Cavity Dumper

Cavity Dumper Kit

User Manual

preliminary

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IMPORTANT – READ CAREFULLY BEFORE USE – KEEP FOR FUTURE REFERENCE

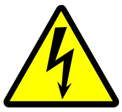
This user manual contains user information for the Cavity Dumper Kit . Read this manual carefully before operating the Cavity Dumper Kit , particularly Section 1 on safety instructions. The Cavity Dumper Kit is only to be used as described in this manual. Differing use may endanger safety and voids warranty.

CAUTION - USE OF CONTROLS OR ADJUSTMENTS OR PERFORMANCE OF PROCEDURES OTHER THAN THOSE SPECIFIED HEREIN MAY RESULT IN HAZARDOUS RADIATION EXPOSURE

Symbols Used in this Manual and on the Measuring System

This symbol is intended to emphasize the presence of important operating instructions.

This symbol is intended to alert the operator to the danger of exposure to hazardous visible or invisible laser radiation.



This symbol is intended to alert the operator to the presence of dangerous voltage within the product's enclosure that may be of sufficient magnitude to constitute a risk of electrical shock and to indicate possible risk of equipment damage.

Warranty

The warranty conditions are specified in the sales contract.
Any unauthorized modification of the **Cavity Dumper Kit** system components or software will result in invalidity of the guarantee and service contract.

Disposal

The **Cavity Dumper Kit** fulfills the European Directive 2011/65/EU for reduction of hazardous substances in electrical and electronic equipment (RoHS).
All electrical and electronic products must be disposed separately from the standard municipal waste system. Proper disposal of your old appliance prevents potential negative consequences for the environment and human health.

Contents

1. Safety Instructions

The European Community requirements for product safety are specified in the "Low Voltage Directive" (2006/95/EC). The "Low Voltage Directive" requires that electronic products comply with the standard EN 61010-1:2010 "Safety Requirements for Electrical Equipment for Measurement, Control and Laboratory Use". Compliance of this product is certified by the CE mark.

1.1. Optical Safety

Since the Cavity Dumper Kit is intended to be used with a laser all safety instructions relevant to the class of your laser have to be observed!

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.

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.

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

Laser beams can be 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 given by the manufacturer of your laser.
2. All alignment procedures described herein shall only be done by qualified users who are familiar with laser safety practices and who are aware of the dangers involved.
3. 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.
4. Maintain experimental setups at low heights to prevent inadvertent beam-eye encounter at eye level.
5. As a precaution against accidental exposure to the laser beam or its reflection, those using the system have to wear laser safety glasses as required by the wavelength being generated.

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. Avoid direct exposure to the laser light. The intensity of the beam can possibly cause flesh burns or ignite clothing.
7. Extreme care must be taken during alignment procedures with the free laser beam. Always start alignment with a beam attenuated to a level that allows for save handling.

1.2. Electrical Safety

The **Cavity Dumper Kit** uses DC voltages in the controller. All units are designed to be operated with protective covers in place.
The device complies with protection Class III / EN 61140:2007, degree of ingress protection IP20, according to EN 60529:2010.

For the connection of the controller and the optical head only the delivered cable may be used. It is only allowed to run the Cavity Dumper Kit with the delivered power supply.

1.3. Electromagnetic Compatibility

The European requirements for Electromagnetic Compliance (EMC) are specified in the EMC Directive (published in 2004/108/EC). Conformance (EMC) is achieved through compliance with the harmonized standards EN 61000. Compliance of the **Cavity Dumper Kit** system with the (EMC) requirements are certified by the CE mark.

2. Introduction and Theory of Operation

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

Mode-locked lasers which are capable of generating very short laser pulses (e.g. picosecond or femtosecond pulses) have pulse repetition rates corresponding to the round trip time of the light in the laser cavity. This frequency is around 80 MHz for many tunable solid state-, ion-, and dye lasers used in scientific applications. This frequency corresponds to a pulse separation time of 12.5 ns. For a number of applications like the 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 A·P·E **Cavity Dumper Kit** is well suited for pulse selection of mode-locked lasers with repetition rates between 50 and 85 MHz (the frequency to be specified at time of order, others on request) inside the laser cavity. The pulse energy increases compared to simple mode-locked operation at the same time. Its function is based on the acousto-optical effect. In a suitable crystal (e.g. fused silica) a modulation of density and thus a refractive index is introduced by applying a high frequency acoustic signal. 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. That way they are separated from the other pulses and coupled out of the laser cavity and can be used in the experiment.

The **Cavity Dumper Kit** consists of the fused silica Bragg cell and mounting kit (if part of the purchase order) and the driver and control electronics module. The Bragg cell as the most important part selects single pulses from the laser beam based on the acousto-optical effect. The intra-cavity beam must be focused into the Bragg cell by suitable spherical mirrors to achieve the necessary fast switching time. The driver electronics provides the modulated RF signal for the Bragg cell with a carrier frequency equal to the fivefold of the laser repetition rate and an output power of up to 16 W (peak). This standard range for the division ratio of the mode-locked laser repetition rate is 1:20 ... 1:5000 (optionally 1:2 ... 1:260000). For synchronization the user must provide a seed signal with the laser repetition rate (for instance from a fast photodiode) and with an amplitude of 30 mV ... 300 mV at 50 Ω. Instead of using the internal frequency divider pulses can be selected by external triggering with a TTL signal at 50 Ω external trigger input. In this case the "SEED" input signal is required as well. Depending on the applied modulator type diffraction efficiencies of > 50 % (fused silica, single pass at 800 nm) can be achieved. Usually the cavity dumper is operated in double pass mode to increase the efficiency. For this the **Cavity Dumper Kit** offers a phase adjustment of the RF carrier frequency. **The incorporation of the Bragg cell into the laser is not part of the Cavity Dumper Kit delivery and lies in the responsibility of the user!**

2.1. Double-pass Cavity Dumping

The schematic layout of the cavity dumper, an acousto-optical Bragg cell placed inside the laser resonator, is depicted in Figure 2.1. 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.

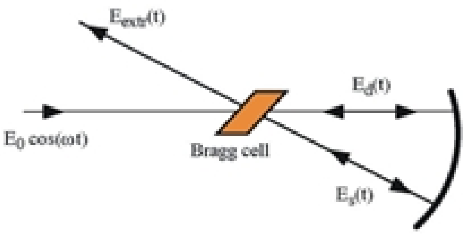


Figure 2.1.: Schematic layout of the double-pass cavity dumping arrangement

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

$$E(t) = E_0 \cos(\omega t) \tag{2.1}$$

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:

$$E_s = \sqrt{\eta} E_0 \cos(\omega t + \Omega t + \Phi) \tag{2.2}$$

$$E_d = \sqrt{(\eta - 1)} E_0 \cos(\omega t + \Omega t + \Phi) \tag{2.3}$$

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:

$$E_{extr} = \sqrt{(\eta - 1)}\sqrt{\eta}\, E_0 (\cos(\omega t + \Omega t + \Phi) + \cos(\omega t - \Omega t - \Phi)) \tag{2.4}$$

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

$$I_{cd} = 4\eta(\eta - 1)|E_0|^2 \cos^2(\Omega t + \Phi) \tag{2.5}$$

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

2.2. Oscillator Gain Dynamics for Kerr Lens Mode-locked Lasers

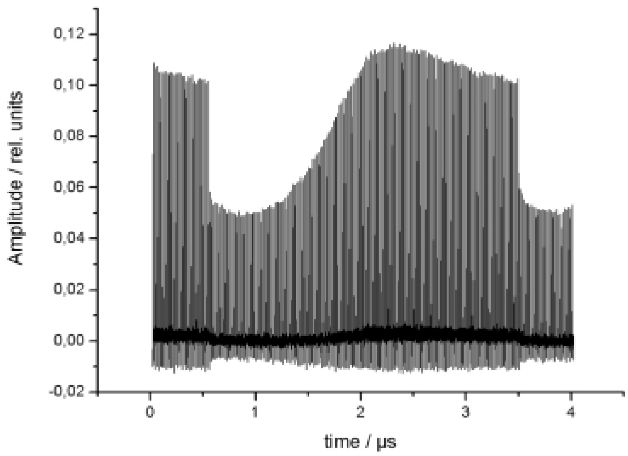


Figure 2.2.: Cavity Dumper pulse train at a repetition rate of 1:160

In Figure 2.2 a typical pulse train of the intracavity pulses is shown. The signal is detected by a fast photodiode behind the laser output coupler, 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.

2.3. Specifications

Input frequency (SEED)		within 1 MHz according to order specifications
Division ratio (internal)		1:20 ... 1:5000 (standard) 1:2 ... 1:260000 (optional) of seed input frequency
Phase shifter		0.02 ... 2.54 ns
External trigger input		single shot ... 3 MHz
Inputs	SEED	30 ... 500 mV; 50 Ω
	EXTERN TRIGGER	TTL, 50 Ω
Outputs	RF	0 ... 16.5 W peak limited to 800 mW mean with internal divider limited to 800 mW mean by overload safety circuit pulse width 5.0 ... 21.0 ns
	SEED MONITOR	monitor of the SEED input pulses, 50 Ω
	PULSE MONITOR	TTL, 50 Ω
Overload safety circuit		~ 1000 mW RF
CW adjustment mode		~ 200 mW RF

2.4. Environmental Requirements

The Cavity Dumper Kit is intended for operation in indoor, dry and dust reduced rooms. It has to be firmly installed on an optical table or on a similar solid, vibration-free board.

During storage, transport, for the installation and during operation, the ambient conditions must be observed. Ensure reasonable transport conditions, free of major shocks, jolt or fall; protect against frost. Use original packing material for relocation. Before unpacking the device wait for at least six hours to allow for acclimatization of all components.

Ambient temperature during transportation:	- 30 ... + 50 °C
Relative humidity during transportation:	10 % ... 80 %, no condensation
Ambient temperature during operation:	+ 18 ... + 27 °C
Relative humidity during operation:	< 60 %, no condensation

3. Installation

3.1. Receiving and Inspection

On receipt of the **Cavity Dumper Kit** system:

1. Inspect the packing crate for signs of rough handling or damage directly at arrival. If you discover any irregularities:
   - Take photographs of the condition of the package, the labels and the inside of the box, if necessary.
   - List all defects on the shipping documents and let the delivery company countersign.
   - Inform your **Cavity Dumper Kit** vendor immediately.
2. Use safe lifting practices.
3. Before unpacking the **Cavity Dumper Kit** wait at least six hours to allow for acclimatization of all components.
4. Unpack the **Cavity Dumper Kit** system.
5. Retain the packaging for future use.

3.2. Contents of Delivery

3.3. Driver Electronics

Figure 3.1 shows the front panel of the driver electronics unit with controls and signal inputs and outputs. In the top left there is a LCD graphic display.

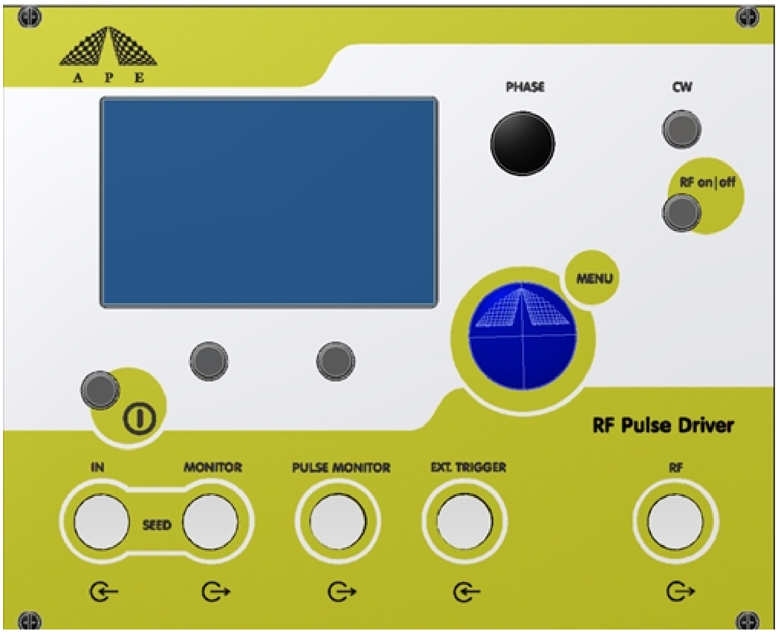


Figure 3.1.: Driver electronics unit front panel

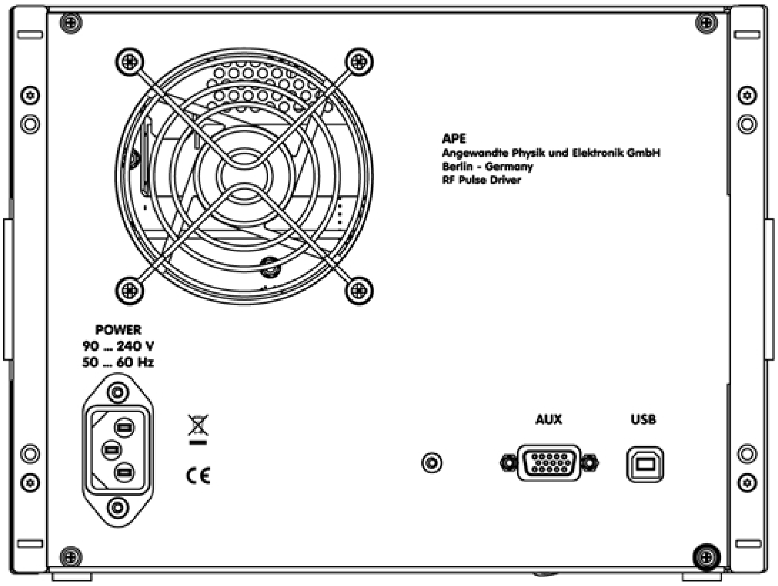


Figure 3.2.: Driver electronics unit rear panel

3.3.1. Cable Connection and Start Up

1. Connect the RF signal input from the Bragg cell to 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.**
2. Connect a synchronization signal from a fast photodiode output to the "SEED" BNC input at the front panel of the driver electronics.
3. At the "PULSE MONITOR" output pulsed signals (500 mV) are available synchronously to the selected laser pulses. For precise triggering it is recommended to use a 50 Ω termination which causes the voltage level to slightly drop down.
4. The "SEED MONITOR" output gives you a monitor signal of the seed input, i.e. the fast photodiode. Connect the "SEED MONITOR" to a fast oscilloscope (min. 400 MHz recommended) and trigger the system with the "PULSE MONITOR".
5. 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 (see also Section 3.3.4.6) in this case. If you do not use the external trigger mode please leave the "EXTERN TRIGGER" input disconnected to avoid disturbances of the RF signal.
6. Connect the power cord to the rear panel of the electronics and the wall socket.
7. After having connected the signal cables the power can be switched on at the rear panel. The front panel will show you all settings and the measured oscillator repetition rate.
8. The RF power can be switched on and off with the "RF ON" button. The "ON" state is indicated by the red LED behind the button.

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

3.3.2. **Setting the Operational Parameters**

The operational parameters are chosen at the driver unit by moving the cursor with the blue rotary knob and pressing it to activate or edit a function. The parameter settings will be stored when the device is switched off and are available when turned on for the next time. For safety reasons RF is always off directly after turning on the device.

3.3.3. **Display**

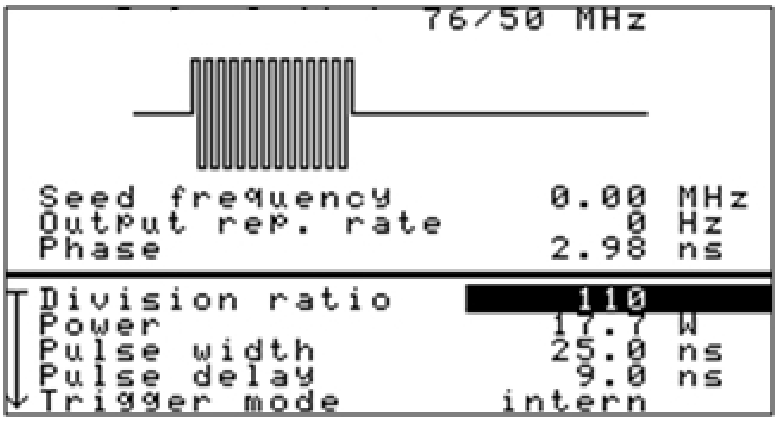


Figure 3.3.: Screenshot of the RF driver electronics unit

3.3.4. **Parameter Settings**

3.3.4.1. **Division Ratio**

This is the division ratio of the internal frequency divider for the laser repetition rate. The synchronization signal of this is connected to the "SEED" input. Please keep in mind that the internal pulse repetition frequency of the oscillator has changed from 80 MHz to 54.3 MHz due to the addition of the Cavity Dumper to the cavity. The division ratio determines the repetition rate of the output signal of the Cavity Dumper. When set to "20", for instance, every 20th laser pulse is selected, if set to "30" every 30th pulse is diffracted and so on. The cavity dumper repetition rate will be displayed on the screen.

Range: 20 ... 5000 (2 ... 260000 optional)

Additionally, for adjustment purposes, a CW RF signal can be given to the modulator by pressing the "CW" button. In this case the output power is limited to about 200 mW in order to avoid damage of the crystal. If the CW mode is used, the CW RF signal will work at a fixed frequency independent of the seed input.

3.3.4.2. **Pulse Width**

This is the width of the single RF pulses in ns.

Range: 4.0 ... 15 ns

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

3.3.4.3. **Delay**

This is the delay of the RF output pulse relative to the synchronization pulses ("SEED").

Range: 1.0 ... 19.9 ns

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

3.3.4.4. **Phase**

The phase of the RF signal relative to the seed input can be shifted from 0.05 ... 3 ns with the black rotary knob labeled PHASE . The value of the phase is shown on the display. The phase has to be optimized to get constructive interference of the first order diffraction in the first and the second pass of the Bragg cell and thus to get maximum output power. A few minutes after switching on RF power or after changing the repetition rate the amplifier has reached thermal equilibrium and the phase may need to be adjusted again.

3.3.4.5. **RF Power**

This is the output RF power in Watts with 50 Ω load. At division ratios < 1:20 the maximum possible setting is automatically limited to a value that avoids damage of the crystal. The actual limit also depends on the chosen setting of the pulse width.

Range: 0.5 ... 17.5 W

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

3.3.4.6. **External Triggering**

For external triggering a TTL level trigger signal (with 50 Ω at the "EXT. TRIGGER" input) is necessary. Activate the external trigger mode in the menu "TRIGGER MODE". Now the next laser pulse following the trigger signal will be diffracted to the first order. 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.

4. **Routine Operation**

To achieve cavity dumping these tasks have to be completed:

- Get the laser into mode-locked operation by pressing the starter button.
- Optimize the driver electronics settings for maximum out-coupled power. You may need to readjust the phase a few minutes after switching on RF power.

In case power is low or unstable mode-locking occurs:

- Switch off RF power.
- Optimize the cavity for maximum power behind the output coupler under mode-locked conditions.

5. **Error Signal LED "FAULT"**

The electronics of the **Cavity Dumper Kit** 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. Possible reasons for this fault can be, for instance, external triggering with high repetition rates at high RF power levels, unstable triggering conditions at the "SEED" input, 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 switch off the mains power, 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 power again. If still no normal operation is possible ("FAULT" is signaled 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.

6. Maintenance and Troubleshooting

6.1. Maintenance

6.1.1. Cleaning

Do not use any aggressive solvents to clean the Cavity Dumper Kit components! Switch the laser OFF or block the input beam and unplug the mains power adapter from the wall power socket for cleaning!

Use a soft lint-free and dry or only slightly moist cloth to clean the covers of the **Cavity Dumper Kit** components.
Use dry methanol and lens cleaning tissue applying common optics cleaning techniques.

6.2. Troubleshooting

Problem	**Solution**
No out-coupled beam can be found	Is the RF cable connected with the Bragg cell? Is the control electronics switched on? Is the Seed input connected with the fast photodiode? Does the system mode-lock? Is the Seed signal > 15 mV, if not realign the beam onto the fast photodiode Check general alignment
The red FAULT LED is illuminated	see Section 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 contrast ratio is low between out-coupled pulse and adjacent pulses	Optimize 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	Optimize phase and delay, raise RF power Check resonator alignment for maximum mode-locked power Optimize Bragg cell position

6.3. Technical Support

For technical questions or problems within Germany, please contact:

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http://www.ape-berlin.de

To contact our international distributors, please have a look at our website:

http://www.ape-berlin.de

A. Installation of the Bragg Cell (with optional mounting kit)

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 [1] to a middle position. Unlock the lock screw for the rough Brewster angle adjustment [2] with a hex key and rotate the modulator holder to zero degree. Lock the screw [2]. There are two small screws accessible through two holes in the side of the modulator holder with a 0.9 mm hex Allen key [3,4]. 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. Manually screw the SMA connector of the cable tightly to the SMA connector of the modulator socket. **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 at the modulator socket [5]. This line must be right-angled to the beam direction. This is the case when the perpendicular line points to the hole near the 230° mark. Set the modulator into the holder and fix it with the two screws [3,4].

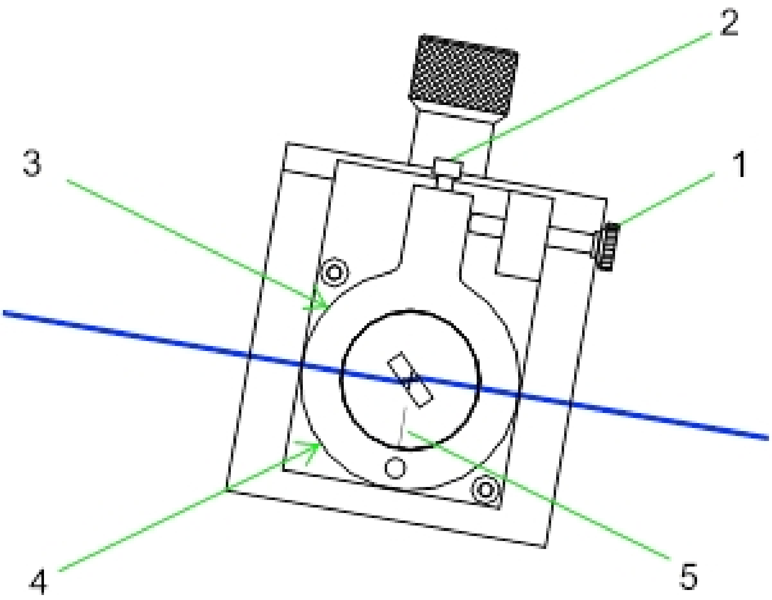

Figure A.1.: Modulator Assembly

1	Brewster angle control
2	Rough Brewster angle adjustment lock screw
3,4	Modulator lock screws, access holes
5	Mark for modulator direction

B. Example for Possible Implementation

The following chapter shows a **possible** implementation of a cavity dumper into a short pulse Kerr lens mode-locked Ti:Sapphire laser. The opto-mechanics for this implementation are available at your vendor.

Figure B.1 shows the elements of the **Cavity Dumper** optics in top view. The optics set up is designed for horizontal polarization of the laser light. 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 the 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 only) will be deflected into the first diffraction order. Zero-order and first-order beam are recollimated by the collimating mirror CM2 and both retro-reflected by the end mirror CM3. Thus first-order and zero-order beam pass through the Bragg cell via CM2 a second time , 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 out-coupling efficiency can be substantially raised in comparison to a single-pass cavity dumper.

The zero-order beam is retro-reflected 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 CM6, and leaves the cavity dumper via CM7 and CM8 through the Brewster window BW.

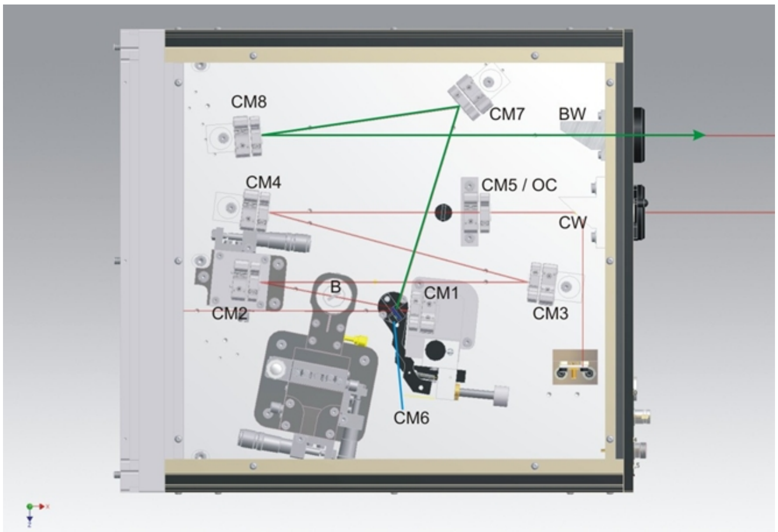

Figure B.1.: Optics - top view (red - intracavity beam; green - out-coupled beam)

CM1	Focusing mirror CM1
CM2	Collimating mirror CM2
CM3, CM4	Folding mirrors
CM5/OC	Cavity dumper output coupler
CM6	Cavity dumped pulse out-couple mirror
CM7, CM8	Cavity dumper steering mirrors
B	Bragg cell, Modulator
CW	Oscillator beam output window
BW	Cavity dumper and bypass output Brewster window

B.1. Basic Alignment

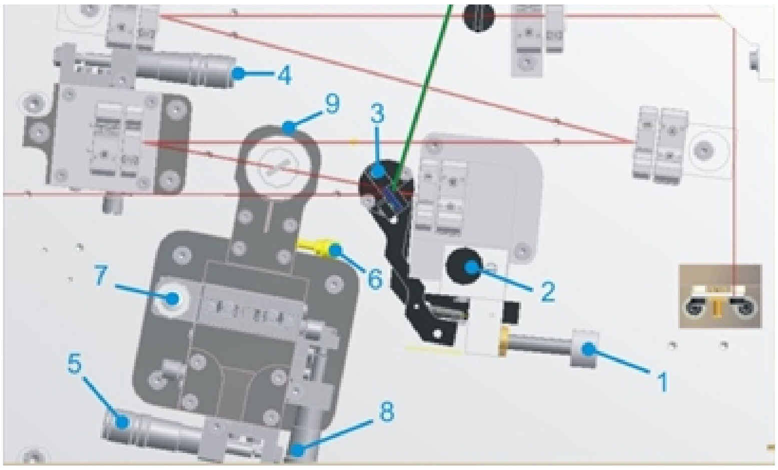

Figure B.2.: Adjustment elements (except mirror tilts) in the cavity dumper optics unit

1 CM6 angle control
2 CM6 vertical position control
3 CM6 translation control
4 CM2 horizontal position adjustment screw
5 Modulator, horizontal X-position adjustment screw
6 Modulator, Bragg angle control
7 Modulator, vertical position adjustment screw
8 Modulator, horizontal Y-position adjustment screw
9 Modulator, Brewster angle locking screw

1. At the beginning of the basic adjustment of the **Cavity Dumper Kit** the Bragg cell has to be driven 2 mm lower (7 in Figure B.2) and the position of CM2 (4 in Figure B.2) 0.5 mm further apart (smaller numbers) from CM1 than the position expected.
2. The horizontal X- and Y-position of the Bragg cell (controls 5 and 8 in Figure B.2) should be set to center the Bragg cell between CM1 and CM2. The distance between CM1 and CM2 (in case r = 100 mirrors are used) is typically in the range between 102 and 106 mm (depending on your cavity design!) and the Bragg cell centered between both mirrors.
3. Switch on the pump laser. The fluorescence spot of the Ti:Sapphire crystal must hit the center of the focusing mirror CM1. (Use an IR viewer if necessary)
4. Lower CM6 (2 in Figure B.2) so that it does not clip the fluorescence.
5. Adjust the fluorescence to pass through the modulator centrally onto CM2. Use the tilt controls of the focusing mirror. If the fluorescence is clipped either by CM6 or the Bragg cell holder, lower them.
6. Use the CM2 tilt controls to steer the fluorescence spot to the center of CM3. Move forward to CM4 and align with CM3, then to CM5 and align with CM4 respectively.
7. Use CM5 to retro-reflect the fluorescence to an aperture in front of CM4 and then CM3. Remove the aperture and adjust CM5, and start the lasing process. Optimize for maximum power behind the output coupler CM5. The cavity will now run in CW mode with high power.

8. Check the beam path inside the crystal with an IR viewer and correct the crystal horizontal Y-position (8 in Figure B.2) to center the beam (see B.3).

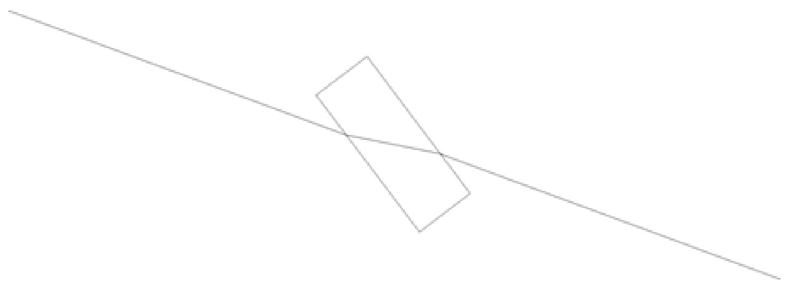

Figure B.3.: Beam path inside the transducer crystal

9. Slowly decrease the distance between CM1 and CM2 while translating CM2 with (4 in Figure B.2) towards the value given in the test protocol while maximizing the output pwer with CM5 until CW output power is about 100 mW. Try to get the laser into mode-locked operation, check with a spectrometer. Mode-locked power is typically about 10 ... 30 % higher than CW power. Adjust output coupler CM5 and the other end mirror for maximum mode-locked power. Slightly change CM2 position to look for the most stable mode-locking with good power. You may need to optimize the dispersion of the system.
10. You should monitor the beam behind the output coupler with a fast photodiode. Typically a reflection from a glass plate should be sufficient. We recommend a photodiode with a rise time of 1 ns. This is the seed input for the control electronics (SEED IN). Connect the SEED OUT BNC to a fast oscilloscope (min. 400 MHz). Align the beam onto the fast photodiode while monitoring it with the oscilloscope.

B.2. **Fine Adjustment of the Optics**

After basic alignment (see Section B.1) and connection of the optics module to the driver electronics (see Section 3.3) open the slit completely, get the system lasing and turn on the mains of the **Cavity Dumper Kit** electronics.

1. Choose CW mode by pressing the "CW" button on the control electronics. By pressing the RF-ON button a CW RF signal of about 200 mW amplitude is given to the modulator crystal. The **Cavity Dumper Kit** 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 first 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 (7 in Figure B.2).

4. While monitoring the aperture slide the crystal horizontally (Y-direction) about 2 mm in each direction from the center position of the beam (8 in Figure B.2) until a spot appears 2 ... 4 mm above the zero order spot. To make sure that this is the first 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 first order intensity by appearance. (Always readjust the cavity with CM5). **If no diffracted beam can be observed over the whole horizontal adjustment range, slightly change the Bragg angle (6 in Figure B.2) and repeat the above steps.**
6. After having optimized the diffracted beam by appearance remove the aperture and adjust the pick up mirror CM6 height (2) and horizontal position, so that the intracavity beam is passing above CM6 and the first order beam hits the mirror CM6 after being reflected by CM1. To adjust the horizontal position tilt the mirror CM6 with screw 3 using an Allen key (see Figure B.4). If the adjustment range is not sufficient loose the mirror from its holder with an Allen key and slide it to the proper position. Then fix CM6 again.

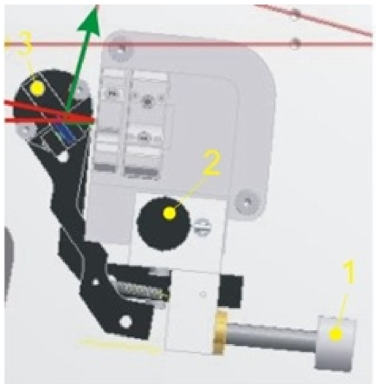

Figure B.4.: Pick up mirror CM6 mount with beam path (red - intracavity beam; green - out-coupled beam)

7. The out-coupled beam (the first order diffraction on CM6) should be reflected to CM7. To adjust the horizontal tilt of CM6 use (1). Adjust CM7 and CM8 so that the deflected beam leaves the cavity dumper through the Brewster window BW.
8. Take a sheet of paper and monitor the output beam profile at a distance of about 1 m. Slightly adjust the horizontal X-position of the modulator (8 in Figure B.2) until only one round spot is to be seen (and not two spots one above each other).
9. Place a laser power meter into the deflected beam. To maximize the diffraction efficiency the horizontal (8) and vertical (7) crystal position must be adjusted by turns, as well as the Bragg angle (6) 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 CM5). After having maximized the power of the diffracted beam in CW mode the **Cavity Dumper Kit** must be optimized for pulsed operation. In order to do this monitor the intracavity pulse train with a fast oscilloscope terminated with 50 Ω by connecting the fast photodiode output of the **Cavity Dumper Kit** with the SEED input and the oscilloscope with the SEED MONITOR of the electronics unit (see previous section). Trigger the oscilloscope with the PULSE MONITOR output signal of the **Cavity Dumper Kit** .

B.3. Achieving Cavity Dumping

Recommended starting values for the **Cavity Dumper Kit** electronics are:

Division ratio	100
Pulse width	12.0 ns
Delay	9.0 ns
Power	5 W

1. Switch off the CW mode at the CW button and the RF power (FR ON button) and bring the system into mode-locked operation. After switching on RF a modulation of the pulse train with a period of 50 pulses should appear on the oscilloscope. The first small pulse of this period is the diffracted pulse. The intracavity pulse then needs about 50 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. Figure B.5 shows a typical intracavity pulse train from the SEED MONITOR output as seen on an oscilloscope.

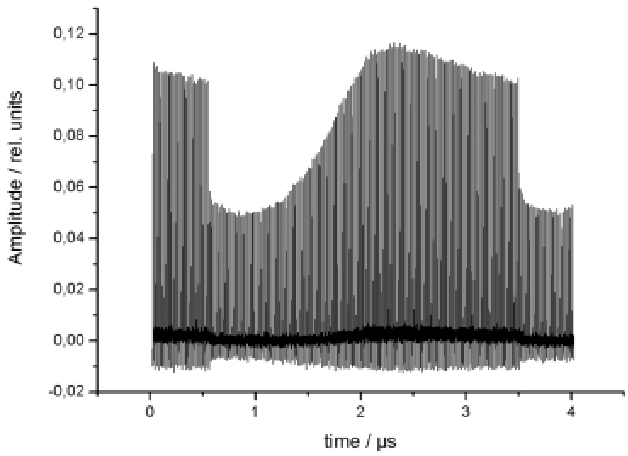

Figure B.5.: Typical intracavity pulse train in cavity dumped operation with approx. 50 % diffraction efficiency

2. Maximize the diffraction efficiency by varying of first phase and delay. 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. Change the delay setting and pulse width to improve the contrast ratio and obtain high diffraction efficiency.
5. Set the division ratio to the desired value. For division ratios < 20: While reducing the division ratio a reduction of the RF power may be necessary to maintain mode-locked operation. If the division ratio is raised a higher RF power may be applied thus getting more energy per pulse.

6. The RF amplifier will be in thermal equilibrium within a few minutes after switching on RF or changing the repetition rate. Thus the phase may need to be optimized again.

Once the optimum adjustment is found it needs only slight corrections when the system is turned on for the next time.

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Substance	**Maximum Limit (ppm)**
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Cadmium (Cd)	100
Mercury (Hg)	1000
Hexavalent Chromium (Cr6+)	1000
Poly Brominated Biphenyls (PBB)	1000
Poly Brominated Diphenyl ethers (PBDE)	1000

Product Identification:
Product

Cavity Dumper Kit (Driver + Bragg Cell)
A·P·E Id: 108207

Signature:

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