FEMTOCHROME® RESEARCH, INC.

FR-103MN AUTOCORRELATOR
INSTRUCTION MANUAL

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TABLE OF CONTENTS

The standard FR-103MN utilizes background-free (noncollinear) second harmonic generation (SHG) for the measurement of the autocorrelation function of repetitive ultrashort laser pulses. The unit can be set to crosscorrelate two synchronized pulses of different wavelengths.[2] Collinear SHG (with background) with interferometric resolution is offered as an option(/IO).[3] The Low Rep Rate Option[4] (/LRR) renders the unit applicable for any rep rate (as low as 4Hz). The optional Fiber Adapter (/FA) or (/FC) facilitate easy alignment and repeatable connection of fiber coupled beams. An optional A/D board installed in the unit and its software (Computer Data Acquisition (/CDA)), provides an interface (RS232) of the FR-103MN with a PC, resulting in a complete pulsewidth monitoring system. Alternatively, the /VGA option renders the unit completely self-contained in a single package including a color TFT display.

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1 For high resolution or best performance at a specific wavelength, a custom crystal can be selected.

2 See 3i. Crosscorrelation, p. 14

3 See 4a. Interferometric Option, p. 16

4 See 4e. Low Rep Rate Option, p.19

1. INTRODUCTION

The Model FR-103MN Rapid Scanning Autocorrelator is a high resolution instrument for continuous monitoring and display of femtosecond and picosecond laser pulses. While its unprecedented resolution makes it ideal for fsec pulses from modelocked lasers with high peak power, the instrument's high sensitivity renders it perfectly suited also for long pulses with low power. The operation ranges of the FR-103MN can be interchangeably selected as follows[1]:

FR-103MN/BBO (410-900 nm):	BBO crystal (0.3 mm/60°)/VS Beamsplitter/VS PMT
FR-103MN/KDP (530-1070 nm):	BBO crystal (0.3 mm/35°)/VS Beamsplitter/VS PMT
FR-103MN/IR (700-1800 nm):	$LiIO_3$ crystal (1 mm/24°)/IR Beamsplitter/IR PMT

<u>Note:</u> The wavelength range of 410-1800nm can be further extended into the IR region optionally, by photodiode detector modules /1000 (1000-2000nm) and /2000 (2000-3000nm). These options utilize the same optics as in the /IR version.

An appropriate set of fundamental blocking filters is included for each operating range.

The unique scanning mechanism[6] of the FR-103MN provides a dispersion free scan range of >60 psec with high linearity. Dispersion is eliminated through the exclusive use of high reflecting metallic coated mirrors, with a focus in the nonlinear (NL) crystal obtained by means of a curved mirror. The pulsewidth resolution is <5 fsec using an ultrathin (<0.05 mm) crystal.

2. THEORY OF OPERATION

The FR-103MN utilizes the SHG method of the 1st kind in the conventional Michelson Interferometer set-up of pulsewidth measurement.[5] In the standard configuration, noncollinear beams lead to the background-free autocorrelation measurement. Repetitive linear delay generation in one arm of the Michelson arrangement is introduced by a pair of parallel (//) mirrors centered about a rotating axis.[6] In the geometry of Figure 1, the rotation of the // mirror assembly leads to an increase (or decrease) of path length for a traversing beam.[6] Thus, the transmitted pulse train is delayed (or advanced) about the reference (zero delay) position. This delay varies with time as a function of the shaft's rotation. For small angular changes, the delay as a function of time is linear and given by[6]

$$T = \{\frac{4\pi f D}{c}\}\, t \qquad (1)$$

where D is the distance between the // mirrors, f is the frequency of rotation,and c is the speed of light.

Rotation of the // mirror assembly leads to a repetitive generation of linear delay which, used in the described SHG configuration, provides a continuous display of the autocorrelation function of the pulses on a conventional high impedance oscilloscope synchronized to this rotation.

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5 E.P. Ippen and C.V. Shank, "Ultrashort Light Pulses," S.L. Shapiro ed., New York: Springer-Verlag (1977)

6 Z.A. Yasa and N.M. Amer, Optics Commun., V36, 406 (1981)

The total scan range is given by[6]

$$T_t = \frac{\sqrt{2}d}{c} \qquad \textbf{(2)}$$

where d is the length of the scanning mirror.

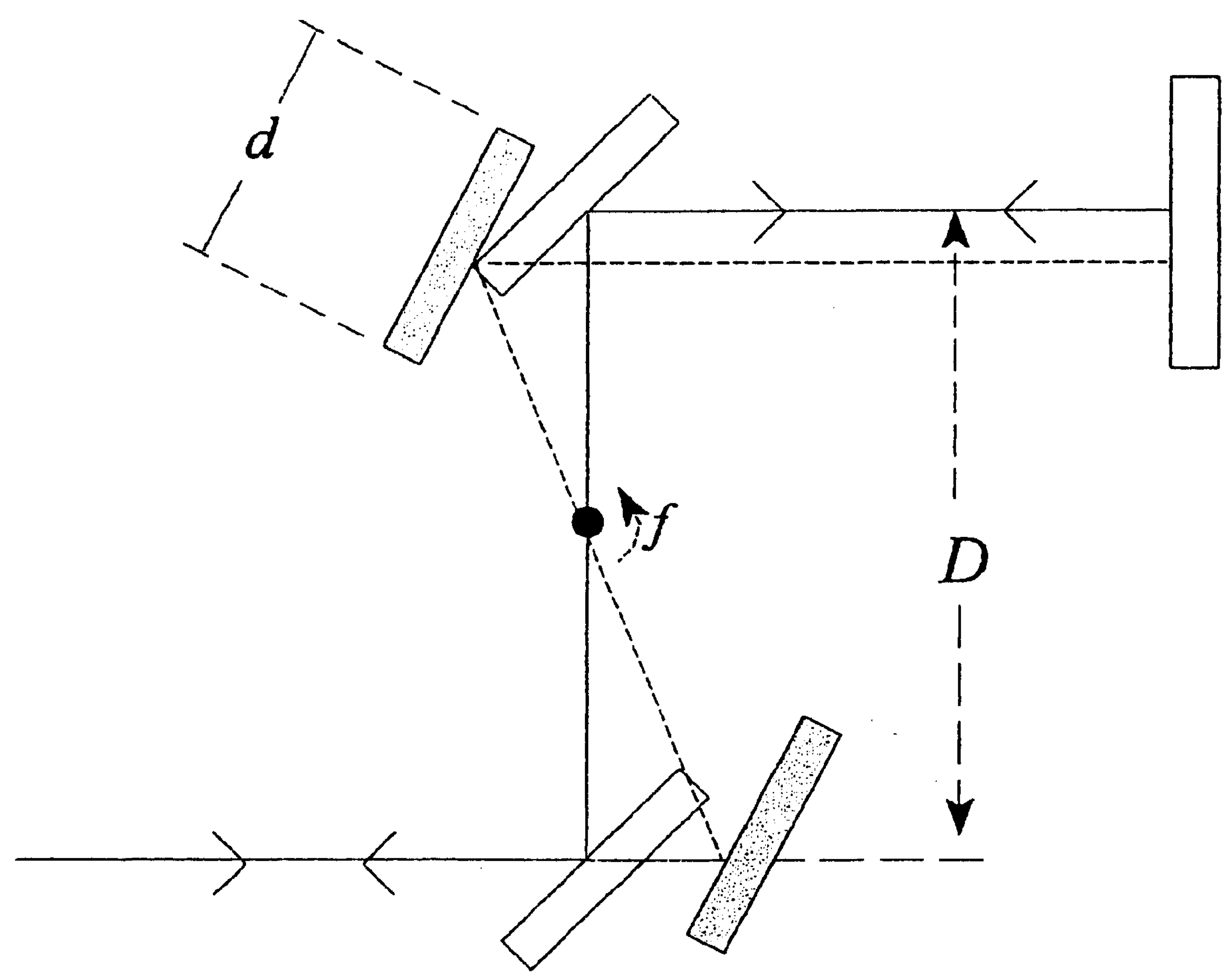

Figure 1 Rotating Parallel (||) Mirrors

A figure of nonlinearity over the full scan range is[6]

$$NL = d/4D \qquad \textbf{(3)}$$

In the standard configuration of the FR-103MN, the scan mirror has a size of d = 0.75" and the mirrors are separated by a distance of D = 1.25". The rotation frequency is **f = 10 Hz. [f=5Hz and 2.5Hz (or /LRR) are also selectable by a slide switch near the // mirrors.]** Hence, the following numerical values follow from Equations (1)-(2):

T/t = 12.5 psec/msec [6.25ps/ms for 5Hz]
T_t = 75psec

3. OPERATING INSTRUCTIONS

3a. Fundamental Characteristics

The SHG autocorrelation function of an incoming train of ultrashort pulses is traced when the SIGNAL output of the FR-103 is input to a >20 MHz bandwidth **(1MΩ)** oscilloscope, triggered externally by the TRIGGER output. The output signals and controls of the FR-103 are described below.

GAIN — The high voltage applied to the PMT (photomultiplier) is varied over the range of 0-1000 volts.

DELAY — The trigger pulse generated by a photointerrupter is variably delayed using this control. The introduced delay is in the range of 0.1-10 msec. This function can be used to expand the time-base of the oscilloscope, for the observation of shorter pulses. The smaller knob near this pot provides finer control of DELAY.

SIGNAL — The SHG signal detected by the PMT is output through a preamplifier circuit. The integration time of this circuit is selected by a five-position slide switch (1 fsec → 1 psec), accessible on the back panel.

TRIGGER — The trigger pulse from the photointerrupter (coupled to the motor) is output through the delay circuit. The oscilloscope trigger channel should be set to: **EXT., NORM.**, and **(+) SLOPE** for proper synchronization. Initially, timebase setting should be 1msec/div or 2msec/div.

TRIG. SELECT A slide switch near the DELAY pot on the front panel disables DELAY when set in Pos.#0. In Pos.#1 & 2 the trigger DELAY is functional.

Notes:

1. In the factory setting of the FR-103MN, the TRIG SELECT switch is set to "0", and the autocorrelation trace peak occurs right at the (+) edge of the DELAY disabled trigger pulse, set about a central position of the full scan range. [The reading of the T-stage micrometer for this setting is indicated on it.] This is the normal recommended mode of operation.

SPEED SELECT A slide switch, accessible inside the right back corner, selects 3 motor speeds for the // mirror assembly: 10Hz/5Hz/2.5Hz. The calibration factor, given in the manual for 10Hz, is proportional to the motor speed. E.g. for 5Hz, the calibration factor is 6.25ps/ms.

The basic properties of the FR-103MN can be summarized as follows:

Scan Range: >75 psec
Resolution[9]: <5 fsec

Delay Calibration Factor (T/t): 12.5 psec/msec(10Hz). The exact value of this factor has a weak dependence on the position of the pulse peak within the delay window (scan range). Experimentally, the instrument is calibrated by micrometer translation of the corner mirror, as described in Section 3g.

Sensitivity: Depending on the operation wavelength and the characteristics of the NL crystal, an average input power (P_{av}) of a few mW is typically sufficient. Using an optimal crystal, the noise equivalent signal level can be as low as $P_{pk}P_{av} = 0.2 \times 10^{-6} W^2$, where P_{pk} is the peak power.

Minimum Pulse Repetition Rate: For pulse repetition rates <1 MHz, the autocorrelation trace displays dips due to the vanishing of the signal between pulses. However, the trace envelope corresponds to the autocorrelation function even for lower pulse repetition rates. In general, a higher minimum pulse repetition rate is needed for shorter pulses, for direct observation on a real time oscilloscope. For lower rep rates, /LRR needs to be used.

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[9] Resolution is limited only by the SHG crystal thickness, which is specified by the customer. The standard crystal thickness is 0.3mm, giving a resolution of ~15fs. Using a thinner (<0.05mm) crystal, a resolution <5fs can be achieved.

3b. Alignment Procedure

The standard optical schematic of the FR-103MN is sketched in Figures 2 and 3. **[When /FA(CC) Option is included, the alternate beam configuration described in section 4.a is applied. In this case, the delayed and fixed beams described below are reversed. See Sect.4a]** The beams lie mainly in the horizontal plane through the centers of M1 and the input aperture. Most of the optical components are factory aligned and need not be reset. Described below, the adjustment of the FR-103MN for proper operation is straightforward.

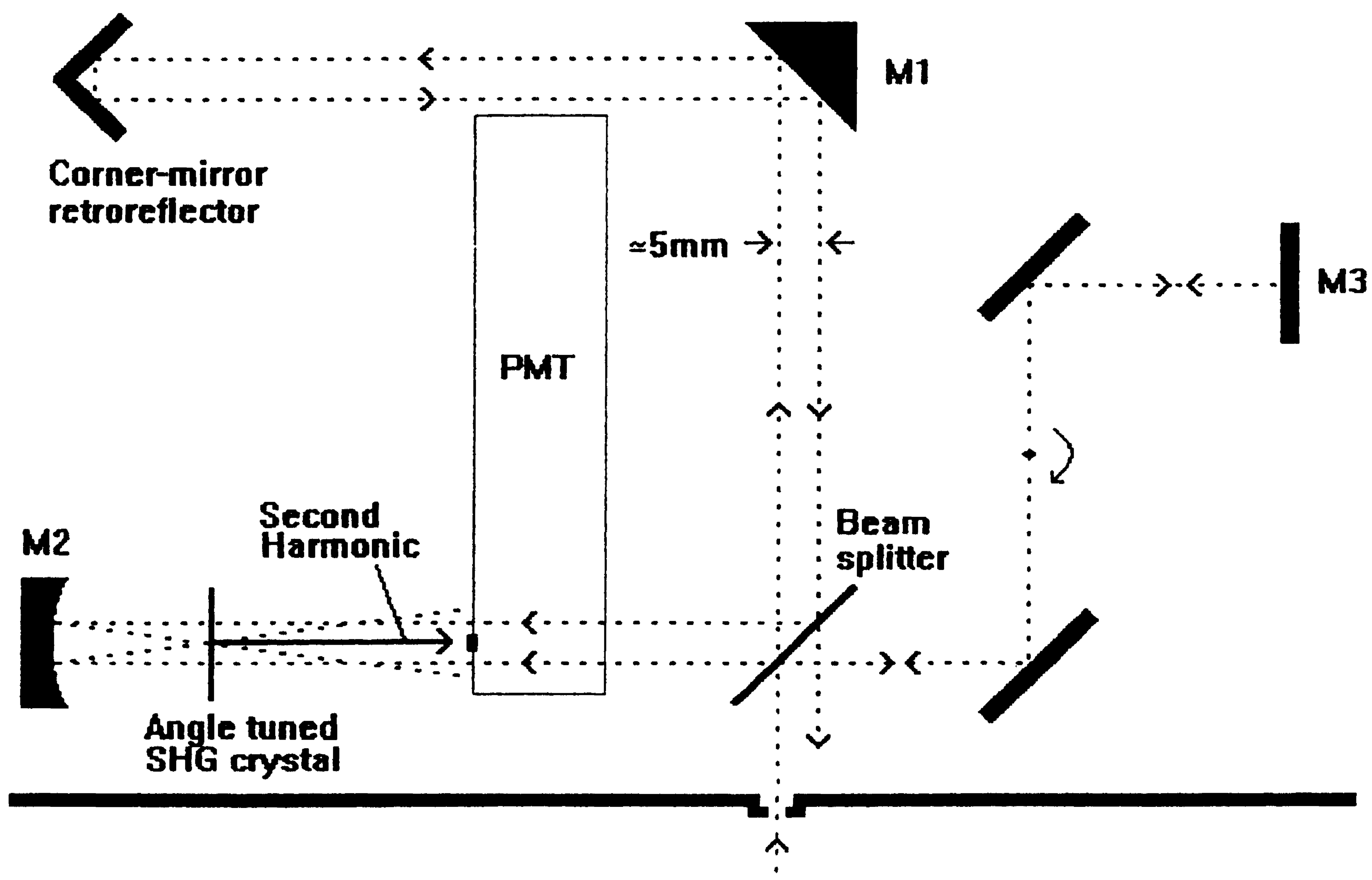

Figure 2 FR-103MN Top View Schematic

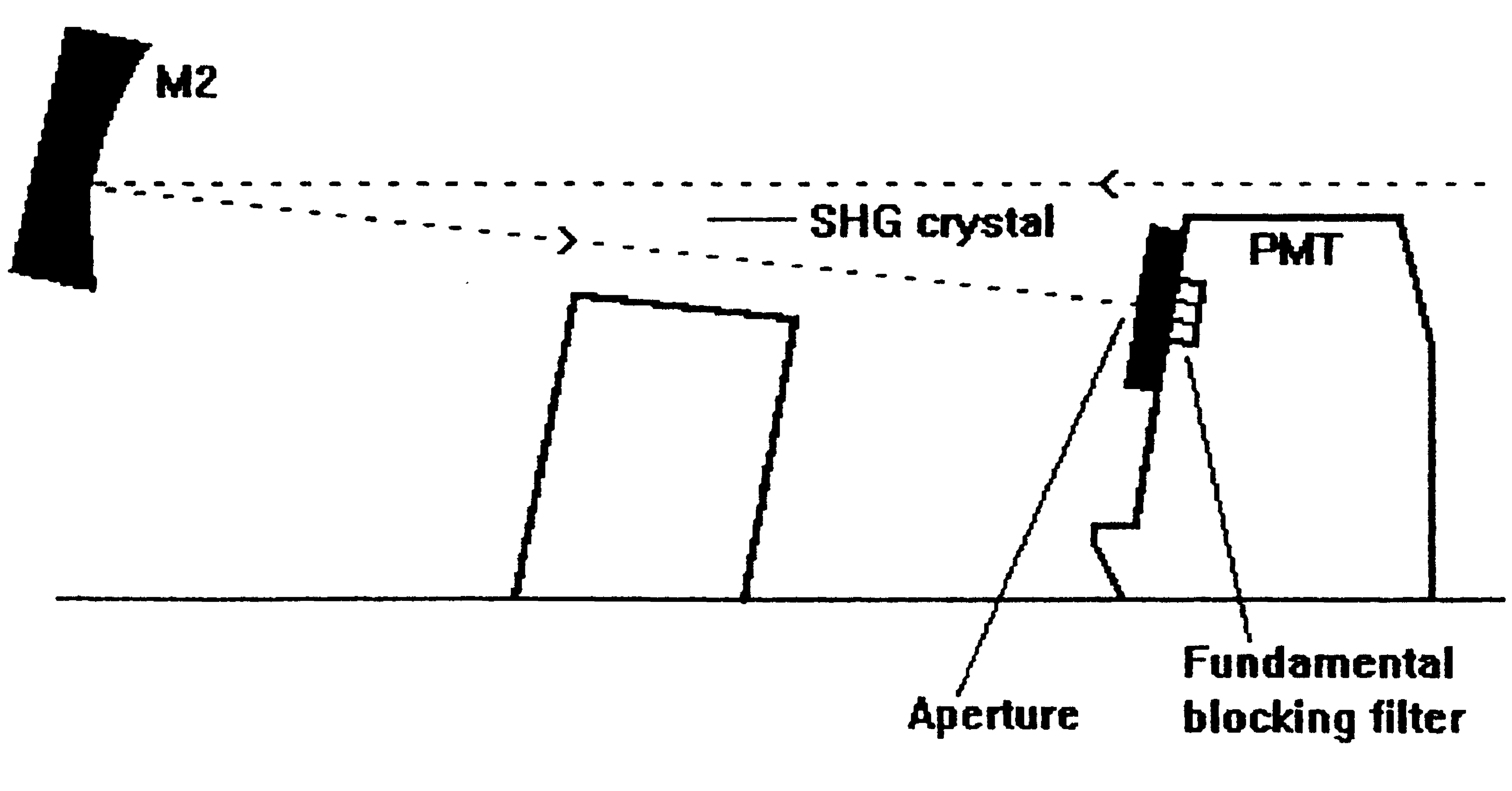

Figure 3 FR-103MN Side View Schematic

(i) Direct the **vertically polarized** input beam through the center of the input aperture and orient the FR-103 (by lateral movement and/or using the level adjustment knobs) such that the incoming beam is incident on M1 slightly left of center (looking from the front side). The return beam from the corner mirror will form a spot on M1 symmetrically displaced to the right by 6-7 mm. Typical positions of the beam spots are illustrated in Figure 4. Lateral movement of the FR-103 will adjust the separation between the incident and return beams to an optimal value of 4-5mm.

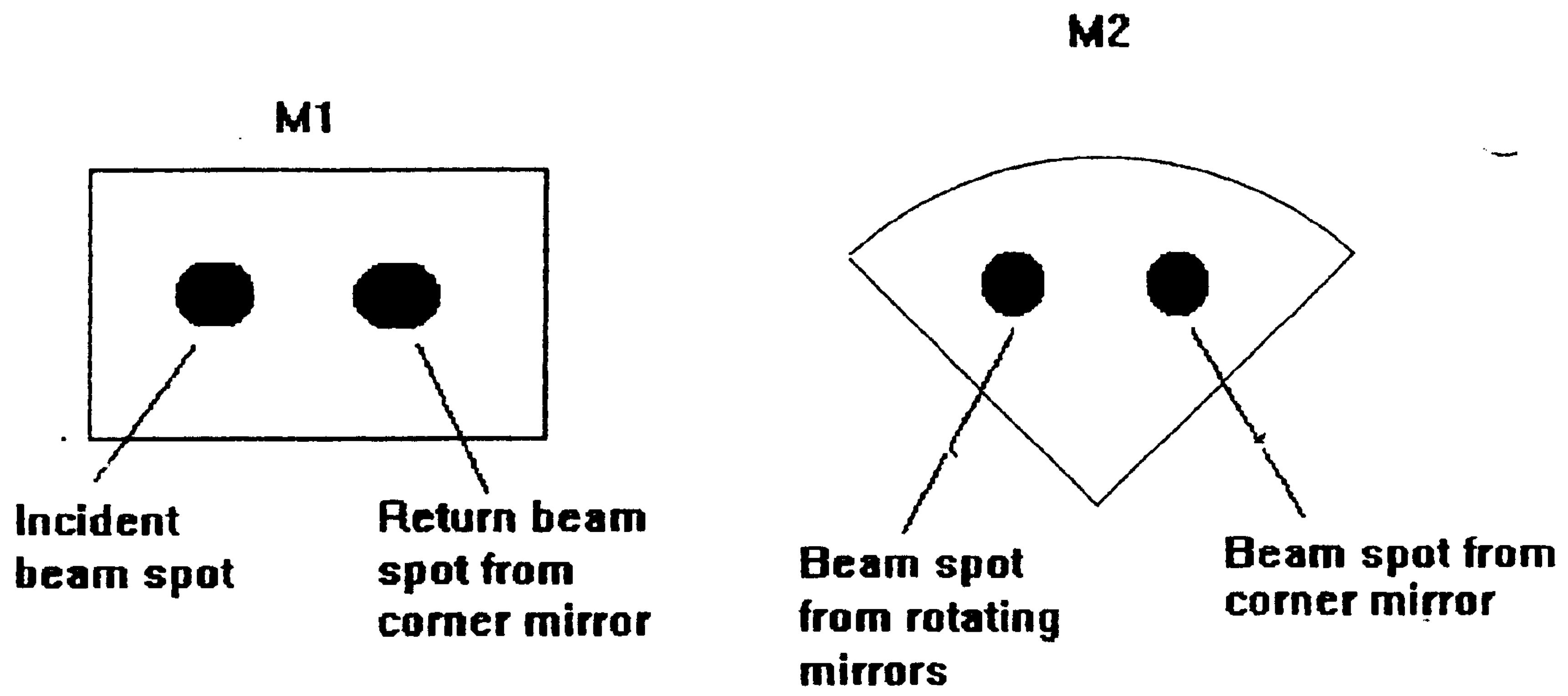

Figure 4 Beam Spots on M1 and M2

(ii) When the described alignment is set, the retroreflected beam from the corner mirror (fixed beam) forms a spot on the PMT housing displaced to the right of the aperture by typically 2 mm (vertical mark) and centered between the indicated horizontal marks, as depicted in Fig 5. **Note that the exact beam positions on M1 and M2 is not critical, and it is only required to center the beam at the input aperture and adjust the FR-103 sideways and height-wise, so that the fixed beam forms a spot at the PMT as shown in Fig.5.**

(iii) The beam from the delay arm of the Michelson Interferometer is retroreflected by the end mirror M3, the control knobs of which are located on the right side of the FR-103. On retroreflection, this beam overlaps with the fixed beam in the crystal and forms a spot on the PMT housing symmetrically displaced to the left of the aperture. (Figure 5)

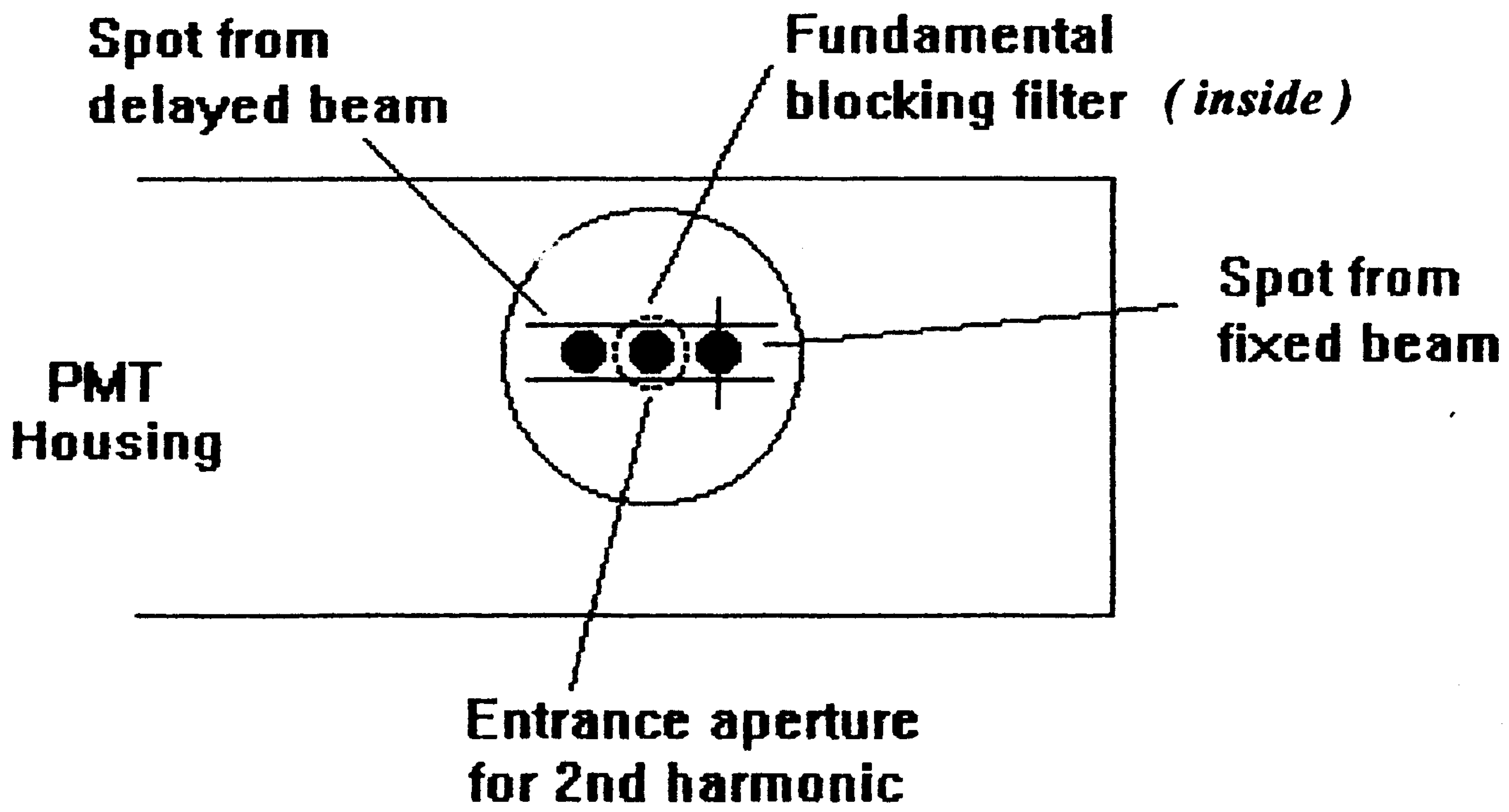

Figure 5 Front View of PMT Housing

(iv) Alignment of M2 is controlled by three fine adjustment screws. Two of these, orthogonally about the central one, render vertical and horizontal tilts. The central screw causes mirror translation and thereby focus adjustment. The factory set controls of M2 should not need to be readjusted.

(v) Vertical alignment of the beam spots is easily accomplished using the levelling knobs of the instrument. If the beam from the retroreflector is low (or high), then raise (or lower) the back. (Figure 6)

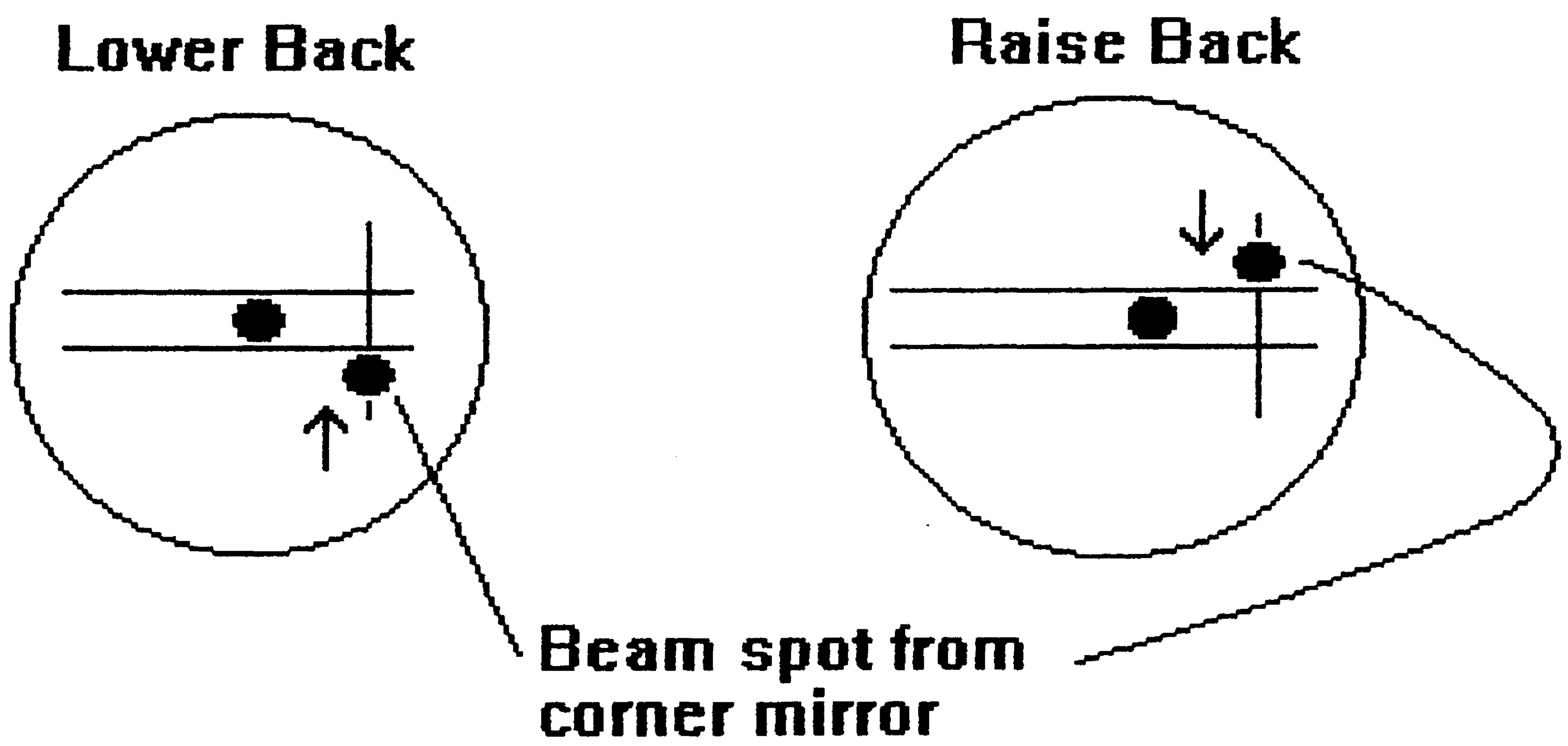

Figure 6 Vertical Alignment of the Beam Spot

(vi) Lateral movement of the FR-103 (while maintaining centering of the incoming beam at the input aperture) adjusts the beam spacing at the PMT housing. (Figure 7) Optimal adjustment will locate the two beam spots w/ 4-5mm in between, on either side of the aperture.

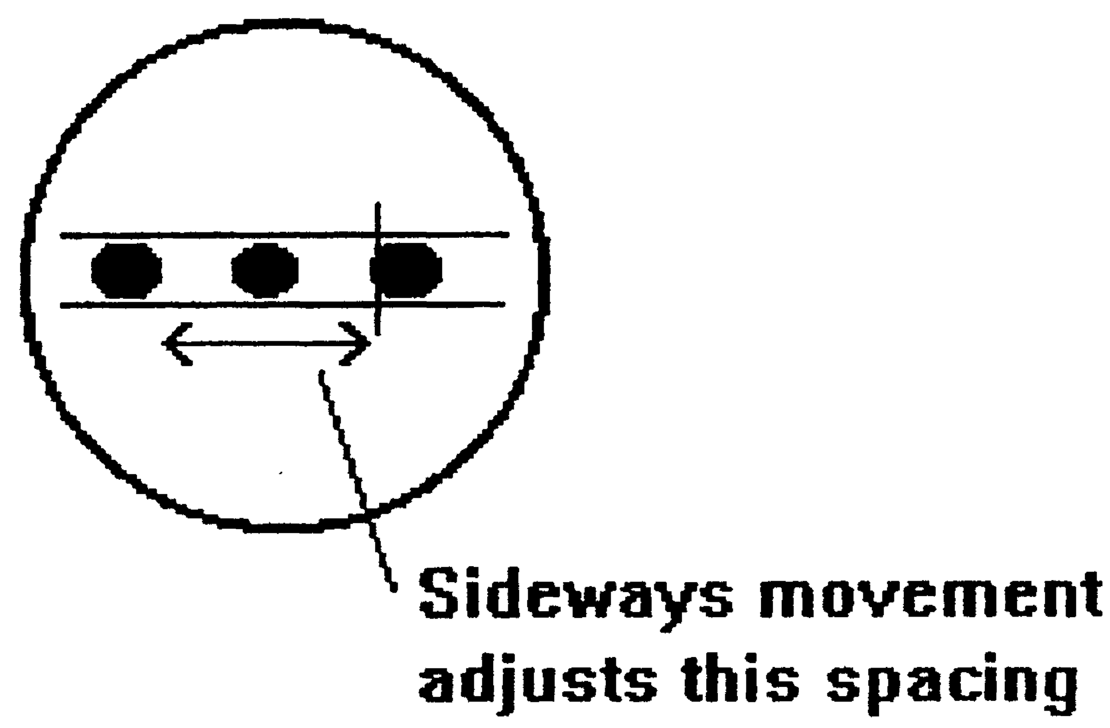

Figure 7 Horizontal Alignment of the Beam Spot

(vii) The 2^{nd} harmonic is generated (when the NL crystal is phase matched by angle tuning, i.e. rotation of the front panel micrometer) in the direction bisecting the two beam paths, and therefore is incident on the PMT aperture.

(viii) **The SHG crystals are generally hygroscopic.** For maximum resolution, the crystals are provided without windows but with single layer MgF_2 AR coatings which yield good protection against exposure to H_2O. A desiccator is also provided as a cover, for long term reliability of the NL crystal. During an experiment, the desiccator is removed and placed beside the crystal assembly. When the unit in not in use, this cover should be kept on the crystal to minimize its exposure to humidity and dust. The desiccant must be periodically replaced as necessary.

(ix) The beamsplitter and M1 alignments are factory set and need not be readjusted unless a major misalignment occurs. In such a case, refer to Section 3h.

(x) A filter transmitting the second harmonic and attenuating the fundamental is placed inside the screw-on stub containing the aperture, on the PMT housing. It may be necessary to change this filter if a major change of wavelength takes place. The unit is supplied with a standard set of filters covering the wavelength range of operation.

3c. Alignment Hints

As described in the previous section, the factory set controls of the optical elements (M1, M2 and Beamsplitter) do not need to be readjusted. In order to obtain the autocorrelation (AC) signal, it is only necessary to have (i) a **vertical** input polarization, (ii) NL crystal micrometer adjusted for the correct phasematching angle and (iii)beams overlap in the crystal (which is adjustable by the two large external knobs on the right hand side (RHS) which control M3). If the signal is not easily observed, with the input beam is properly aligned as described in Sec.3b., the steps below should be followed:

(1) Ensure that the input polarization is **vertical** and proper fundamental blocking filter for the wavelength of operation is installed behind the PMT aperture stub. If provided, remove the IR sensor cap off the PMT aperture.

(2) Using the horizontal control of M3 (RHS top knob) steer the delayed beam directly into the PMT aperture. Use 1ms/div, EXT, NORM. trigger w/ (+)SLOPE on the scope. With some GAIN on (depending on the input level) and adjusting the crystal micrometer, a square signal (about 6ms) should be observed at the correct phasematching angle. The (+) edge of the DELAY DISABLED ["0"] is about the center of this observed scan range.

[At this step, depending on the PMT response at the fundamental operation wavelength and the duty cycle of the pulses, there may be some linear response (signal independent of the crystal angle) which may need to be further filtered out with an additional external fundamental blocking filter. Such a linear response will also be observed if the IR sensor cap provided (which upconverts the fundamental) is kept on the PMT aperture.]

(3) **If a fiber coupled beam is being used (w/FA), it is necessary to control input polarization for vertical, simultaneously with the phase matching angle.**

(4) Once this square SHG signal (vanishing outside a narrow range of the x'tal micrometer) is observed, adjust **and fix input polarization at maximum signal**. Note the micrometer reading.

(5) Move the delayed beam to its proper position (left side of the PMT aperture, symmetrical to the fixed beam spot), using the horizontal M3 control knob on the RHS.

(6) Turn the x'tal micrometer counterclockwise slightly (about half a turn).
(7) Carefully readjust the two RHS external knobs of M3 (which steer the delayed beam vertically and horizontally), until the AC signal is observed. At this step, the beams overlap in the NL x'tal is to be obtained and an incremental step by step procedure may need to be carried out. The AC trace peak will appear within the ~6ms window defined by the square pulse observed in step(2), depending on the setting of the corner-mirror T-stage micrometer.
(8) That the correct AC signal is being observed should be checked by (i) vanishing of the signal outside a narrow range of the NL x'tal mike, and (ii) vanishing of the signal when the fixed beam is blocked (by means of e.g. a piece of paper in front of the corner-mirror T-stage).
(9) Once the AC signal is observed, x'tal micrometer, the two RHS knobs and input polarization should be readjusted for a maximum signal. The T-stage micrometer can be adjusted to center the trace peak within the ~ 6ms scan range.

3d. Wavelength Dependence

The phase matching angle for the NL crystal, for any given wavelength, is adjustable by the front panel micrometer. The rotational stage the NL crystal is mounted on allows a wide range of angles, and provides for a single standard NL crystal to readily angle tune over its entire wavelength range.

3e. Wide Scan Range/Scan Nonlinearity

The delay range of the FR-103MN is proportional to the mirror size used in the // mirror assembly. For long pulsewidths, the effect of scan nonlinearity needs to be taken into account. The pulse delay, as the // mirrors rotate, is a sinusoidal function of the rotation angle (time), and linear only for small angles. It can be shown that[6], to 3rd order, the pulsewidth measured must be multiplied by the factor $[1-\pi^2(\text{FWHM}/100)^2/6]$, where FWHM is the full width at half max of the trace measured in msecs, to yield the actual pulsewidth. Therefore, even for a pulsewidth as long as 25 psec (FWHM = 5 msec), the pulsewidth measurement error due to scan nonlinearity is <0.5%.

3f. Input Beam Polarization

The FR-103 is set for a **vertical** input beam polarization. [It is also possible to convert the unit for use w/ a **horizontal** input polarization. However, this is not recommended, since a horizontally polarized input beam is incident on the pellicle beamsplitter as P-polarized. This orientation results in lower beam intensities incident on the crystal, since in general, the reflectance of the beamsplitter is lower for P-polarization than S-polarization (vertical input polarization). The 2nd harmonic generated for horizontal input polarization is therefore as much as ten times less than for vertical input beam polarization, this factor being wavelength dependent. Please consult factory for operation w/ a horizontal input polarization.]

3g. Pulsewidth Calibration

Calibration of the FR-103 can be determined by translation of the micrometer driven retroreflector stage in the stationary arm. For a given translation x, the corresponding shift s in the position of the trace peak (Figure 8) yields the **calibration factor** using the conversion formula

$$\frac{T}{t} = \frac{2x}{0.3s} \quad (psec/msec) \qquad \textbf{(3)}$$

where x is in mm and s is in msec. The result will be found to be close to the theoretically calculated value of 7.5 psec/msec. However, there is a weak dependence of the calibration factor on the position of the pulse peak within the scan range. Therefore, the exact experimental calibration factor must be determined by the translation of the corner-mirror forward and backward about a given measurement position and the mean value of the two corresponding calibration factors determined must be used.

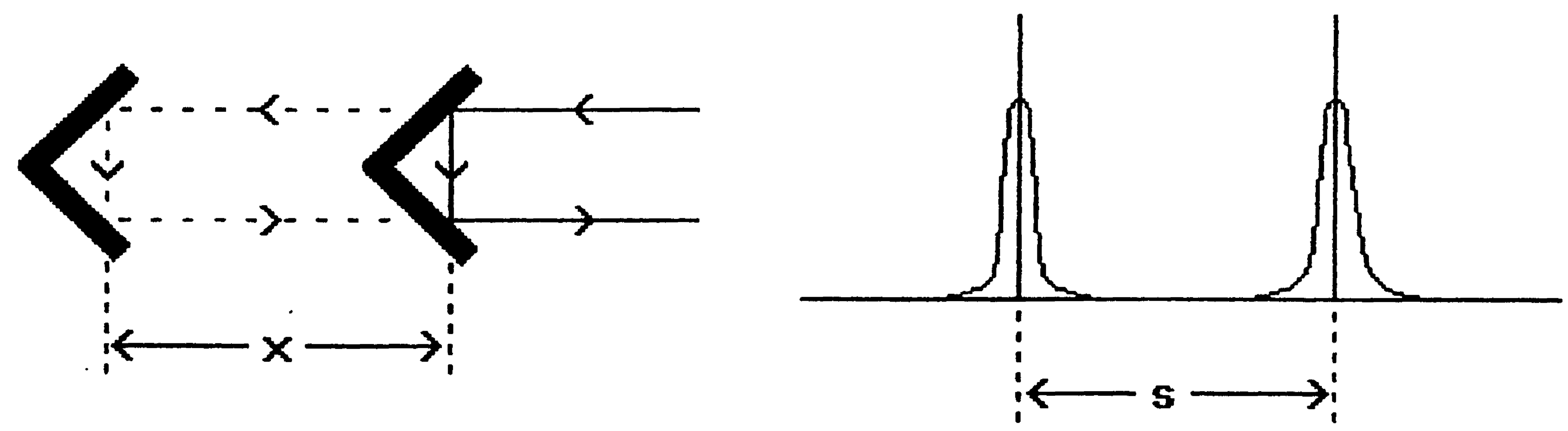

Figure 8 Corner Mirror Translation x (mm) and trace shift s (msec)

The conversion from the FWHM autocorrelation trace width (ΔT) to the FWHM pulsewidth (Δt) is a function of the assumed pulse shape. In Table 1, Δt/ΔT is given for commonly used pulse shapes.

Pulse Shape	Δt/ΔT
Hyperbolic Secant $Sech^2(1.763t/\Delta t)$	0.648
Gaussian $Exp[-2.77(t/\Delta t)^2]$	0.707
Single-Sided Exponential	0.5

Table 1. Relationship between autocorrelation width and pulsewidth for various pulse shapes.

3h. Major Optics Alignment

Realignment of the pellicle beamsplitter (PBS) and the fold mirror M1 may be necessary if either component has been moved.

Fold Mirror (M1) Alignment

(i) Direct the input beam, using the level adjustment knobs and/or lateral movement of the FR-103, such that it is incident on M1 slightly to the left of center as depicted in Figure 4.

(ii) Using a small screwdriver, carefully adjust the vertical and horizontal control screws on M1 such that the return beam from the corner mirror forms a spot at a symmetrically opposite position, as depicted in Figure 4.

Beamsplitter Alignment

The ultrathin (~1 μm) pellicle beamsplitter used in the FR-103 must be handled with extreme caution. **THE PBS CANNOT BE CLEANED BY CONVENTIONAL METHODS.** Keeping the plastic cover over the PBS mount when the unit is not in use will minimize the accumulation of dust on the pellicle surfaces, eliminating the need for cleaning. If absolutely necessary, a gentle flow of dry air can be tried.

Alignment of the PBS is achieved as follows: With the input beam properly directed and M1 correctly aligned, the beam returned by the corner mirror should form a spot on M2 as described in Figure 4. Adjustment of this beam position is controlled by the horizontal and vertical tilts of the PBS. Vertical control is reached from above using a screwdriver. Horizontal control is achieved by loosening two 4-40 screws holding the PBS mount and readjusting it. The return beam retroreflected from the // mirrors can be blocked out during this procedure. When the rotor is set in a scan position and M3 is properly adjusted for <u>retroreflection</u> (by means of the external right side panel knobs), the delayed beam forms a symmetrical spot on M2. (Figure 4) The focus mirror vertical and horizontal controls (on the left side panel) may need to be readjusted to set the two beams symmetrical about the PMT aperture.

4.OPTIONS

4a. Crosscorrelation

The FR-103MN can readily be used to crosscorrelate ultrashort pulses from two separate beams. The second beam for crosscorrelation (CC) is introduced thru' the center of the opening in the right side plate.(A fiber adapter [/FA(CC)] can be installed at this port, also.)

Note:

The zero position of relative delay (ZPD) needs to be externally adjusted. For the midrange of the corner-mirror T-stage, the pathlength to the crystal for the 2nd beam is about 50mm longer than the middle position of the scan range for the 1st beam , measured from their respective entrance faces of the FR-103MN.[Externally, the pathlength for the 1st beam should be longer by this amount (~50mm)].

The FR-103MN can be set for crosscorrelation, as follows:

(i) The first beam is incident at the front aperture with the unit aligned as for autocorrelation (AC) (position [1] of corner mirror in Figure 9 below).

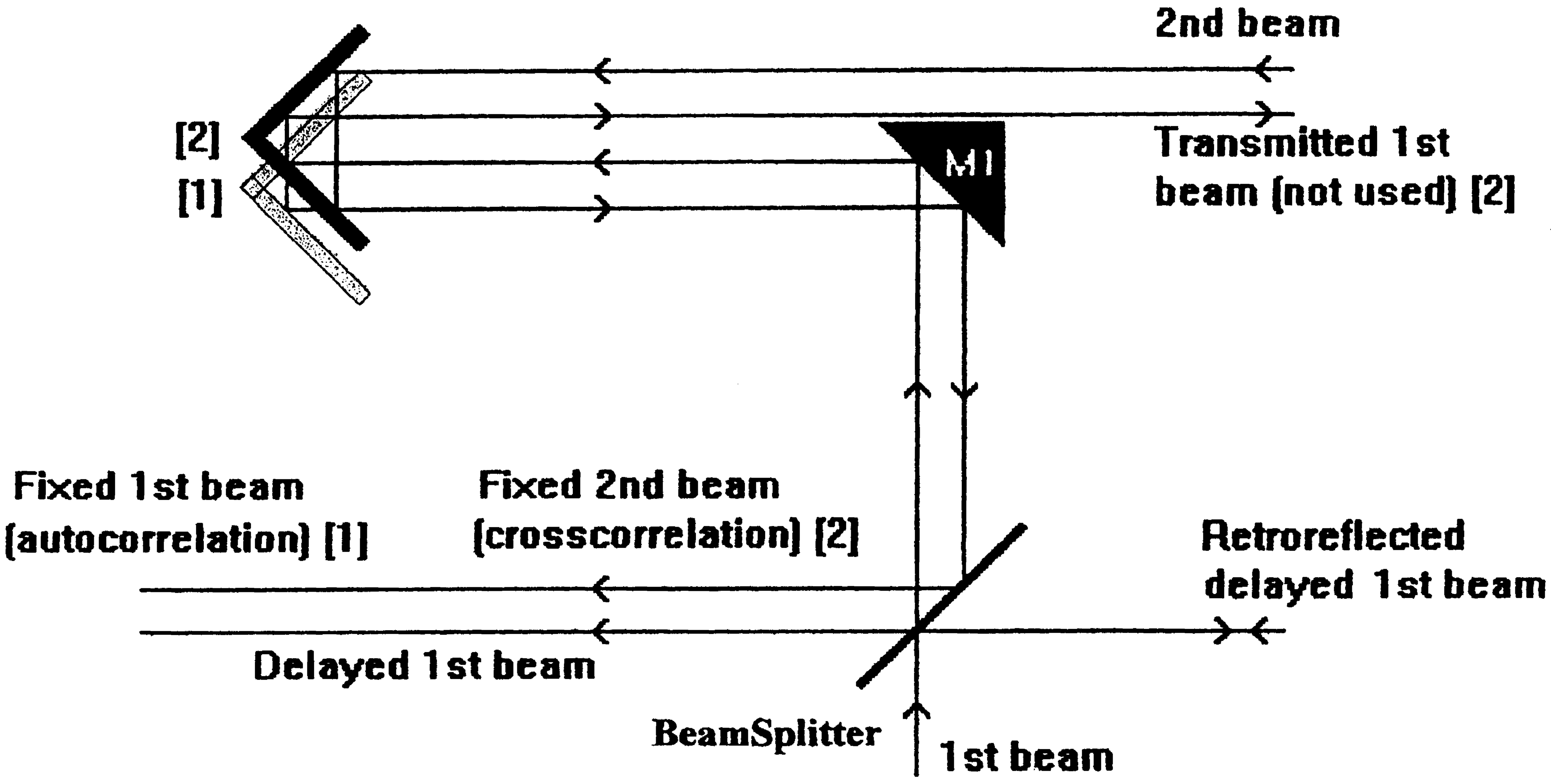

Figure 9 FR-103MN Schematic of Crosscorrelation Operation

(ii) The corner mirror is then shifted by ~1/4" to position [2] such that the first beam is transmitted at the back side of M1. The second beam is introduced (after removing the plug) through the aperture on the Right Side Panel, in a direction opposite but parallel to the first (with a shift of ~1/4"), such that it is translated by the corner mirror to traverse the first beam's path in autocorrelation.

5. Set the integration time constant switch to 1 fsec, and the motor speed to lowest (2.5Hz).

6. Fringe resolved autocorrelation will now be observed, when the retroreflecting mirror on the // mirrors side is properly aligned using the control knobs on the Right Side Panel.

7. The beams can be given a small vertical deflection off the perfect retroreflection condition. This prevents feedback to the laser without affecting interferometric operation. The beams going back towards the laser form secondary spots on the semi-closed variable input aperture of the FR-103. These beams (from the two Michelson arms) should be set to overlap above or below the main incident beam which enters the center of the input aperture.

8. Since the 1 fsec position has low gain and integration, sufficiently high beam power may be needed, depending on the pulsewidth, wavelength, and crystal type. A small percentage of the output of a typical modelocked Ti-Sapphire laser is usually sufficient using the KDP crystal.

9. When the corner-mirror is installed back for noncollinear (background-free) operation, it should be positioned such that the edge of its mount lines up with a scratch marked on the T-stage.

4b. Interferometric Option (/IO)

1.The FR-103 is aligned for the standard noncollinear (background free autocorrelation) operation, with the retroreflecting corner mirror in its proper position on the translation stage.

2.The corner-mirror is then removed and the Interferometric Option is mounted on the T-stage, using mounting threads closest to the micrometer driving it. Alignment screws of the /IO mount are accessible from the Left Side Panel through two 1/4" holes.

3. Align the interferometric plane mirror to retroreflect the incident beam [factory aligned].The beams from the two arms of the Michelson will then be overlapping and collinearly incident on the NL crystal.

4. Direct the common spot of the two beams into the PMT aperture using the focus mirror horizontal adjustment screw. Effective filtering of the fundamental is more critical in this mode since the fundamental is not spatially blocked out as in the noncollinear operation. It may be necessary to use an additional fundamental blocking filter externally, depending on wavelength.

4c. Fiber Adapter(/FA)

A single mode fiber coupled beam can be input to the FR-103 by means of the Fiber Adapter. A broadband AR coated single aspheric lens provides beam collimation. Housed in a mirror mount, the adapter/lens assembly is aligned through horizontal and vertical tilt controls. Once aligned, the adapter offers excellent repeatability.

In the standard version, a short (25cm) dispersion shifted fiber(DSF) patchcord is connected to the input FC/PC adapter of the /FA. The input beam should be connected to the second FC/PC (or FC/APC) end of the patchcord. [Other connector options are possible]. The use of the patchcord eliminates any possibility of beam changes.

The Fiber Adapter also includes a rotatable holder for the addition of a $\lambda/2$ plate which may be used for polarization control.[10]

The easily removable Fiber Adapter assembly mounts onto the 3/4" diameter stub on the front panel of the FR-103 in which the variable aperture is installed. The aperture should remain open during the use of the fiber adapter.

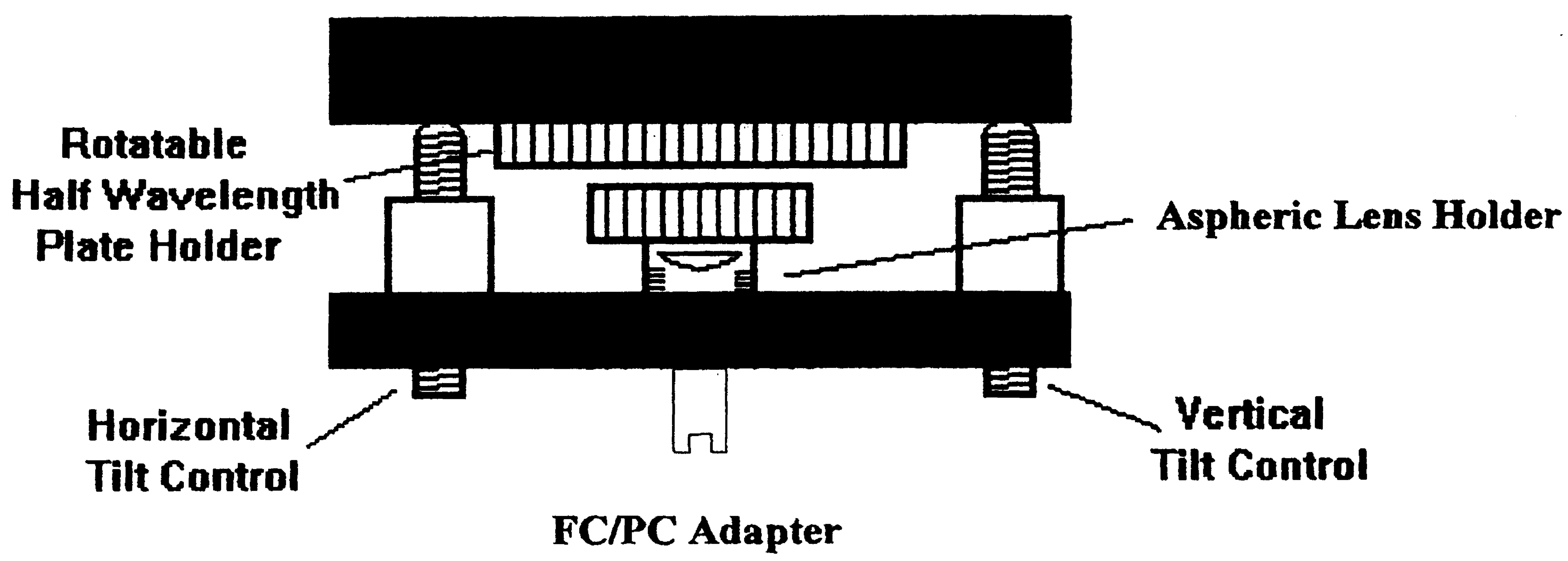

Figure 10 Top View of the Fiber Adapter

4d. Fiber Coupled (/FC)

In this version, a fixed FC/PC beam collimator is installed at the input of the FR-103, with an attached DSF (or PM) patchcord. Since not removable, this option is suitable for applications (such as 1550nm telecom.) using fiber coupled beams only. Very robust and alignment-free operation is attained at these wavelengths. It is recommended that the attached patchcord is always used.

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[10] Polarization may be more conveniently adjusted externally using a mechanical controller.

4e. Low Rep Rate Option (/LRR)

The /LRR option renders the FR-103 to be operable with any pulse repetition rate (>4Hz). Whereas autocorrelation traces can be directly displayed on an analog scope for high pulse rep rates (>200kHz), for lower rep rates, the autocorrelation traces can be directly accumulated and displayed on a digital oscilloscope with **persistence** set to ∞, utilizing the /LRR option.

Introduction

Selected by the motor speed switch near the // mirrors assembly (inside right back corner), a PLL circuit synchronizes the rotation rate of the // mirrors with the freq f_{in} (or submultiple) of a TTL input at the REF IN port on the back panel of the FR-103.

The rotation rate of the // mirrors is phaselocked such that one incoming pulse is captured within a small range near the central region of the // mirrors, for each sweep.

The phase of the // mirrors is linearly modulated with an amplitude selected by the green marked dip switches (5 6) and the SCAN pot on the back panel, setting the delay range swept.

Operating Instructions

1. Align the FR-103 in the standard rapid scan mode (10Hz), with modelocked high rep rate pulses. **With the TRIG. SELECT switch set to Pos.#0, adjust the T-stage micrometer, so that the pulse peak appears at the beginning of the o'scope trace. Mike Reading=**
Always keep the micrometer at this reading.
2. Set the 3-position speed selection switch near the // mirror assembly (right-back inside corner), to furthest away from the 10Hz position. In the absence of a trigger input at the REF IN port on the back panel, synchronized with the low rep rate laser pulses, // mirrors will rotate at about 4Hz.
3. Select the proper setting of the dip switches on the back panel, for the rep rate f_{in} of the trigger pulses to be used, in accordance with the chart below. Note that in any selection, only 2 connections are switched ON, and others are all OFF (x):

DIP switches(as seen on the back side): ON ↑ 12345678 1234(56)78 ON ↑

Switches ON	f_{in}(Hz)	÷
1xxxxxxx I xxxxxxx8	5-10Hz	1
x2xxxxxx I xxxxxxx8	10-20	2
xx3xxxxx I xxxxxxx8	20-40	4
xx34xxxx I xxxxxxxx	40-80	8
1xxxxxxx I 1xxxxxxx	80-160	16
1xxxxxxx I xx3xxxxx	160-320	32
1xxxxxxx I xxx4xxxx	320-640	64
1xxxxxxx I x2xxxxxx	640-1250	128
1xxxx6xx I xxxxxxxx	1250-2500	256
1xxx5xxx I xxxxxxxx	2500-5000	512
1xxxxx7x I xxxxxxxx	5000-10kHz	1024
1xxxxxx8 I xxxxxxxx	10-20kHz	2048
x2xxxxx8 I xxxxxxxx	20-40kHz	4096
xx3xxxx8 I xxxxxxxx	40-80kHz	8192
xx3xxxxx I xxxxxx7x	80-160kHz	16,384

Note that the rotation rate of the motor (f_r) is to be

$$f_r = f_{in}/(\div)$$

4. Apply trigger pulses (+going w/4-12Volts amplitude, + edge synchronized with the laser pulses within ± μsec), to the REF IN BNC on the back Panel. The FR-103 should be turned ON, before this input is applied. Motor speed variation, till full locking occurs, is to be noticed.

5. With the TRIG. SELECT switch set to **Pos.#1**, and the SCAN pot on the back panel fully counterclockwise, autocorrelation (AC) spikes will be observed (w/ the scope time base set to 1ms/div or 0.5ms/div) when the beams are overlapped in the NL crystal [adjusting the two external knobs on the right side panel] with the phasematching micrometer correctly set.
That the pulses observed indeed correspond to AC must be carefully checked by:
(i) dependence on the NL x'tal angle and (ii) vanishing of the signal when either one of the beams from the two Michelson arms is blocked [i.e. signal spikes are present only when the two beams are overlapped in the x'tal.]

6. **Amplified pulses may need to be strongly attenuated, to avoid saturation of the PMT, or any damage to the NL x'tal. Typically, pulse energy must be kept <1μJ/pulse.**
Linearity of the response (square law decrease in the signal as the input is decreased) should always be checked, as a general rule.

7. Select the proper PMT response time constant, by setting the 5-position switch at the base of the PMT enclosure to the largest value << pulsewidth to be observed.

8. The SCAN pot adjusts the delay range swept. The green marked switches (56), when ON, set the max (SCAN pot fully clockwise) of this delay range, approximately as :

5 ..... 60ps
6 ..... 15ps
Both OFF.... 1ps

9. Increase of the SCAN pot results in the peaks of the pulses being observed on the o'scope to trace out the AC. The envelope of the traces collected (using /CDA, /VGA or a digital o'scope w/ envelope function or persistence set to ∞), approaches the intensity autocorrelation function.

10. The **delay calibration factor** is a function of the rotation rate of the // mirrors (f_r). f_r should be determined checking the pulses at the TRIGGER output of the unit, with SCAN pot fully counterclockwise. For any rotation rate f_r,

$$\text{Calibration factor}|_{fr} = [f_r/10\text{Hz}].\text{Calibration factor}|_{10\text{Hz}}$$

e.g. If f_r= 7Hz, then the delay calibration factor =0.7(12.5ps/ms)=8.75ps/ms.

4f. Computer Data Acquisition (/CDA) Option

Introduction

The Computer Data Acquisition (CDA) option allows the FR-103 Auto/Crosscorrelator to be connected to a PC via the RS232 serial port. The accompanying software provides 'real-time' monitoring and characterization of the pulses. Data is collected for the current pulse profile, the average of the accumulated data, and the envelope data [when /LRR is being used, for low rep rates]. Pulsewidth is computed for each data set, accumulated average or envelope. Selections are provided to compare the autocorrelation traces with standard pulse shapes (Gaussian, Sech^2) of the same FWHM. In addition to being displayed on the monitor, the current and average data can be printed, or saved to a text file.

Operation

There are two modes of operation of the FR-103/CDA: Rapid Scan and Low Rep Rate (LRR. If the input pulse rep rate is high (>100kHz), the Rapid Scan mode directly displays the autocorrelation (AC) trace at each scan. For lower pulse rep rates, the AC trace is accumulated by capturing and storing the signal at each pulse, using the LRR mode. The peak of these pulses are acquired over a user selectable # of scans (#acq.) and the accumulated envelope yields the intensity AC trace. At the end of #acq scans, the envelope trace is refreshed after being added into an avg. envelope trace.

Hardware

The **RS-232** connector on the back panel provides the digitized output of the A/D board mounted inside the FR-103, to a serial port (COM1 or COM2) of a PC to be used, using a 9-pin straight serial cable.

Software

The accompanying disk contains seven files: the display program (MN.EXE), and six display driver files (*.bgi). One of these driver files (the one specific for the user's display) or all have to be loaded into the same directory with the MN.EXE.

In order to <u>print</u> the displayed graphs, you MUST load the DOS graphics printer driver <u>before</u> beginning data acquisition. To do so, type the following at the DOS prompt:

GRAPHICS [printer]

where [printer] is replaced by the DOS option that matches your printer type.

For list of printer types that the DOS graphics print drivers support, type:

HELP GRAPHICS

at the DOS prompt. E.g., if you are using a Hewlett-Packard LaserJet II or compatible, typing:

GRAPHICS LASERJETII

loads the appropriate print driver such that the print option in the data acquisition software will work properly.

Alternately, the appropriate GRAPHICS command line given above can be added to your computer's AUTOEXEC.BAT file so that it is automatically loaded each time the computer boots. The GRAPHICS driver requires approximately 6 KB of RAM.

Note: If a laptop PC has been supplied in conjunction w/CDA, the display program MN.EXE) and the appropriate display driver file (*.bgi) is loaded into the directory **C:\CDA**, and the proper serial port **(COM1)** has been selected.
With the autocorrelator turned ON and connected to the PC, begin data acquisition by typing:

MN

at the DOS prompt. If the directory containing the Femtochrome files is not included in your DOS path variable, you must be in the directory containing the MN.EXE program (C:\CDA). Specify which PC serial port the autocorrelator is connected to (1=COM1, 2=COM2).
The mode of operation is then selected by pressing 0 (Rapid Scan) or1(Low Rep Rate (LRR)).

Using the Menu Options

While data acquisition is taking place, either the current data, accumulated average data or the envelope data can be viewed. The CDA board selects and transmits 512 data points ranging in value from 0-255 with each sweep. The graphing display, utilizing 512x256 pixels, provides a one to one correspondence with the acquired data.
The A/D, operating at the clock rate of 10MHz, digitizes the data window and equally spaced 512 data points are selected and transmitted to the PC. The time interval between each data point δ is user selectable, with the resolution setting (1 → 60). For highest resolution, selecting 1, results in δ = 1 x 1.25fsec and the total width of the display window is 512x1x1.25fsec = 640fs.(the calibration factor of 1.25 can be checked by translating the corner-mirror of the FR-103 and noting the time shift observed). For lowest resolution, selection of 60 yields δ =60x1.25fsec = 75fsec and the total display window width is 512x60x1.25fs = 38.4 psec. For low resolution settings (large display window width), the DELAY pot setting on the FR-103 may limit the available autocorrelation range. The DELAY knob must be turned counterclockwise for large autocorrelation ranges. For operation with shorter time scales (higher resolution), the DELAY on the FR-103 must be used to set the autocorrelation trace close to the beginning of the display window. Viewing with high resolution is then possible without the trace moving out of the display window on the PC.

The display of the **current data window** is altered depending on the choice for LRR =1. If this has been selected, the current data is written over the previous ones without clearing the screen. The AC trace is accumulated typically in 10secs when /LRR is used.

The **current data window** includes the following options. The menu accepts both upper and lower case letters.

(>)(<) Increase (Decrease) resolution - By pressing “>” (or “<”) the previously set resolution can be increased (decreased). Sufficient interval should be allowed for the new choise to be effective. If this parameter registers erroneously, repeated pressing of the (>)(or <) buttons may be necessary.

(A) Average data - By pressing "A", the **current data window** is replaced by the **average data window**, producing a graph of the average data accumulated thus far.

(P) Print screen - By pressing "P", the current data displayed on the screen at that instant will be printed. The printing process will briefly interrupt data acquisition.
NOTE: The DOS GRAPHICS printer driver must be loaded for this option to work properly. See "Set Up" for details.

(L) File - By pressing "L", the user can select to save either the current or average data to a text file. Filenames are specified in the format MMDDHHMntMnt.txt, where M=month, D=day, H=hour, and Mnt=minute, of the current date /time. Note that one file can be saved in one minute of operation, without overwriting. Memory would also be recycled yearly. The data is written to the file with one data point per line. Each data point is specified with two digits to the right of the decimal point. Note: It is necessary to manually record the δ value (time interval between each point) for the files saved.

(E) Envelope - By pressing "E", the envelope data (max value at each pixel) is produced.

(Q) Quit - The program exits when a "Q" is typed.

The **average data window** also includes the "(L) File" and "(Q) Quit" menu options. The "(P) Print screen" option will print the average data that is currently displayed. The following options are also provided in the average data window:

(C) Current data - By pressing "C", the **average data window** is replaced by the **current data window**. When "C" is pressed, the vertical display scale is normalized to the peak of the signal, expanding or contracting, to allow the data to be properly viewed.

(R) Reset average - By pressing "R", the average data and the number of sweeps collected are reset to zero, allowing a new data collection sequence to proceed. Since there is no longer average data to be displayed, the program returns to the **current data window**.

(U) Update average - By pressing "U", the **average data window** is refreshed, displaying the current state of the average data accumulation. The values of Y_{max}, FWHM, and # Sweeps are also updated.

(G) Gaussian - By pressing "G", the average data is compared to a Gaussian pulse shape of the same FWHM. The comparison is based on a computation of the average data's pulse width and height as described below under "Pulse Analysis". When "G" is pressed, the menu option is replaced by the pulsewidth (PW) of the Gaussian that was generated.

(S) $Sech^2$ - By pressing "S", the average data is compared to a $Sech^2$ curve in the same manner as the Gaussian comparison. Similarly, when "S" is pressed, the menu option is replaced by the pulsewidth (PW) of the $Sech^2$ that was generated.

In the **envelope data window** , there are four new menu options:

(T) Avg Envelope - By pressing "T", the accumulated average of envelope data traces (each being collected over #acq scans) is plotted.

(N) ReNew Envelope - By pressing "N", the envelope trace is refreshed after a new one is collected (#acq scans).

(←) Left arrow key reduces #acq.

(→) Right arrow key increases #acq.

Pulse Analysis

The maximum y value of the curve (Y_{max}) and the full width at half maximum (FWHM) are computed for each incoming set of data and each time the average data is displayed. The display is normalized to the Y_{max} obtained for the 1st data set, allowing for fluctuations in the data to appear in subsequent data collections. The value displayed for Y_{max} is the actual signal in Volts. This must satisfy $0<Y_{max}<4V$. The GAIN control of the FR-103 must be used to set Y_{max} in this range, optimally close to 4V. Vertical Resolution is 15 mV.
The FWHM of the autocorrelation trace is displayed in fsecs.

The number of sweeps (# sweeps) counts the data sets accumulated in producing the average data. The # sweeps is set to zero each time the program begins and whenever the "(R) Reset average" option is selected.
The value of the factor δ is controlled by the resolution setting (see previous section).The value, displayed in fsecs, gives the time interval between the individual data points collected to produce the digitized trace.

4g. VGA Display Option(/VGA)

An embedded PC is installed in the FR-103, and an LCD display and keyboard are incorporated on the unit. The operation with this option follows /CDA, and starts with the command C:\>**MN**.

The data which has been saved can be transferred to another PC, using the application **FT.exe.** [Command C:\>**FT.**] The contents of the floppy disk accompanying this option [**RC.exe**]needs to have been installed into the PC to be used for this purpose. Important data files individually, or all of the stored data can be transferred using these applications and the serial ports of the FR-103 and the PC. Do not delete the data files (*.txt) saved in the FR-103 until the memory gets full (about 2000 files). A straight 9-pin serial cable needs to be used to connect to the PC.

Traces displayed can be printed ("P") in a laser printer supported by the graphics driver Laserjet II using the 25-pin printer port on the back panel of the FR-103.The laser printer needs to have DOS support. A recommended printer is Brother model HL-1440.

4h. Extended Wavelength (IR) Options

The wavelength range of operation can be extended by photodiodes as plug-in detector modules mounting in front of the PMT enclosure. There are two wavelength ranges covered:

/1000 (1000-2000nm) (Si photodiode)
/2000 (2000-3000nm) (InGaAs photodiode)

Since these detectors have much less gain than available with the PMT, higher input signal levels are needed. Typically a min. avg. power of 5mW would be needed for a modelocked pulse of one picosecond width.

There is a 5-position slide switch on the side of these detector modules providing different gain and integration times to cover the pulsewidth range for the FR-103XL. The switch setting should be such that the integration time is << pulsewidth, so that the autocorrelation trace is not affected by the electronic resolution.

If a PMT is included in the unit, a two-position slide switch is also mounted on the back panel, to select the output which is sent to SIGNAL OUT : PMT or PD.

5. SPARE PARTS LIST

The following is a parts list for the major components of the FR-103MN.

Optical Components

Femtochrome Part #	Description
103MN-001	// Mirror Assembly
103MN-002	Pellicle Beamsplitter (specify VS/IR)
103MN-003	Folding Mirror (M1)
103MN-004	Focusing Mirror (M2)
103MN-005	End Mirror (M3)
103MN-006	Corner Mirror
103MN-007	PMT (specify VS/IR)
103MN-008	SHG Crystal (specify type/wavelength/thickness)
103MN-009	Fundamental Blocking Filter (specify wavelength)

Electrical Components

Femtochrome Part #	Description
103MN-010	DC Power Supply with Delay Circuit
103MN-011	PMT Power Supply (HV)
103MN-012	Motor
103MN-013	PMT Assembly w/ preamplifier
103MN-014	S/H Circuit

6. WARRANTY INFORMATION

Femtochrome Research, Inc. warrants all its products to be free from defects in materials and factory workmanship and agrees to repair or replace any unit that fails to perform to data sheet specifications for a twelve month period from the date of invoice.

This warranty shall not apply to any unit that has been subject to misuse, negligence, or accident. Femtochrome shall in no way be liable for damages consequential or incidental to defects in any of the products, for injuries resulting from its use, or for any other cause.

This limited warranty constitutes the full understanding of Femtochrome and the buyer, and no term, conditions, understanding, or agreement purporting to modify or vary the terms thereof shall be binding unless made in writing and signed by two corporate officers of Femtochrome Research, Inc.