Focussing Lens |
| C | Shg Crystal |
| F | UV Filter |
| D | Variable Gain PMT |

The autocorrelator uses approximately a 10° convergence angle between the two recombined beams. The mixing crystal is tilted until a sum signal is observed. Tuning curves for standard crystal cuts are shown in Figure 2 for LFM, KDP, $LiIO_3$, and $LiNbO_3$; Figure 3 exhibits the tuning curves for BBO. The blocking filters may be changed when necessary to accommodate diverse wavelength ranges. The cathode of the photomultiplier (pmt) is either a sensitive bialkali (for visible lasers) or multialkali (for IR, as well as, visible lasers) film which must be properly shielded from stray light. It is highly recommended that the pmt voltage be reduced to zero when not in use and that the voltage be increased only while observing the signal on an oscilloscope.

The front support plate contains the input aperture and connection to the line power cord. The rear support plate holds the electronics panel and provides access to the autocorrelation intensity signal and timing. The rear panel contains a POWER ON switch with indicator lamp. A TRIGGER OUT BNC jack yields a positive 5 volt to ground step at the beginning of each autocorrelation sweep. This falling edge can be used to trigger the time base sweep of an oscilloscope. The rising edge of the TRIGGER OUT signal, which is delayed from the falling edge, can be used to trigger a delayed sweep. The ten turn potentiometer, which is positioned next to the BNC connector, can be used to vary this delay between 0.4 and 11 milliseconds.

The rotation of the glass blocks is fixed at 15 Hz for the standard 5-14 autocorrelator. Although two autocorrelation sweeps are produced for each complete rotation of the glass blocks, only one normally is observed in order to avoid "retrace" differences.

With the Slow Scan option, the rotation rate of the glass blocks is stepwise variable over two orders of magnitude from 15 Hz to 0.15 Hz. The delay trigger feature is omitted when the Slow Scan option is provided.

Figure 2.

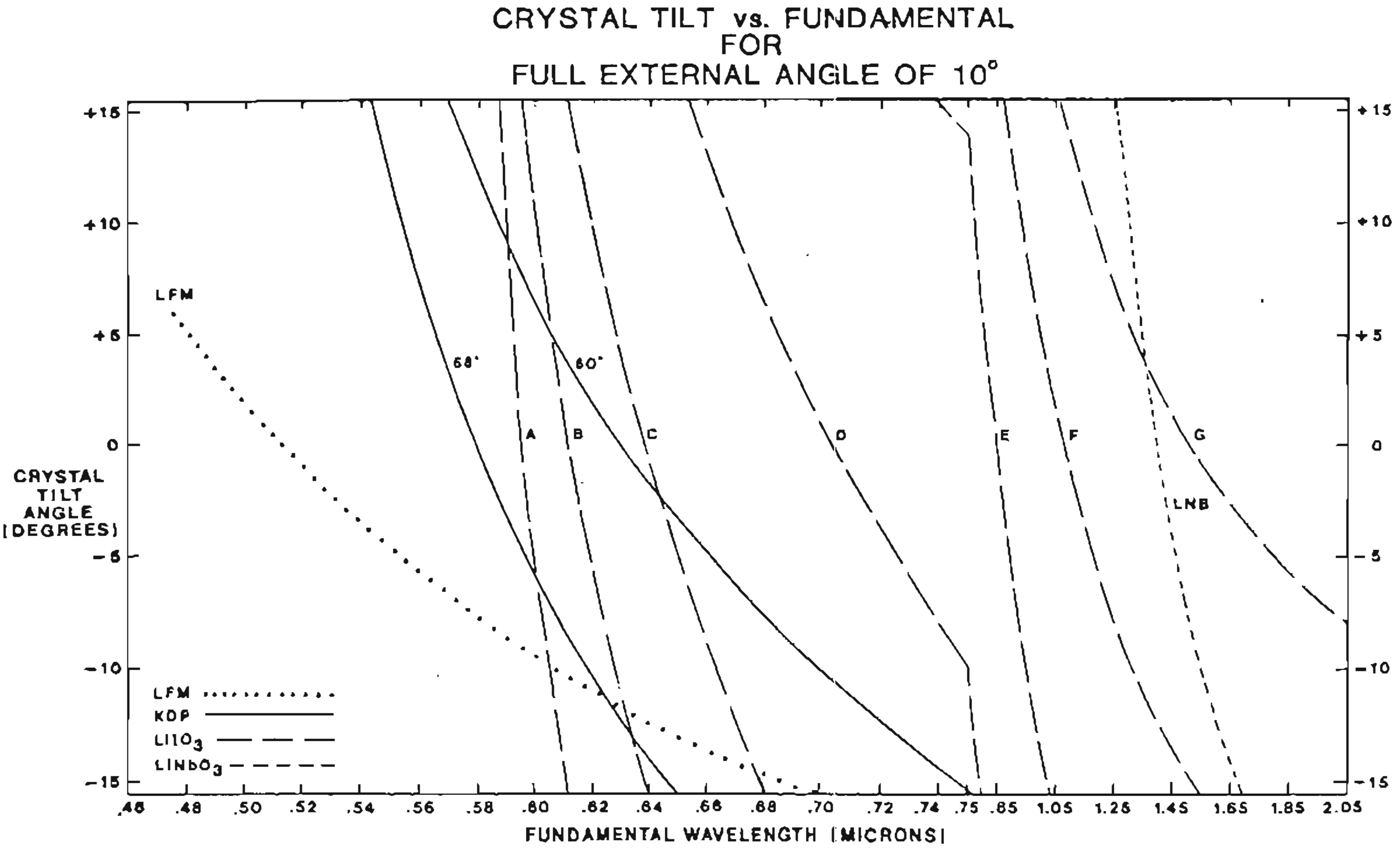
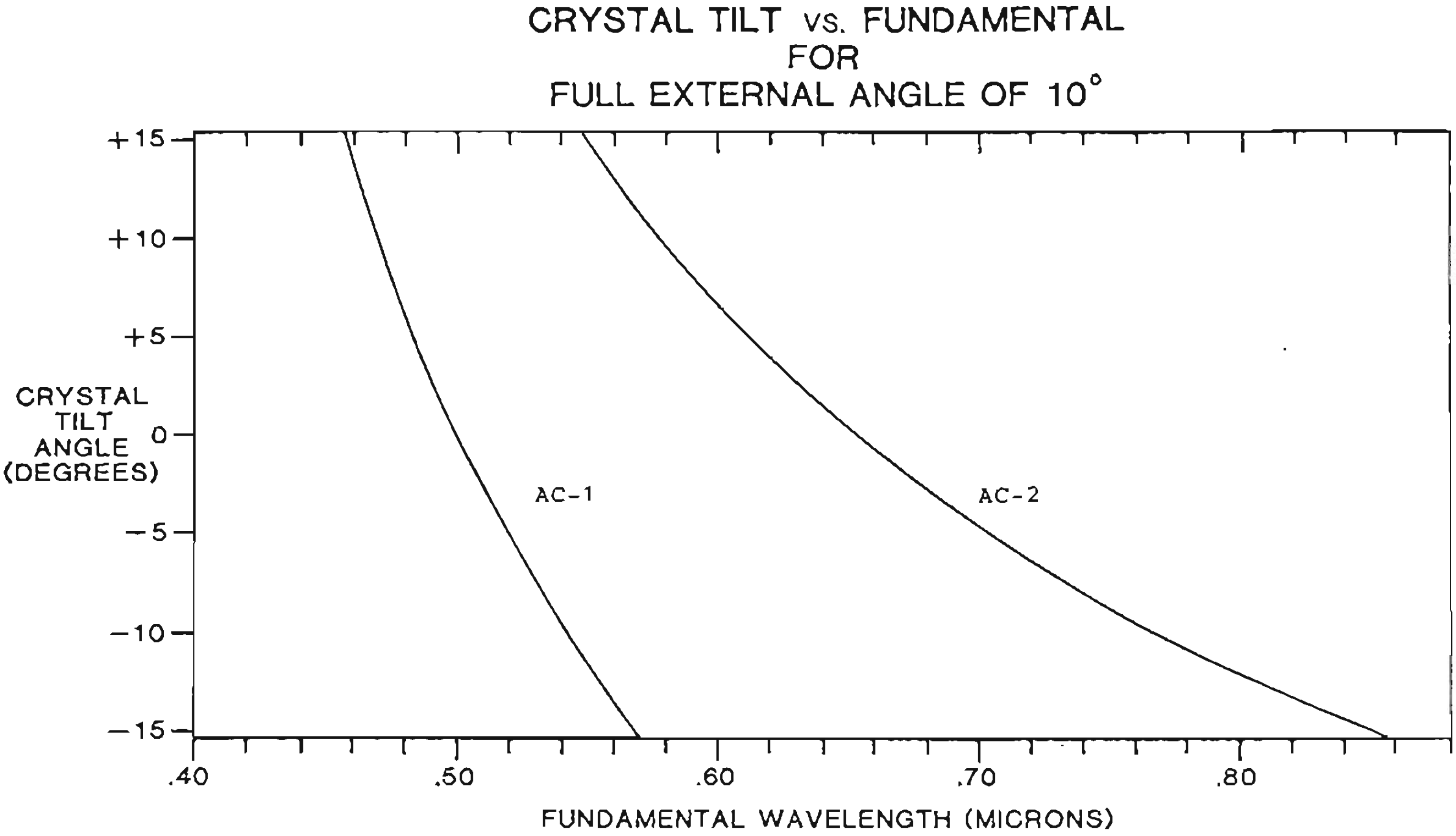

CRYSTAL TILT vs. FUNDAMENTAL
FOR
FULL EXTERNAL ANGLE OF 10°
CRYSTAL TILT ANGLE (DEGREES)
+15
+10
+5
0
-5
-10
-15
FUNDAMENTAL WAVELENGTH (MICRONS)
.46
.48
.50
.52
.54
.56
.58
.60
.62
.64
.66
.68
.70
.72
.74
.75
.85
1.05
1.25
1.45
1.65
1.85
2.05
LFM
58°
60°
A
B
C
D
E
F
G
LNB
LFM
KDP
LiIO3
LiNbO3

**Figure 3.**



Tuning Range of beta-barium borate (BBO).

The pmt voltage is variable between zero and 1000 volts in a roughly linear fashion by adjustment of the ten turn pot. The autocorrelation intensity information is available at the rear panel BNC jack labeled SIGNAL. An eight position time constant switch is located on the electronics panel. Clockwise rotation of the switch produces a larger signal with less random noise.

One can externally trigger the time base of an oscilloscope with the TRIGGER output while observing the SIGNAL as input to a vertical channel of the oscilloscope. Increasing signal amplitude produces a larger negative voltage.

With the Slow Scan Option, a sample and hold (S/H ON) detection feature may be used at low repetition rates that will convert the SIGNAL from a pulsed format into a steplike one.

## III. Configurations

Various configurations of the standard Model 5-14 are possible dependent on the wavelength and time resolution required. The following table is a guide to the parameters that must be considered when changing lasers.

**Table 1.** CONFIGURATION GUIDE

| **VARIABLE** | **CHOICE** | |
|---|---|---|
| Beamsplitter | Blue | (0.42 - 0.64 μm) |
| | Visible | (0.48 - 0.80 μm) |
| | Intermediate | (0.75 - 1.15 μm) |
| | IR | (1.1 - 1.6μm) |
| Block Thickness | Pico (35 mm) | 119 psec range |
| | Femto (2.9mm) | 10 psec range |
| | Ultra (0.35mm) | 0.98 psec range |
| Crystal | Separately ordered by Customer<br>(See Figure 2 and Figure 3) | |
| Filter | Wavelength Dependent<br>(see Section X Test Ticket) | |
| Photomultiplier | Visible (Bialkali) or<br>IR (Multialkali) | |

The autocorrelator is configured in the appropriate manner at the factory based on information supplied at time of purchase.

## IV. Alignment Procedure

The autocorrelator was aligned at the factory. Simplest operation will be attained if one presents a reasonably level laser beam to the autocorrelator. The following procedure will produce autocorrelation curves within a matter of minutes:

A. Remove the top cover of the autocorrelator.

B. Level the autocorrelator and center the vertically polarized beam in the input aperture.

C. Laterally shift the back end of the entire unit and raise or lower the back end, by means of the levelling screws, until one observes on a card at the entrance to the pmt chamber two separate spots 2¼" above the cut-out baseplate and symmetrically displaced about the pmt input aperture.

D. Check the micrometer settings, recorded on the factory test ticket, which place the non-linear crystal at the focus of the lens and which center the autocorrelation trace on the display.

E. Replace the cover.

F. Connect the SIGNAL BNC output to the input channel of a high impedance (1MZ) oscilloscope and set the gain to 1 Volt/cm.

G. Connect the TRIGGER BNC output to the external trigger input of the oscilloscope. The undelayed trigger is a +5 Volt falling edge. Select a time base of 5 msec/cm.

H. Turn the SHG GAIN potentiometer down to zero.

I. Turn on the autocorrelator power. This will start the glass blocks rotating.

J. While observing the SIGNAL on the oscilloscope, increase the SHG gain until noise appears.

K. Tilt the SHG crystal and look for a signal on the oscilloscope. The 5 msec time base allows one to discriminate against background noise since the two beams can be present at the crystal for no more than approximately one-third of the block rotation cycle. One can discriminate against doubling of the two beams individually by the shape of the signal or alternately blocking the two beam paths individually.

L. Jockey the vertical control (faceplate opening) of mirror M1 and the crystal translation in order to improve the signal displayed on the oscilloscope. The M1 mirror adjustment will require only 1/4 turn or less. Also, adjust the crystal tilt angle for maximum signal. The SHG GAIN, which controls the overall pmt voltage, can be adjusted to produce a large signal without exceeding the 10 Volt limit of the electronics. The mirror adjustment can be operated through the port provided on the front end plate and the crystal adjustments by controls on the back end plate. The time base of the oscilloscope can be switched to faster times once the signal is found.

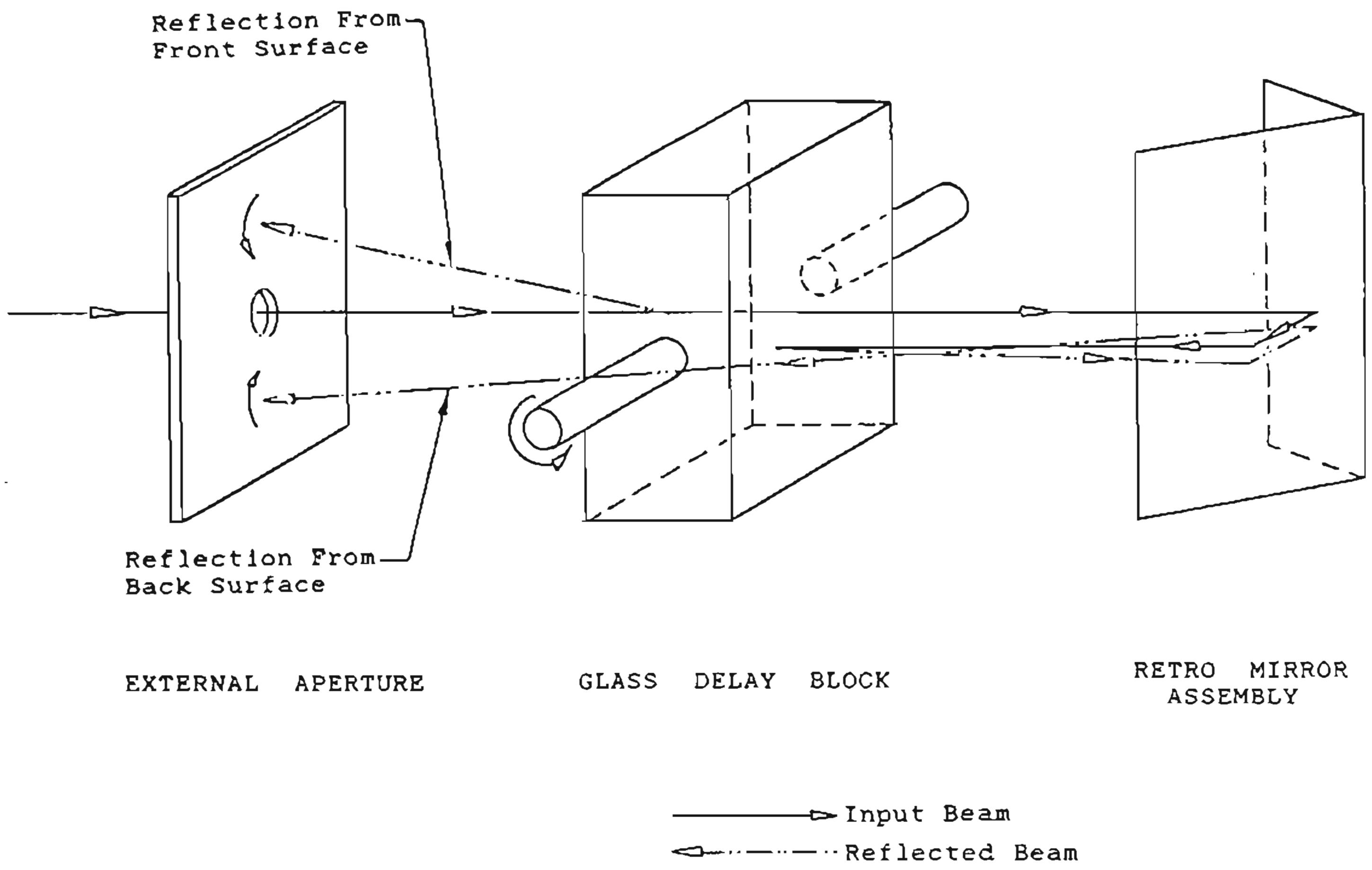
M. If necessary, attenuate the input laser power to keep the PMT voltage setting > 4.0.

Should a more thorough alignment be required, one may proceed as instructed on the previous pages except for replacement of the C procedure by the following C1. and C2. procedures.

C1. Adjust the lateral angle and the four levelling feet of the autocorrelator so that the retroreflections from both directions through the glass delay block G1 almost overlap on the input beam. See Figure 4 for an illustration of this procedure. One must tilt the block in order to see these reflections which have opposite senses - as the block is rotated one spot moves up and the other spot moves down. First, laterally shift the autocorrelator to center the line of retroreflections on the external aperture. Then, adjust the two levelling feet nearest the electronics panel to make the two beams overlap at the external aperture. One will want to direct the retroreflections slightly off in the horizontal plane in order to avoid optical feedback into the laser.

C2. In a similar manner, adjust the mirror M1 so that the two retroreflections from block G2 also overlap at the external aperture. One mirror adjustment moves the beams laterally and the second controls the height at which the two retroreflections overlap. The slight lateral spread in the retroreflections is due to a small error in the retroreflector's construction and should be of no concern. The two transmitted beams from the two delay arms are now roughly parallel.

Figure 4.


Reflection From Front Surface
Reflection From Back Surface
EXTERNAL APERTURE
GLASS DELAY BLOCK
RETRO MIRROR ASSEMBLY
Input Beam
Reflected Beam

## V. Scan rate

The relative delay between the two portions of the divided pulse is given by the following formula:

$$\Delta t = \frac{2 \times T}{0.3} \{ \sqrt{n^2 - \sin^2(\Theta + 29.7^\circ)} - \sqrt{n^2 - \sin^2(\Theta - 29.7^\circ)} + 2 \sin \Theta \sin(29.7^\circ) \}$$

Where $\Delta t$ is the relative delay in picoseconds,

T is the block thickness in millimeters (35, 2.9, or 0.35);

$\Theta$ is the average block tilt away from normal incidence; and

n is the refractive index of the glass blocks.

For the Schott LaK-9 glass blocks (35 or 2.9 mm thickness),

$$n^2 = 2.8081456 - (1.4266626 \times 10^{-2})y^2 + (1.800816 \times 10^{-2})y^{-2} + (5.6748764 \times 10^{-4})y^{-4} - (3.2899281 \times 10^{-5})y^{-6} + (2.0438076 \times 10^{-6})y^{-8}$$

Here y is the wavelength in microns.

Representative values of n for LaK-9 are given in Table 2.

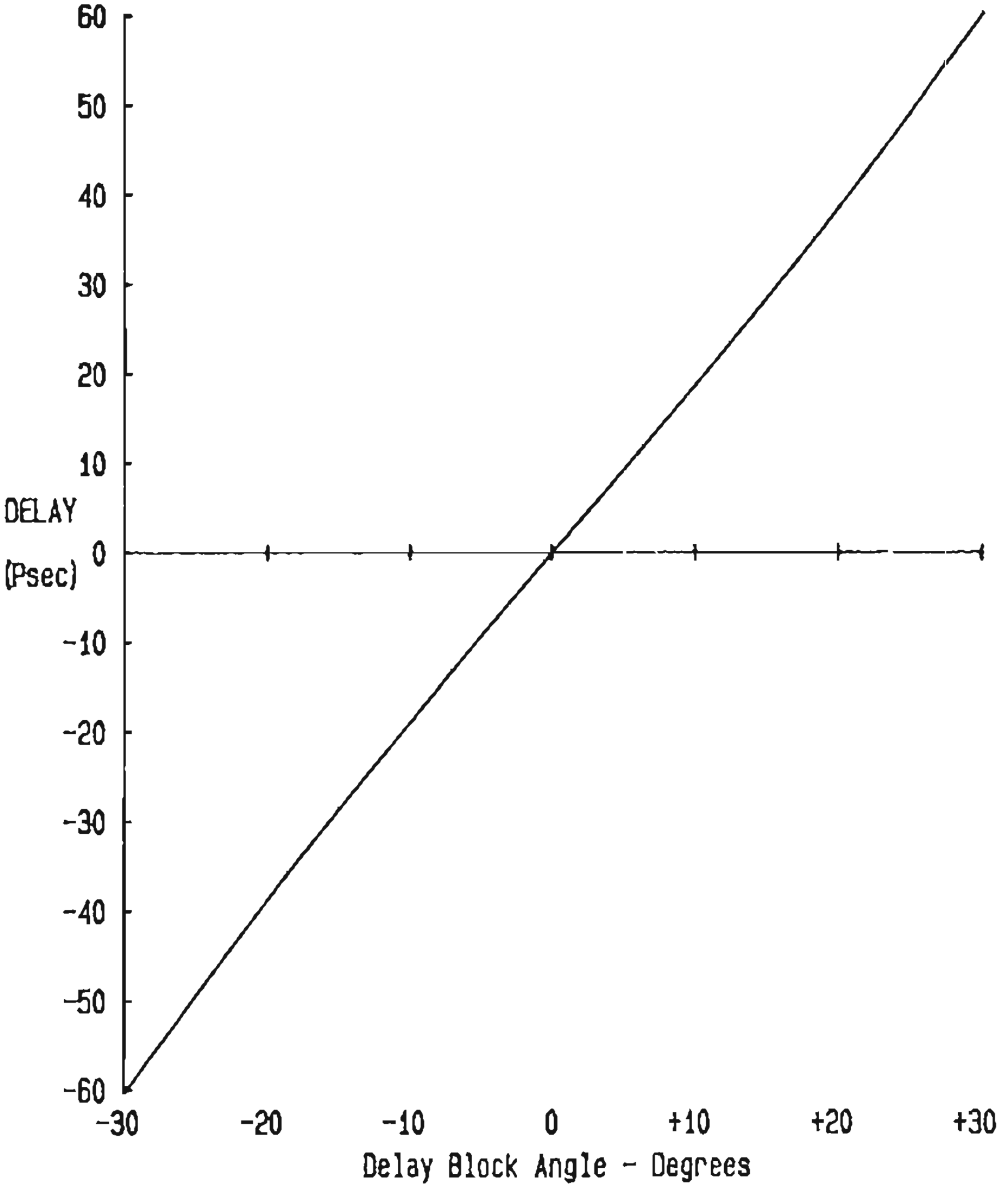
**Table 2.** Glass Block Refractive Index

| $\lambda$ ($\mu$m) | n |
|---|---|
| .435 | 1.70681 |
| .600 | 1.69022 |
| .850 | 1.68041 |
| 1.1 | 1.66858 |

The 0.35 mm blocks are made of fused silica.

A plot of relative delay versus block rotation angle is shown in Figure 5 for light of 0.600 $\mu$m wavelength. One notes that the delay is quite linear over the central thirty degrees of rotation and displays some nonlinearity toward the extremes of the rotation.

Figure 5.


60
50
40
30
20
10
DELAY
(Psec)
0
-10
-20
-30
-40
-50
-60
-30
-20
-10
0
+10
+20
+30
Delay Block Angle - Degrees

The average scan rate as a function of $\theta$ at the 15 Hz block rotation speed is given in Table 3 for the thick delay blocks.

**Table 3**. Scan Rate Linearity Picoseconds/Millisecond

| **Angle Degrees** | **Lambda Microns** | |
|---|---|---|
| $\theta$ | .600 | 1.500 |
| 0 - 5 | 10.1 | 9.9 |
| 5 - 10 | 10.2 | 10.1 |
| 10 - 15 | 10.5 | 10.3 |
| 15 - 20 | 10.9 | 10.7 |
| 20 - 25 | 11.4 | 11.2 |
| 25 - 30 | 12.0 | 11.9 |

Delay rates at the center of a scan are given in Table 4 for representative wavelengths with various block options.

**Table 4**. Scan Rates for Several Delay Block Options - Picoseconds/Millisecond

| | **BLOCK THICKNESS** | | |
|---|---|---|---|
| Lambda Microns | Pico (35mm) | Femto (2.9mm) | Ultra (0.35mm) |
| 0.45 | 10.2 | 0.84 | 0.081 |
| 0.60 | 10.1 | 0.84 | 0.080 |
| 1.05 | 10.0 | 0.83 | 0.079 |
| 1.55 | 9.9 | 0.82 | 0.078 |

Calibration of the delay rate can be made by micrometer adjustment of the length of one delay arm. For example, a shortening by one millimeter will shift the signal toward the left on the display by 6.67 picoseconds. Since the non-collinear mixing is very sensitive to misalignment, the signal may need to be optimized after a micrometer adjustment is made.

With the Slow Scan Option, seven speeds are switch selectable and are labeled by the approximate delay rates for the thick glass blocks.

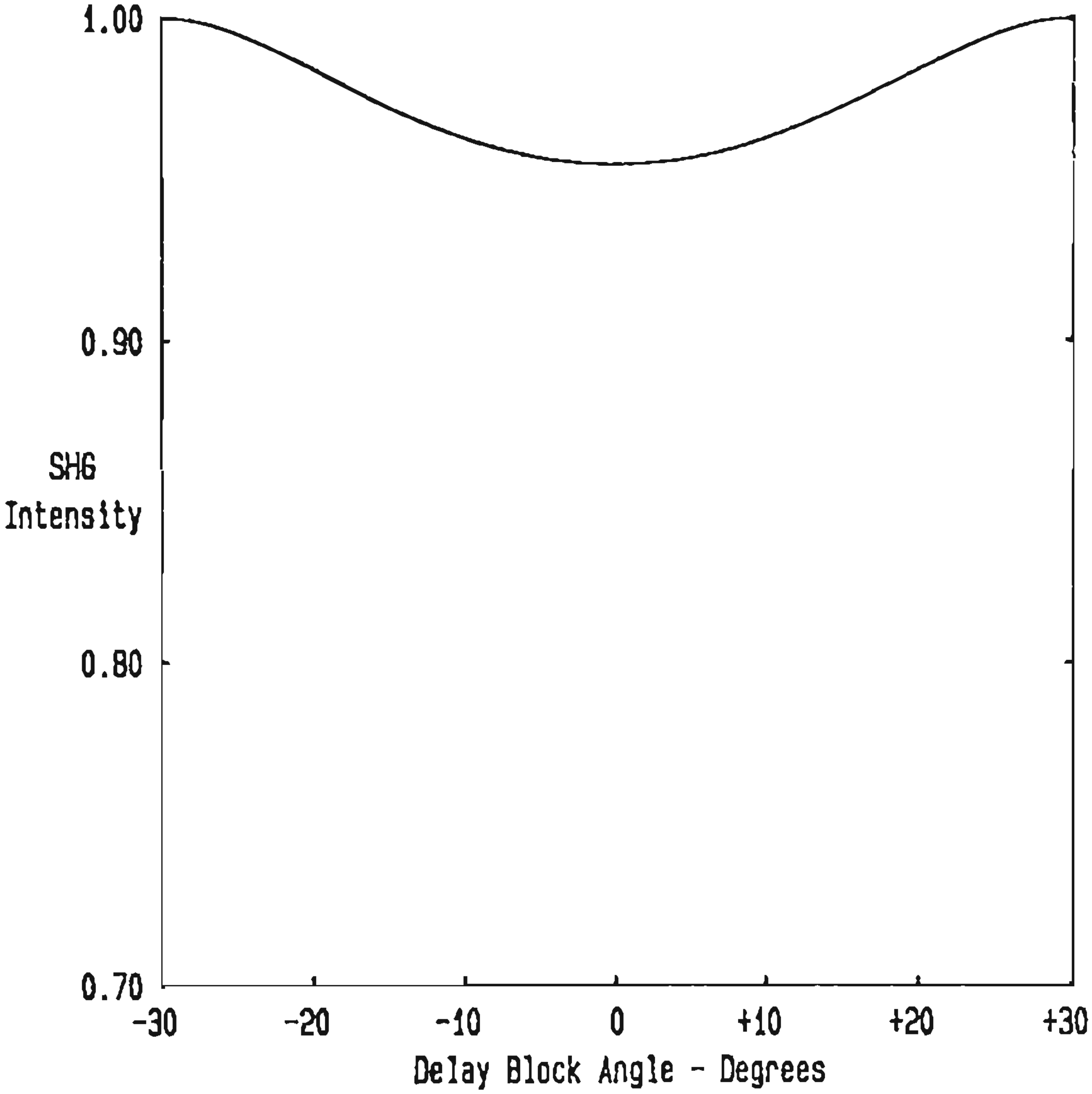
## VI. Intensity response

Due to Fresnel losses, the intensity of the SHG signal is not a flat function of the block rotation angle. The normalized intensity of the SHG signal due to these reflective losses is plotted as Figure 6.

One can identify a collinear SHG signal produced by a beam from only one arm of the interferometer by its characteristic shape. The SHG trace attains a maximum at either the left or right hand side of the oscilloscope trace and monotonically decreases.

The linearity of the photomultiplier can be verified by comparing the autocorrelation trace to one obtained with an attenuated input beam and a higher photomultiplier setting.

## Figure 6


1.00
0.90
0.80
0.70
SHG
Intensity
-30
-20
-10
0
+10
+20
+30
Delay Block Angle - Degrees

## VII. Change of Photomultiplier and Filters

1. Remove the top cover of the autocorrelator by removing the six screws which hold it in place.
2. Remove the two #4 screws holding the cover of the pmt chamber from the top and remove the cover.
3. By removing the two #4 screws holding the filter plate, the filter may be changed.
4. Unscrew the two #4 screws which arrest the pmt shield and remove the shield.
5. Remove the pmt from the pmt socket.
6. Place the new pmt into the pmt socket; replace the metal shield.
7. Replace the cushion and pmt retainer plate with two #4 screws.
8. Replace the cover over the pmt and screw down the two #4 screws.
9. Replace the top cover of the unit.

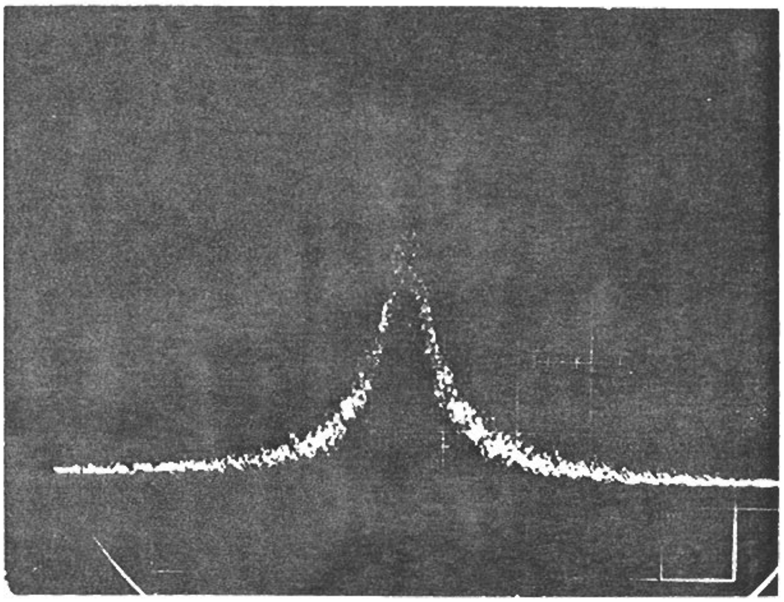
## VIII. Block Changes

To use the autocorrelator at extremely high resolution, one will want to use thin blocks. Thick blocks are installed as standard equipment unless thin blocks are specified at time of purchase. In order to change block assemblies, first remove the bottom cover. It is helpful to have a reference reflection from the glass blocks so that the new assembly can be laterally positioned. Then block the reference laser beam, remove the cover plate over the assembly, and remove only the outer bearing support of the assembly. Slip the belt off the motor pulley. Slide the assembly out from the other bearing support noting to clear the optointerrupter with the cut out disc. Reverse these steps to replace with the new assembly. Before tightening the bearing support, position it so that the reference reflection is similar to the reflection from the former assembly. Verify that the cut out disc rotates through the optointerrupter without interference.

## IX. Examples

Figure 7 shows an autocorrelation trace from a visible dye laser. The oscilloscope time base was set at 0.2 msec/cm; thin (3.5mm) glass blocks were used. The full width at half maximum of the autocorrelation trace is 0.7 divisions or 0.14 msec. We find that the half width of the autocorrelation function in real time is (0.14 msec x 1.01 psec/msec) 0.141 psec. Assumption of a Gaussian pulse shape allows one to calculate the actual pulse width as 0.141 x .707 = .100 psec or 100 femtoseconds.

**Figure 7.**

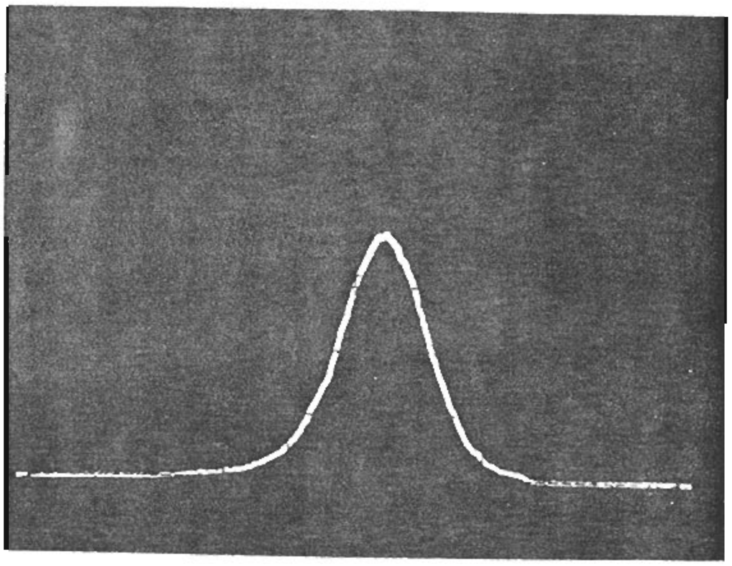


FEMTO SECOND VISIBLE AUTOCORRELATION TRACE.

Autocorrelation trace of 0.6 micron dye laser using thin glass blocks. Time base is 0.2 msec/division. Courtesy Gerard Mourou, University of Rochester.

Figure 8 shows an autocorrelation trace from an F-center laser operating at 1.5 microns. The oscilloscope time base was set at 2 msec/cm and thick glass blocks were used. The half width of the autocorrelation function is (1.6 divisions x 2 msec/division x 9.9 psec/msec) 31.7 picoseconds. If a Gaussian pulse shape is assumed, the actual pulse width may be calculated as (31.7 psec x .707) 22.4 psec.

Figure 8.



PICOSECOND INFRARED AUTOCORRELATION TRACE

Autocorrelation trace of 1.5 micron F-center laser using standard thick glass blocks. Time base is 2.0 msec/division. Courtesy Burleigh Instruments, Fishers, New York.

## PHOTOMULTIPLIER TUBE COLOR FILTER IDENTIFICATION

| MODEL | COLOR | LIGHT |
|---|---|---|
| BG-3 | purple/blue | incandescent |
| BG-18 | light green | incandescent |
| BG-39 | turquoise/blue green | incandescent |
| UG-5 | purple/blue | fluorescent |
| UG-11 | very dark red | high intensity |
| RG-630 | red | incandescent |
| RG-665 | dark red | fluorescent |
| KG-2 | clear | incandescent |
| G-530 | dark green | incandescent |

**Table 5**. Relationship of Pulse Width to Autocorrelation Width for Representative Pulse Shapes

| I(t)<br>**Pulse Shape** | G(T)<br>**Autocorrelation Function** | $t^{1/2} / T^{1/2}$ |
|---|---|---|
| square | square | 1.000 |
| Gaussian | Gaussian | 0.707 |
| Lorentzian | Lorentzian | .500 |
| one-sided exponential | two-sided symmetric exponential | .500 |

I(t) = pulse shape; t is real time.

G(T) $\propto$ second harmonic signal $\propto \int_{-\infty}^{+\infty} I(t)\, I(t+T)dt$; T is relative delay.

Note that G(T) must be symmetric.

## X. Test Ticket

# 5-14B AUTOCORRELATOR

S/N: ____________________ FILTERS: ______________

MICROMETER SETTINGS: FOCUS ______________________

TRACE CENTER ______________________

CHECKLIST:

☐ POWER CABLE
☐ MANUAL
☐ COMMENTS
☐ VISIBLE BEAMSPLITTER
☐ IR BEAMSPLITTER
☐ INTERMEDIATE BEAMSPLITTER
☐ BLUE BEAMSPLITTER
☐ R212UH PHOTOMULTIPLIER
☐ R928 PHOTOMULTIPLIER
☐ PICOSECOND BLOCKS
☐ FEMTOSECOND BLOCKS
☐ ULTRATHIN BLOCKS
☐ 110 V/60 Hz
☐ 220 V/50 Hz

*EIGHT POSITION (0-7) TIME CONSTANT SWITCH, ON ELECTRONICS PANEL, IS SET AT POSITION THREE. TURN CLOCKWISE FOR MORE R.C.; TURN CCW FOR LESS R.C.*

*REMOVE TRANSPORT TAPE FROM GIMBAL ASSEMBLY AND PULSE DELAYING ASSEMBLY BEFORE USE.*

**Table 6.** AUTOCORRELATOR PMT FILTERS

| FUNDAMENTAL WAVELENGTH RANGE | FILTER DESIGNATION | FILTER DESIGNATION |
|---|---|---|
| 1.5 | KG-2 | RG-665 |
| 1.3 | KG-2 | RG-630 |
| 1.06 | BG-18 | G-530 |
| 0.9 - 1.2 | BG-18 | BG-39 |
| 0.8 - 0.9 | BG-18 | BG-3 |
| 0.7 - 0.8 | BG-3 | BG-39 |
| 0.56 - 0.7 | UG-11 | |
| 0.50 - 0.56 | UG-5 | |
| 0.42 - 0.50 | IF-230 | |

*TECHNICIAN* ________________ *DATE* ________________

# WARRANTY

Subject to the exceptions and upon the conditions specified below, INRAD agrees to correct, either by repair, or, at its election, by replacement, any defects of material or workmanship which develop within one (1) year after delivery of the products to the original Buyer by INRAD or by an authorized representative, provided that investigation and factory inspection by INRAD discloses that such defect developed under normal and proper use.

Some components and accessories by their nature are not intended to and will not function for one (1) year. A complete list of such components or accessories is maintained at INRAD. The lists applicable to the products sold hereunder shall be deemed to be part of this warranty. If any such component or accessory fails to give reasonable service for a reasonable period of time, INRAD will repair, or at its election, replace such component or accessory. What constitutes either reasonable service and a reasonable period of time shall be determined solely by INRAD.

Any product claimed to be defective must, if requested by INRAD, be returned to the factory, transportation charges prepaid, and will be returned to the Buyer with the transportation charges collect unless the product is found to be defective in which case INRAD will pay all transportation charges.

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