*pulse*Switch

Cavity Dumper

User Manual

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1. Introduction and Theory of Operation

A cavity dumper extends the usability of a mode-locked laser system. It offers higher peak power at lower repetition rates.

The femtosecond Ti:Sa oscillator Coherent Mira 900 is a mode-locked laser, which is capable of generating short laser pulses (~130 femtosecond) at a pulse repetition rate of 76 MHz. This corresponds to a round trip time of 13.2 ns for the pulses in the laser cavity.

For a number of applications like measurement of longer fluorescence delay times or some pump and probe experiments it is desirable, however, to have a lower repetition rate. This can be achieved with different methods acting inside or outside the laser cavity.

The pulse energy from a Ti:Sa oscillator is rather low, especially for nonlinear experiments or generation of higher harmonics. Using so called pulse pickers, which are acting outside the laser cavity, to reduce the repetition rate will cause an additional loss of ~40% of the pulse energy. Thus to variably reduce the repetition rate and to even raise the pulse energy by several times, the use of intracavity techniques is required. For this purpose we developed the cavity dumper PulseSwitch for use with the Coherent Mira.

Its function is based on the acoustooptic effect. In a suitable crystal (fused silica) a modulation of density and thus of refractive index is introduced by applying an acoustic signal with high frequency. This acts as a three-dimensional optical grating on a laser beam passing the crystal and leads to a diffraction of the beam. The acoustic wave inside the crystal is generated by applying an electrical RF signal to a piezoelectric transducer cemented on the crystal. By using short RF pulses single laser pulses can be selected out of the pulse train and deflected to the first diffraction order. So they are separated from the other pulses and are available for usage in the experiment.

The PulseSwitch consists of the optics module and the driver and control electronics module. The optics module becomes part of the laser cavity of the Ti:Sa oscillator. To achieve this, it has to be placed directly behind the Mira and mechanically connected with it, see below. Then the Brewster window for the output beam in the Mira and the outcoupler have to be removed. As a last step the adjustable slit has to be relocated from the Mira into the PulseSwitch optics module.

The optics contains the Bragg cell as the most important part which selects single pulses from the laser beam based on the acoustooptical effect. Further it contains the focusing and the collimating mirror CM1 and CM2 and the plane end mirror CM3 as cavity mirrors and the mirrors M4 to M6 as steering mirrors for the outcoupled pulses.

The driver electronics provides the modulated RF signal for the Bragg cell with a carrier frequency of 380 MHz equal to the sevenfold of the laser repetition rate and an output power of up to 16.5 W (peak).

The standard range for the division ratio of the laser repetition rate is 1:6 to 1:260,000. For synchronization the user must connect the output of the fast photodiode of the Mira with the Seed input of the driver electronics. Instead of using the internal frequency divider pulses can be selected by external triggering with a TTL signal at the 50 Ω external trigger input. Also in this case the „SEED“ input signal is required.

Depending on the chosen repetition rate intracavity pulse dumping efficiencies of > 60 % can be achieved.

1.1 Double-pass Cavity Dumping

The schematic layout of the cavity-dumper, an acoustooptic Bragg cell placed inside the laser resonator, is depicted in Fig. 1. As the pulse that circulates in the cavity enters the Bragg cell, part of the radiation is scattered on the RF-induced refractive index grating under a specific angle.

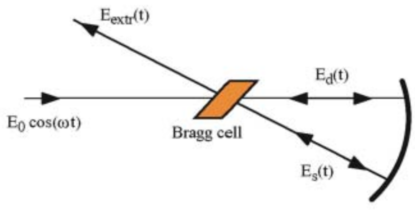


Fig. 1 Schematic layout of the double-pass cavity dumping arrangement. For the definitions of the electric fields see text.

For the description of the dumping process the optical pulse is assumed to be given by:

$$E(t)=E_0\cos(\omega t)$$

with E denoting the time dependent envelope and ω the laser carrier frequency. The scattering of the light on the RF-induced sound wave causes a frequency shift of the pulse by an amount equal to the RF frequency (Ω).

The expressions for the scattered pulse E_s and the depleted cavity pulse E_d after the first pass through the Bragg cell are given by:

$$E_s = \sqrt{\eta}\, E_0\cos(\omega t + \Omega t + \Phi)$$

$$E_d = \sqrt{(\eta-1)}\, E_0\cos(\omega t + \Omega t + \Phi)$$

where the intensity diffraction efficiency is denoted by η, and Φ is the adjustable phase of the RF carrier. After the pulse has passed the Bragg cell for the second time, the total extracted pulse is given by the sum of the two scattering contributions as:

$$E_{extr} = \sqrt{(\eta-1)}\, \sqrt{\eta}\, E_0\, [\cos(\omega t + \Omega t + \Phi) + \cos(\omega t - \Omega t - \Phi)]$$

Thus the output depends on the specific phase relation between the two adding pulses. Thus the resulting intensity of the dumped output of the laser is:

$$I_{cd} = 4\, \eta\, (\eta-1)\, |E_0|^2 \cos^2(\Omega t + \Phi)$$

The dumping efficiency can be enhanced in case the interference is constructive, or decreased for destructive interference. For optimum dumping efficiency thus it is inevitable to optimise the phase of the RF-signal.

1.2 Oscillator Gain Dynamics

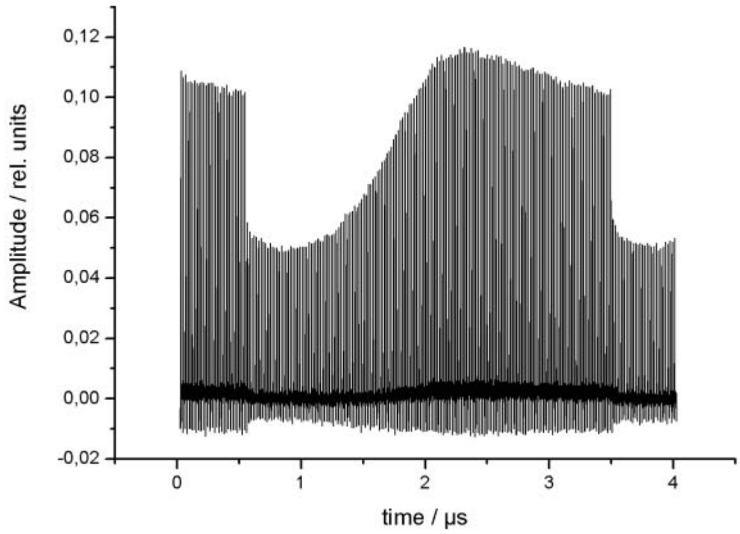


Fig. 2 Cavity Dumper pulse train at a repetition rate of 1:160

In Fig. 2 a typical pulse train of the intracavity pulses is shown. The signal was detected by the fast photodiode of the Mira diagnostics, which is also used as the synchronization seed signal for the Cavity Dumper, and recorded by a digital sampling oscilloscope. Every 160th pulse was dumped with an efficiency of ~50%. As can be clearly seen, the mode-locking process is disturbed by the dumped pulse.

The transient dynamics capture some intriguing aspects of the pulse generation in a Kerr lens mode-locked laser. Due to the significant reduction of the intracavity pulse power after the dumping event, the saturation of the gain is relaxed. With the pump rate being constant an exponential initial growth of the intracavity energy should be expected. However, the intracavity pulse energy remains almost constant for a period as long as 50 round trips. A decrease in the intracavity pulse energy reduces the self-focusing of the cavity mode thereby increasing the diameter of beam waist in the gain medium. As a consequence the spatial overlap between the cavity mode and pump beam decreases due to longitudinal pumping leading to a drop in the gain. It is only after some time, because of accumulation of population inversion in the gain medium, the pulse energy starts to grow considerably, going through an overshoot before relaxing to the steady-state level.

At repetition rates higher than 250 kHz the laser can also be stably mode-locked but with lower dumping efficiency. For instance, at 500 kHz the pulse energy is typically 60 nJ (@ 800nm), but at 4 MHz it decreases to about 60% of this level. In case the high dumping efficiencies are maintained at high repetition rates the laser ceases mode-locking. Inspecting the transient behaviour after the dumping event and the relaxation back to the steady state conditions, a cavity recovery time of up to 4 µs (compare Fig. 2) can be detected. From this, the maximum dumping frequency for the largest efficiency is estimated to be in the range of 250 kHz. For higher dumping repetition rates, smaller dumping efficiencies must be applied to keep the laser in mode-locked operation.

1.3 Intracavity Pulse Energies and Limitation of Pump Power

The Mira / PulseSwitch cavity only has high reflective mirrors and no output coupler (OC). Therefore the laser resonator has much lower losses in comparison to the standard Mira. Thus with the modulator switched off, the steady state intracavity energy stored is much higher compared to the Mira with OC for the same pump power. With dumping efficiencies of 60% in comparison to ~20% transmission of a typical OC and much higher intracavity power the cavity dumped pulses have a several fold higher pulse energy compared to the Mira in normal operation.

But from a certain intracavity power onwards multiple pulse formation in the mode-locked regime overbalances single pulse mode-locking. Thus in the Mira / PulseSwitch configuration less pump power can be applied to avoid this multiple pulse formation. For 800 nm the typical pump energy is ~4.5 W, for wavelength further away from the Ti:Sa power maximum the maximum pump energy is higher.

2. Installation and Basic Adjustment

2.1 Description of the Optics Unit

Fig. 3 shows the optical unit of the cavity dumper PulseSwitch with its various tuning elements, the output aperture, the RF BNC connector and the purge inlet connector.

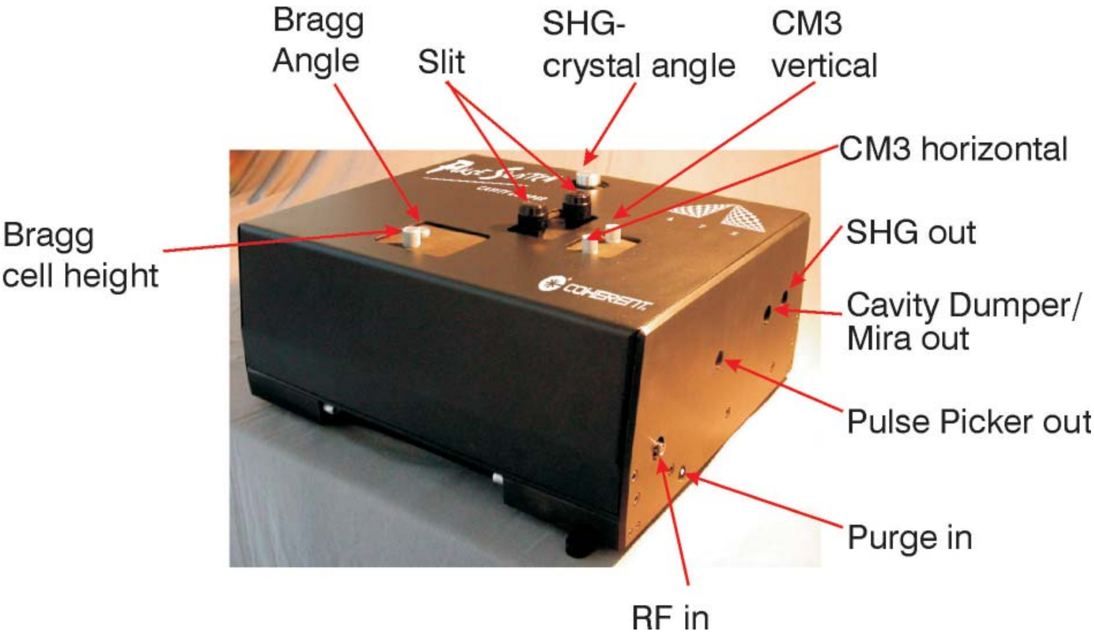
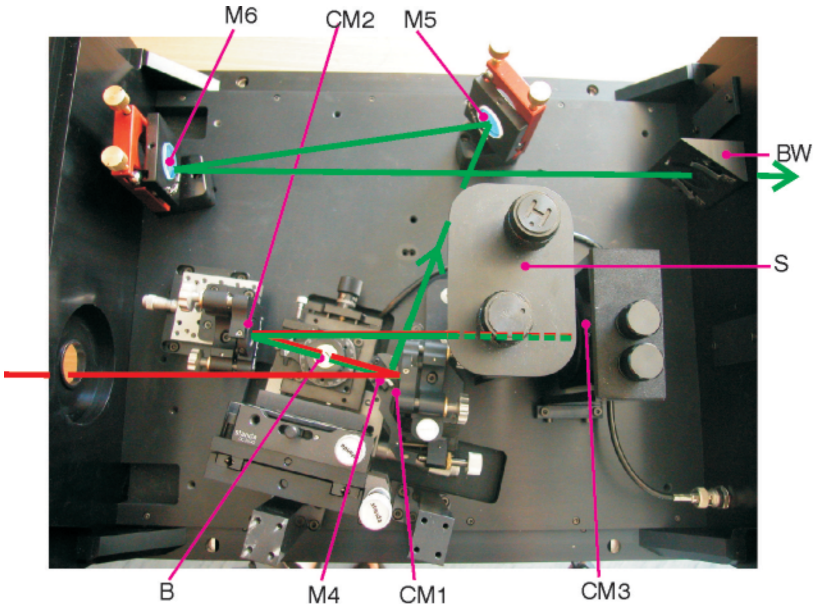


Fig. 3 PulseSwitch optics unit

Fig. 4 shows the elements of the PulseSwitch optics in top view. The optics set up is designed for horizontal polarization of the laser light as it is for the Mira. The beam goes through the input onto the focusing mirror CM1. From there it is reflected and focused into the Bragg cell, which is arranged at Brewster angle to the beam. By applying the modulated RF signal from the driver electronics to the Bragg cell a part of the beam (selected pulses) will be deflected into the first diffraction order. Zero-order and first-order beam are recollimated by the collimating mirror CM2 and both retroreflected by the end mirror CM3. Thus first-order and zero-order beam pass via CM2 a second time through the Bragg cell, where a part of the zero order is deflected into the first and a part of the first back into the zero order depending on RF pulse length, delay and phase. By optimizing these parameters the outcoupling efficiency can be substantially raised in comparison to a single-pass Cavity Dumper.

The zero-order beam is retroreflected into the Mira and does not leave the cavity, whereas the first-order beam passes the Bragg cell and CM1 for a second time, hits the beam steering mirror M4, and leaves the PulseSwitch via M5 and M6 through the Brewster window BW.



CM1 -	Focusing mirror CM1
CM2 -	Collimating mirror CM2
CM3 -	Cavity Dumper end mirror
M4 -	Cavity-dumped pulse outcouple mirror
M5, M6 -	CD steering mirrors
B -	Bragg cell, Modulator
S -	Mira slit
BW -	Cavity Dumper and Mira bypass output Brewster window

Fig. 4 Optics - top view (red - intracavity beam; green - outcoupled beam)

Make sure the mirror M6 is mounted in the proper position as shown in Fig. 4. Fig. 5 shows the mounting holes for mirror M6 in standard cavity dumper operation (without SHG).

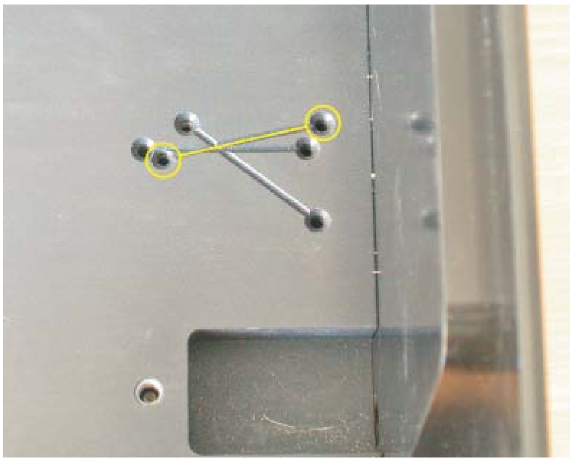


Fig. 5 Mounting holes for M6 in standard Cavity Dumper operation

2.2 Installation

Warning! Pay attention to the safety rules according to the class of your laser! The installation and adjustment should only be done by personnel skilled in the handling of optics and lasers!

- Before installation the optical parts of the Verdi, Mira and the PulseSwitch (Brewster windows, mirrors, and crystal) should be cleaned using common optics cleaning techniques and methanol as detergent.
- Switch on the Verdi (your pump laser) / Mira and adjust the Mira optics for maximum mode-locked operation at 800nm and 4.5 W pump power. Pay attention, that the beam is centred on the output coupler. Close the shutter of your pump laser again.

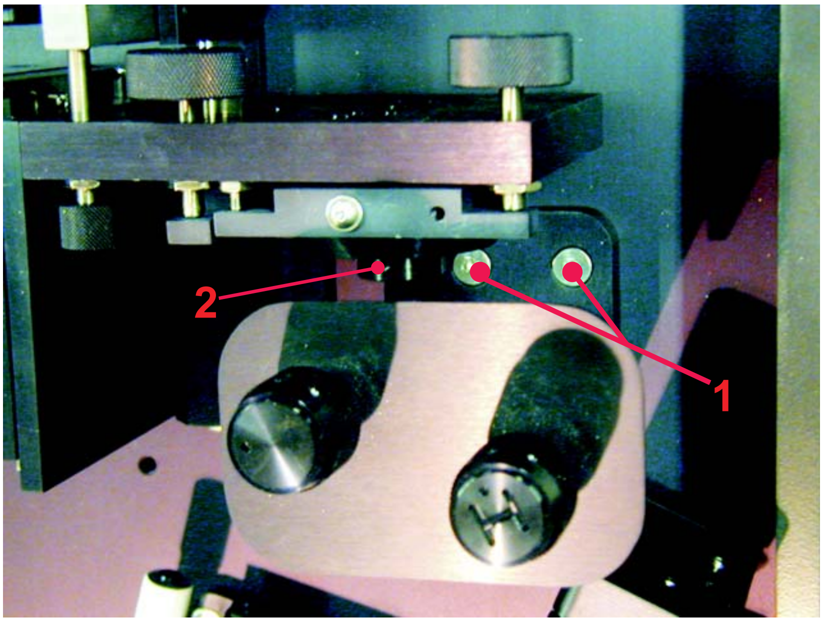


Fig. 6 Mira slit and retaining screws (1) and holder for output coupler (2)

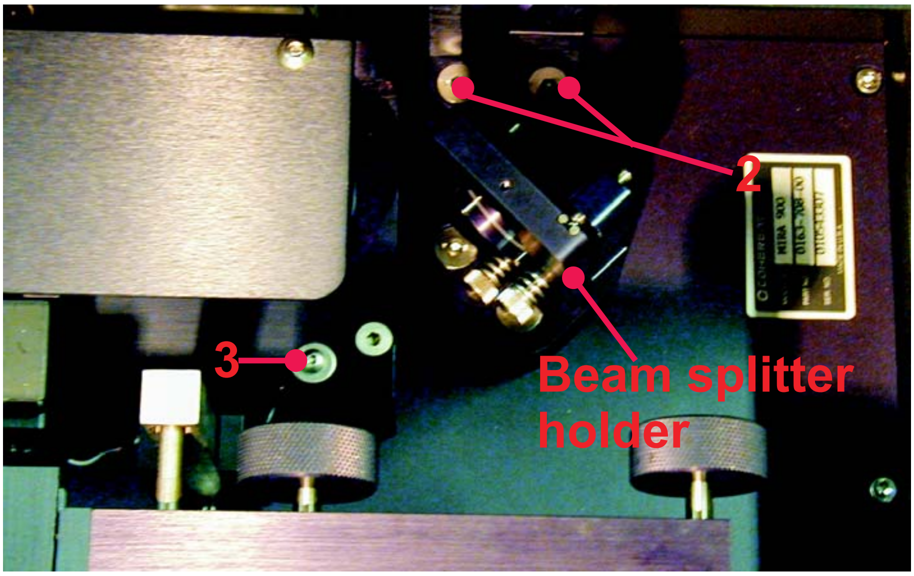


Fig. 7 Mira: showing beam splitter holder, locking screws for Brewster window (2) and retaining screw for electronics unit (3)

1. Open the Mira housing and remove the slit (the screws are needed again for mounting the slit in the PulseSwitch) (1 in fig 6), the output coupler M1 (2 in Fig. 6) and the output beam Brewster window (retaining screws: [2] in Fig.7). Take out the beam splitter (1 inch glass plate) from its holder (Fig. 7) and replace it with the delivered one.

Fig. 8 Neutral density filter (left) and filter holder (right)

2. Loosen the retaining screw of the Mira diagnostics electronic (3 in Fig. 7). Slide the delivered filter holder (Fig. 8) under the retaining screw and tighten the screw again. Then place the neutral density filter into the holder. (see Fig. 9).

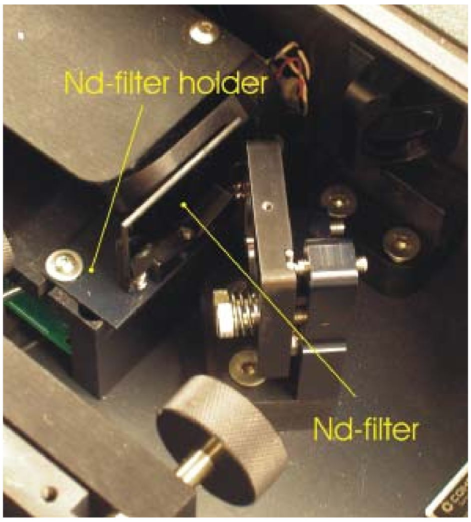


Fig. 9 Mira diagnostics unit with installed filter holder and neutral density filter

3. Close the hole in the Coherent Mira cover, which is normally used for the slit, with the lid provided, see Fig. 11. Remove the output beam aperture ring of the Mira (the black ring on the outside of the Mira housing, Fig. 10). Remove the two outer connection screws (Fig. 10) from the cover.

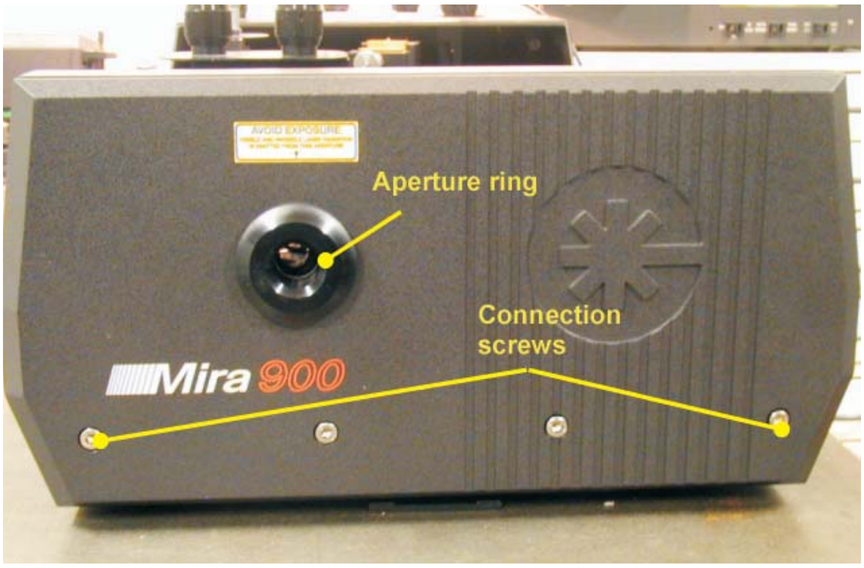


Fig. 10 Mira front side with output aperture and connection screws

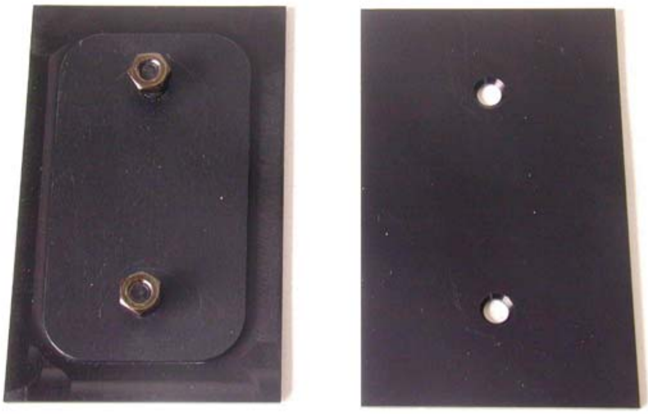


Fig. 11 Lid for slit hole in the Mira cover

4. Place the PulseSwitch optics module in front of the Mira and connect the Mira housing with the PulseSwitch housing mechanically with the delivered screws (use the washers from the outer connection screws from the Mira) and the Mira aperture ring (see Fig. 12). Before completely tightening the screws and the aperture ring adjust the height of the PulseSwitch foot screws carefully to achieve a stress-free connection of the Mira and PulseSwitch front panels. Do not clamp the PulseSwitch to the optical table to allow for free floating.

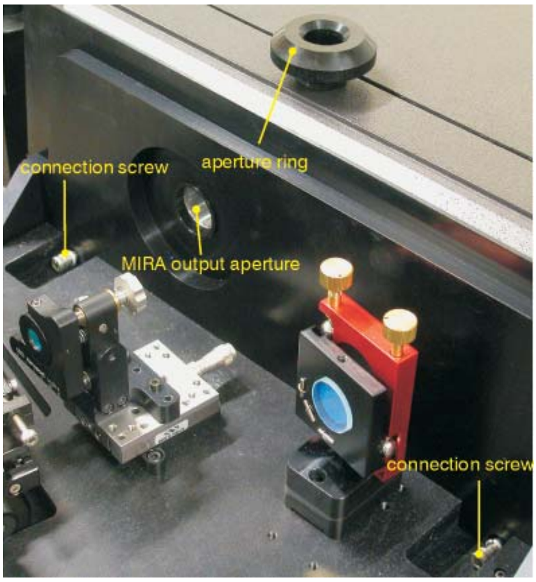
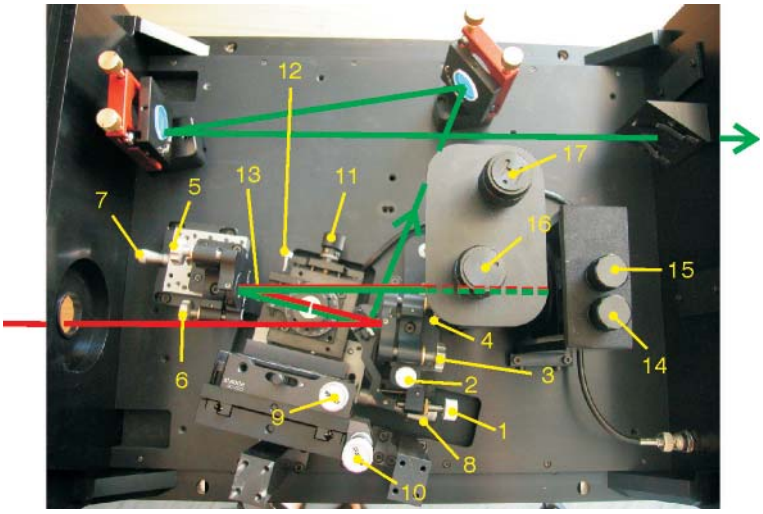


Fig 12 Connection of PulseSwitch with Mira using the two delivered screws together with the washers from the Mira connection screws and the Mira output aperture

2.3 Basic alignment



1 -	M4 angle control
2 -	M4 vertical position control
3 -	CM1, vertical tilt control
4 -	CM1, horizontal tilt control
5 -	CM2, vertical tilt control
6 -	CM2, horizontal tilt control
7 -	CM2, horizontal position adjustment screw
8-	Modulator, horizontal X-position adjustment screw
9 -	Modulator, Bragg-angle control
10 -	Modulator, vertical position adjustment screw
11 -	Modulator, horizontal Y-position adjustment screw
12 -	Modulator, Brewster-angle control
13 -	Modulator, rough Brewster-angle lock screw
14 -	CM3, vertical tilt control
15 -	CM3, horizontal tilt control
16 -	Slit width control
17 -	Slit horizontal translation adjustment

Fig. 13 Beam path for cavity dumper operation (red - intracavity beam; green - outcoupled beam)

1. At the beginning of the basic adjustment of the PulseSwitch the Bragg cell has to be driven 2 mm lower than the position given in the test protocol [10 in Fig. 13].
2. The following elements should be set to the reference values given in the test protocol. Typical starting values are given here in case the protocol got lost.

Typical values

- Bragg-angle [9 in Fig. 13],	-2°
- Brewster-angle [12 in Fig. 13]	0°
- horizontal position of the collimating mirror CM2 [7 in Fig. 13]	2.5 mm
- horizontal X-position of the Modulator [8 in Fig. 13]	13.5 mm

If this is done, the distance between CM1 and CM2 should be approximately 105mm and the Bragg cell in the middle between both mirrors.

3. Switch on the pump laser of the Mira and set it to 4.5 W (if a Verdi is used). The fluorescence spot of the Ti:Sa crystal must enter the optics module and hit the centre of the focusing mirror CM1. (Use an infrared viewer if necessary.) Use the Mira mirror M2 for alignment. You can use the delivered alignment aperture for checking the proper height of the fluorescence spot.
4. Lower M4 [2 in Fig. 13] so it does not clip the fluorescence.
5. Adjust the fluorescence to pass through the modulator and fall centrally onto CM2. Use the tilt controls of the focusing mirror [3, 4 in Fig. 13]! If the fluorescence is clipped either by M4 or the Bragg cell holder, lower them.
6. Use the CM2 tilt controls [5,6 in Fig. 13] to steer the fluorescence spot to the centre of CM3.
7. Use the CM3 to retroreflect the fluorescence to CM2. Adjust the CM3 tilt controls [14,15 in Fig. 13] to start the lasing process and to optimise for maximum intracavity power by using the power display on the Mira controller as monitor.
8. Realign the cavity that the laser spot falls centrally onto the mirrors. Use Mira mirror tilt control of M2 for centring the beam onto CM1, CM1 for CM2 and CM2 for CM3. If the system is properly aligned, the intracavity power should not drop when placing the alignment aperture in front of CM1, CM2 or CM3.
9. Use the tilt control of the beam splitter holder in the Mira to optimise the power reading of the Mira controller (i.e. directing the reflection onto the detection diode). Realign the cavity for maximum intracavity power by using CM3 and the Mira end mirror.
10. Optimise the Brewster-angle of the Bragg cell (only needs to be done once at installation) by changing the angle in 0.5° steps using [12 in Fig. 13] and bring the system to lasing again with CM3. Optimise for maximum power and compare with the previous value. The intracavity power is maximum at the Brewster-angle.
11. Check the beam path inside the crystal with an IR-viewer and correct the crystal horizontal Y position [11 in Fig. 13] to get the beam to the centre (see Fig. 14).

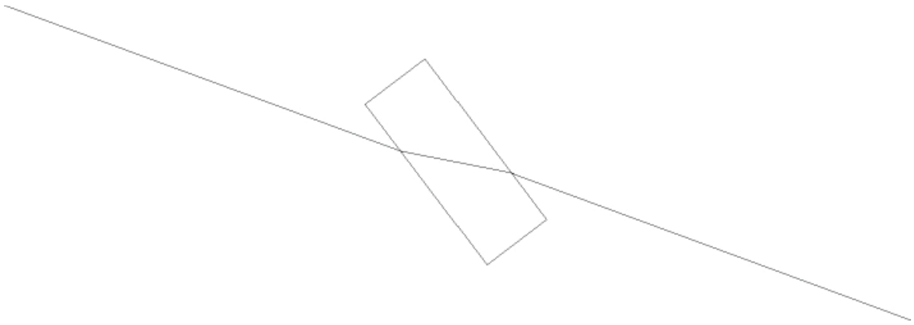


Fig. 14 Beam path inside the transducer crystal

12. Place the Mira slit into its position in the PulseSwitch, fix it using the screws from the Mira (see Fig. 4 and 13), centre the horizontal position [17] and adjust the slit width [16] to get the system lasing again.
13. Switch to mode-locked operation using the same procedure as for the Mira, refer to the description in the Coherent Mira manual. Take into account, that the slit now is in the PulseSwitch and is rotated by 180 degrees, thus the knob for the horizontal position [17] (marked with ‘H’) and the knob for slit width control [16] just changed position in comparison to the Mira.

You should monitor the fast photodiode output of the Mira with a fast oscilloscope (min. 400 MHz), to check whether the system mode-locks properly or if it generates double pulses. In case of double pulsing close the slit further.

As an alternative of monitoring the fast photodiode connect the photodiode to the SEED input signal to the PulseSwitch electronics and connect the SEED MONITOR to the oscilloscope. This is the standard setup for the PulseSwitch operation (See next chapter).

If the system does not start mode-locking check for the distance between CM1 and CM2 (101 mm) and optimise the distance with screw [7] for maximum intracavity power (use the Mira controller as monitor) in mode-locked operation by changing it between 100 and 102 mm in steps of 0.5 mm.

3. Driver Electronics

Fig. 15 and 16 show the front and back panel of the driver electronics module with controls and signal inputs and outputs. On the left top of the front panel there is a LCD graphic display.

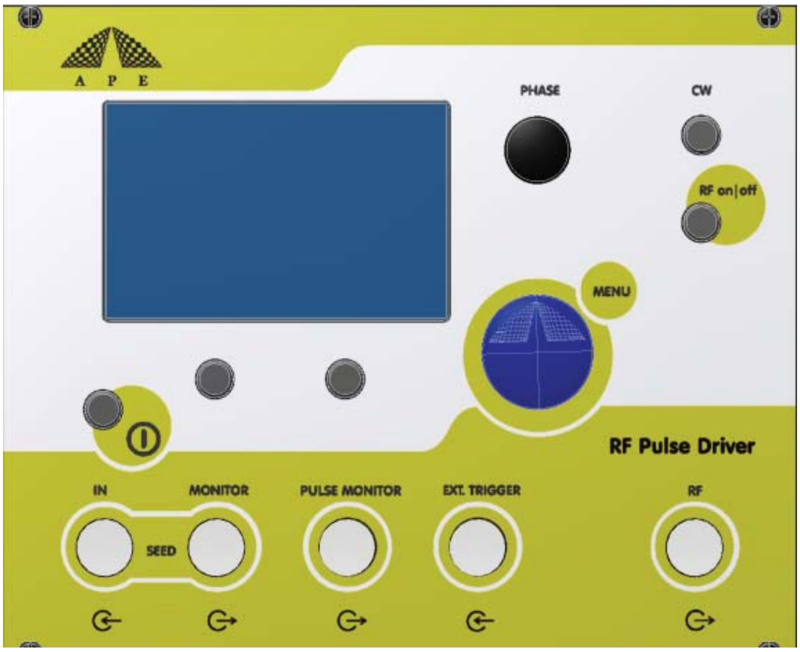


Fig.15 Driver electronice unit front panel

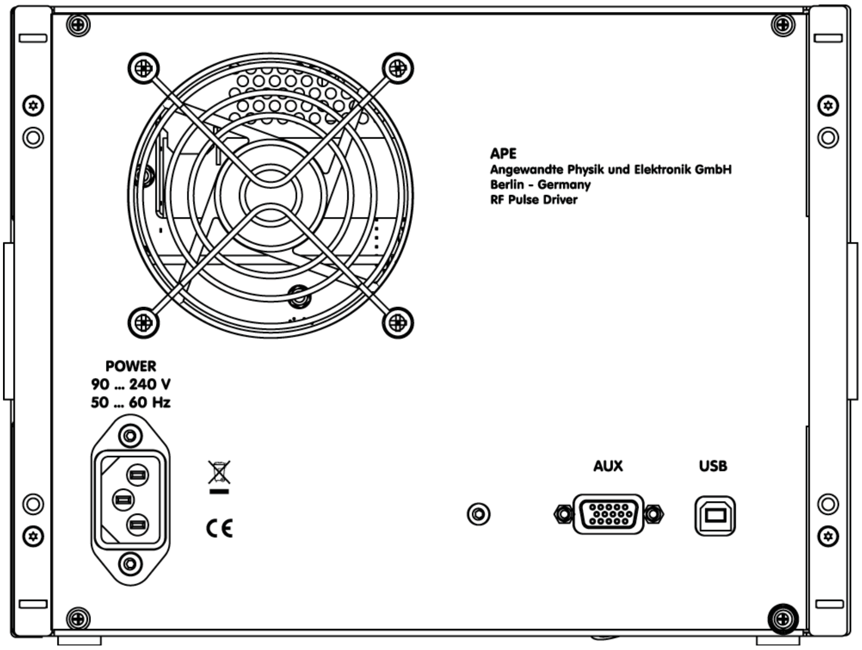


Fig. 16 Driver electronics unit rear panel

3.1 Cable Connection and Start Up

- Connect the RF signal input cable of the optics module with the TNC output “RF” at the front panel of the driver electronics. You should only use the delivered RF connection cable without extension to ensure an optimum fitting of the RF components.
- Give the synchronization signal with laser repetition rate (from a fast photo diode output of the mira) to the „SEED“ BNC input at the front panel of the driver electronics.
- At the “PULSE MONITOR” output pulsed signals (500 mV) synchronously to the selected laser pulses are available. For precise triggering it is recommended to use a 50 Ω termination which causes the voltage level to slightly drop down.
- The “SEED MONITOR” output gives you a monitor signal of the seed input, i.e.the fast photodiode of the Mira. Connect the “SEED MONITOR” to a fast oscilloscope (>400 MHz recommended) and trigger the system with the “PulseMonitor”.
- The “EXT. TRIGGER“ input can be used for external triggering up to 3 MHz with a TTL signal. In this case the laser pulse following the trigger signal will be selected. Choose the „EXTERN“ operation mode at the controller in this case (see also paragraph “External triggering” in this manual). If you do not use the external trigger mode please leave the “EXTERN TRIGGER“ input disconnected to avoid disturbances of the RF signal.
- Connect the power cord to the rear panel of the electronics and the wall socket.
- After having connected the signal cables the power can be switched on at the front panel. The „ON” state is indicated by a red LED in the „ON“ button. The display will show you all settings and the measured oscillator repetition rate.
- The RF power can be switched on and off at the „RF ON“ button. The „ON“ state is indicated by the green LED in the RF button.

CAUTION! Connect or disconnect the RF-signal cables only when the RF power is switched off!

3.2 Function of buttons

RF on|off

RF button switches on and off the RF power. Green lightning button signalize RF power on. Green blinking or red signalize an error, RF output is disabled. See error messages for details.

CW

The CW button switch to a mode with a continues RF signal. To turn on the RF signal, the „RF ON/OFF“ button should be pressed. The RF signal is generated by an internal oscillator without an external seed signal. The RF power in CW mode is about 400 mW.

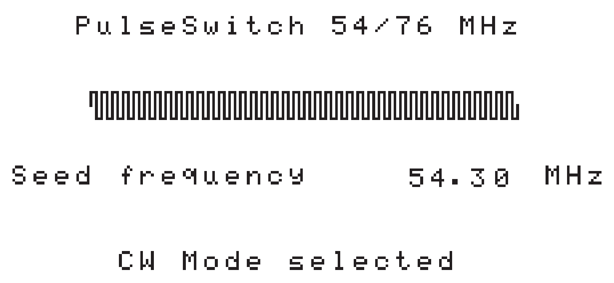


Fig. 17 Display in CW mode

Softkey1/2

The keys below the display has variable function (moving cursor or accept messages), depending the menu state.

PHASE knob

Adjust the RF signal phase using the Phase knob.

MENU knob

Menu navigation and parameter adjustment is simply made with the menu knob (see below 3.4).

3.3 Display

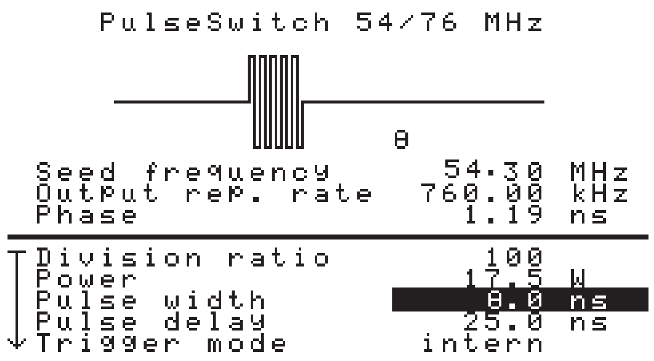


Fig. 18a

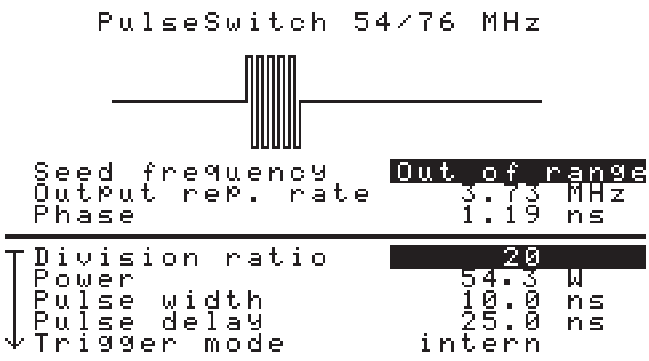


Fig 18b

The Display shows in the upper a sketch of the RF-burst-pulse (Fig. 18a). Above this sketch the name of the unit and the predifined laser repetition rate (as ordered) is displayed. The seed frequency should be within a range of ± 1 MHz of this value.

- SEED FREQUENCY

Below the pulse skectch the measured seed input frequency is displayed. The frequency is measured every second. When the frequency leaves valid range (± 1 MHz of the predefined repetition rate given in the top line) a blinking message appear (see Fig. 18b).

- OUTPUT REPETITION RATE

When internal trigger mode is selected, repetition rate is calculated by deviding the seed frequency by the division ratio. During external trigger mode the frequency of the external trigger input is measured and displayed.

- PHASE

The phase of the RF signal can be controlled by the separate phase knob. The phase shift causes a shift in the range from 0 to 3 ns.

- PARAMETER SETTINGS

In the bottom half the menus for parameter setting are placed.

3.4 Setting the Operational Parameters

The operational parameters are chosen at the controller unit with the two button below the display and the blue rotary knob. To adjust the phase, there is separate the black knob. Parameters will be saved at power off and restored next power on. For safety reasons RF is always off directly after turning on the device.

Menu

By turning the blue menu knob you can navigate via the menus. To change a parameter, select the corresponding line and press the blue knob. When you see a blinking cursor square, the corresponding dezimal position of parameter can be changed by turning the menu knob. With the two buttons below the display you can shift the cursor left or right to control more raw or fine. Changes will be set immediately. To leave edit mode press menu knob again.

To enter a submenu (identified by ‚-->‘) also press the menu knob. To move back to the upper menu, select the last line containing ‚Back   <--‘ and press menu knob.

Main Menu	Division ratio
	Power
	Pulse width
	Pulse delay
	Trigger mode
	Display
	LCD Backlight
	Default values
	Settings
Settings Menu	Seed trigger lev.
	Beep
	Factory defaults
	Firmware update
	Back

Fig. 19 Menu structure

MAIN MENU

Division Ratio („DR“)

Division ratio of the internal frequency divider for the laser repetition rate, the synchronization signal of which is connected to the „SEED“ input. It determines the repetition rate of the output signal of the pulse selector shown in the upper part of the display. When set to „200“, for instance, every 200th laser pulse is diffracted to the 1st order, when set to „300“ every 300th pulse is diffracted and so on.

Range: 2 ... 260000 optional

Power

Range: 0.5 ... 17.5 W

This is the output RF power in Watts with 50 Ω load. At division ratios smaler than 1:20 the maximum possible setting is automatically limited to a value to avoid damage of the crystal. This is indicated by „!!“ on the display (see Fig. 20). To unmark selection go to power value and press menu knob. The actual limit also depends on the chosen setting of the pulse width.

Adjust this parameter while watching the output laser pulses with a fast photodiode and an oscilloscope and optimise for high diffraction efficiency and high pulse to pulse contrast ratio!

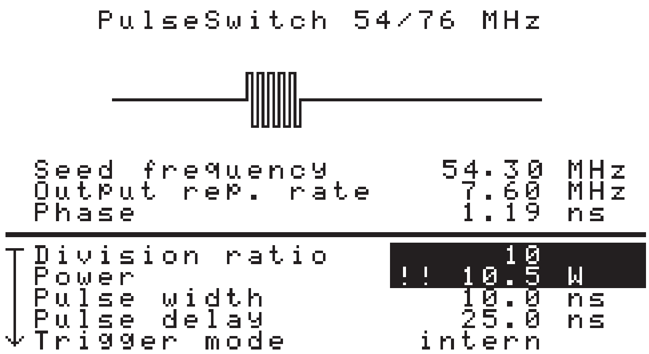


Fig. 20

Pulse Width

Width of the single RF pulses in ns.

Range: 4.0 ... 15.0 ns

Adjust this parameter while watching the output laser pulses with a fast photodiode and an oscilloscope and optimize for high diffraction efficiency and high pulse to pulse contrast ratio!

For the 25 ns pulse width option and high repetition rates the pulse width may be reduced automatically to get a minimum „ OFF” time of 7 ns betwen two output pulses. In this case the pulse width is marked by „!!“. To unmark item go to pulse width and press menu knob.

Pulse Delay

Delay of the RF output pulse relative to the synchronization pulses („SEED“).

Range: 0 ... 50.0 ns

Adjust this parameter while watching the output laser pulses with a fast photodiode and an oscilloscope and optimize for high diffraction efficiency and high pulse to pulse contrast ratio!

Trigger Mode

Range: intern/extern

Synchronization of the RF pulse can be achieved by internal or external trigger signal. Internal trigger signal is generated by the internal frequency divider for the laser repetition rate. The repetition rate is controlled by the division ratio.

When selecting external trigger mode the “EXT. TRIGGER” input must be used for external triggering with a TTL signal (see Fig. 21). In this case the laser pulse following the trigger signal will be selected.

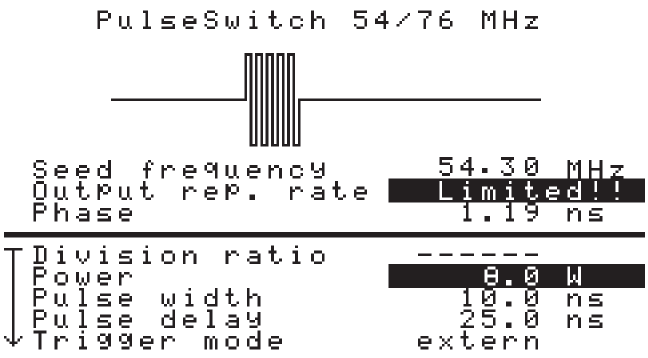


Fig. 21

If you do not use the external trigger mode, the “EXTERN TRIGGER“ input should be left open, otherwise the RF pulse quality could be affected.

The maximum repetition rate achievable with external triggering is 3 MHz. If the frequency of the external trigger exceed 3 MHz the message “Limited!!“ appears at the output repetition rate display.

DISPLAY

Range: ON/OFF

The display light can be switched ON/OFF by pressing menu knob.

LCD BACKLIGHT

Range: 10..100%

The Display backlight can be dimmed down to 10% to avoid unintentional light.

DEFAULT VALUES

This Item is used to set the parameters Division ratio, Pulse delay, Pulse Width, Trigger mode and RF Power to default value.

SETTINGS

Switches to the submenu SETTINGS.

SETTING MENU

SEED TRIGGER LEVEL

Range: 15..300 mV

In some cases it can be necessary to adjust the trigger level for the seed input.

BEEP

Range: ON/OFF

When on, a buzzer signalize errors and warnings. Also if you reach the end of parameter range a signal ton is generated.

FACTORY DEFAULTS

When this item is selected the seed trigger level can be reset to the factory calibration value. The value will be reset only when the appearing message was accepted with OK.

FIRMWARE UPDATE

For future use the device firmware can be updated. Only available in agreement with service personnel.

BACK

Leave the Settings menu, go back to main menu. Setting the Operational Parameter.

4. Error Signal „Fault”

The electronics of the PulseSwitch has an integrated safety circuit that prevents the system from putting out high RF power levels that could damage the modulator crystal. A „FAULT“ message on the screen indicates a cw output power level exceeding 0.8 W. In this case the RF output will be switched off automatically and the LED turns to the colour red at the top.

Possible reasons for this fault can be, for instance, unstable triggering conditions at the „SEED“ input or loose cable connections at RF OUT to the optics and following back reflections and defective electronics.

In the case the „FAULT“ lights up during operation, check the system for possible error sources (for instance external triggering with high frequency, unstable seed input signal, loose cable connections) and eliminate them, switch on the RF. Confirm the „FAULT“ message on the display. Then it is possible to switch on the PR power signal again. If still no normal operation is possible („FAULT“ is signalled again after switching on RF output) or the error occurs repeatedly during operation with the internal frequency divider, please contact the service personnel of your supplier for technical support.

5. Routine operation

To achieve cavity dumping, three tasks have to be completed:

- optimise the cavity for maximum intracavity power under mode-locked conditions
- optimise the Bragg cell position
- optimise the driver electronics settings for maximum outcoupled power

5.1 Fine Adjustment of the Optics

After basic alignment (see chapter 2.3) and connection of the optics module to the driver electronics (see chapter 3) open the slit completely, get the system lasing and turn on the mains of the PulseSwitch electronics.

1. Choose cw mode by pressing the „CW“ button below the display. By pressing the RF-ON button a cw RF signal of about 200 mW amplitude is given to the modulator crystal. The PulseSwitch electronics now works with its internal oscillator, thus the laser does not need to mode-lock. Now the modulator crystal (Bragg cell) has to be adjusted so that a diffracted beam in the 1st order is to be seen. While adjusting the Bragg cell, always readjust CM3 to keep the laser running. For readjusting the laser cavity always switch the RF power off. Proceed in the following steps:
2. Place the delivered aperture in front of the collimating mirror CM2 in a way that the laser beam is not clipped by the aperture. Use an IR viewer to watch the white paper above the aperture for an eventual appearance of a spot.
3. Now adjust the vertical position of the modulator to have the beam at about 1/4 of the modulator height from the transducer. The transducer is located at the bottom of the modulator crystal. Use the vertical position adjustment screw [10].
4. While monitoring the aperture slide the crystal horizontally (Y-direction) about 2 mm in each direction from the centre position of the beam (use [11]) until a spot appears 2 ... 4 mm above the zero order spot. To make sure that this is the 1st order beam switch off the RF signal („RF ON“ button). Then the spot must disappear.
5. Switch on the RF signal again and adjust the horizontal modulator position and the Bragg-angle by turns to roughly maximize the 1st order intensity by appearance. (Always readjust the cavity with CM3 [14, 15 in Fig. 13])

If no diffracted beam can be observed over the whole horizontal adjustment range, slightly change the Bragg-angle (with [9] in Fig. 13) and repeat the above steps.

6. After having optimised the diffracted beam by appearance remove the aperture and adjust the output mirror M4 height [2] and horizontal position, so that the intracavity beam is passing above M4 and the 1st order beam hits the mirror M4 after being reflected by CM1. To adjust the horizontal position, tilt the mirror M4 with screw 3 using an Allen key, see Fig. 22. If the adjustment range is not sufficient loosen the mirror from its holder (use an Allen key) and slide it to the proper position. Then fix M4 again.

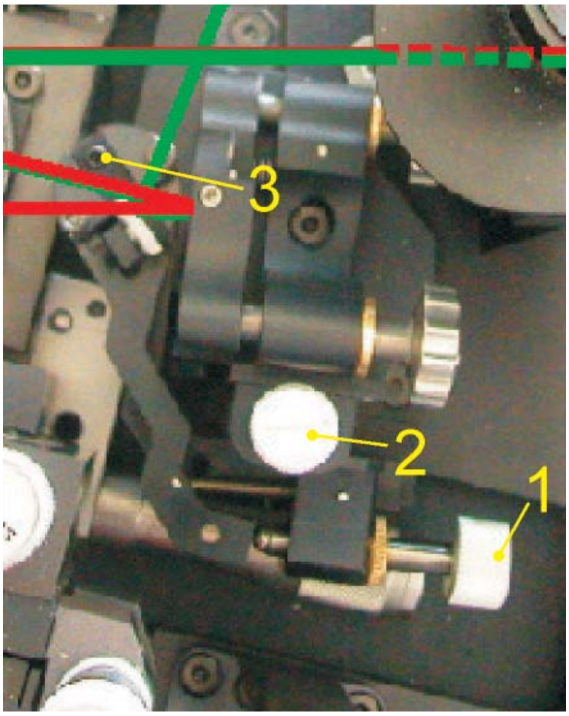


Fig. 22 Mirror M4 mount with beam path (red - intracavity beam; green - outcoupled beam)

7. The outcoupled beam (the first order diffraction on M4) should be reflected to M5. To adjust the horizontal tilt of M4 use [1]. Adjust M5 and M6, so that the deflected beam leaves the cavity dumper through BW.
8. Take a sheet of paper and monitor the output beam profile at a distance of about 1m. Slightly adjust the horizontal X-position of the modulator [8 in Fig. 13] until only one round spot is to be seen (and not 2 spots above each other).
9. Place a laser power meter into the deflected beam. To maximize the diffraction efficiency the horizontal [11] and vertical [10] crystal position must be adjusted by turns, as well as the Bragg-[9] and Brewster-[12] angles of the crystal. The vertical position should be adjusted to let the beam pass the crystal as close as possible to the transducer at the bottom of the crystal. (Always correct the cavity alignment with CM3). After having maximized the power of the diffracted beam in cw mode the PulseSwitch must be optimised for pulsed operation. To do this monitor the intracavity pulse train with a fast oscilloscope terminated with 50 Ω by connecting the fast photodiode output of the Mira with the SEED input and the oscilloscope with the SEED MONITOR of the electronics unit (see previous chapter). Trigger the oscilloscope with the PULSE MONITOR output signal of the PulseSwitch.

5.2 Achieving Cavity Dumping

Starting values for the PulseSwitch electronics are:

DR = 100
PW = 12.0 ns
DE = 9.0 ns
PO = 8 W

1. Switch off the cw mode at the CW button and the RF-Power (RF-ON button) and bring the system into mode-locked operation by closing the slit and monitoring the pulse with an oscilloscope. Pay attention that the system does not generate double pulses. Switch on the RF-ON button. Now a modulation of the pulse train with a period of 100 pulses should appear on the oscilloscope. The first small pulse of this period is the diffracted pulse. The intracavity pulse then needs about 100 (or even more) round trips to reach the steady state energy level again. The amplitude ratio between the diffracted pulse and its preceding non-diffracted pulse is a measure of the diffraction efficiency. Fig. 23 shows a typical intracavity pulse train from the SEED MONITOR output as seen on an oscilloscope.

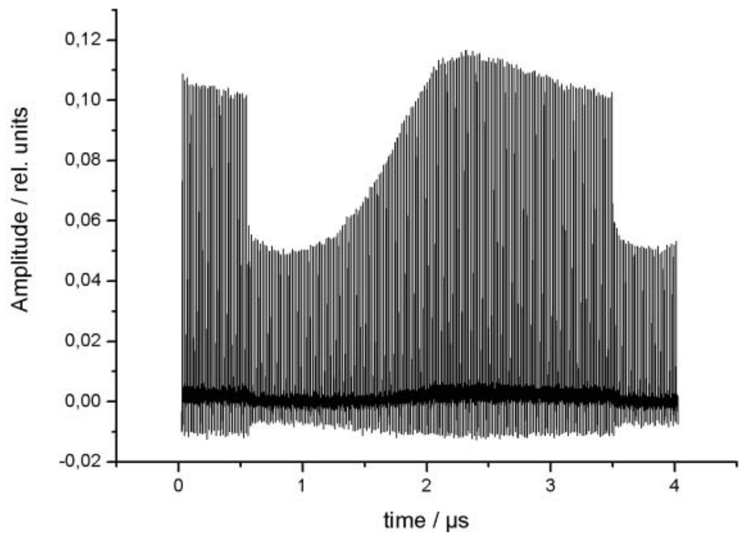


Fig. 23 Typical intracavity pulse train in cavity dumped operation with approximately 50% diffraction efficiency

2. Maximize the diffraction efficiency by varying of first Phase (PH) and Delay (DE). If the mode-locking breaks down, reduce the RF-power.
3. Raise the RF-power as long as mode-locking is stable. The phase always has to be adjusted after changing the RF-power. Then reduce the RF-power by 0.5 W to ensure stable mode-locking and cavity dumping operation.
4. Observe the diffracted beam with a fast photodiode to ensure a good contrast ratio between diffracted and non-diffracted pulses. To improve the contrast ratio and obtain high diffraction efficiency change the Delay setting (DE) and Pulse width (PW).

5. Set the Division Ratio (DR) to the desired value. For division ratios < 200: While reducing the division ratio a reduction of the RF-power may be necessary to maintain mode-locked operation. When the division ratio is raised, a higher RF-power may be applied, thus getting more energy per pulse.
6. To get maximum output power, switch off the RF-Power, raise the Verdi pump power by 0.5 W, optimise the cavity dumping as described above (start with 2., no change in pulse width and delay needed) and compare the output power. If the output power is higher, raise the pump power again, if it did not change or even lowered, reduce pump power. Please note, as higher the pump power, as more susceptible is the system to develop two or more pulses simultaneously in the mode-locked regime (double pulsing).

Once the optimum adjustment is found it needs only slight correction when the system is turned on next time. If you change the laser wavelength drastically, the Bragg-angle [9] may need to be readjusted slightly. This is done best with open slit and CW-operation of the PulseSwitch electronics.

5.3. Changing the Wavelength

To change the wavelength of the Mira / Cavity Dumper follow the steps below:

1. Set the Verdi pump power to 4.5 W (start with 6W for wavelength > 900nm)
2. Set the Mira electronics to cw,
3. Open the slit and switch the PulseSwitch electronics to cw-operation (press “CW” and “RF ON”, both LEDs should be lit).
4. Change the wavelength with the procedure described in the Mira manual (change the birefringend filter position with the micrometer screw and move the prism for dispersion compensation).
5. Switch off the RF-signal and adjust for the optimum prism position. Correct the Mira end mirror and the PulseSwitch CM3 mirror for maximum output power. Switch the RF-signal on again. (cw-mode)
6. The Bragg-angle is relatively insensitive to the wavelength, thus in most cases readjustment of the Bragg-angle is not necessary. If you want to adjust the Bragg-angle place a power meter behind the cavity dumper and adjust the Bragg-angle for maximum output power. Switch off the RF-power and adjust the cavity with CM3 using the power display from the Mira electronics. Switch on the RF-power and check for the Bragg-angle again.
7. Switch off the “CW”-RF power (press CW and RF-ON), switch the Mira electronics to ML (mode-locked regime) and close the slit until you have mode-locked operation. Check the peak voltage of the fast photodiode. If the peak voltage drops below 30 mW take out the neutral density filter in front of the Mia control diagnostics. (this may be necessary for wavelength below 740nm or above 900nm.) The filter has to be replaced if the fast photodiode starts saturating or the Mira control electronics shows: STAGE SATURATION ERROR. Switch on the RF-power (“RF-ON”) and optimise phase, delay and RF-power as described in chapter 7.1.
8. To get maximum output power raise the Verdi pump power by 0.5 W, go to step 7 and compare the output power. If the output power is higher, raise the pump power again, if it did not change or even lowered, reduce pump power.
9. Above 900nm strong water absorption lines do occur. Purge the cavity with dry nitrogen on both, the Mira end and the PulseSwitch end.

6. Standard Mira Operation without Removing PulseSwitch Optics

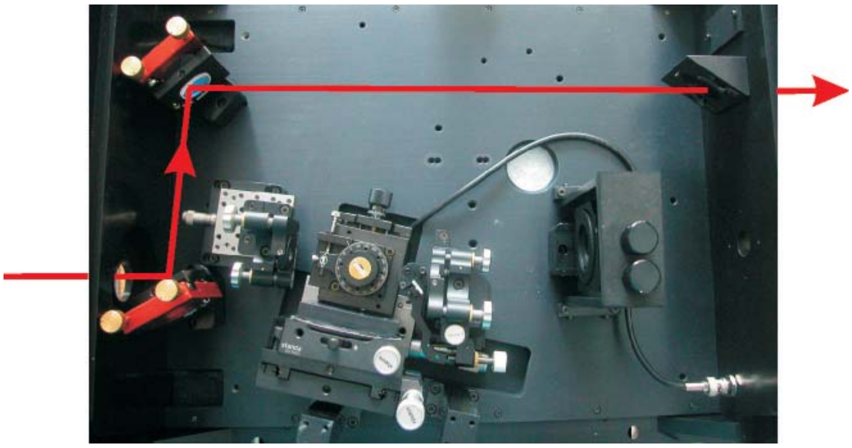


Fig.24 Beam path through the PulseSwitch during normal Mira operation

The Mira can be operated in its standard configuration without removing the PulseSwitch optics.

- You just need to move M5 and rotate M6 as shown in Fig. 24. Unscrew the mounting block of M5 and place the mirror in front of the input aperture of the PulseSwitch. Use the two threads in the bottom to fix M5 again. Unscrew the M6 mounting block, rotate it by approximately. 30 degrees and fix it using the designated mounting holes on the bottom. (Fig. 25)
- Insert the output coupler in the Mira. Then place a beam block in front of the input aperture of the PulseSwitch, take out the Slit and place it into the Mira.
- Remove the neutral density filter from the Mira, exchange the coated beam splitter with the original uncoated one in the Mira (Fig. 8).
- Bring the Mira to normal operation again. Reduce output power, take out the beam block from the PulseSwitch and use M5 and M6 to direct the beam through the Brewster-window BW as shown in Fig. 25.
- Close the hole for the Slit in the cover of the PulseSwitch with the delivered lid. (Fig. 12, it is the same lid to cover the Slit hole in the Mira cover.)
- Now you can bring the Mira to the desired power and operate as usual.

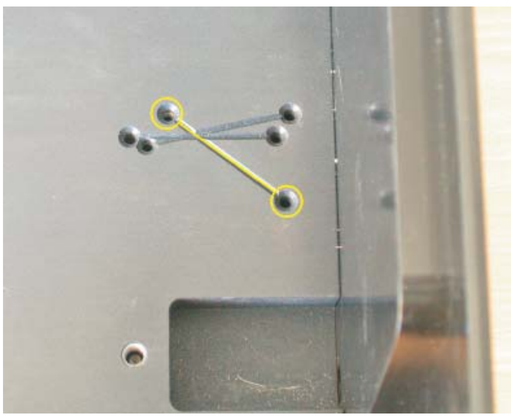


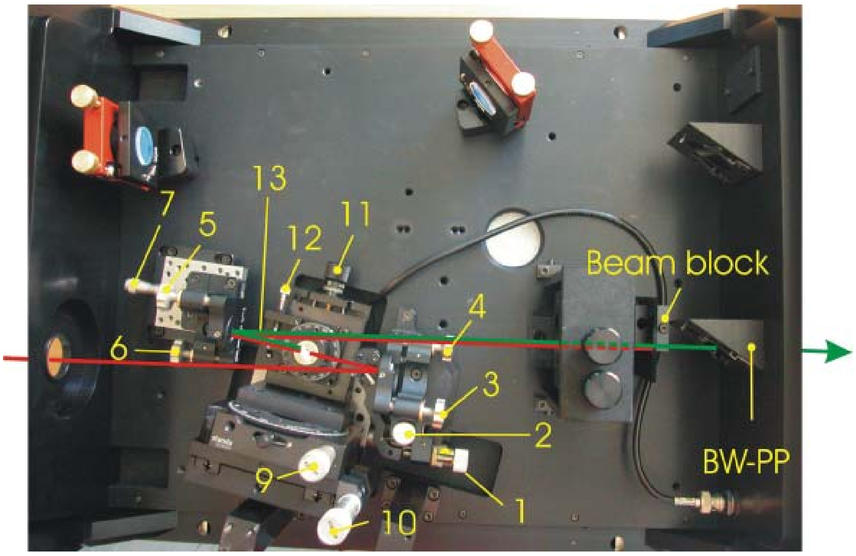
Fig. 25 Mounting holes for mirror M6

7. Pulse-Picker Operation (optional)

For certain applications as ps-operation of the Mira no cavity dumper operation is possible, but still a reduction of the repetition rate is necessary. Therefore the PulseSwitch can be ordered as dual system: Cavity Dumper / Pulse Picker. Also a later upgrade of the PulseSwitch to a dual system is possible. Please ask your local salesperson or contact APE directly.

The conversion of the PulseSwitch to Pulse Picker operation is easily done.

7.1 Pulse-Picker Installation and Basic Adjustment



2 -	M4 vertical position control
3 -	CM1, vertical tilt control
4 -	CM1, horizontal tilt control
5 -	CM2, vertical tilt control
6 -	CM2, horizontal tilt control
7 -	CM2, horizontal position adjustment screw
8-	Modulator, horizontal X-position adjustment screw
9 -	Modulator, Bragg-angle control
10 -	Modulator, vertical position adjustment screw
11 -	Modulator, horizontal Y-position adjustment screw
12 -	Modulator, Brewster-angle control
13 -	Modulator, rough Brewster-angle lock screw

Fig. 26 Pulse picker beam path and adjustment elements (green - deflected beam)

1. Place a beam block in the PulseSwitch, so the laser beam can not hit CM1. Loosen the locking screws of the PulseSwitch optics unit from the optical table.
2. Rebuild the Mira to its normal operation. Place the Mira output coupler (M1) into its holder and relocate the slit to its original position (Fig. 7). Remove the neutral density filter behind the beam splitter from its holder (Fig. 10).
3. Remove the lid for the slit hole (Fig. 12) from the Mira cover and mount it into the PulseSwitch cover.
4. Remove the Mirror CM3 from its holder (see Fig. 4). Drive the modulator with the micrometer screw ([10] in Fig. 20), mirror M4 ([2] in Fig. 26) and the beam block out of the beam path.
5. By adjusting the output coupler M1 of the Mira bring the Mira back to lasing operation again. Optimise the output power with help of the Mira diagnostics electronic. Maximize the power reading of the diagnostics electronics by adjusting the Mira beam splitter mount behind the output-coupler. Optimise power again with output-coupler and Mira end mirror.
6. Attenuate the output power by reducing the pump power of the Verdi.
7. The following elements should be set to the reference values given in the test protocol. Typical starting values are given here in case the protocol got lost.

Typical value

- Bragg-angle [9 in Fig. 26],	-3°
- Brewster-angle [12 in Fig. 26]	0°
- horizontal position of the collimating mirror CM2 [7 in Fig. 26]	2.5 mm
- horizontal X-position of the Modulator [8 in Fig. 26]	12.5 mm

If this is done, the distance between CM1 and CM2 should be approximately 101mm and the Bragg cell in the middle between both mirrors. Drive the Bragg cell out of the beam path with the vertical position adjustment screw ([10] in Fig. 26) of the modulator .

8. Make sure the beam hits CM1. If not, try to walk the beam in the Mira cavity by using Mira mirrors M2 and the output coupler.
9. Adjust the beam to fall onto the collimating mirror at middle height and about 2 mm right from centre. Use the tilt controls of the focusing mirror CM1 [3, 4]!
10. Now the modulator crystal can be driven into the beam path with the vertical position adjustment screw ([10] Fig. 26). While doing that, the horizontal position adjustment screw [11] should be in a middle position. Now the beam should fall into the centre of the collimating mirror. Use the tilt controls of the focusing mirror [3, 4] to correct!
11. Check the beam path inside the crystal with an IR-viewer and correct the horizontal Y-position of the crystal ([11] in Fig. 26) to get the beam to the centre (see Fig. 27).

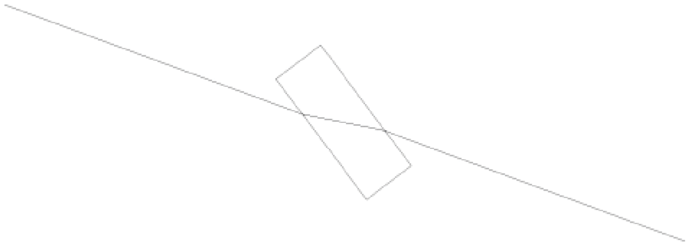


Fig 27 Beam path inside the transducer crystal

12. Direction and collimation of the output beam can be adjusted with the tilt controls ([5,6] in Fig. 26) and horizontal position control [7] of the collimating mirror CM2.

7.2 Pulse-Picker Fine Adjustment of the Optics

The fine adjustment of the optics should also be done at first with attenuated laser beam. After basic adjustment and connection of the optics module to the driver electronics the power can be switched on at the electronics. Choose cw mode by pressing the „CW“ button below the display. Now a cw RF signal of about 200 mW amplitude is given to the modulator crystal.

Now the modulator crystal has to be adjusted so that a diffracted beam in the 1st order is to be seen. Proceed in the following steps:

1. Place a beam stop (for instance black aluminium) in front of the collimating mirror to screen the laser spot. Use an IR viewer to watch the spot.
2. Now adjust the vertical position of the modulator to have the beam at about 1/4 of the modulator height from the transducer. The transducer is located at the bottom of the modulator crystal. Use the vertical position adjustment screw [10].
3. While watching the spot on the screen slide the crystal horizontally about 2 mm in each direction from the centre position of the beam (use 11 in Fig. 26) until a second spot appears 2 ... 4 mm above the zero order spot. To make sure that this is the 1st order beam switch off the RF signal („RF ON“ button). Then the spot must disappear.
4. Switch on the RF signal again and adjust the horizontal modulator position and the Bragg-angle by turns to roughly maximize the 1st order intensity by appearance.

   If no diffracted beam can be observed over the whole horizontal adjustment range, slightly change the Bragg-angle and repeat the above steps.
5. Now remove the attenuators from the beam path to ensure maximum beam quality. Observe again the diffracted beam and correct Bragg-angle and horizontal position of the crystal, if necessary.
6. After having optimised the diffracted beam by appearance remove the beam stop (screen) and adjust the collimating mirror tilt controls [5, 6 in Fig. 26] to let the diffracted beam leave the optics through the output Brewster-window parallel to the table top. Use the adjustable beam stop [see Fig. 24] to suppress the zero order beam.
7. Use a laser power meter to further maximize the diffracted beam. To do this the horizontal and vertical crystal position must be adjusted by turns, as well as the Bragg-and Brewster-angles of the crystal.

The vertical position should be adjusted to let the beam pass the crystal as close as possible to the transducer at the bottom of the crystal.

After having maximized the power of the diffracted beam in cw mode the PulseSwitch must be optimised for pulsed operation. To do this allow the zero order beam to pass the output aperture (slide the beam stop out of the beam) and detect the out coming pulses with a fast photodiode and an oscilloscope. Trigger the oscilloscope with the „PULSE MONITOR“ output signal of the PulseSwitch.

8. Switch off the cw mode at the „CW“ button and adjust the PulseSwitch to the following settings: DR = 20, PW = 8.0 ns, DE = 1.0 ns, PO = 16.5 W. Now every 20th pulse should appear with smaller amplitude on the oscilloscope. The ratio between diffracted and non-diffracted pulses is a measure of the diffraction efficiency.

9. Maximize the diffraction efficiency by variation of Pulse width (PW), RF-Power (PO), and Delay (DE).

10. Improve the diffraction efficiency by changing the Bragg-and Brewster-angles of the crystal again [8, 9]. Change the Brewster-angle in small steps always correcting the horizontal position.

11. The diffraction efficiency and contrast ratio can now be further optimised by adjusting the horizontal position of the modulator (Bragg cell) [8]. Doing this the focal length can be fitted to the beam divergence of the laser. Change in small steps always correcting the horizontal modulator position [11].

12. Observe the diffracted beam with the photodiode to ensure a good contrast ratio between diffracted and non-diffracted pulses.

13. After having found the optimum adjustment and operational parameters adjust the position and collimation of the output beam with the collimating mirror controls [5, 6, 7]. Use the height adjustable beam block [see Fig. 20] to block the zero order beam.

14. Set the Division Ratio (DR) to the desired value.

Once the optimum adjustment is found it needs only slight correction when the system is turned on next time. If you change the laser wavelength, the Bragg-angle ([9] in Fig. 26) must be readjusted.

7.3 Pulse Picker Specification

Wavelength	700 ... 1000 nm
Efficiency	> 50% [1)]
Contrast ratio	> 500 : 1 [2)]
Max. optical input power (P_{AV})	1500 mW [3)]
Input frequency (f_{REP})	76 MHz +/- 1MHz
Division ratio	f_{REP} /2 ... f_{REP} /260000 or externally triggered

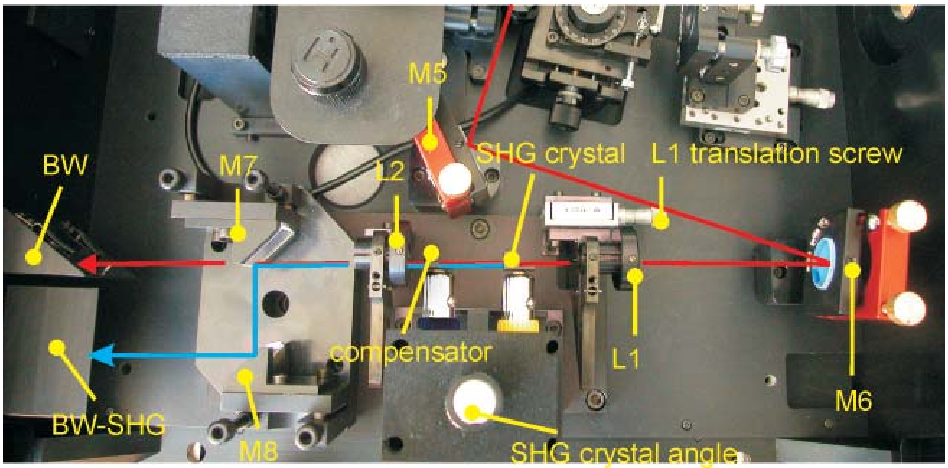
[1)] Percentage of incident pulse energy in diffracted output pulse, measured at 800 nm and division ratio f_{REP} /20. At division ratio f_{REP} /2 the efficiency is >20%.
[2)] > 500:1 applies for non-adjacent pulses. Main pulse to adjacent pulse contrast ratio is >75:1 (@ 800 nm, f_{REP} /20).
[3)] These values depend on the laser spot diameter in the crystal and thus apply only for a certain system configuration. Please consult our technical staff to determine the maximum input power level applicable for your laser system.

8. SHG Operation (optional)

8.1 SHG Description

The PulseSwitch SHG unit is used for the frequency doubling of Ti:Sa laser beams by means of nonlinear interaction in optical crystals. It is designed for the application with tuneable cw-mode-locked laser systems (e.g. Ti:Sapphire lasers) and optimised for use in the APE cavity dumper PulseSwitch. Every PulseSwitch can be upgrades with an SHG unit easily.

8.2 SHG Construction and Function



BW	Brewster-window for residual fundamental
BW-SHG	Brewster-window for SHG output
L1	Focus lens
L2	Collimating lens
M5, M6 -	Steering mirrors
M7, M8 -	Dichroic mirrors

Fig. 28 Optical alignment of SHG unit (blue - SHG; red - fundamental beam)

The cavity dumped laser beam is directed with the steering mirrors M5 and M6 centrally onto the focusing lens L1. This lens generates a small beam waist with high energy density inside the nonlinear SHG-crystal. There the fundamental radiation is converted into radiation with half wavelength (SHG). The efficiency of this conversion process depends strongly on the relation between wavelength and crystal cut (phase matching). After the conversion the SHG beam and the remaining (depleted) fundamental beam pass a glass block Co that compensates the geometrical beam deviation introduced by the SHG crystal rotation.

The crystal drive is necessary for the angular movement of the crystal (phase matching) and the counter directional one of the compensator. By means of the lens L2 the beams are recollimated. The dichroic mirror M7 separates the frequency-doubled beam (90° reflected) from the depleted fundamental beam (transmitted to output BW). Another dichroic mirror M8 separates the SHG signal from the remaining fundamental parts and directs the SHG beam to output BW-SHG.

Fig. 29 Femtosecond-compensator (black ring) in mount (the fs-SHG crystal looks similar, but has a yellow ring)

The crystal drive is used for fixing and tilting SHG crystal and compensator. Both are mounted on plug adaptors with bayonet mount for simple exchange, see Fig. 23, (for different pulse durations and wavelength ranges) and marked with coloured rings for differentiation (see chapter 8.5 SHG Routine operation).

With the tuning knob (SHG crystal angle) the crystal is tilted to meet the optimum angle between crystal axis and beam axis (phase matching angle) according to the current wavelength. When tilting the crystal the compensator is automatically tilted in the opposite direction by the same value. With this the geometrical beam displacement caused by the transmission through an optical plate is compensated (ps only).

8.3 SHG-Specification

Wavelength range	700 ... 1100 nm	
Doubling crystal	fs	2 mm BBO
	ps	6 mm BBO
SHG efficiencies	fs	typical: 40% efficiency @ 800nm, 40nJ
	specification: 35% efficiency @ 800nm, 40nJ	
	ps	typical: 15% efficiency @ 800nm, 40nJ

8.4 SHG Installation, Handling

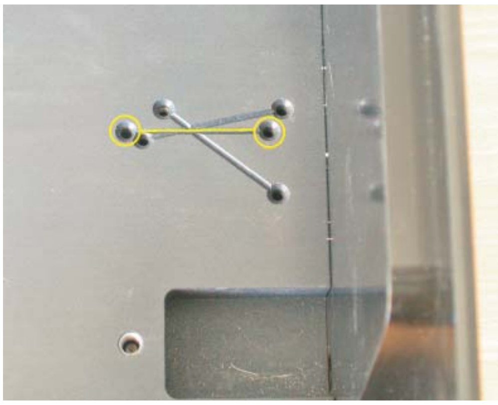


Fig. 30 Mounting holes for mirror M6 for SHG configuration

1. If the SHG unit is not mounted yet, take out mirror M5 and place it to the position shown in Fig. 28. Unscrew the mirror M6 and rotate it slightly. To fasten mirror M6 use the mounting holes shown in Fig. 30.
2. Place the SHG optics module into the PulseSwitch housing, see Fig. 22 and fix it with the 3 delivered M6 screws.
3. Remove the round lid from the top cover of the PulseSwitch housing for the SHG tuning knob
4. Tune the laser to a well visible wavelength
5. Block the beam
6. Install crystal and compensator according to your actual pulse duration (ps: red / white, fs yellow / black, see also chapter Routine operation)
7. Place a beam trap behind the instrument, remove L1, introduce the laser beam into the input and adjust the beam with M5 and M6 that the beam passes the centres of the L1 mount, the SHG crystal, the compensator and L2
8. If L1 mount, SHG-crystal, compensator and L2 are not in line, correct it by adjusting L1- and L2 mount
9. Insert and fix L1, so that the distance between L1 and the SHG crystal is approx. 50mm
10. Open the beam and check if it passes crystal and compensator centred, if not realign L1 mount and/ or M5/M6
11. Tilt the crystal with the tuning knob to a perpendicular position, check if the available tuning angle is nearly the same in both directions and if the compensator is parallel with the crystal (if not correct the angular position of crystal and compensator at their mounts)
12. Tune the crystal angle until a SHG beam is generated, optimise its intensity with focus position (L1 translation screw) and angle fine tuning
13. Align SHG-beam with dichroic mirror M7 to the centre of mirror M8 and with M8 further to the centre of output BW-SHG

14. Put a beam block about 1m behind the beam output, loosen L2 and slide it back and forth to collimate the SHG beam and fix L2 again.

8.5 SHG Routine operation

Marks of the crystals and compensators with respect to the pulse duration:

- ps-SHG crystal	red ring
- fs-SHG crystal	yellow ring
- ps-compensator	white ring
- fs-compensator	black ring

- Check beam alignment (position in crystal)
- Tune phase matching angle and focusing to their optimum (maximum of SHG signal)
- Realign phase matching angle (tilt tuning knob) when tuning the laser

8.6 SHG Troubleshooting

No or only very weak SHG signal

- No pulse generation of the laser or cavity dumper
- Crystal length not according to pulse duration
- Mixed up order of crystal and compensator
- Focusing point misaligned

Distortions of the mode-locking process in the laser by

- Back reflections from the crystal → tilt the crystal mount at a vertical axis that the reflected beam is horizontally tilted with respect to the incoming beam

Appendix 1: Cavity Dumper Specification

Wavelength	710 … 990 nm for 8W pumped Mira 710 … 900 nm for 5W pumped Mira (with X-wave mirror and Verdi pump laser)
Pulse energy	> 40 nJ / pulse (@500kHz, 800nm)
Contrast ratio	> 500 : 1 (for non adjacent pulses) > 300 : 1 (typical, for adjacent pulses)
Internal oscillator	integrated (200 mW RF power)
Frequency (f_{REP})	54.3 MHz (internal repetition rate, app. for central frequency, frequency changes when changing wavelength)
Division ratio	f_{REP}/2 ... f_{REP} /260000 or externally triggered
Pulse length	<150 fs @ 500kHz, 800nm (typical 120 fs)
Spatial Mode	TEM00
Polarization	horizontal

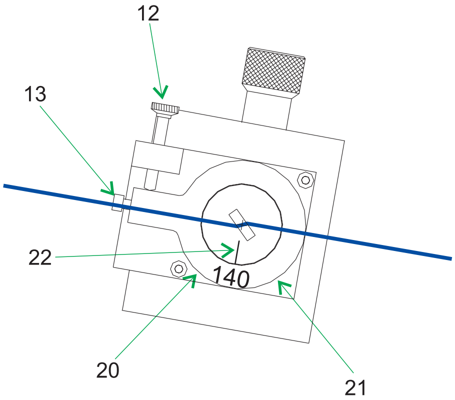
Beam quality (typical values)
- M^2 1.15
- beam diameter ($1/e^2$) 1.1 mm at exit port
- beam divergence 1.4 mrad (full angle)

Appendix 2: Installation of the Bragg-Cell

Caution! Do not touch the modulator crystal! The modulator is very sensitive against all kinds of pollution, scratching, and mechanical shock.

Set the Brewster-angle adjustment screw [12] to a middle position. Unlock the lock screw for the rough Brewster-angle adjustment [13] with a hex key and rotate the modulator holder to 0 degree. Lock the screw [13].

There are two small screws accessible through two holes in the side of the modulator holder with a 0.9 mm hex Allen key (see Fig. 31). These two screws hold the modulator socket. Loosen the screws so far that the modulator socket fits into the 1 inch hole of the modulator holder. Remove the modulator again. Thread the modulator RF cable from the bottom side through the 1 inch hole of the modulator holder. Screw the SMA connector of the cable tightly to the SMA connector of the modulator socket by hand. Do not use a tool! Try to leave the cable stress-free when holding the modulator in its later direction. The correct direction is given by the line mark [22] at the modulator socket. This line must be right-angled to the beam direction. This is given when the line points to the hole near the 140° mark. Set the modulator into the holder and fix it with the two screws [20, 21].



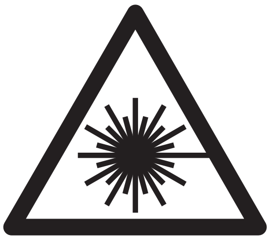
12	-	Brewster-angle control
13	-	Rough Brewster-angle adjustment lock screw
20, 21	-	Modulator lock screws, access holes
22	-	Mark for modulator direction

Fig. 31 Modulator assembly

Appendix 3: General Safety

Optical Safety

Laser light, because of its special properties, poses safety hazards not associated with light from conventional sources. The safe use of lasers requires that all laser users, and everyone near the laser system, are aware of the dangers involved. The safe use of the laser depends upon the user being familiar with the instrument and the properties of coherent, intense beams of light.

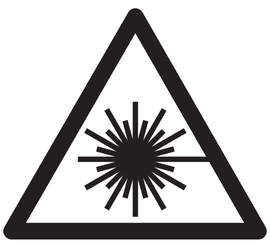


Direct eye contact with the output beam from the laser will cause serious damage and possible blindness.

The greatest concern when using a laser is eye safety. In addition to the main beam, there are often many smaller beams present at various angles near the laser system. These beams are formed by specular reflections of the main beam at polished surfaces such as lenses or beam splitters. Although weaker than the main beam, such beams may still be sufficiently intense to cause eye damage.

Laser beams are powerful enough to burn skin, clothing or paint. They can ignite volatile substances such as alcohol, gasoline, ether and other solvents, and can damage light-sensitive elements in video cameras, photomultipliers and photodiodes. The laser beam can ignite substances in its path, even at some distance. The beam may also cause damage if contacted indirectly from reflective surfaces. For these reasons and others, the user is advised to follow the precautions below.

1. Observe all safety precautions in the preinstallation and operators manual.
2. Extreme caution should be exercised when using solvents in the area of the laser.
3. Limit access to the laser to qualified users who are familiar with laser safety practices and who are aware of the dangers involved.
4. Never look directly into the laser light source or at scattered laser light from any reflective surface. Never sight down the beam into the source.
5. Maintain experimental setups at low heights to prevent inadvertent beam-eye encounter at eye level.



Laser safety glasses can present a hazard as well as a benefit; while they protect the eye from potentially damaging exposure, they block light at the laser wavelengths, which prevents the operator from seeing the beam. Therefore, use extreme caution even when using safety glasses.

6. As a precaution against accidental exposure to the output beam or its reflection, those using the system should wear laser safety glasses as required by the wavelength being generated.
7. Avoid direct exposure to the laser light. The intensity of the beam can easily cause flesh burns or ignite clothing.
8. Use the laser in an enclosed room. Laser light will remain collimated over long distances and therefore presents a potential hazard if not confined.
9. Post warning signs in the area of the laser beam to alert those present.
10. Advise all those using the laser of these precautions. It is good practice to operate the laser in a room with controlled and restricted access.

Electrical Safety

The Mira-PulseSwitch uses DC voltages in the laser head. All units are designed to be operated with protective covers in place. Certain procedures in this manual require removal of the protective covers. These procedures are normally used by a qualified trained service personnel. Safety information contained in the procedures must be strictly observed by anyone using the procedures.

Pump Source

Observe all safety precautions associated with the pump laser. Refer to the pump laser operators manual for additional safety precautions.

Safety Features and Compliance to Government Requirements

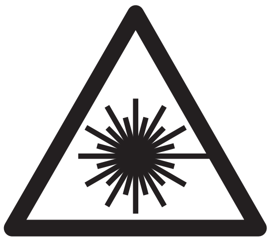
The following features are incorporated into the instrument to conform to several government requirements. The applicable United States Government requirements are contained in 21 CFR, subchapter J, part II administered by the Centre for Devices and Radiological Health (CDRH). The European Community requirements for product safety are specified in the „Low Voltage Directive“ (published in 73/23/EEC and amended in 93/68/EEC). The „Low Voltage Directive“ requires that lasers comply with the standard EN 61010-1 „Safety Requirements For Electrical Equipment For Measurement, Control and Laboratory Use“ and EN 60825-1 „Radiation Safety of Laser Products“. Compliance of this laser with the requirement is certified by the CE mark.

Laser Classification

The governmental standards and requirements specify that the laser must be classified according to the output power or energy and the laser wavelength. The Mira-PulseSwitch is classified as Class IV based on 21 CFR, subchapter J, part II, section 1040-10 (d). According to the European Community standards, the Mira-PulseSwitch is classified as Class 4 based on EN 60825-1, clause 9. In the manual and other documentation of the Mira-PulseSwitch, the classification will be referred to as Class 4.

Protective Housing

The laser head is enclosed in a protective housing that prevents human access to radiation in excess of the limits of Class I radiation as specified in the Federal Register, July 31, 1975, Part II, Section 1040.10 (f) (1) and Table 1-A/EN 60825-1, clause 4.2 except for the output beam, which is Class IV.



Use of controls or adjustments or performance of procedures other than those specified in the manual may result in hazardous radiation exposure. Use of the system in a manner other than that described herein may impair the protection provided by the system.

Location of Safety Labels

Refer to Fig. 11 for a description and location of all safety labels. These include warning labels indicating removable or displaceable protective housings, apertures through which laser radiation is emitted and labels of certification and identification [CFR 1040.10(g), CFR 1040.2, and CFR 1010.3/ EN60825-1, Clause 5].

When the pumping beam is allowed to impinge on the titanium: sapphire crystal, both laser and collateral radiation are produced. The laser beam is emitted from the laser aperture which is clearly labelled:

Fig. 32 Safety features and labels

Appendix 4: Troubleshooting

Problem	Solution
No outcoupled beam can be found	Is the RF-cable connected with the optics? Is the control electronics switched on? Is the Seed input connected with the fast photodiode of the Mira? Does the system mode-lock? Is the Seed signal >15mV, if not take out the neutral density filter in front of the detection electronics in the Mira Check general alignment, see chapter 4
The red FAULT LED is illuminated	See chapter 5
The beam profile is distorted (two spots above each other)	Correct the horizontal X-position of the Bragg cell
The beam profile shows interference fringes	Correct the phase
The beam profile is clipped	Check M4 alignment
The contrast ratio is low between outcoupled pulse and adjacent pulses	Optimise Delay DE and reduce pulse width PW
The pulse is noisy	Reduce RF-power, adjust phase, check for more stable mode-locking operation
Low output power	Optimise phase and delay, raise RF-power Check resonator alignment for maximum intracavity power Optimise Bragg cell position (chapter 4) If wavelength >900nm purge the system with dry nitrogen and try to increase pump power (see chapter 4)