Autotracker III

Harmonic Generation System

Model AT-III

Applications...

- **Automatic Second Harmonic and Third Harmonic Generation of UV Wavelengths**
- **Automatic Production of IR Wavelengths by Difference Frequency Mixing**
- **SHG of Scanning Short Pulse Lasers**

Features...

- **Compact Optical Head with Hand-Held Controller**
- **Averaging Capability for Display and Control**
- **Wide Wavelength Coverage**
- **RS-232 Port for Control by External Computer**
- **Stand-Alone Operation**
- **Graphic Display of Output Power and Error Signal**
- **Easy Conversion Between UV and IR Operations**
- **Display of Crystal Tilt Angle**
- **Ability to Track High or Low Repetition Rate Lasers**

Description

The Autotracker III is a stand-alone servo system designed for frequency mixing of pulsed lasers in nonlinear crystals. The system senses the frequency mixed output of an angle tuned crystal and servos to the phase match angle. This active feedback design accommodates wavelength changes due to active laser scanning and compensates for bulk crystal temperature changes produced by either ambient or laser induced heating.

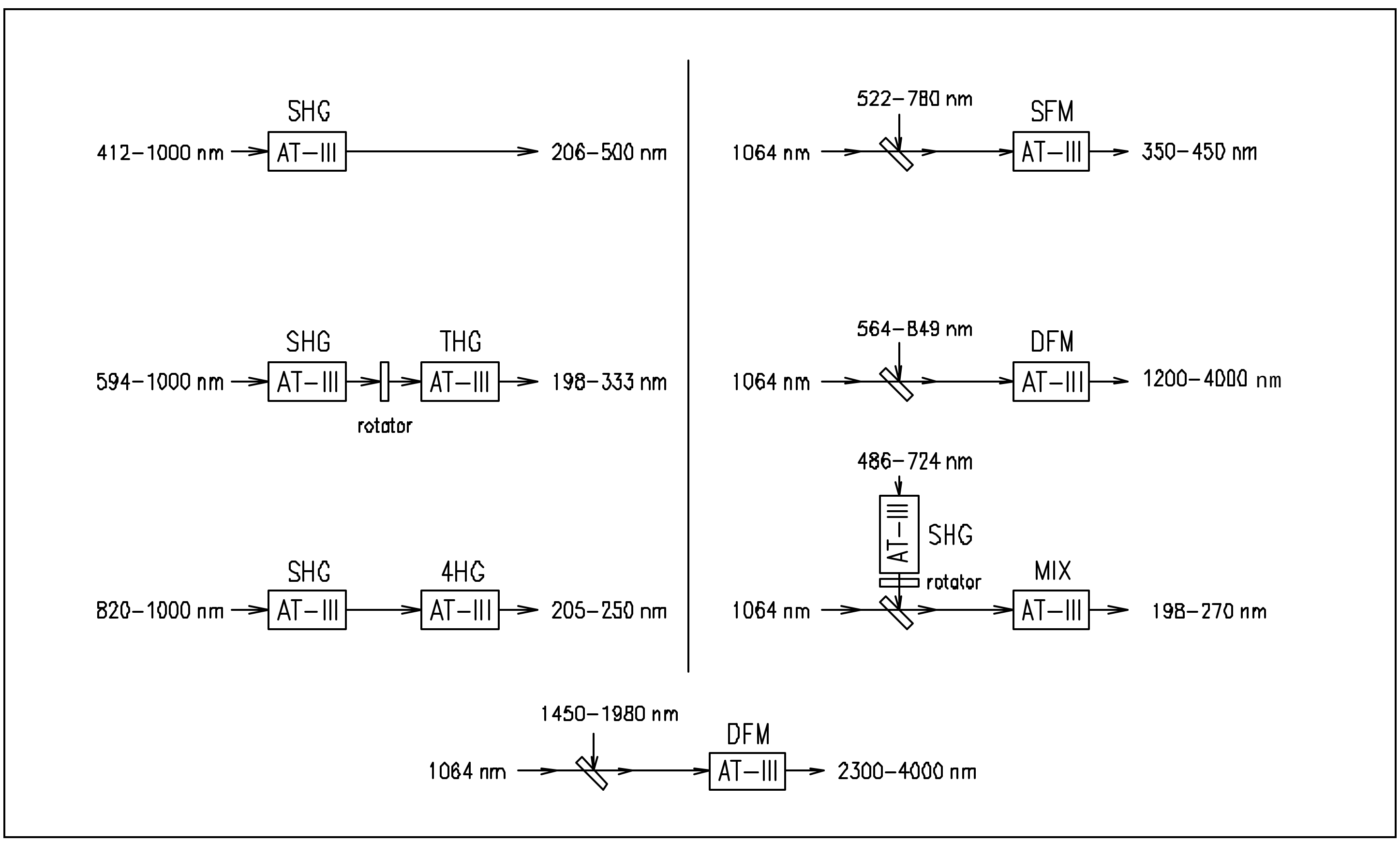
The Autotracker III consists of an optical assembly tethered to a hand held control unit. The control unit directs the positioning of the phasematch crystal located within the Autotracker III optical assembly, with the help of feedback from sensors located in the optical assembly. An RS-232 port permits the Autotracker III to be controlled by an external computer.

The stand-alone feature of the Autotracker III means that it works well with the extremely wide variety of dye and solid-state lasers that currently are in the commercial marketplace. These lasers have repetition rates from less than 10 Hz up through many tens of MHz and pulse widths ranging from sub-picosecond to tens of nanoseconds. Several frequency mixing configurations are shown in Figure 1.

Flexibility is provided by the extensive array of standard and non-standard doubling and mixing crystals that can be mounted in the optical head. Wavelength coverage that extends from ultraviolet wavelengths as short as 198 nm out to infrared wavelengths of 4.0 microns has justified the reputation of the Autotracker as a versatile laboratory performer. Because of its modular design with respect to crystal selection, the Autotracker III uses the type of nonlinear material, orientation, and thickness that is most appropriate for the task at hand; as improved crystals become available, the Autotracker III will be able to use them.

The optical head has a footprint less then 20 cm x 30 cm (8" x 12") and it fits easily on a lab bench where space is limited. The small size also makes it portable enough to be shared between several different lasers.

Figure 1
Autotracker III Mixing Configurations



The Autotracker III works well with a wide range of laser repetition rates. This means that an off-the-shelf, well documented system can be employed for a number of different lasers without having to pay the development costs of a custom unit. It also provides flexibility such that one unit can be used with several different lasers.

High repetition rate lasers, very slow wavelength scans, or noisy lasers will benefit from the ability to average the tracking signal before making an angular correction. Independently, the intensities that are displayed on the liquid crystal display of the hand held controller can be averaged for long term monitoring of tracking performance.

IR and UV conversion kits for the Autotracker III permit easy interchange between sum frequency mixing that generates ultraviolet light and difference frequency mixing that produces infrared wavelengths. This flexibility allows two applications to be performed at the capital expense of one base system. Also, as the needs of the laboratory change over a period of time, the Autotracker III can be adapted economically to those changing needs.

Laboratory automation plans will be helped by the ability to control the Autotracker III from a laboratory computer. An RS-232 connection on the optical unit makes it easy to take command of all of the functions normally controlled from the hand held controller.

The tracking signal can be graphically displayed on the hand held controller. This allows the system to be aligned for optimal tracking performance. Observation of the tracking signal can verify that the system is set up properly so that it will track well.

The crystal tilt is displayed on the hand held controller. This makes it convenient to find the correct phasematch angle in day to day operation. Phasematching curves, located in the appendix of the manual, show the crystal tilt angle for the standard crystals offered by INRAD.

The Autotracker should be differentiated from other tracking systems that use a look-up table to determine the phasematch angle. Because the required angular adjustment is very fine, other systems can become confused easily. The Autotracker, however, actively detects the generated wavelength and continually adjusts the crystal tilt for optimum output power.

System Configuration

The Autotracker III basic system consists of an optical assembly in one of three versions, a hand held controller, and a power cord (see Figure 2, next page).

A set of components used inside the optical assembly determines whether the Autotracker III is a "UV", "NIR", or "IR" version (see Table 1). The UV version is used for producing wavelengths between 198 nm and 470 nm. The IR version is used with low repetition rate lasers for which difference frequency mixing is used to produce wavelengths between 1.2 and 4.0 microns. The NIR version is used typically with lasers of high repetition rate to produce wavelengths between 1.3 and 1.6 microns.

No special action needs to be taken with high repetition rate lasers for UV and NIR units.

For mode locked lasers, a focusing lens is placed inside the optical head to increase the power density inside the crystal for better efficiency (OPTION/MLSHG).

A complete mixing system consists of the Autotracker III mechanics and several wavelength-specific optical components that mount inside the optical assembly of the Autotracker III (see Figure 2, next page).

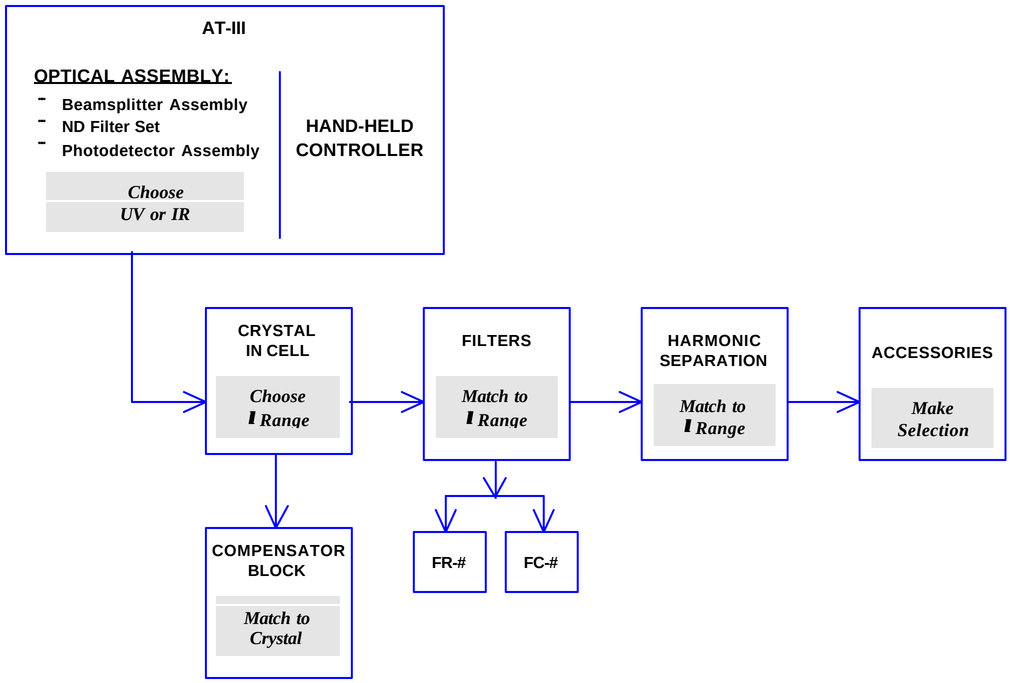
Additional optical components that mount inside the optical assembly of the Autotracker III are a nonlinear crystal mounted in a cell, a compensator block that matches the nonlinear crystal, and reflective filters and color filters to transmit the generated light and attenuate the wavelengths that were mixed together in the crystal.

Table 1
Autotracker III Versions

Designation	Wavelength Generated	Repetition Rate
UV	198 nm - 470 nm	5 Hz - 100 MHz
NIR	1300 nm - 1600 nm	5 Hz - 100 MHz
IR	1200 nm - 4000 nm	1 Hz - 200 Hz

Figure 2

Autotracker III Configuration



Optical Assembly

Opto-Mechanical Layout

The optical assembly contains the crystal positioning motor with gearing, various optical components, photodetectors, microcontroller, and system power supply. The layout of the Autotracker III optical assembly with labeled components is shown as Figure 3.

Depending on the output polarization direction of the generated light, one of two distinct optical paths is followed in order to minimize reflective losses for the generated light at the beamsplitter. For generated light that is vertically polarized, the beamsplitter is oriented to reflect a portion of the beam upward, as shown in Figure 3; for generated light that is horizontally polarized, the beamsplitter, instead, is oriented to reflect a portion of the beam to the side in the horizontal plane.

A turntable assembly holds the compensator block and mixing crystal. The compensator block serves to counteract the refractive displacement caused by tilt of the mixing crystal. The turntable may be rotated by 90° in order to attain the proper crystal tuning direction for the particular crystal in use and polarization directions of the incoming beams. The mounted crystal and compensator blockcan be changed readily when work in a different wavelength region requires it.

Beam sampling generates the signals used to control the servo motor. Less than 1% of the harmonic beam is directed toward the balance sensor by one surface of an uncoated beamsplitter. The reflection from the second surface is not used. A second beamsplitter directs scattered light into a photodiode to provide a synchronization pulse and to compensate for the beam deviation introduced by the first beamsplitter.

The beamsplitter assembly can be rotated by 90° in order to accommodate the situations when the generated light is polarized in either the horizontal or vertical direction.

For the situation in which the beamsplitter reflects a portion of the beam horizontally, the sampled beam undergoes elevation by one of five FR-# subassemblies on its way toward the right-angle turning optic.

Otherwise, a portion of the beam is reflected upward and then across to a right-angle turning optic. In line, FR-#-L, reflective filters may be used as filters in this configuration.

After making a right angle turn, the beam undergoes filtration and attenuation by FC-# and, if necessary, FD-# plug-in filters.

The FR-# and/or FC-# units filter the sampled beam so that only the appropriate wavelength impinges on the balance sensor. The FD-# units attenuate the sampled beam to a workable level. There is a set of FD-# filters for UV operation and a set of FD-IR-# for IR operation.

Power Supply, Signal Processing, and Microcontroller

All electronics are located in the lower portion of the optical assembly. The system power supply, microcontroller, and signal processing and motor drive circuitry are compactly packaged in this region. The IR version requires a separate power supply for the photodetector and also is housed in the lower section of the optical assembly.

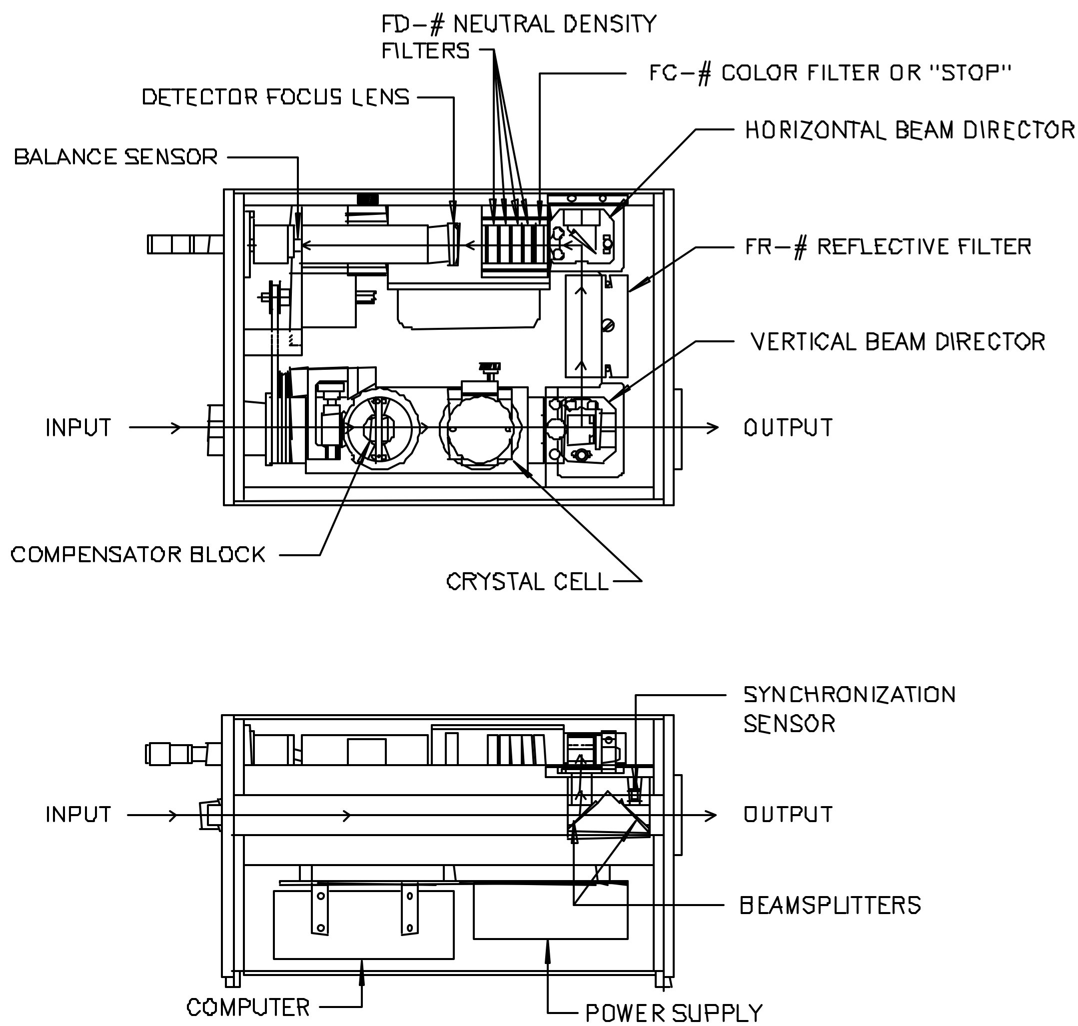
Controller Program Logic

The software program controls the flow of operations and angular positioning of the crystal. Crystal positioning depends on the signals received from sensors in the optical head and certain control variables entered by the user.

Keypad commands allow the user to position the crystal in a forward or reverse direction, adjust the rate for the motor positioning speed in the MANUAL mode, place the crystal control into an AUTO positioning mode, control the servo loop gain in the AUTO mode, and select the number of laser pluses to be averaged before making a tilt adjustment in AUTO mode. The number of pulses averaged before being displayed on the hand held controller also is selected by keypad commands.

Figure 3

Autotracker III Layout



Wavelength Coverage For Autotracker III

BBO Designation	Wavelength Coverage (±15°)	Process
TSS	636 nm - 1000 nm → 318 nm - 500 nm	SHG
	(906 nm - 2100 nm) + (453 nm - 1050 nm) → 302 nm - 700 nm	THG
TST	496 nm - 675 nm → 248 nm - 337 nm	SHG
	(710 nm - 960 nm) + (355 nm - 480 nm) → 237 nm - 320 nm	THG
0	418 nm - 464 nm → 209 nm - 232 nm	SHG
	(600 nm - 665 nm) + (300 nm - 331 nm) → 200 nm - 220 nm	THG
1	454 nm - 560 nm → 227 nm - 280 nm	SHG
	(651 nm - 800 nm) + (325 nm - 400 nm) → 217 nm - 266 nm	THG
2	542 nm - 820 nm → 271 nm - 410 nm	SHG
	(774 nm - 1165 nm) + (387 nm - 582 nm) → 258 nm - 388 nm	THG
A	410 nm - 433 nm → 205 nm - 216 nm	SHG
	(594 nm - 620 nm) + (297 nm - 310 nm) → 198 nm - 206 nm	THG
B	448 nm - 543 nm → 224 nm - 271 nm	SHG
	(642 nm - 775 nm) + (321 nm - 358 nm) → 214 nm - 258 nm	THG
C	423 nm - 480 nm → 211 nm - 240 nm	SHG
	(608 nm - 687 nm) + (304 nm - 343 nm) → 203 nm - 229 nm	THG
OPO1	549 nm - 844 nm → 275 nm - 422 nm	SHG
	(784 nm - 1200 nm) + (392 nm - 600 nm) → 262 nm - 400 nm	THG
OPO2	440 nm - 525 nm → 220 nm - 262 nm	SHG
	(632 nm - 750 nm) + (316 nm - 375 nm) → 211 nm - 250 nm	THG

(Note: All BBO crystals have a protective coating of MgF_2)

Wavelength Coverage For Autotracker III

KDP Designation	Wavelength Coverage (±12°)			Process
A	518 nm - 535 nm	→	259 nm - 267 nm	SHG
B	531 nm - 595 nm	→	266 nm - 297 nm	SHG
B1	524 nm - 571 nm	→	262 nm - 285 nm	SHG
R6G	559 nm - 673 nm	→	280 nm - 336 nm	SHG
C	585 nm - 754 nm	→	293 nm - 377 nm	SHG
D	648 nm - 940 nm	→	324 nm - 470 nm	SHG
M2	543 nm - 648 nm	→	2721 nm - 324 nm	SHG
	1064 nm + (294 nm - 383 nm)	→	231 nm - 281 nm	Mixing
M3	520 nm - 557 nm	→	260 nm - 278 nm	SHG
	1064 nm + (273 - 307 nm)	→	217 nm - 238 nm	Mixing

KD*P Designation	Wavelength Coverage (±12°)			Process
M1	1064 nm + (421 nm - 100 nm)	→	302 nm - 515 nm	Mixing - Type II

$LiNbO_3$	Wavelength Coverage (±12°)			Process
A	(561 nm - 607 nm) - 1064 nm	→	1188 nm - 1412 nm	IR Mixing
B	(597 nm - 603 nm) - 1064 nm	→	1362 nm - 1828 nm	IR Mixing
C	(657 nm - 841 nm) - 1064 nm	→	1716 nm - 4000 nm	IR Mixing

(Note: All BBO crystals have a protective coating of MgF_2)

Hand Held Controller

The Autotracker III is controlled by commands entered from the hand held controller, or optionally, by similar commands entered through the RS-232 port.

There are two display formats. The initial display shows the intensity level of PD1 and PD2, the two signals from the balance sensor, as bar graphs. The other display shows a time display of the SUM of PD1 and PD2 and the DIFFERENCE between PD1 and PD2.

Several control variables are displayed. The two motor positioning rates, MRATE and ARATE, both are displayed. The MRATE is associated with manually adjusting the crystal tilt; the ARATE is associated with the automatic servo rate. The photodetector GAIN, which is adjustable, is displayed. Averaging the displayed pulses is shown by the DSP number, and averaging the pulses for control of the angular positioning of the crystal is show by the CTL number. The angle position of the turntable is always displayed.

Polarizations for Several Mixing Schemes

To the right are shown crystal orientations for several mixing schemes (Figure 4). The crystal rotation axis, phasematching angle, θ, and the required polarization directions are shown. In the first two examples, the beamsplitter inside the AT-III would be oriented to reflect light toward the side.

Figure 4

Crystal Orientation and Polarizations

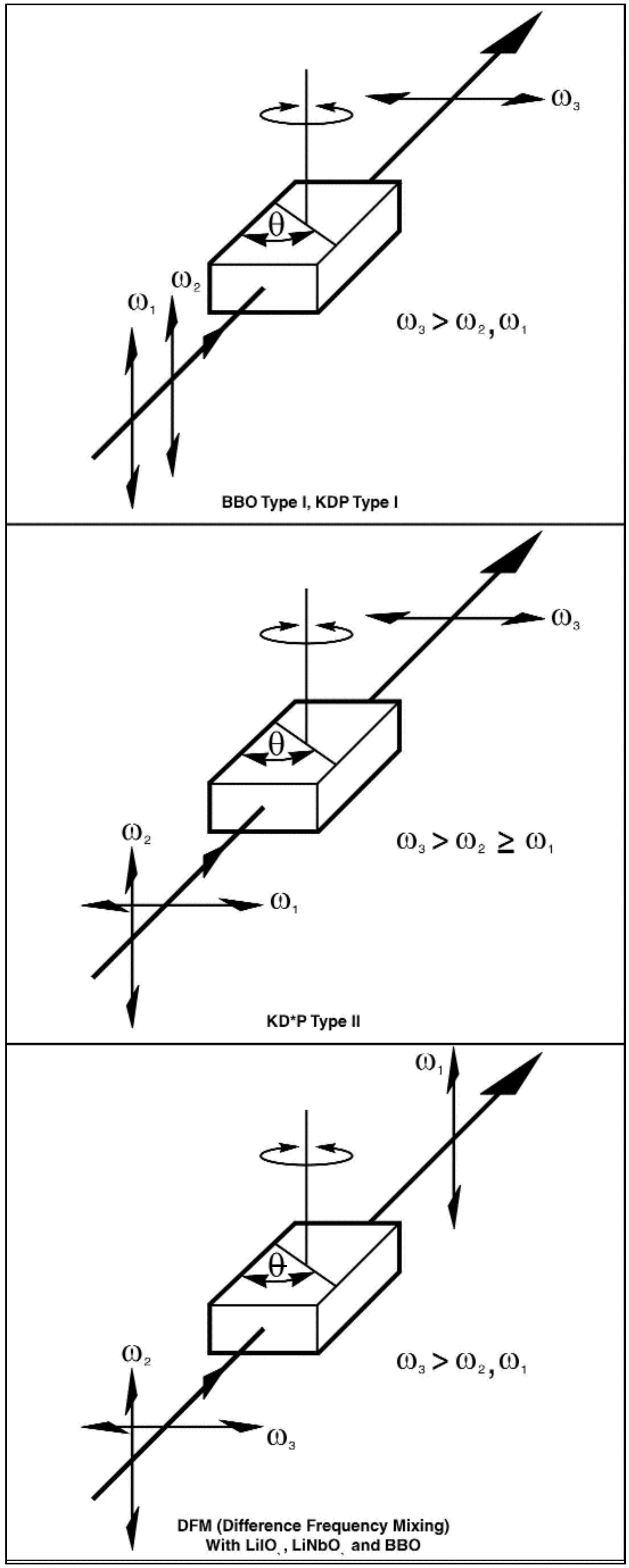
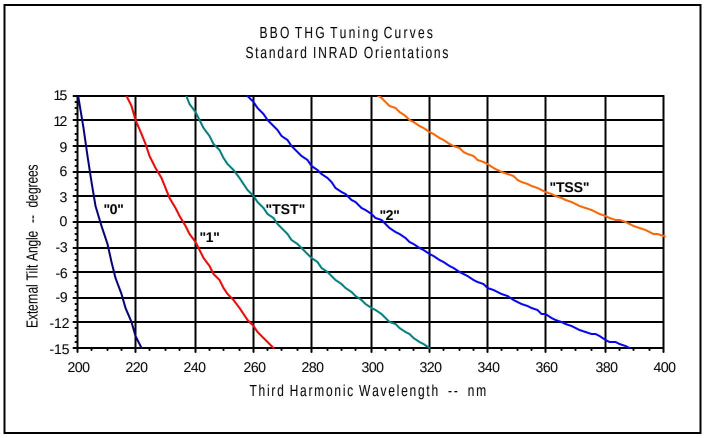
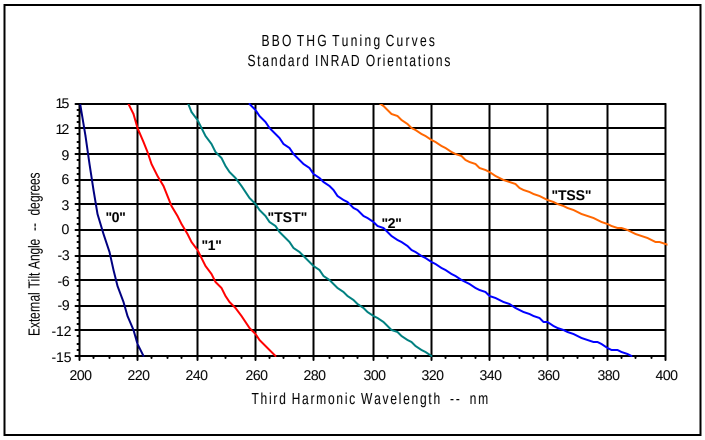
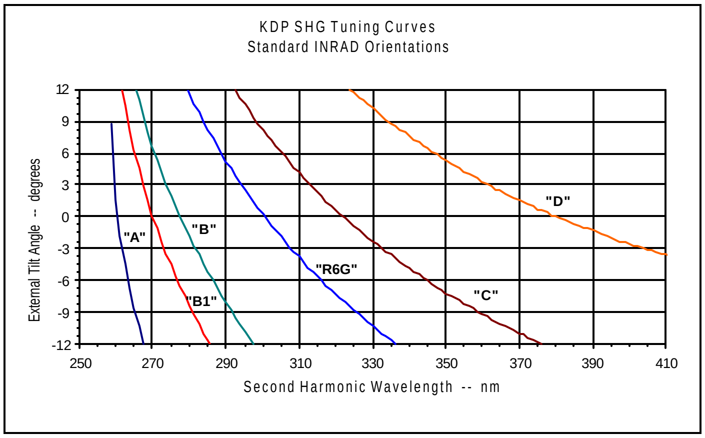


Figure 5

Tuning Curves







Ordering Information

AT-III Configuration

With the help of Table 1, specify the Autotracker III version type (UV, NIR or IR). Specify the polarization of the generated light; the beamsplitter will be oriented to accommodate this configuration at the factory. The beam-splitter orientation can be changed in the field to accommodate the other polarization direction also.

For mode locked lasers, a focusing lens can be place inside the optical head to increase the power density inside the crystal for better efficiency (specify option:/MLSHG).

Autotracker III Beam Height

The imput beam height to the Autotracker III Optical Assembly is a fixed 10.8 cm (4.25").

If you add Model AHL, Adjustable Height Legs, then the height is adjustable between 16.1 cm and 19.0 cm (6.31" - 7.50"). These three legs screw in and take the place of the standard rest buttons. Optional legs allow adjustment over a 17.3 - 20.3 cm range (AHL-2).

Alternatively, if you add a Model A-1001, Adjustable Height Platform, then the height is adjustable between 17.7 cm and 20.7 cm (6.95" - 8.15"). The platform measures 20.3 cm x 42.2 cm (8" x 16.63").

Other height can be accommodated on a custom basis.

Crystal Selection

Refer to the standard tuning curves and table for help in choosing the crystal or crystals for you application (SHG, THG, SFM, DFM,…).

For frequency doubling of visible light, either KDP or BBO can be used. The shorter wavelengths can be doubled only by BBO. KDP has an advantage at longer wavelengths because it is less expensive in large cross-section. For difference frequency mixing into the infrared, crystals can be selected from amongst either BBO, KTP, $LiNbO_3$, or $LiIO_3$.

In most instances, there is clearly a best crystal to use for a given application. Please consult INRAD for assistance.

Crystal Cell

BBO crystals are housed in 561-044 cells. KDP, KD*P, and $LiNbO_3$ are mounted in 563-1117 (11 mm x 17 mm clear aperture) cells, which can hold either 1 or 2 crystals.

Compensator Block

The frequency mixing crystal must be matched with a compensator block in order to avoid an overall refracting beam displacement as the crystal is angled (see Table 2).

BBO crystals can either be matched with a CB-4S compensator block for second harmonic generation applications or with a CB-4T block for third harmonic use. The BBO compensator blocks should be matched to the length of the crystal at the time an order is placed for the BBO crystal since a given application may require a unique crystal interaction length.

The coating of the CB-4S block is a broadband visible AR coating (450 nm - 750 nm) and the coating on the CB-4T block is a single layer of MgF_2. The CB-4T is used when many different wavelengths, outside the 450 nm - 750 nm range, are input to the crystal.

The BBO crystals in Autotracker III are coated with a protective layer of MgF_2 so that they can be used without windows. The lengths of the compensator blocks have been calculated, based on a BBO crystal without windows.

A CB-1 compensator block is used with KDP, KD*P, or $LiNbO_3$ crystals for second harmonic, sum frequency mixing of visible light with 1064 nm, and difference frequency mixing to produce infrared light. The cells that hold these crystals generally are designed to be used with windows.

The CB-3 compensator block is used with the KDP "M2" and KDP "M3" crystals when they are used for sum frequency mixing of 1064 nm light with near ultraviolet light (doubled dye). This block is the same length as the CB-1 block, but the AR coatings on it favor ultraviolet transmission.

Reflective and Colored Filter Combinations

Reflective and colored filters are used to selectively transmit the generated light to the dector in the Autotracker III. The filters attenuate the input wavelengths of light so that a tracking signal can be extracted from the photodector signal.

The filters are chosen based on the output wavelengths being generated (see Table 3).

Reflective filters can be either the standard elevation type (FR-#) or an in-line type (FR-#-L). The elevation type will be used if the Autotracker III beamsplitter first deflects the sampled beam in the horizontal plane; the in-line type will be used if the beamsplitter deflects the sampled beam upward. By studying the diagrams in Figure 4, one can determine the polarization direction of the generated light. Although the user can change the orientation of the beamsplitter, the order should state the initial orientation so that the system can be aligned this way at the factory.

Special reflective filters were developed for SHG and THG of the 700- 900 nm Ti:Sapphire wavelengths. These filters have uniform transmission at these wavelengths and good rejection of unwanted light and are designated TSSHG and TSTHG.

As can be seen from Table 3, the filter selection for DFM applications is considerably simpler.

Table 2
Compensator Block Matching

Crystal	Compensation Block	Application
BBO	CB-4S	Second Harmonic Generation
	CB-4T	Third Harmonic Generation Sum Frequency Mixing
KDP, KD*P, $LiNbO_3$	CB-1	Second Harmonic Generation Near UV Sum Frequency Generation Difference Frequency Mixing
KDP “M2” and “M3”	CB-3	Deep UV Frequency Generation

Table 3
Autotracker III Filter Selection

	Output	Reflective Filter	Reflective Filter (In Line)	Color Filter
UV	198 nm - 220 nm	FR-4	FR-4L	NONE
	217 nm - 235 nm	FR-2	FR-2L	NONE
	235 nm - 270 nm	FR-1	FR-1L	NONE
	270 nm - 310 nm	FR-ϕ	NONE	FC-1
	310 nm - 340 nm	FR-ϕ	NONE	FC-2
	340 nm - 350 nm	FR-ϕ	NONE	FC-2 (2 each)
	350 nm - 410 nm	FR-ϕ	NONE	FC-3 + FC-5
	410 nm - 470 nm	FR-ϕ	NONE	FC-3 + FC-7
	233 nm - 300 nm	FR-TSTHG	FR-TSTHG	NONE
	350 nm - 470 nm	FR-TSSHG	FR-TSSHG	NONE
	265 nm - 325 nm	FR-5	FR-5L	NONE
IR	1200 nm - 4200 nm	FR-ϕ or none		FC-6 (2 each)

An FR-ϕ is supplied with each unit as part of the optical assembly, and therefore does not have to be ordered separately. Similarly, the appropriate set of neutral density filters is supplied with each unit as part of the optical assembly. There is a UV neutral density filter set and an IR neutral density filter set.

Autotracker Accessories

- ***UV Harmonic Separator***

For UV applications, the four prism filter, M/N 752-104, selects the shortest wavelength generated in a wavelength summing process. This harmonic separation is maintained even if one or both of the combining beams is varied in wavelength. Attractive features of the filter are high transmission efficiency, high power handling capability, a spatially stationary transmitted beam, and the compactness of the package.

- ***IR Harmonic Separator***

For IR applications, the M/N 752-105 IR Harmonic Separator offers a convenient method for extracting the longest wavelength in a difference-frequency mixing process.

- ***Polarization Rotator***

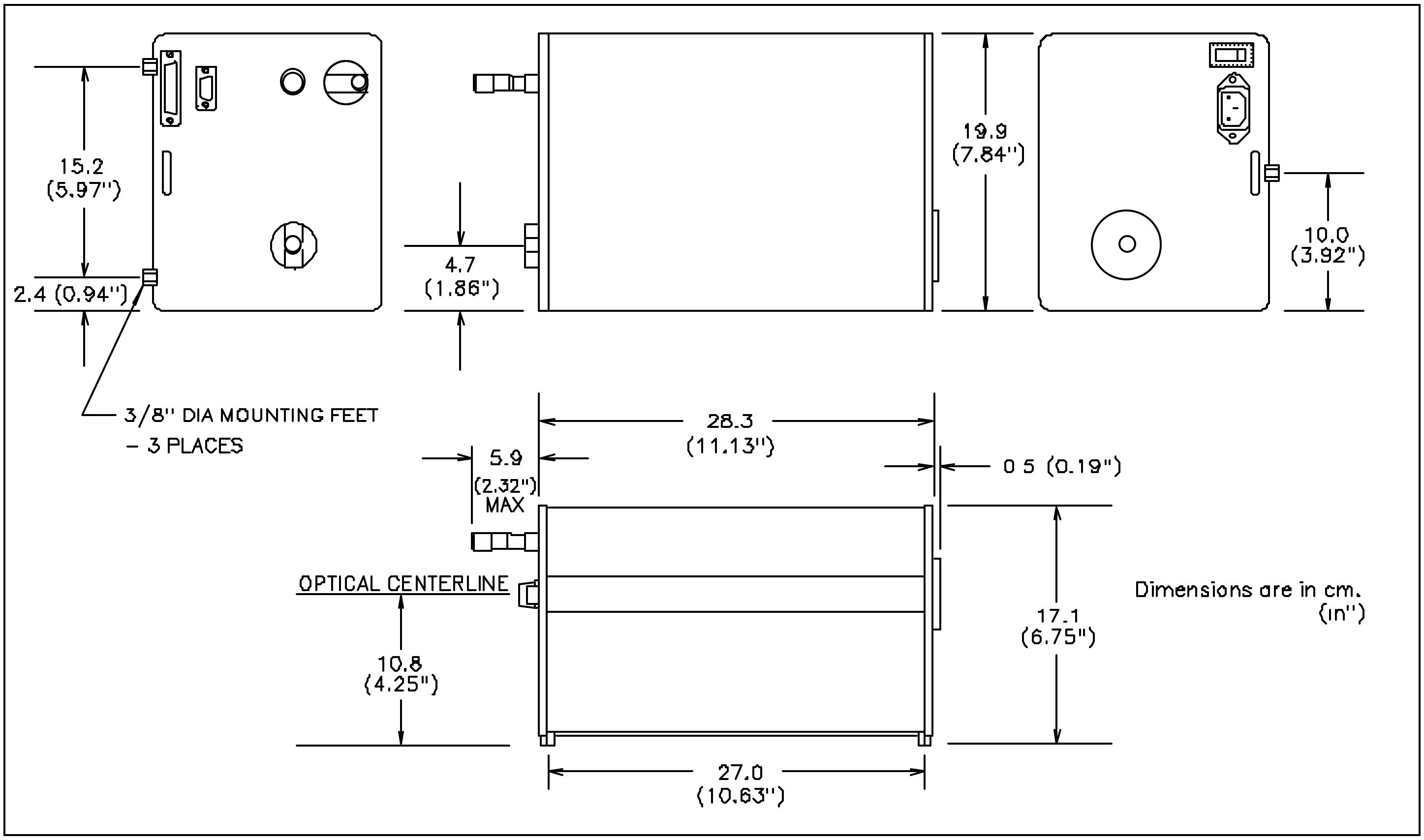
A polarization rotator is used to align the polarization directions of the two wavelengths exiting from an SHG crystal before being combined in a third harmonic generation crystal. For most practical applications a simple quartz rotator is sufficient. It rotates the polarization direction of the second harmonic by 90°, while causing only a slight rotation of the polarization of the fundamental wavelength.

- ***Beam combiners and Mounts***

INRAD can provide a number of dielectrically coated optics and stable mirror mounts for numerous frequency mixing configurations.

Figure 6

Autotracker III Outline Drawing



Specifications

Laser Requirements

Repetition Rate	>5 Hz
Beam Diameter	<10 mm
Peak Power	>5 kW

Performance

Conversion Efficiency	>90% of optimally tuned static crystal
Scanning Rate	0.1 nm/sec max
Beam Dither	<0.1 mrad
Wavelength Range	198 nm through 4000 nm
Output Stability (constant input)	±1%
Turntable Tilt Range	±12.5%
BBO Tilt Range	up to ±22.5%

Dimensional Data (See Figure 5)

Optical Assembly	17. 1 cm x 19.9 cm x 28.3 cm (6.75" x 7.84" x 11.3")
Hand Held Controller	19.1 cm x 10.2 cm x 5.1 cm (7.5" x 4.0" x 2.0")
Optical Centerline	10.9 cm (4.25") above horizontal base plate
with standard support legs	16.1 cm - 19.0 cm (6.31" - 7.50")
with optional support legs	17.3 cm - 20.3 cm (6.81" - 8.00")
with platform mounting	17.7 cm - 20.7 cm (6.95" - 8.15")
Utility Requirements	0.5 amps

Note: All units will operate with the common voltages of 110V/60Hz, 100V/50Hz, or 220V/50Hz without modification.