Tunable CW Frequency Doubler

User Manual

Version 3.2

Spectra-Physics

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0 HOW TO READ THIS MANUAL

The manual is divided into 6 chapters.

The first chapter contains important information which should be read before opening the package containing the WAVETRAIN\textsuperscript{SC}.

The second chapter describes the physical principles of the system. This information gives you a better understanding of the system but is not necessary for operation by all means.

In the third chapter you will find a description of all components. You should read this chapter to understand the alignment instructions in the next chapter.

Chapter four describes all the alignment procedures needed for initial setup and also for daily operation.

Chapter five deals with the main procedures used for daily operation, maintenance and troubleshooting.

Chapter six summarizes the technical data.
1 INSTALLATION

1.1 Unpacking

Check all packages for external damage after receipt of the delivery. In case of a damage please inform the distributor by letter. In case of a serious damage just keep the parcels unchanged and do not try to open them. Only in case of a slight damage you may open the parcels and look for damages of the content. Please ascertain the entirety of the shipment. Please inform the distributor immediately about any damage or incompleteness.

The delivered unit basically consists of (may vary because of different optical equipment):

- \textsc{wavetrain}^{\textsc{sc}} base plate with 3 adjustable feet
- electronic control unit
- connection cable with 25 pin connectors at both ends
- mains cable
- this manual

1.2 Warranty

LAS GmbH guarantees that all equipment is free of damage in material and quality. Titles have to be made by letter describing the damages and their effects. LAS GmbH or their representatives will then get into contact with the client and repair or remedy the defect free of charge. Titles due to inexpert treatment or accidents are not covered by warranty.

The warranty is limited to 90 days for optical components. No long-term degradation of the crystal and no damages caused by improper handling are covered by warranty.

LAS GmbH refuses any liability in case of modifications or extensions of the equipment which affect their normal function. All repairs, adjustments or changes effected by persons who were not explicitly authorized by LAS, dispense LAS GmbH from their obligations. This includes all cases where the equipment has not been installed and operated according to the instructions in this manual and/or the instructions given during the installation.

1.3 Safety Rules
PLEASE READ THE FOLLOWING SAFETY RULES CAREFULLY AND USE YOUR LASER ACCORDINGLY.

The WAVETRAIN® frequency doubling unit is used in connection with an intensive pump laser. The direct beam as well as stray light or partially reflected light may cause lasting damages in eyes and skin. This applies to the generated harmonic wave as well as to the pump laser.

The following safety rules should not be understood being complete but they only describe the minimum of precautionary measures. LAS GmbH is not liable to physical or material damages caused by laser beam.

RULE 1:
CONDUCT ALL LIGHT GENERATED BY LASERS IN DETERMINED AND MARKED FIELDS.

During normal laboratory activity laser beams very often pass through the room just on eyes’ level of sitting persons. Forestall the dangers resulting from this by stationary installed beam dumps around the danger area which stop each beam arising there. Special caution is requested when using invisible radiation. Verify the way of each reflection with an appropriate detector and make sure that it does not leave the danger area.

Never work sitting on a chair the eyes right on the level of the laser beams or the stray light. It is recommended to install all shields redundantly because experience shows that many people negligently do not wear safety glasses. Fix a door-plate at the entrance "CAUTION - LASER RADIATION!" and indicate the wavelength being used.

RULE 2:
EACH PERSON WORKING WITH THE LASER AS WELL AS OTHER PERSONS IN THE ROOM HAVE TO WEAR LASER BEAM SAFETY GLASSES.

Note that the safety glasses have to protect against all beams generated by the whole laser system. This includes beams of the pump laser as well as light generated by the frequency doubling unit. Suitable glasses which cover a complete protection against all wavelengths can be found. You should own a personal pair of glasses and have always spares for guests.

A special problem may occur if you deal with visible laser beams and you have to wear strongly attenuating glasses; you could be induced to take off the glasses to avoid working blindly. You will have the same situation if you work with invisible laser radiation. In this case you should use a converter card instead of taking off the glasses.

Generally, you should work with a bright background lighting. It is recommendable to have a light switch nearby the experiment.
**RULE 3:**
DO NOT LOOK INTO THE BEAM EXIT APERTURE OF THE LASER IN ANY CASE. DO NOT TRY TO FOLLOW THE BEAM PATH THROUGH ANY OPTICAL INSTRUMENT WITH YOUR EYES.

**RULE 4:**
MAKE SURE THAT YOU HAVE SAFETY EQUIPMENT AVAILABLE LIKE BEAM DUMPS, WARNING LAMPS, ATTENUATORS, SAFETY GLASSES, ETC. ON DELIVERY OF THE LASER.

The expenses are very low compared to the cost of a laser system. We recommend to buy these things before the installation of the laser because it will not be done afterwards!

**RULE 5:**

The best procedure is to make a sketch of the new or modified set-up before the installation and to verify where the laser light and reflections will occur.

Please note:
1. Plano-convex lenses with a focal length f have a focused reflection at
   - $f/2$ if their convex side is situated on the laser side (The plane side acts like a plane mirror behind a lens and generates autocollimation).
   - $f/4$ if their convex side is situated in beam direction (The convex side acts like a focal mirror).

2. Biconvex lenses with a focal length f generate a focused reflection at $f/3$.

As to prevent destruction of optical equipment or even of the laser itself always place the optical components in a slope way or outside the optical axis in the beam path. Make sure to follow rule 1 if you change the beam path.

**RULE 6:**
KEEP THE PUMP LASER ON MINIMAL OUTPUT ENERGY (LOWER mW-RANGE) BEFORE AND WHILE ALIGNING THE FREQUENCY DOUBLING UNIT.

Do not use full power before the fundamental wave beam is not aligned on its prescribed path in the frequency doubling unit and a beam dump keeps the beam exits of the frequency doubling unit in the danger area (see rule 1).
Reduce the fundamental wave beam by lowering the power or by using attenuators. Attenuators should only be mounted in the beam path in a slope way to make sure that the back reflection falls down on the laser housing or a beam dump instead of falling back into the laser. As to avoid the attenuator to fall over fix it on stable feet. DO NOT MAKE ANY IMPROVISATION!

1.4 Location of Laser Safety Labels
1.5 Requirements to the Pump Laser

The laser generating the fundamental wave has to meet certain requirements for successful frequency doubling (in the order of their importance):

- It has to be continuous wave (cw) laser radiation.
- Single-mode operation is necessary for the correct function of the stabilization of the cavity length.
- The intensity distribution in the beam profile must be describable by a near diffraction limited Gaussian beam. The profile should be circular in shape.
- Line width and remaining frequency jitter have to be smaller than the response frequency width of the doubling resonator (about 5 MHz).
- Intensity noise should be low. The harmonic intensity noise will be about twice of the fundamental noise.
- Large scale frequency tuning should be performed slower than 10GHz per second.
Chapter 2: BASICS OF FREQUENCY DOUBLING

You will find a short introduction into the general theory of resonant harmonic generation and the peculiarities used in the WAVETRAIN® resonator.

2.1 Frequency Doubling

A strong light wave traversing a solid, transparent material can affect the electron distribution in the material. This results in a non-linear relationship between the strength of the electric field of the injected light wave (fundamental wave) and the polarization of the material causing the generation of a light wave with doubled frequency (Second Harmonic Generation, SHG). In order to get a high portion of the second harmonic wave materials with exceptionally high non-linearity, the so called nonlinear optical crystals, are preferably used for frequency doubling.

For a given material the conversion efficiency, i.e. the ratio of the harmonic power to the injected fundamental power, reaches its maximum value if the phase matching condition is fulfilled. This means that the phase velocity of the harmonic wave equals the phase velocity of the fundamental wave in the material.

There are two methods allowing to achieve phase matching conditions: The non-critical phase matching utilizes the temperature dependence of the crystal’s refractive indices to achieve phase matching by adjusting the crystal temperature according to the fundamental wavelength. The wavelength range which can be doubled by this method is generally quite small on the other hand the conversion efficiency reaches the highest possible values. The angle phase matching utilizes the angle dependence of the refractive indices. This method offers much larger wavelength ranges for the crystals available on the market, especially in the deep UV range. In the WAVETRAIN® generally angle phase matching is used.

An unpleasant property of the angle phase matching is the elliptical beam profile of the harmonic wave. In the WAVETRAIN® the elliptical beam shape is imaged into a circular beam by a mode shaping lens.

In a first approximation the power of the generated harmonic wave $P_2$ is proportional to the square of the fundamental wave power $P_1$:

$$P_2 = c P_1^2$$
Chapter 2: BASICS OF FREQUENCY DOUBLING

c is called the conversion coefficient. It depends on the refractive index, the wavelength of the fundamental wave, the angle of the phase matching, the crystal length, the crystal waist, the birefringence angle and the non-linear coefficient which is a characteristic crystal constant. Boyd and Kleinman (G. D. Boyd, D. A. Kleinman, J. Appl. Phys. 39 (8) (1968)) have calculated this dependence for a Gaussian beam profile. The value of c covers the range between $10^{-5}$ W$^{-1}$ and $10^{-3}$ W$^{-1}$.

### 2.2 The Passive Resonator

The technology for second harmonic generation of continuous wave (cw) lasers is substantially different from arrangements used for pulsed laser systems. This is due to the square dependence of the fundamental input power. For pulsed systems powers in the kW or MW range provide sufficiently high conversion efficiencies in simple direct conversion arrangements whereas the typical available power of 1W in the cw field represents a challenge. The right way here is the amplification of the light wave in a resonator. The purpose of this resonator is to store the energy of many light round-trips and to obtain an increase of the injected light power by constructive superposition within the resonator. If the nonlinear crystal is arranged inside such a resonator the conversion efficiency is increased compared to a direct conversion arrangement (M. Brieger, A. Hese, A. Renn, Opt. Comm. 38, 423 (1981)). It is state-of-the-art technology to use a ring resonator which avoids problems with back reflections into the laser resonator and with the cumbersome recombination of two counterpropagating second harmonic waves.

The characteristic quantity for the quality of a resonator is the relationship between the power circulating in the resonator $I_R$ and the injected power $I_0$ the so-called enhancement $A$:

$$A = \frac{I_R}{I_0}$$

Under certain conditions (laser band width < width of the transmission peaks of the resonator) the enhancement can be expressed by the reflectivity of the input mirror $R_1$ and the losses per round-trip $V$ ($V$ does not include transmission losses through the input mirror):

$$A = \frac{1-R_1}{(1-\sqrt{R_1(1-V)})^2}$$

The enhancement reaches its maximum of:
Chapter 2: BASICS OF FREQUENCY DOUBLING

\[ A = \frac{1}{V} \]

when the *impedance matching* condition

\[ V = 1 - R_1 \]

is fulfilled, that is to say, the transmission of the input mirror has to match the losses \( V \).

Any light wave in free space is subject to diverge while propagating with a certain (half) angle \( \theta \) defined by the relation

\[ \theta = \frac{\lambda}{\pi w_0} \]

where \( \lambda \) is the wavelength and \( w_0 \) the smallest beam radius, called the *beamwaist*. By using spherically curved resonator mirrors the beam is periodically refocused in the resonator, thereby keeping the beam size small even after many round-trips and avoiding large diffraction losses at the finite mirror apertures. The mirror curvatures and distances have to obey certain relations to form an optically stable resonator, i.e. a resonator capable to reproduce a beam shape after each round-trip.

To ensure that all of the light injected into the resonator is reproduced after each round-trip the incoming beam has to match the beam properties of the stable resonator, a condition which is called *mode matching*. Therefore a carefully designed optics has to be placed between the laser and the passive resonator in order to get the maximum possible enhancement of the original beam.

Several elements in the resonator, like the curved mirrors and the nonlinear crystal, cause astigmatism which means that the beam size and divergence angle are different for the two transversal directions (meridional and sagittal plane). In spite of that, the injected laser beam usually has a circular shape. For a perfect mode matching a compensation of the astigmatism is necessary. This is done by a careful calculation of the mirror radii, distances and incidence angles, considering all astigmatic elements in the resonator. Also the optimum size of the beamwaist inside the nonlinear crystal has to be taken into account.

An often used resonator design is the so called double-Z shaped resonator,
consisting of four mirrors M1 through M4 and the nonlinear crystal X:

![Double-Z resonator diagram](image1)

**Figure 1: Double-Z resonator**

To get a constructive multiple beam interference inside the resonator and hence to get a considerable enhancement of the beam the total length of the beam path in the resonator has to be a multiple of the wavelength. This resonance condition must be kept very precisely at every moment. Due to the always present vibrations by acoustic noise it is necessary to actively stabilize the resonator length. Usually this is done by mounting one of the resonator mirrors, e.g. M3, to a piezo element PZT which is driven by a servo loop.

### 2.3 The DeltaConcept

The patented DELTACONCEPT design used in the WAVETRAIN\textsuperscript{SC} surpasses the classical double-Z resonator in many aspects. As shown in the figure 2 below, only two mirrors M1 and M2 are used for this resonator:

![DeltaConcept resonator diagram](image2)

**Figure 2: Deltaconcept resonator**

A ring cavity is formed by deflecting the beam path using the prism P. The resonator is tuned by translating the prism along its symmetry axis via the piezoelectric transducer PZT. Both the prism P and the nonlinear crystal X are cut for Brewster’s angle to minimize reflection losses.
As explained above, the resonator losses $V$ are the main limiting factor for the power enhancement and hence for the SHG conversion efficiency. The main task in constructing a resonant doubler with highest efficiency is therefore to reduce the losses. The losses produced by brewster surfaces are far below the transmission losses of dielectric mirrors therefore the substitution of the two dielectric mirrors M3 and M4 by a brewster-angled element results in a substantial reduction of the losses in the resonator. Moreover, the DELTACONCEPT design reduces the dimensions of the resonator resulting in a considerable increase of the spectral width of the resonator modes. This reduced the linewidth requirements for the laser source to be doubled.

In the DELTACONCEPT design optics exchange needed for large wavelength changes is confined to mirrors M1, M2 and the crystal X making an exchange more easily. Particularly no exchange of the piezo driven element is necessary allowing a rigid mounting of the prism to the piezo with optimum dynamic behavior.

The symmetric beam path in the prism and the translation along the symmetry axis gives the resonator most favorable tuning properties because the beam path remains completely unaffected by the prism translation and is also insensitive to unwanted tilt motion of the piezo.

### 2.4 Active Resonator Stabilization


The WAVETRAINSC is equipped with the Pound-Drever stabilization method which is most suitable if laser radiation in a wide spectral range is to be doubled. A sketch of the Pound-Drever method is shown below:
Before entering the cavity the incoming beam first passes an electro-optic phase modulator PM which is electrically driven at a radio frequency source OSC. The effect of this modulation is to add sidebands in the distance of the modulation frequency to the spectrum of the laser line. The beam reflected by M1 and the transmitted beam from wave inside the cavity interfere with each other. The superposition of both waves carries an rf modulation signal which is monitored by a photo diode PD. Phase sensitive detection of the photo diode signal is performed by a double balanced mixer which outputs the error signal $U_{\text{err}}$.

The sidebands generated by the phase modulator PM are not transmitted into the cavity because the cavity acts like a high finesse interferometric filter whose line width is substantially smaller than the frequency shift of the sidebands. As a consequence, the harmonic beam generated by the crystal inside the cavity is also free of sidebands.

The main advantage of this method is the absence of wavelength dependent optical parts like $\lambda/4$ and $\lambda/2$ plates which would have to be realigned or even exchanged after large wavelength changes.

### 2.5 Auto Reset and Auto Rekick

Due to the active stabilization, the resonator will automatically follow any frequency change of the injected laser beam. In many applications the laser has to be scanned continuously over a certain frequency range. During a scan the resonator length is tracked according the frequency variation by servo loop. If the frequency variation exceeds the maximum travel range of the piezo the servo loop gets out of lock causing a breakdown of the harmonic output power. The auto reset function avoids this breakdown by resetting the piezo voltage to a medium value from where the servo loop starts to search for a new lock point and then continues to track the resonator. Therefore the harmonic output power is off only for some milliseconds.

When the stabilization servo loop has been started, either by the operator, or automatically after an auto reset event the piezo position is generally at a random distance to the next lock point. If this position is accidentally close to the center between two adjacent lock points the correction signal is zero and the servo loop remains at this quasistable point with zero harmonic output. This unwanted situation is avoided by the auto rekick function which prevents the servo loop from locking to such a quasi stable point.
3 COMPONENT’S DESCRIPTION

This chapter contains the functional description of all optical and electronic elements.

3.1 Optical Components and Beam Path description

Figure 4 shows the beam path and all the optical components of the WAVETRAIN®:

- The fundamental input beam first passes an optional polarization rotator PR. This device is needed if the input beam has not a horizontal polarization as required for the enhancement cavity.
- Then the input beam traverses the phase modulator PM which performs a phase modulation of the light wave. The modulator comprises the electro-optic crystals (2 KDP crystals), a fast photo diode for the detection of the modulation signal as well as the electronics for the phase sensitive detection (double balanced mixer).
- The lenses L1 and L2 are responsible for the correct mode matching of the input beam with respect to the resonator. Lens L2 is mounted on a rotation stage to allow a nonzero incidence angle into the lens for astigmatic compensation. The factory setting of the incidence angle is 10 degrees.
- Bending mirrors BM1 and BM2 are used for rough alignment of the input beam into the cavity.
Chapter 3: COMPONENT'S DESCRIPTION

- The Beam Shifter BS allows very fine adjustments of the input beam by rotation of an AR-coated plane parallel plate.
- The beam then enters the resonator block RB through a brewster window BW which is needed for a complete sealing of the resonator block.
- The beam reflected by the resonator input mirror M1 is partly coupled into an optical fiber OF by the fiber coupler FC. The fiber carries the light to the detector inside the phase modulator PM.
- After the input mirror M1, the beam traverses the nonlinear crystal X inside the resonator. In order to minimize reflection losses of the fundamental beam at the crystal surfaces the crystal is oriented at Brewster’s angle for horizontal polarization. In the fundamental wavelength range 410nm to 600nm BBO crystals are used, in the range above LBO crystals are used. Phase matching of the crystal is done by tilting the crystal around a horizontal axis perpendicular to the beam path inside the crystal.
- The second resonator mirror M2 reflects the fundamental beam and transmits the harmonic beam generated in the crystal.
- The prism P deflects the fundamental beam thereby closing the beam path in the ring cavity. On the other hand, the cavity length is tuned by translating the prism via the piezoelectric transducer PZT the prism is mounted to.
- The harmonic beam exits the resonator block via the 2nd brewster window BW which is oriented to transmit the vertical polarized harmonic wavelength with minimum losses.
- The beam shaping cylindrical lens BT transforms the elliptical harmonic mode into a circular beam.
- The harmonic beam is deflected by the bending mirrors BM3 and BM4 into the output direction. Due to the dichroitic coatings, reflecting the harmonic wavelength and transmitting the fundamental wavelength, the mirrors act as a filter which suppresses the fundamental portion in the output beam.
- The fundamental detector FD is located behind the bending mirror BM3. It measures the cavity leakage field intensity which is proportional to the fundamental field intensity inside the cavity. The signal of this detector can be used as criterion for the goodness of the cavity alignment.
- The harmonic detector HD is located behind the bending mirror BM4. The signal of this detector is proportional to the harmonic output power. It can be used as criterion for the goodness of the crystal alignment.
3.2 Control Unit: Components and Functional Description

The WAVETRAIN®SC is connected to the control unit by a single cable with 25-pin connectors on both sides. The corresponding connector of the control unit is located on the back side. Also the line socket and the mains switch is on the back side. The front side of the control unit is composed of several modules as shown in the figure below:

- The leftmost module is the HV Amplifier driving the piezo element of the WAVETRAIN®SC resonator. The actual piezo voltage is displayed roughly on a LED bar display ranging from 0V to 150V. The downscaled piezo voltage can be accessed at the BNC-connector labeled “HV Monitor” which outputs a voltage proportional to the high voltage output in the range 0V to 10V. The BNC-connector labeled “Reserve In” is an additional input of the high voltage amplifier where customer signals for various purposes in the range –10V to +10V can be applied to. The “Zero Level” trim pot allows the setting of the start value for the piezo voltage when the servo loop is turned on.
- The 2nd module is the power supply of the whole device. It has no control or display elements.
- The 3rd module is the PID Controller which supplies the input voltage for the HV amplifier. Depending on the position of the “Mode Switch”, located above the two BNC connectors, the HV amplifier is either driven by a ramp voltage (position “scan”, used for alignment) or by the stabilization signal (position “stabilize”, normal operation). At the BNC connector “PID Out” the stabilization signal can be accessed for control purposes. The “Scope Trigger” output can be used to trigger an oscilloscope which is needed.
during the alignment procedure. With the precision potentiometer knob the total gain of the stabilization loop can be adjusted. Varying input powers can be compensated by this adjustment. With the switches and trim pots labeled “D”, “I” and “P” the frequency response of the stabilization loop can be influenced. They are adjusted for optimum stabilization performance in the factory.

- In the **PM Controller** module the error signal from the phase modulator electronics as well as the photodiode signals from the fundamental detector FD and the harmonic detector HD are amplified to an appropriate level. Due to the wide range of possible input powers from some Milliwatts up to several Watts the corresponding gain switches have to be set to a suitable position in the range 0 to 7. The switch position 7 corresponds to the highest gain. The amplified error signal can be accessed at the “**Error Monitor**” BNC output. With the “**Balance**” knob any DC offset on the error signal can be compensated. Depending on the “Detector Source” switch position “**Fundamental**” or “**Harmonic**” the intensity level of either the fundamental detector FD or the harmonic detector HD is displayed on a LED bar display and is supplied at the “**Intensity Monitor**” connector to be displayed on an oscilloscope.

- The crystal temperature controller is located behind the rightmost panel. There are no display and no control elements on this panel.

Figure 6 shows the function of the control unit as a circuit block diagram:
Chapter 4: ALIGNMENT INSTRUCTIONS

4 ALIGNMENT INSTRUCTIONS

In this chapter all the alignment procedures needed to get the full performance of the WAVETRAIN\textsuperscript{SC} are described. During the first installation or after significant changes of the relative positions of the laser and the doubler all the procedures have to be performed. When mirrors or the crystal is replaced in order to change the wavelength range the mode matching and the initial setup procedure can be omitted.

Before starting the alignment, you should familiarize yourself with the different components of the doubling unit by reading chapter 3.

In order to achieve the maximum possible output powers a power meter for the harmonic output as well as for the fundamental input beam should be available. For doubling of near infrared wavelengths the use of an infrared viewer during the alignment is recommended. For the fine adjustment of the WAVETRAIN\textsuperscript{SC} resonator a standard 2-channel-oscilloscope with a set of three BNC cables is needed. For some alignment steps a white piece of paper or a business card should be at hand.

Both the fundamental laser source and the WAVETRAIN\textsuperscript{SC} have to be mounted on the same stable optical table which is vibrationally isolated against any sources of acoustic noise.

4.1 Mode Matching

As has been explained in chapter 2, the fundamental input beam has to be coupled into the WAVETRAIN\textsuperscript{SC} under mode matching conditions to ensure that all the input power is coupled into a single mode of the doubler cavity. For this, the distance between the laser source and the WAVETRAIN\textsuperscript{SC} as well as the positions of the mode matching lenses $L_1$ and $L_2$ have to obey certain conditions depending on the beam parameters of the laser source. The relevant distances $l_w$, $l_1$ and $l_2$ are indicated in Figure 7.

For the factory setting of the lens positions the laser source ($\lambda=800\text{nm}$) is expected to have a waist radius of $300\mu\text{m}$ at about $l_w=70\text{mm}$ in front of the WAVETRAIN\textsuperscript{SC} entrance resulting from lens distances $l_1=337\text{mm}$ and $l_2=75\text{mm}$.

For other beam parameters of the laser source the relevant lens distances $l_1$ and $l_2$ may be determined from the diagrams in figure 10 and 11 which refer to fundamental wavelengths 800nm and 500nm, respectively. The waist distance of the laser source to the WAVETRAIN\textsuperscript{SC} entrance (measured from the edge of the base plate) corresponds to the horizontal axis in the diagrams. The positions $l_1$ of lens 1 are drawn as solid curves and are read from the left hand vertical axis. The positions $l_2$ of lens 2 are drawn as dotted curves and are read from the right hand vertical axis. Each curve is labeled with the waist radius (not the waist diameter!) of the laser source.
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For example, if your fundamental laser with a wavelength of 800nm has waist of 400µm at 500mm in front of the Wavetrain SC, you select in figure 10 the solid curve labeled “400µ” and read \( l_1 = 392\)mm from the left hand vertical axis for the lens 1 distance to the Wavetrain SC entrance. For the distance of lens 2 to the resonator block you select the dotted curve also labeled “400µ” and read \( l_2 = 94\)mm from the right hand vertical axis. To set the lenses to the distances you have to loosen the holding forks of the lenses using a 5mm allen screw driver and to move the lenses to their corresponding positions. The distances \( l_1 \) and \( l_2 \) are measured with respect to the center plane of the lenses. Don’t forget to fasten the holding forks again.

For other wavelengths than 800nm or 500nm you can calculate the lens positions by interpolating the values determined for 800nm and 500nm. If the waist size is somewhere between the values shown in figures 10 and 11 the lens positions are also to be calculated by interpolation.

![Diagram](image)

**Figure 7: Relevant Distances for Mode Matching**

If the laser source to be doubled has a waist size far outside the range 200µm to 500µm, displayed in the diagrams, an external lens has to be used to image the laser waist to an appropriate size and distance. The correct distances \( d_{1,2} \) between the waists and the lenses as indicated in figure 8 can be calculated by the following formulas:

\[
d_1 = f \pm \frac{w_1}{w_2} \sqrt{f^2 - \left(\frac{\pi}{\lambda} w_1 w_2\right)^2}
\]

\[
d_2 = f \pm \frac{w_2}{w_1} \sqrt{f^2 - \left(\frac{\pi}{\lambda} w_1 w_2\right)^2}
\]
Here \( w_{1,2} \) are the sizes of the source and the image waist, respectively, \( f \) is the focal length of the lens and \( \lambda \) the fundamental wavelength. In general, there will be two solutions for the distances \( d_1 \) and \( d_2 \) using either the “+” sign or the “-” sign for both values \( d_1 \) and \( d_2 \). It is mainly a question of table space and availability of lenses which solution is to be preferred.

**Figure 8: Waist Imaging by an External Lens**

If a lens with suitable focal length is not available or if the distances \( d_1 \) and \( d_2 \) are too large for the optical table dimensions the laser waist \( w_1 \) may also be imaged to the WAVETRAIN SC’s intermediate waist. This may be accomplished by removing the lens \( L_1 \) from the WAVETRAIN SC base plate and calculating the distances \( d_1 \) and \( d_2 \) with respect to the intermediate waist \( w_2 \) as indicated in figure 9. The size and location of the intermediate waist can be determined from figures 12 and 13. Adjusting the distance of \( L_2 \) to the resonator block may also be helpful to find a correct arrangement for the waist imaging.

**Figure 9: Mode Matching using the Intermediate Waist**
Figure 10: Lens Positions for $\lambda = 800\text{nm}$
Figure 11: Lens Positions for $\lambda=500\text{nm}$
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Figure 12: Intermediate Waist data for 800nm (lens L1 removed)

Figure 13: Intermediate Waist data for 500nm (lens L1 removed)
4.2 Initial Setup Procedure

Before starting the alignment, verify that the wavelength range of the built-in mirrors and crystal includes the wavelength to be doubled. Also check the source laser for stable single mode operation by using a scanning Fabry-Perot interferometer. In the standard equipment of the WAVETRAINSC a polarization rotator is not included. In this case you also have to ensure that the polarization of your source laser is horizontal.

Refer to figure 14 to identify the designations of the components used in the alignment procedure.

Alignment steps:

1. Set up both the laser source and the WAVETRAINSC on the same table with a distance according to the explanations in section 4.1 to ensure mode matching conditions. Adjust the fundamental beam horizontally with a beam height in the range 105mm to 145mm (4.1 to 5.7 inches).

2. Connect the WAVETRAINSC with the control unit via the 25-pin cable and plug in the power line cable. Set the Mode Switch of the control unit to the “Scan” position and the Detector Source Switch to the “Fundamental” position. Turn on the mains switch on the back side of the control unit.

3. If possible set the output power of the fundamental laser to the lowest level which still allows to observe the beam spot on a piece of paper either directly in the visible or by the IR-viewer in the IR range. If the power level cannot be controlled electronically use a suitable attenuation filter just behind the laser output.

4. Adjust the feet of the WAVETRAINSC and/or the fundamental input beam direction in such a way that the beam crosses both the input and output aperture of the phase modulator PM well in the center. Then the beam should hit the bending mirror BM1 roughly in the center.

5. Adjust BM1 to set the reflected beam onto the center of BM2.

6. Open the cover of the Resonator Block RB by loosening the four screws on the top using a 4mm allen screw driver. Adjust the crystal tilt screw CT (see figure 15) to align the crystal to an approximately horizontal position.

7. Align the bending mirror BM1 so that the beam hits the input mirror M1 well in the center. If the laser power is not sufficient to observe the spot on the mirror carefully increase the laser power until you can see the spot.

8. With a narrow strip of paper follow the beam path inside the resonator block from M1 to the crystal X. If necessary adjust BM2 to ensure that the beam passes the crystal without being clipped by the crystal aperture.
9. If your system is equipped with a polarization rotator PR the polarization direction now can be adjusted roughly. Observing the spot reflected by the crystal incidence surface you minimize the intensity of this spot by rotating the PR.

10. Observe the beam spot position at the output mirror M2. If necessary increase the laser power or darken the room light to increase the sensitivity of your eyes. Normally the beam will not hit the center of M2. It may take some iterative adjustments of mirrors BM1 and BM2 to get the beam centered to M1 as well as centered to M2. A (slowly converging) method is to center the beam alternatively to M2 using BM1 and to M1 using BM2.

11. After the beam has been precisely centered to both M1 and M2 check the spot position on the crystal’s surfaces. To center the beam horizontally inside the crystal loosen the fixing screw S (2mm allen screw driver) and translate the crystal by turning the wheel W in figure 15. Don’t forget to fasten again the screw S.

12. If the beam is not approximately centered vertically in the crystal repeat step 8 to translate the beam accordingly in the vertical direction.

13. Adjust the top screws of mirror M2 to direct the beam reflected by M2 through the prism P. Again use a narrow piece of paper to follow the beam path between M2 and the prism. Verify that the beam is not clipped by the aperture of the prism. Follow the beam path with the paper until it hits mirror M1.

14. Adjust mirror M2 until the spot of the beam reflected by M2 coincides the spot of the incident beam on M1.

15. Find the beam reflected by M1 using your stripe of paper. If necessary put a hole of about 1mm diameter into the paper to transmit the incident beam from M1. Follow the beam path of the reflected beam between M1 and M2. Adjust the top screws of M1 until the beam hits the center of M2.

16. Adjust M1 and M2 iteratively until the spot of the incident beam and the reflected beam coincide on both mirrors. At the end of this procedure you should see a diamond-shaped interference pattern on both mirrors originating from the multiple reflections inside the resonator.

17. Close the resonator block RB and fasten the 4 screws of the cover.

18. Check the beam path of the incident beam outside the resonator block after being reflected by M1. The reflected beam should be caught completely by the fiber coupler FC. If not loosen the holding fork of the FC and adjust its position until all the reflected light goes inside the FC.
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**Figure 14:** Optical Components

**Figure 15:** Resonator Block
4.3 Resonator Optimization and Error Signal Adjustment

1. Keep the resonator block RB closed and set the laser power to a medium value.

2. The further alignment of the doubling unit now requires the use of the oscilloscope. Connect channel 1 of the scope with the “Error Monitor” output, channel 2 with the “Intensity Monitor” output and the external trigger input of the scope with the “Scope Trigger” output of the WAVETRAIN\textsuperscript{Sc} control unit. Set the scope trigger source to “External”, channel 1 to 200mV/div, channel 2 to 1V/div and the time base to 2ms/div.

3. Observe the channel 2 trace (Intensity Monitor signal). Set the fundamental gain switch to a level (between 0 and 7) where you can observe a spectrum-like pattern on the scope. If you can’t see any signal check if the Mode Switch is in position “Scan” and the Detector Source Switch in position “Fundamental”. If necessary increase input sensitivity of the channel 2 input until you see a signal.

4. Adjust each single screw of both M1 and M2 to increase the peak height of the signal shown on the channel 2 trace. If overranging occurs reduce the scope channel 2 sensitivity back to 1V/div and, if necessary, the level of the fundamental gain switch on the WAVETRAIN\textsuperscript{Sc} control unit.

5. Now an iterative procedure (step 6 through 13) is used to optimize the mode pattern shown on trace 2 of the scope. The goal of this procedure is to enlarge the main longitudinal modes (TEM\textsubscript{00}) and to suppress the transversal modes as good as possible. The lower scope trace in figure 16 shows the typical mode pattern after this procedure. The transversal modes are suppressed at least by a factor 10 compared to the main modes. The first task in this procedure is to identify the main modes in the mode pattern.

6. Turn the vertical screw (red knob) of M2 by an amount big enough to cause a substantial change in the mode pattern on the scope but with still enough intensity.

7. Optimize the mode pattern by adjusting the vertical screw (red knob) of M1. If the mode intensity cannot be increased compared to the initial state repeat step 6 with the opposite direction.

8. Turn the horizontal screw (yellow knob) of M2 by an amount big enough to cause a substantial change in the mode pattern on the scope but with still enough intensity.

9. Optimize the mode pattern by adjusting the horizontal screw (yellow knob) of M1. If the mode intensity cannot be increased compared to the initial state repeat step 8 with the opposite direction.

10. Continue with step 6 until the mode pattern cannot be improved any more.

11. Optimize the mode pattern by adjusting both screws (horizontal and vertical) of the beam shifter BS which allows very fine beam translations.
12. Optimize the mode pattern by adjusting both screws (horizontal and vertical) of the lens holder L1 which allows very fine angle adjustments of the beam.

13. Repeat steps 6 to 12 until the mode pattern looks similar to the lower trace of figure 16.

14. If the mode pattern cannot be improved to satisfactory state the mode matching seems to be not accurate enough. In this case the incidence angle and the position of lens L2 should be varied by means of the fine control screws of the lens mount. Then repeat the procedure step 6 to 13 until you get a satisfactory mode pattern.

15. Unscrew the fiber from the phase modulator PM and direct the fiber output to a white surface to observe the light intensity coupled into the fiber. Loosen the fixing screw (1.5mm allen screw) which fixes the tube of the fiber coupler. Maximize the light output of the fiber by rotating and shifting the tube then fix it again. Screw the fiber output back into the PM light input.

16. Observe the channel 1 trace on the scope. A signal similar to the upper trace in figure 16 should be visible. If not increase the gain level of the error signal gain switch until the peak-to-peak amplitude of the error signal is in the range 100mV to 300mV.

17. Adjust the DC offset of the error signal to 0V using the balance potentiometer on the PM controller panel.

18. If your system is equipped with a polarization rotator PR now the final adjustment of the polarization direction has to be done. Maximize the intensity of the main modes on the scope by rotating the PR carefully.

4.4 Crystal Phase Matching Alignment

1. Set the Detector Source Switch of the PM Controller module to the “Harmonic” position. Increase the gain level for the harmonic detector until you see a mode pattern on the channel 2 trace of the scope. If there is no signal even at the highest gain level 7 remove the mirror BM4 from its mount (loosen the allen screw) to increase the light intensity falling on the detector. If you now see a signal put a piece of white paper (preferably a white business card) in front of the beam shaper BT switch back to “Fundamental” and continue with step 6.

2. If there is no signal at all place a piece of paper between the resonator output window and the bending mirror BM3. Set the Detector Source Switch of the PM Controller module back to the “Fundamental” position.

3. Turn the vertical (red) adjustment screw of M2 in either direction while watching the paper for blue light until you either see blue light or the mode intensity on the scope is decreased to about half level.

4. Maximize the mode intensity by adjusting the crystal tilt screw CT. Don’t care about the blue light at this step!
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5. Repeat steps 3 and 4 for some times. If no blue light appears repeat steps 3 and 4 with opposite rotations until you see harmonic output. Put a piece of white paper in front of the beam shaper BT.

6. Maximize the blue light intensity on the paper by alternatively adjusting the vertical (red) screw of M2 and the crystal tilt angle. **This procedure will converge only if you maximize the blue light by adjusting the vertical M2 screw and maximize the mode intensity by adjusting the crystal tilt angle.**

7. Set the Detector Source Switch of the PM Controller module to the “Harmonic” position.

8. Set the harmonic gain switch to an appropriate level so that the peak voltage of the main modes is below 10V. If the peak voltage cannot be decreased below 10V by the gain switch insert the bending mirror BM4 back into the mount and fix the screw.

9. Maximize the mode intensity by adjusting the following screws, one after the other: vertical (red) screw of M2, crystal tilt screw CT, vertical screw of the beam shifter BS, vertical screw of lens L1, horizontal (yellow) screw of M2, horizontal screw of BS, horizontal screw of lens L1.

10. Repeat step 9 until the mode intensity cannot be improved any more.

4.5 Harmonic Beam Shape Adjustment

The harmonic beam generated in the WAVE\textsuperscript{SC} has an elliptical shape which is a physical consequence of the nonlinear process in the crystal. After leaving the resonator block RB the beam traverses the beam shaping lens BT which transforms the beam shape into a circular form.

1. Loosen the 5mm allen screw of the holding fork and remove the BT from the base plate.

2. Adjust BM3 and BM4 to align the harmonic beam in a horizontal direction with a beam height of 63.5mm (=2.5inches), 43mm apart from the edge of the base plate.

3. Reinsert the BT to a position where the beam passes the lens in the center just behind the resonator block RB. The distance between the end of the rods and the RB should not exceed 2mm.

4. Adjust the horizontal position of the lens mount to set the beam again parallel to the edge of the base plate. Fix the 5mm allen screw again.

5. Loosen the two fixing screws of the lens holder (use a small “-“ screw driver).

6. Place a paper screen at about 1m distance from the WAVE\textsuperscript{SC} exit and observe the harmonic beam profile.

7. Rotate the lens of the BT to obtain an exactly horizontal elliptical shape.
8. Translate the lens along the optical rod bench to get a circular beam profile.
9. Fasten the fixing screws of the lens holder.

### 4.6 Harmonic Power Optimization

1. Insert the bending mirror BM4 back into the mount and fix the screw if you haven’t done that already. If a power meter is available place it at the beam exit of the WAVETRAIN\textsuperscript{SC} to measure the harmonic output power.
2. With a piece of paper follow the beam path of the harmonic output beam from the resonator output window and if necessary adjust mirrors BM3 and BM4 to guide the beam to the exit position of the WAVETRAIN\textsuperscript{SC}.
3. Set the Detector Source Switch of the PM Controller module to the “Fundamental” position. Set the peak voltage of the main modes on channel 2 of the scope to a value between 2V and 8V by selecting an appropriate gain level for the fundamental detector. For the auto-rekick feature explained in section 2.5 it is important that the peak voltage is at least above 1V.
4. Check the error signal on trace 1 of the scope. Set the peak-to-peak amplitude of the error signal to a value between 100mV and 300mV by choosing an appropriate error gain level.
5. Adjust DC offset of the error signal to 0V using the “Balance” pot on the PM Controller module.
6. Set the Mode Switch of the PID controller module to the ”Stabilize” position. The fundamental intensity signal displayed on the channel 2 trace should now jump to a DC level comparable with the peak maximum of the mode spectrum seen before.
7. Adjust the total gain pot on the PID Controller module to minimize the noise of the channel 2 signal. At a certain level of the total gain oscillations will occur on the signal. Then the gain level has to be decreased to an uncritical gain value where oscillations are avoided by sure.
8. Set the Detector Source Switch of the PM Controller module to the “Harmonic” position. Select a harmonic gain level to get a clear signal display on the scope. If necessary change also the channel 2 sensitivity of the scope.
9. Adjust mirrors M1, M2, the crystal tilt, the beam shifter BS and the lens L1 alternatively for maximum harmonic intensity using either the internal harmonic detector or the external power meter.
10. Repeat step 9 until the harmonic power cannot be improved any more.
Figure 16: Oscilloscope screen in “Scan” operation, optimized alignment

Figure 17: Oscilloscope screen in “Stabilize” operation
5 OPERATION

This chapter deals with daily operation, troubleshooting and maintenance procedures.

5.1 Start-up and Shut-down Procedure

The following procedure should be performed to start the WAVETRAIN<sup>SC</sup>:

1. Check the connection cable between the control unit and the main unit of the WAVETRAIN<sup>SC</sup> to be plugged in.
2. Check the “Mode Switch” on the PID Controller module to be in position “Scan”.
3. Switch on the mains switch on the back side of the control unit.
4. Turn on the source laser system with low power level and verify that the beam is not clipped at any aperture in the WAVETRAIN<sup>SC</sup>.
5. Increase the source laser power to full operating level
6. Put the “Mode Switch” on the PID Controller to the “Stabilize” position.

During longer measurement breaks the system should be switched off in order to increase the lifetime of the piezo element. The shut-down procedure is done in the following order:

1. Put the “Mode Switch” on the PID Controller into the “Scan” position.
2. Turn off the source laser system.
3. Turn off the mains switch on the back side of the control unit.

5.2 Continuous Wavelength Scan

In operating mode (“Stabilize” position of the mode switch) the resonator servo loop will automatically follow any frequency change of the source laser as long as the change does not exceed the maximum travel speed or the translation range of the piezo transducer. Therefore no additional steps are necessary to perform a laser frequency scan.

The piezo travel range corresponds to a certain frequency range of the source laser which depends on the actual wavelength. At 500nm the maximum frequency range which can be followed by the servo loop is about 65GHz, at 800nm it is about 40GHz (fundamental frequency change).

The actual voltage applied to the piezo and hence the piezo position can be observed on the LED bar display of the HV Amplifier module. If the piezo voltage reaches either the low side (0V) or the high side (150V) limit an automatic reset will set the voltage back to a preset value. The factory setting of this preset value is the center of the voltage range, i.e. 75V. The stabilization loop then will automatically relock to the cavity mode which is most close to the
actual cavity length. With the factory setting of the preset voltage the maximum possible symmetric scan range is supplied allowing scans to both directions of half the total scan range. If an experiment requires the maximum possible scan range to one direction the preset voltage should be set close to the lower or to the upper limit of the voltage range depending on the scan direction during the experiment. This can be performed by adjusting the “Zero Level” trim pot of the HV Amplifier module (see section 3.2).

If the scan speed of the source laser exceeds 10GHz/s the scan range which can be followed by the servo loop will drop substantially because the piezo voltage has to precede the steady state value in order to accelerate the piezo.

5.3 Wavelength Change and Optics´ Tuning Ranges

The wavelength tuning range of the WAVETRAIN$^{\text{SC}}$ doubler depends on the optics equipment which is actually in use. The wavelength range for a single crystal varies with the crystal's center wavelength, the crystal material and also slightly with the fundamental input power. For fundamental wavelengths between 410nm and 600nm BBO crystals are used. The tuning range (in the harmonic scale) for a specific BBO crystal cut can be estimated from figures 21 and 22. For fundamental wavelengths above 600nm LBO crystals are used. The tuning ranges for specific LBO crystal cuts can be estimated from figures 23 and 24.

For wavelength changes smaller than the acceptance range of the doubling crystal no adjustments has to be done. The acceptance range of the doubling crystal is strongly dependent on the crystal material and the fundamental wavelength. For an LBO crystal around 800nm the half width of the tuning curve with constant crystal tilt angle is about 4nm (fundamental scale).

If the laser wavelength is changed more than the acceptance range of the doubling crystal a realignment of the crystal's matching angle will be necessary according to the “Crystal Phase Matching Alignment” procedure described in section 4.4. If the wavelength is to be changed far outside the acceptance range of the crystal's matching angle it is recommended to change the laser wavelength in steps of some nanometers and to realign the crystal and the cavity mirrors for each step according to the procedure in section 4.4.

If the wavelength change exceeds the tuning range of the crystal, the mirror coatings or other optical elements of the WAVETRAIN$^{\text{SC}}$ those parts have to be replaced.

Crystals may be ordered with any center wavelength in the specified range with a precision of 1%. The mirror coatings can be chosen from the table at the end of this section. The crystal center wavelength should be not too close at the edge of the mirror coating range in order to avoid the clipping of the tuning curve at the edge of the mirror range. The replacement procedure for the crystal and the mirrors are described in sections 5.4 and 5.5.
The optical elements between the beam entrance and the resonator block are broadband antireflection-coated for either the visible or the near IR range of the fundamental wavelength. The useful range of all optical elements can be derived from figure 18. Please make sure that at least all bending mirrors BM1, BM2, BM3 and BM4 are used within their wavelength range. The polarization rotator PR, phase modulator PM, lenses L1, L2, BT and the beam shifter BS can also be used outside their specified wavelength range. But the full system performance can be expected only if all elements have been replaced. Please contact LAS GmbH or the local representative for more details.
The available optics are listed below.

Art. No.: L2380020  M1, M2: Set of Cavity Mirrors

Standard wavelength ranges (fundamental wave) available as follows:

<table>
<thead>
<tr>
<th>Range</th>
<th>Art. No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>410 - 425 nm</td>
<td>L2380020</td>
<td>M1, M2: Set of Cavity Mirrors</td>
</tr>
<tr>
<td>425 - 440 nm</td>
<td>L2380020</td>
<td>M1, M2: Set of Cavity Mirrors</td>
</tr>
<tr>
<td>440 - 455 nm</td>
<td>L2380020</td>
<td>M1, M2: Set of Cavity Mirrors</td>
</tr>
<tr>
<td>455 - 470 nm</td>
<td>L2380020</td>
<td>M1, M2: Set of Cavity Mirrors</td>
</tr>
<tr>
<td>470 - 485 nm</td>
<td>L2380020</td>
<td>M1, M2: Set of Cavity Mirrors</td>
</tr>
<tr>
<td>485 - 520 nm</td>
<td>L2380020</td>
<td>M1, M2: Set of Cavity Mirrors</td>
</tr>
<tr>
<td>520 - 570 nm</td>
<td>L2380020</td>
<td>M1, M2: Set of Cavity Mirrors</td>
</tr>
<tr>
<td>570 - 625 nm</td>
<td>L2380020</td>
<td>M1, M2: Set of Cavity Mirrors</td>
</tr>
<tr>
<td>625 - 700 nm</td>
<td>L2380020</td>
<td>M1, M2: Set of Cavity Mirrors</td>
</tr>
<tr>
<td>700 - 800 nm</td>
<td>L2380020</td>
<td>M1, M2: Set of Cavity Mirrors</td>
</tr>
<tr>
<td>800 - 900 nm</td>
<td>L2380020</td>
<td>M1, M2: Set of Cavity Mirrors</td>
</tr>
<tr>
<td>900 - 1000 nm</td>
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<td>M1, M2: Set of Cavity Mirrors</td>
</tr>
<tr>
<td>1000 - 1100 nm</td>
<td>L2380020</td>
<td>M1, M2: Set of Cavity Mirrors</td>
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<td>M1, M2: Set of Cavity Mirrors</td>
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<tr>
<td>1200 - 1300 nm</td>
<td>L2380020</td>
<td>M1, M2: Set of Cavity Mirrors</td>
</tr>
<tr>
<td>1300 - 1400 nm</td>
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<tr>
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<td>L2380020</td>
<td>M1, M2: Set of Cavity Mirrors</td>
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<tr>
<td>1500 - 1600 nm</td>
<td>L2380020</td>
<td>M1, M2: Set of Cavity Mirrors</td>
</tr>
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</table>

Art. No.: L2380010  X: LBO Crystal, specify wavelength
Art. No.: L2380015  X: BBO Crystal, specify wavelength
Art. No.: L2380040  PR: Fresnel Rhombus VIS (410 - 700 nm)
Art. No.: L2380042  PR: Fresnel Rhombus NIR (500 - 1000 nm)
Art. No.: L1380036  PM: Phase Modulator VIS (410 - 850 nm)
Art. No.: L1380038  PM: Phase Modulator NIR (660 - 1050 nm)
Art. No.: L2380072  L1, L2, BS: Matching Optics VIS (400 - 700 nm)
Art. No.: L2380074  L1, L2, BS: Matching Optics NIR (633 - 1064 nm)
Art. No.: L2380062  BM1, BM2: Bending Mirrors VIS (430 - 700 nm)
Art. No.: L2380064  BM1, BM2: Bending Mirrors NIR (620 - 950 nm)
Art. No.: L2380052  BM3, BM4: Bending Mirrors UV1 (205 - 230 nm)
Art. No.: L2380054  BM3, BM4: Bending Mirrors UV2 (230 - 350 nm)
Art. No.: L2380056  BM3, BM4: Bending Mirrors UV3 (300 - 550 nm)
Art. No.: L1380052  BT: Beam shaping optics UV1 (205 - 400 nm)
Art. No.: L1380054  BT: Beam shaping optics UV2 (350 - 550 nm)
5.4 Crystal Replacement

Crystal replacement is done by the following steps:

1. Open the four screws of the resonator cover (4mm allen screw driver) and remove the cover.
2. Unscrew the two mounting screws MS (3mm allen screw driver) of the crystal mount (see figure 19).
3. Pull out carefully the total crystal mount from the resonator block and put it on a table in a clean environment.
4. Loosen the two knurled head screws KS (see figure 20).
5. Grab the crystal frame XF by pressing the two knurled head screws together and remove it from the mount. Store the crystal in a dry and clean receptacle. The label on the top of the crystal frame contains the information about the crystal material (L=LBO, B=BBO) and the center wavelength in nanometers. By this, each crystal can be identified easily. Never touch the crystal surfaces! Don’t remove the crystal from its frame.
6. Put the replacement crystal on the crystal mount and fasten the knurled head screws KS.
7. Put the crystal mount back into the resonator block and fasten the mounting screws MS.
8. Put the cover back onto the resonator block and fasten the four screws.
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**Figure 18:** Removing Crystal Mount

**Figure 19:** Crystal Replacement
Figure 20: Typical BBO tuning curves for 800mW input power

Figure 21: Typical BBO tuning curves for 200mW input power
Figure 22: Typical LBO tuning curves for 800mW input power

Figure 23: Typical LBO tuning curves for 200mW input power
5.5 Mirror Replacement

Replacement of the resonator mirrors is described in the following procedure:

1. Open the four screws of the resonator cover (4mm allen screw driver) and remove the cover.
2. Unscrew the two mounting screws MS (3mm allen screw driver) of the crystal mount (see figure 19).
3. Pull out carefully the total crystal mount from the resonator block and store it at a clean place.
4. Unscrew the brass rings containing the mirrors M1 and M2 (see figure 19) from their mounts. They are labeled as “M1” or “M2” together with the fundamental wavelength range of the coating. Don’t remove the mirror substrates from the brass rings! Don’t touch the mirror surfaces! Put them in a dry and clean receptacle.
5. Put the replacement mirrors into their corresponding mounts (M1 right mount, M2 left mount) and screw them in hand-tight.
6. Put the crystal mount back into and the cover back onto the resonator block and fasten the screws.
## 5.6 Troubleshooting

<table>
<thead>
<tr>
<th>Fault</th>
<th>Repair</th>
</tr>
</thead>
</table>
| Low conversion efficiency                                           | Check alignment according to sections 4.4, 4.6  
|                                                                      | Translate the crystal according to step 11 of section 4.2 to find a clean part of the crystal surfaces.  
|                                                                      | Clean optics according to section 5.7  |
| Unusual shape of harmonic beam (circular with horizontal interference lines), very low power | “Ghost” spot due to an internal reflection in the crystal. Search for the true phase matching angle in a wide range according to section 4.4.  |
| System does not lock to a main cavity mode, intensity monitor signal (trace 2 in figure 17) remains on low level | Switch to “Scan” mode and to “Fundamental” detector. Check the main modes to be above 2V and all transversal modes below 0.5V. If necessary change the gain level of the fundamental detector. If it does not help realign the resonator according to section 4.3.  |
| System does not lock to a main cavity mode, the LED bar display of the HV Amplifier sweeps periodically, “clicking” of the piezo | Switch to “Scan” mode and adjust the error signal offset (trace 1 of figure 16) to zero.  |
| Periodical noise on the harmonic output power, oscillations on the “Intensity” signal (trace 2 of figure 17). | Reduce the total gain by turning the potentiometer of the PID Controller counterclockwise.  |
5.7 Maintenance

The system performance of the WAVETRAIN\textsuperscript{SC} degrades very quickly with increasing optics contamination. Therefore the whole system should be operated in a clean environment. As long as the system is not operated the acrylic dust cover should always be mounted on the unit. Unless during initial alignment or during replacement of the crystal or the resonator mirrors the resonator block should always be kept closed.

The resonator block contains a cartridge DC (see figure 15) filled with desiccant to provide a dry atmosphere inside. Check the color of the moisture indicator window every month to be blue. If it appears white the cartridge has to be refreshed. Follow the procedure:

1. Unscrew the optical fiber and remove it from the phase modulator PM.
2. Loosen the cartridge by rotating it ccw with the help of a small screw driver which may be inserted into the small hole of the cartridge.
3. Heat the cartridge in an oven at about 80°C for some hours.
4. Reinsert the cartridge into the resonator block RB and fix it hand-tight by rotating cw.
5. Reconnect the fiber to the PM.

The most common reason for a dramatic drop in the conversion efficiency is a contamination of the mirrors, the crystal or the prism inside the resonator. In a first step use dry nitrogen, canned air or a rubber squeeze bulb to blow away dust from the optical surfaces. If the contamination cannot be blown away use the following cleaning procedure:

1. Fold a new sheet of lens tissue to a small shape according to the size of the optics surface to be cleaned. Don’t touch the part of the tissue used for cleaning with your fingers.
2. Clamp the folded tissue with hemostats.
3. Put one or two drops of reagent grade methanol on the tissue.
4. Wipe once across the optical surface in one direction (see figures 25 and 26). If necessary repeat with a new tissue. Don’t touch the optical surfaces with the hemostats!

The resonator mirrors M1 and M2 have to be removed from their mounts before cleaning (do not remove the mirror substrates from the brass rings!). Before cleaning the prism you have to remove the protection ring PR by loosening the 1.5mm allen screw (see figure 19). Don’t forget to reinstall the protection ring!

Crystal cleaning should be avoided as long as it is not necessary. You always should clean all the other components and check for sufficient conversion efficiency before cleaning the crystal.
Figure 24: Crystal cleaning

Figure 25: Mirror cleaning
Chapter 6: TECHNICAL DATA

6 TECHNICAL DATA

6.1 Mechanical and Optical Data

Physical Dimensions:
WAVETRAIN\textsuperscript{\textsc{sc}} main unit:
L x W x H = 570mm x 400mm x 230mm
Beam Height: 105mm to 145mm adjustable
Weight: 20kg

Control Unit:
L x W x H = 340mm x 380mm x 160mm
Weight: 7kg
Power Supply: 220V/100VAC, 80VA, 50-60Hz

Optical:
Maximum Fundamental Input Power: 5W
Fundamental Wavelength Range: 410nm – 1600nm
   (actual range depending on optical equipment)
Piezo Scan Range: 65 GHz @ 500nm
    40 GHz @ 800nm
Piezo Scan Speed: 10GHz/sec
6.2 Pin Definitions

Pin definition of the 25 pin D-connector of the WAVETRAIN\textsuperscript{sc} main unit and the control unit:

| Pin No. | Signal          |
|---------|----------------|----------------|
| 3       | FD Cathode     |
| 4       | FD Anode       |
| 5       | HD Cathode     |
| 6       | HD Anode       |
| 10      | NTC 1          |
| 11      | NTC 2          |
| 12      | TEC +          |
| 13      | TEC -          |
| 17      | PM –15V        |
| 18      | PM GND         |
| 19      | PM +15V        |
| 20      | PM Error       |
| 24      | Piezo +        |
| 25      | Piezo -        |
Pin definition of the 9-pin D-connector at the resonator block and the 4-pin MTA connector „NTC/TEC“ at the WAVETRAIN™ connector terminal:

<table>
<thead>
<tr>
<th>Pin No</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NTC 1</td>
</tr>
<tr>
<td>2</td>
<td>NTC 2</td>
</tr>
<tr>
<td>3</td>
<td>TEC +</td>
</tr>
<tr>
<td>4</td>
<td>TEC -</td>
</tr>
</tbody>
</table>

Pin definition of the 3-pin MTA connector "Piezo" at the WAVETRAIN™ connector terminal:

<table>
<thead>
<tr>
<th>Pin No</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Piezo-</td>
</tr>
<tr>
<td>2</td>
<td>Piezo+</td>
</tr>
</tbody>
</table>

Pin definition of the 8-pin RJ45 connector at the phase modulator:

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 red</td>
<td>+15V</td>
</tr>
<tr>
<td>2 blue</td>
<td>-15V</td>
</tr>
<tr>
<td>3 green</td>
<td>GND</td>
</tr>
<tr>
<td>4 brown</td>
<td>PM Error</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>GND</td>
</tr>
<tr>
<td>8</td>
<td>GND</td>
</tr>
<tr>
<td>Shield</td>
<td>GND</td>
</tr>
</tbody>
</table>
Pin definition of the 6-pin MTA connector "PM" at the WAVETRAIN<sup>Sc</sup> connector terminal:

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>+15V</td>
</tr>
<tr>
<td>2</td>
<td>GND</td>
</tr>
<tr>
<td>3</td>
<td>-15V</td>
</tr>
<tr>
<td>4</td>
<td>PM Error</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
</tr>
</tbody>
</table>