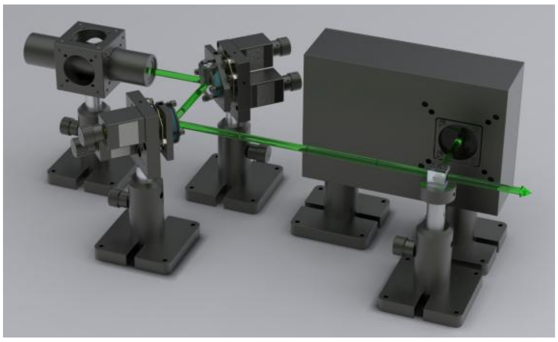
User Manual

# *Aligna® 4D*

Modular Rack Case Version

Version 2.4

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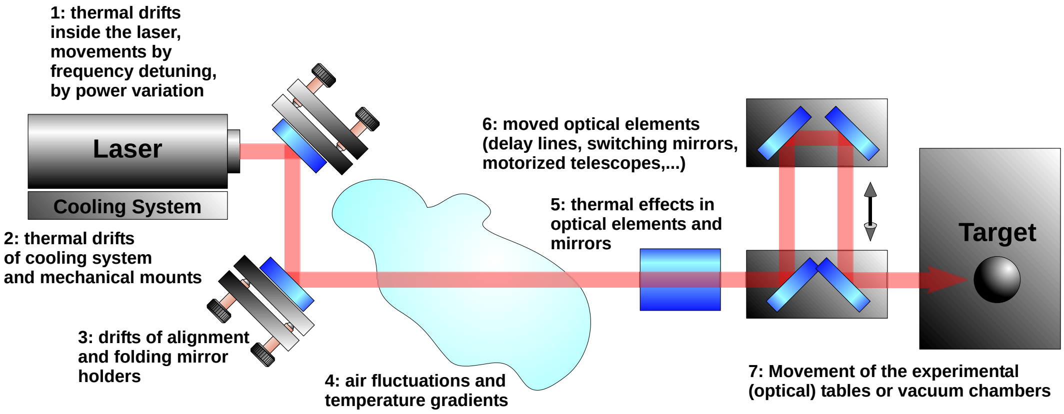
# 1 Introduction

Laser beams, used in an experiment or in industrial applications, can move in space by many reasons:




1. Thermal properties of the laser itself
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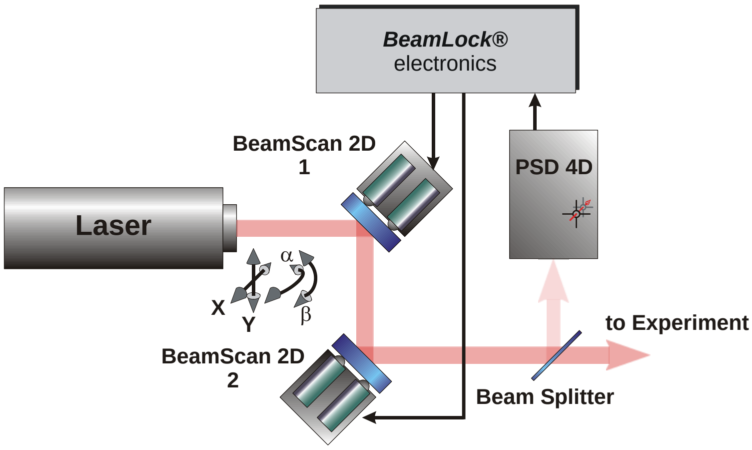
4. Air turbulences and temperature gradients in the air
5. Thermal effects of optical elements
6. Mechanically moved optical elements (delay lines, switching mirrors, motorized telescopes, …)
7. Movement of the experimental (optical) tables or vacuum chambers

(In the chapter “Reasons of Pointing Instabilities” these topics will be discussed in more detail.)

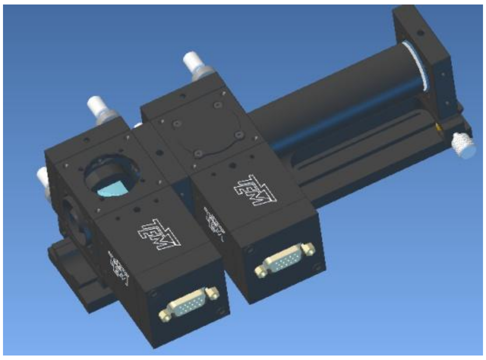
The laser beam pointing stabilization system ***Aligna***® compensates for all of these disturbances. The laser beam position and its angle are measured by the 4D position sensitive detector ***PSD 4D*** in four degrees of freedom (two beam positions “X” and “Y”, and two angles “$\alpha$” and “$\beta$”). The position of a (collimated) laser beam is characterized by these four values, like a line in space. The measured deviation signals of the laser axis with respect to the reference axis are processed continuously by the ***Aligna***® electronics. Herein control signals for four piezo actuators of the ***BeamScan*** mirrors and/or motorized mirror mounts (*Aligna60*, e.g.) are generated. Two 2D movable mirrors, which control these four degrees of freedom in four fast closed lock loops keep the laser beam exactly at the reference axis.



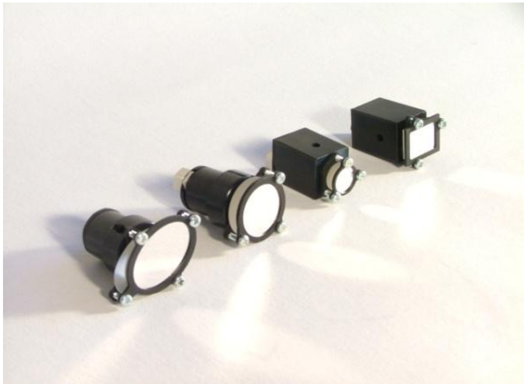

***Aligna***® is a modular system, consisting of different elements, which can be adapted to the individual application: Different types of scanners (with various values of displacement, beam diameters, mirror types, movement speeds) and different types of PSDs (Position Sensitive

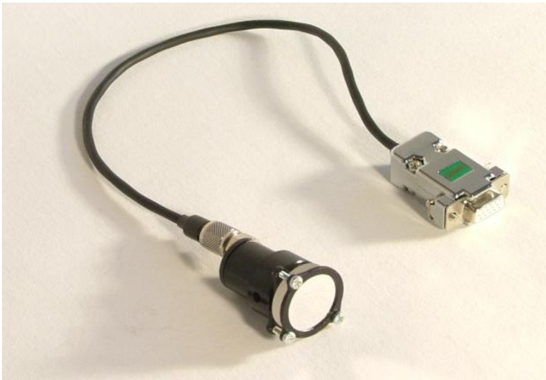
Detectors) with various types of sensors (wavelength, beam diameter, resolution, dimensions, QUAD detectors, duo/tetra lateral PSDs, or CCD/CMOS cameras) are available.

In some applications a 2D stabilization (instead of 4D) may be suitable. In this case only one 2D scanner ***BamScan 2D*** is necessary. (This reduction, however, can be more critical and takes more effort in positioning the PSD. Please refer to chapter “2D or 4D stabilization”!)

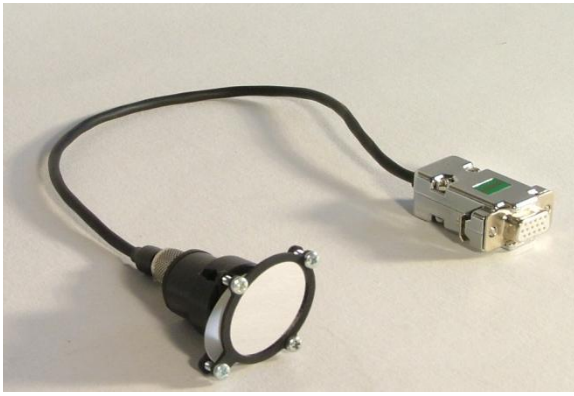


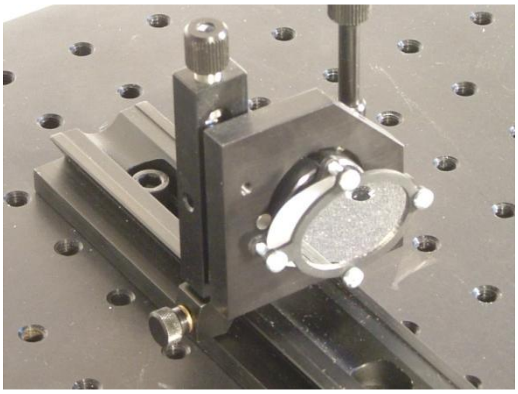
***Aligna*® *4D*** electronics 4D detector ***PSD 4D*** e



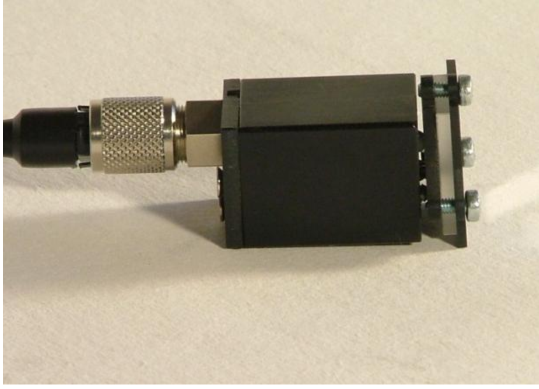


***BeamScan2D*** with different mirror shapes, 1-inch and square bodies

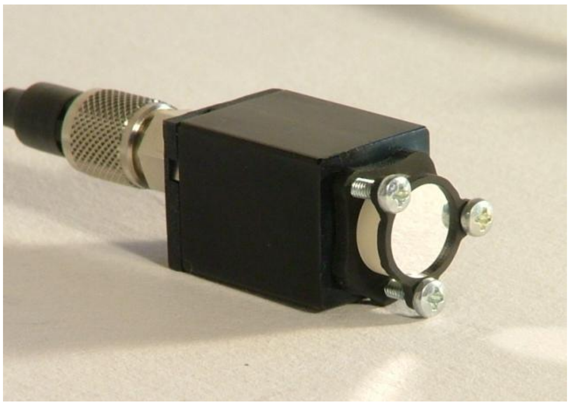
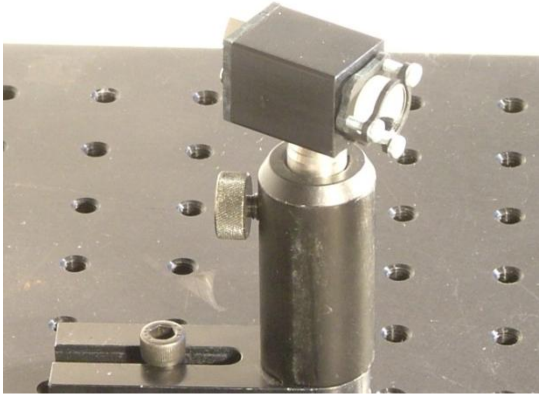




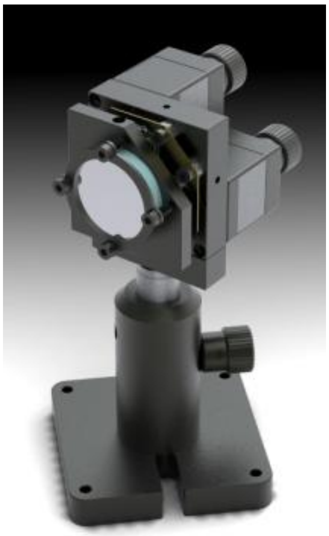
Elliptical mirror 22 x 32 mm, (5mm thick), fitting into std 1-inch mirror holder

rectangular broadband mirror 15 x 20 x 2.5 mm, in rectangular corpus

Half-inch mirror, rectangular corpus



***Aligna®*** also can be controlled by a PC or by other electronic devices within a control system. In this case both the 2D beam position and the 2D beam direction can be set by the control system; a very precise stabilized 2D or 4D fast scanning of the laser beam is possible.

Via the USB or serial interface, the following parameters can be set and controlled:

- Switching each servo channel on or off
- control of the set points (position X, Y, and angle $\alpha$, $\beta$)
- Gain of the PSD amplifiers (sensor sensitivity)
- …

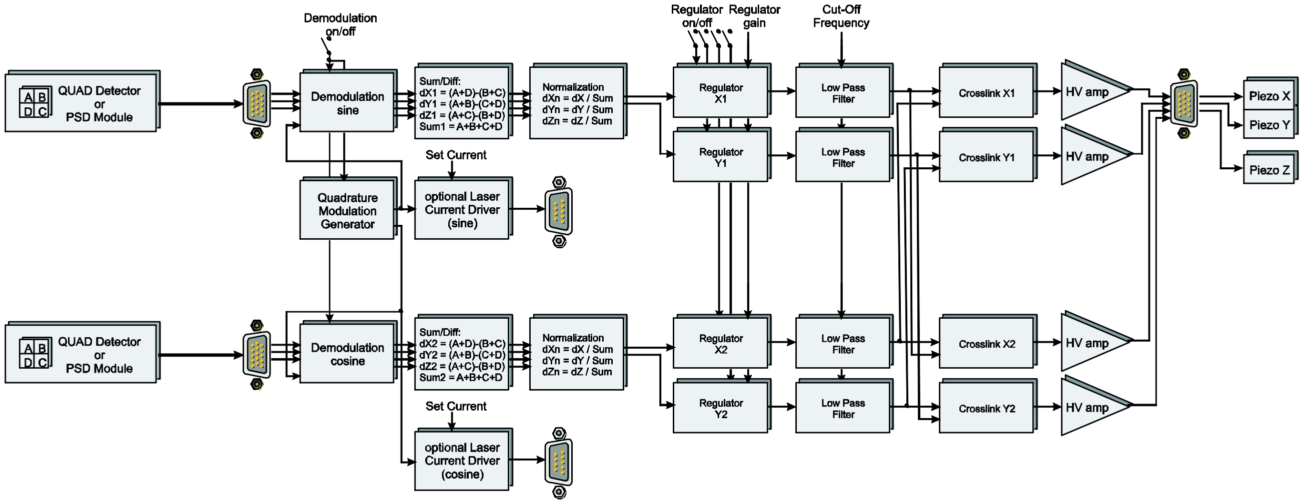
For detailed information please consult the Software Manual.

In addition all relevant signals (4D position signals, 4D error signals, 4D regulation signals,…) can be read as analog signals or via USB interface.

# 2 Block Diagram *Aligna® 4D*

In the following, the block diagram of the ***Aligna® 4D*** electronics is described.

Note: This chapter is preliminary: It still contains additional information related to former versions.



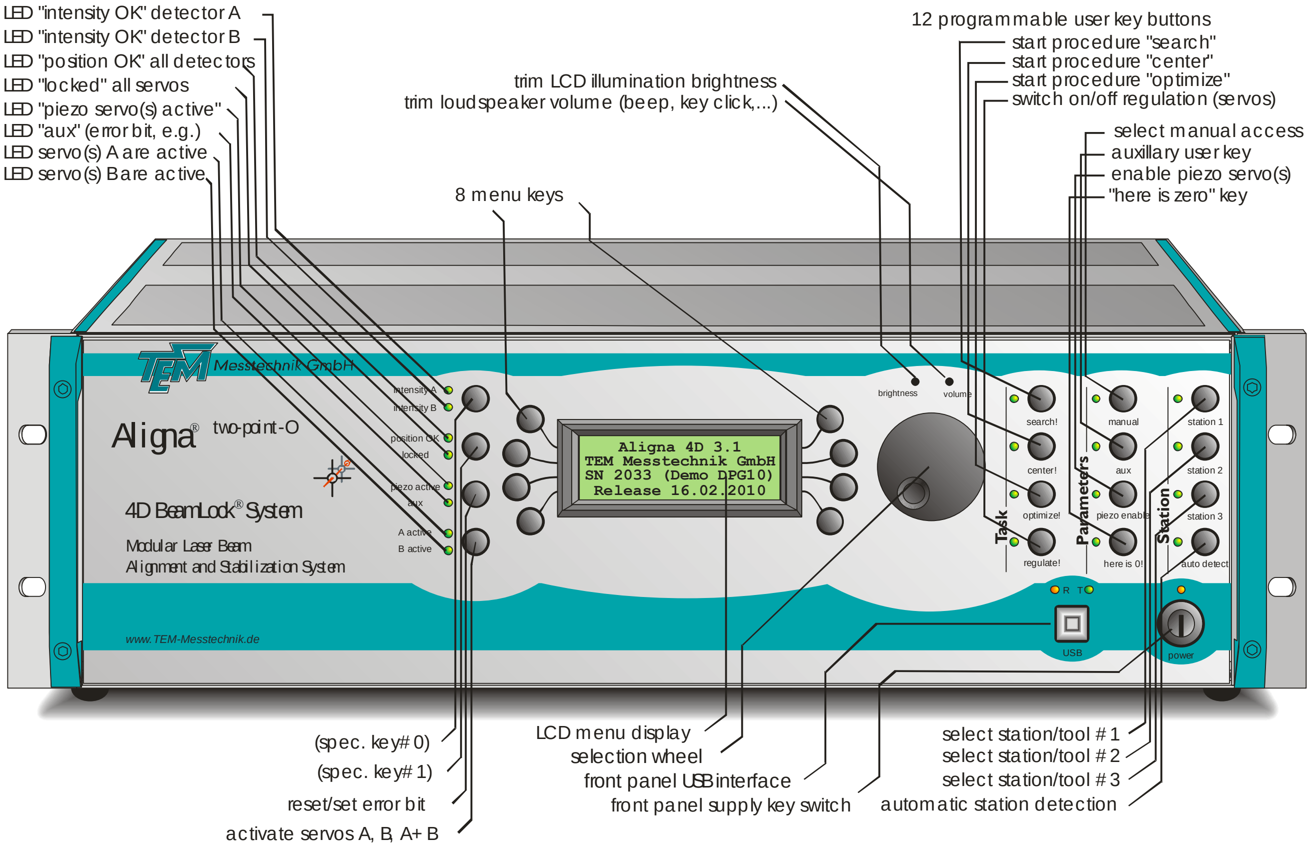

Two 2D sensors ***"PSD 2D"*** (or one 4D sensor ***"PSD 4D"***) detect both 2D position ("X", "Y") and 2D angle ("α", "β") of a laser beam. The detector electronics contain (dependent on the detector type):

- The position sensitive chip: A variety of detector sizes and types is available: 2x2 mm, 4x4 mm, 9x9 mm, 12x12 mm, others on request, as well as quadrant detectors of different sizes. Different speed options are available, please refer to PSD manual.
  The detectors are located at a small PCB, which also contains transimpedance amplifiers and filter networks to achieve very linear low noise robust signals.

The detectors are connected with the cables "PSD 1" to "PSD 4" with the ***Aligna® 4D*** electronics, which contains following functions.

- signal range and clip check for each channel Ax, Ay, Bx, By
- Input Cross-link Matrix circuitry (ICL Matrix) (calculation of pure Angle and BeamPosition signals)
- Set point definition (SetpAx, SetpAy, SetpBx, SetBy), fixed, external analog control or digital control (including test generator)
- Error calculation (4D actual position – 4D set position)
- Gain and regulator control logic
- Four PIDT$_2$ regulators
- Output Cross-link Matrix circuitry (OCL Matrix) (calculation of the combination movement)
- Monitor multiplexer for observation of all relevant signals
- 
- HV Piezo amplifiers
- Motor Drivers
- MicroController Module, including USB Interface, Serial Interface, (Ethernet optionally)
- Power Supply

# 3 Short Description of the Front Panel Elements

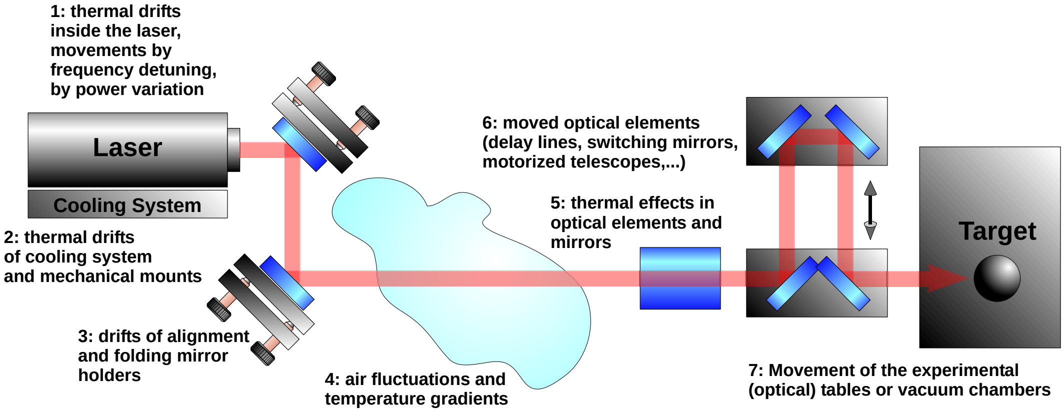



Pinnings of connectors are described in appendix “Connectors and Cables”.

# 4 Principles of Laser Pointing Stabilization

## 4.1 Reasons of Pointing Instabilities

Laser beams, used in an experiment or in industrial applications, can move in space by many reasons. Even small movements at the laser outlet may result in rather large movements of the laser spot, depending on the distance to the target, and on the optical components in the beam path. In the following, some of the most important reasons of pointing instabilities will be named.




Reasons of Pointing Instabilities

### 4.1.1 Thermal properties of the laser itself

Often a high local power is dissipated in a small spatial region; even small thermal movements can be transformed by collimating lenses of short focal lengths to relatively large angle movements. Local heating may be caused by pump diodes, by gas discharges, flash lamps, or by electrical excitation of the laser medium itself.

### 4.1.2 Thermal movement by the laser cooling system

If the laser medium is producing heat the laser is often cooled by Thermo-Electric Coolers (TEC, Peltier elements), by fans or by a water cooling system. Those techniques produce temperature gradients within the mechanical setup. If the development of the device is not done in a perfectly temperature compensated manner, position and angle changes will result. Even if the laser medium itself is stabilized and held at an exact constant temperature the cooling system has to react on changing temperatures of the environment and it has to compensate for the temperature change of the heat sinks. This will lead to pointing drifts.

### 4.1.3 Drifts of alignment and folding mirrors

Adjustment tools and element holders typically consist of different materials: Aluminum, stainless steel, brass and other materials, with different thermal expansion coefficients each. Caused by a change of the environment temperature the different thermal expansions can lead to position and –more critical- angle movements of the laser beam. The strength of these effects strongly depends on the construction, the materials, and –of course- on the temperature variations of the environment.

### 4.1.4 Air turbulences and temperature gradients in the air

Air fluctuations may cause large pointing fluctuations, particularly at long distances. But even one meter distance can produce pointing fluctuations in the order of some ten microns, which may be too much for critical applications. Air fluctuations often play the main role in beam pointing instabilities, especially at long distances between laser and target of several meters or even several tens or even hundreds of meters. Using evacuated tubes for beam guiding over long distances helps, of course, but even small effects at the path from the laser outlet to the vacuum tube will be transformed to large effects at the end of the (long) tube. Please note, using evacuated tubes may cause drifts depending on local air pressure variations.

In addition, evacuated tubes are expensive, bulky and inconvenient to handle.

If a laser is lead between different rooms through holes in the wall temperature and pressure differences between these rooms may lead to strong local air density gradients and thus to strong pointing drifts. Local pressure differences between the rooms (by air conditioning systems or by laminar flow systems, e.g.) will cause a strong air flow and air density turbulences.

### 4.1.5 Thermal effects of optical elements

Every optical element absorbs a distinct amount of the laser beam, which is true for both reflecting and transmitting elements. So-called thermal lenses lead to well-known influences of the collimation properties of the laser beam. With high quality of the materials and coatings and/or at low intensities the focusing/defocusing effect may be negligible.
But: the (very small) absorbed power leads to a local change of the temperature itself and thus the temperature gradient, which leads to a pointing deviation. The related time constants can be very slow, no equilibrium may be reached in many hours.

### 4.1.6 Mechanically moved optical elements (delay lines, e.g.)

Sometimes optical elements have to be moved within the application:

#### 4.1.6.1 Delay Lines

In short pulse laser systems (ps or fs durations) so-called delay lines are often used to match or shift two laser pulses in time with respect to each others. A set of several mirrors is moved by a motorized sleigh which has to be aligned to be exactly parallel to the optical path. This can only be done to a certain extent; it is difficult to align better than some ten micro radiants.

In addition, the motorized rail is not perfectly straight; there will be curvatures in the order of typically some ten up to some 100 microns, depending on the length and the price of the rail.

#### 4.1.6.2 Motorized or Manual Telescopes or Zoom Expanders

In some applications, setups of optical lenses have to be moved (telescopes, zoom telescopes, expanders,…). It is impossible to position and move these elements exactly at the optical axis. Thus, a beam pointing movement will be observed during the movement of the optical element.

#### 4.1.6.3 Switching Mirrors

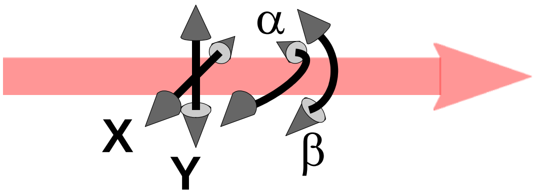
In some applications, the laser beam is switched between two paths of the experiment by a manually operated or by a motorized switching mirror. The reproducibility of the mirror position may be very high, but will not be perfect. Residual uncertainties of approx. ten µradiant are typical.

### 4.1.7 Movement of the experimental (optical) tables or vacuum chambers

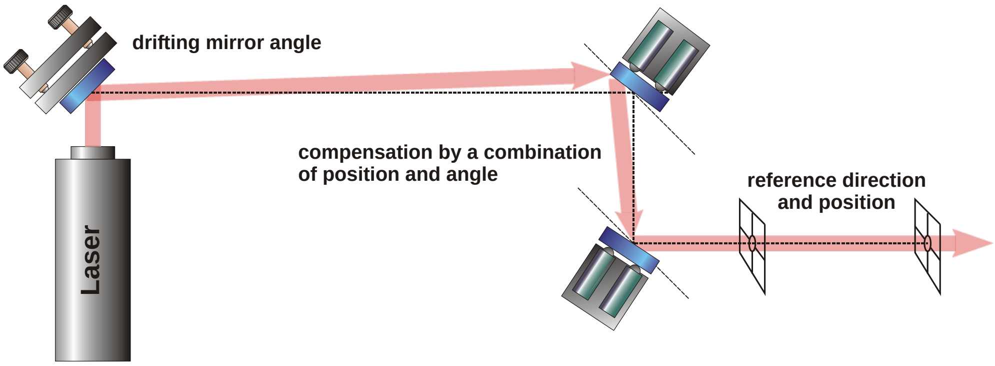
Often the laser and the experimental target are mounted at different optical tables. Many experiments are located in small or large vacuum chambers. Those components will be at different and changing temperature values. This leads to relative pointing drifts, even if each element is very stable by itself.

## 4.2 2D or 4D Stabilization?

The movement of a collimated beam can be separated into four dimensions: two translational ("X", "Y") and two rotational ("α", "β")

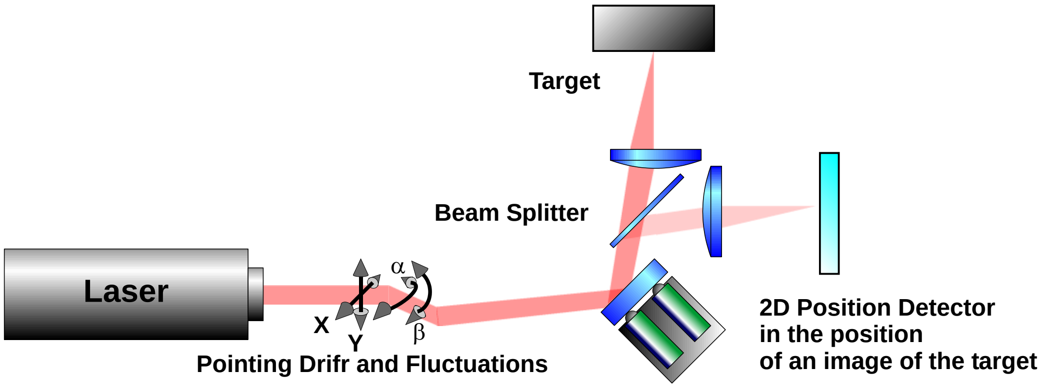



These degrees of freedom are not really independent: If, for example, one mirror holder drifts by 100 µrad due to the change of the room temperature the translation error of some µm will be negligible compared to the beam diameter of let's say some mm close to the mirror. After one meter free propagation, however, this leads to a movement of 0.1 mm, after 10 meters this is 1 mm, which is really not negligible any more. (Note: the angle drift is not directly dependent on the propagation length in this example. In reality, however, angle fluctuations due to air fluctuations increase with the length with a factor of sqrt(L))

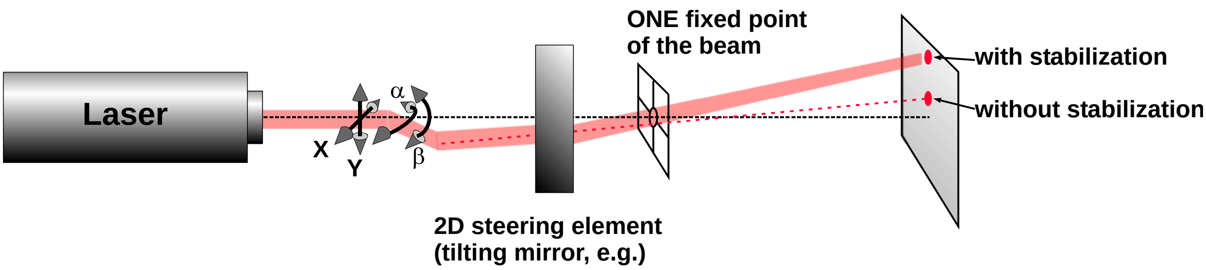



Even if the nature of the drift (in this example) is a pure angle drift (just 2D) it leads to a combination of angle and position movement after a distance of propagation (near the experiment) and cannot be compensated for by one single 2D moving mirror. It has to be compensated for with a combination of position and angle correction, e.g. by two 2D moved mirrors.

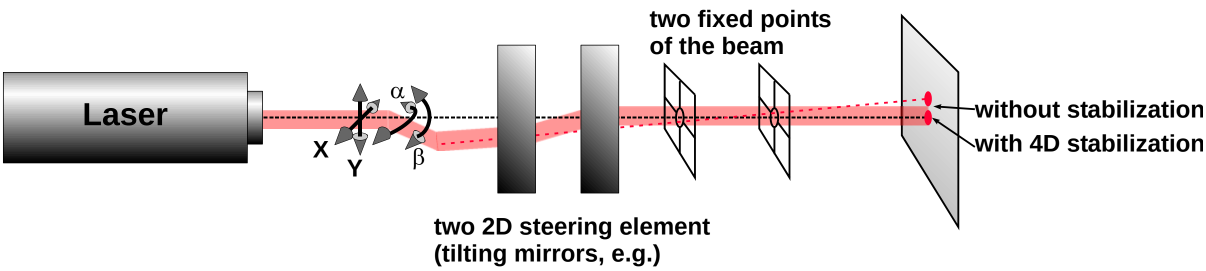
In many applications it is not really necessary to keep the laser beam fixed both in position AND direction at the place of the experimental target. In the case of laser material processing, for example, it is very important to keep the focused laser spot at an exactly defined position at the target surface. The angle, however, is not that critical. So one could think, a 2D correction might be sufficient. A beam splitter (also called beam sampler) separates a small part of the main beam. This part is handled exactly as the main beam (distances, focusing elements, etc.). If the laser spot is actively held fixed by the actuator at the detector position, it will be fixed in the plane of the target, too.




In principle this works. But: The detector has to be positioned in an exact (!) image of the target. Therefore it has to be aligned mechanically very well. Often it is difficult to find the correct Z-position for the detector. If this Z-position of the detector is wrong the stabilization can even ENLARGE the pointing fluctuations, compared to the situation WITHOUT any stabilization!




This shows: the fixed point of a laser beam has to be well matched with the target requirements. In normal cases this needs additional optics in the detection path, corresponding to the main optics and distances in the main path, and it needs a precise and critical alignment of the detector and the related optics.




With a 4D stabilization, in contrast, two points of the beam are fixed in space, instead of one point in case of 2D. As a result, ALL points of the output beam are fixed. For this it is not important WHICH two points are fixed. They only have to have a certain distance from each other to get enough resolution for the angle measurement. The Z-positions of the detectors are not critical. They can be positioned within a coarse spatial range and need not to be aligned precisely.

If PSDs are used (not quadrant detectors, see description on "detectors", “PSDs or QUAD detectors”) it is not important to hit exactly the center of the detectors: PSDs create a linear signal proportional to the spot position within the detector area, independent of the spot size and of the spot shape. (In contrast, quad detectors can only be used exactly in the physical center of the detectors; they show a strong dependence of the position error signal from the spot size and shape.) Thus PSDs do not have to be aligned precisely in X and Y position, because the servo loop (the user, respectively) can select the working point by applying an electronical DC set point signal (X and Y, $\alpha$ and $\beta$) to the regulator electronics. (Thus even the stabilized beam can be scanned quickly and precisely.)

As a result, the PSD 4D detector box has to be aligned just coarsely. It can be fixed firmly without the need of precision alignment mechanics. The exact reference optical axis can be controlled by electronic signals, instead of fine mechanical alignment!

Of course a 4D lock system needs a little bit higher effort in the electronic system, compared to a 2D system (two 2D detectors, two actuator mirrors), but:

- <u>A 4D stabilization leads to a much more robust and easy to handle system, without the necessity of mechanical fine alignment and very low mechanical drift!</u>
- <u>It compensates for both angle AND position shifting effects.</u>
- <u>Both position AND angle will be corrected without optimizing for one of them, without detailed analysis of the movements and drifts.</u>
- <u>No fine adjustment of the detectors is necessary.</u>

***Aligna® 4D*** gives you both possibilities: It can be switched to 2D or to 4D stabilization. Even in the 2D mode you have the advantage of watching both, position and direction, by help of the 4D detector.

In addition, a 2D stabilization can be performed by a combination movement of all four actuators.

Moreover, the servo speeds may be selected different for angle and position stabilization, which leads to higher precision, as described later.

## 4.3 Positioning of Actuator and Detectors

In the following, we will discuss different setups to get the best setup of positions of the piezo-controlled mirrors, the motorized mirror mounts, and the 4D detector system.

It is obvious that the detection of the beam movement has to be located BEHIND the actuators. Otherwise a movement of the actuators cannot be observed by the detectors for pointing correction in a closed servo loop.

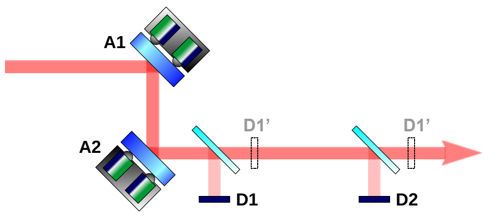
In addition, it is obvious that the detectors should be located near the target (or experiment). Then, all disturbances appearing at the path from the laser, passing maybe many folding mirrors and optical elements, will be detected and compensated for.

It is NOT the case that both actuators should be located in the near of the experiment. The two actuators may be located anywhere in the path up to the detectors. Of course, different positions have advantages and disadvantages, which will be discussed now:

### 4.3.1 Setup 1: Two Beam Samplers

We will start with the perhaps most easy to understand setup:

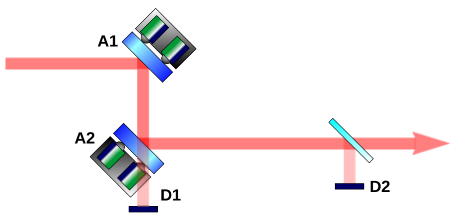
Two mirrors are mounted at piezo-controlled mirror holders. Four piezos can control four degrees of freedom: Two translational (X, Y), two rotational ($\alpha$, $\beta$).




Two 2D detectors represent two points of the laser beam. The electronics keeps the beam exactly in the center of both detectors. That means that two points of the beam are fixed. Thus the complete beam will be fixed (as far as no disturbance will happen BEHIND the detectors).

The position resolution is directly given by the position sensitivity of D1. A large distance between D1 and D2 leads to a high angle resolution. (The angle deviation is the difference of both position deviations.) On the other hand, both detectors should be placed near by the experiment. Therefore, a good compromise has to be found.

### 4.3.2 Setup 2: Second Mirror Acts as Beam Sampler




In the practical use it might be somewhat inconvenient to use two beam samplers. We can use the second actuator mirror as a beam sampler, because even very highly reflecting mirrors will transmit a small amount of light. We only need power in the order of some microwatts.

In this setup, detector D1 only observes the movement of actuator A1. In fact, a movement of A2 will also cause a very little beam movement at D1 due to beam shifting. However, this effect is negligible under nearly all conditions. Detector D2, in contrast, observes a movement of A1 AND A2.

### 4.3.3 Problems with Beam Sampler Plates

- A beam sampling glass plate (or a beam splitter cube), located in the main beam path, may influence the beam quality, if the flatness, the transmission properties or the polishing is non-perfect. High quality elements have to be used.

In most applications, beam sampler glass plates **with parallel surfaces** or beam splitter cubes are NOT APPRECIATED:

- A glass plate may cause interference effects due to multiple reflections between surfaces. Because of this effect, glass plates **with a small angle (wedge plates)** are preferred. However, they cause a (very small) angle deviation from the original direction.

- In femtosecond laser applications the glass in the beam path may cause unwanted dispersion effects.
  However, the problem of interference will not appear with fs laser applications: A pulse of 50 fs, e.g., has an optical length of approx 15 microns. The optical path length difference between both reflections of a 1 mm glass plate is 100 times longer! Therefore, both reflected pulses would not interfere. here it is not necessary to use plates with an angle.
  In this case thin plates (1...2 mm) are preferred. In most applications, the dispersion effects can then be neglected.
  It is very important to mount the glass plates without mechanical stress to avoid birefringence and deforming of the surfaces. Note: The reflected beam will define the reference axis for the pointing stabilization. Any movement of this reference beam will directly lead to movements of the main beam! Thus, a very thin glass thickness of less than 1 mm is not recommended.

- An uncovered glass plate at 45° splits approx. 1% of the beam for one polarization direction (p-light) and 12 % for the other polarization direction (s-light). Both values differ by more than an order of magnitude, which leads to strong unwanted polarization dependence of the test beam intensity.

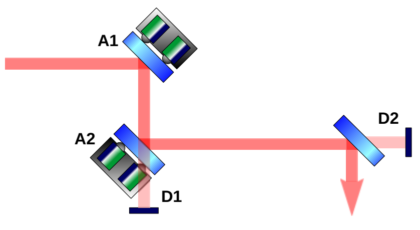
- In most applications both values (1% and 12%) lead to test beam intensities which are far above the necessary intensities of some microwatt. These test beam intensities have to be reduced by strong optical filters, and they are lost for the main beam.

- With horizontally polarized laser light, it is possible to get very low reflection rates by using a reflection angle of around Brewster's angle, approx. 57°. This angle will be slightly more difficult to align compared to a 45° angle.

- One (or both) surfaces can be AR (anti-reflex coated) for the target wavelength at 45° deflection. However, it is not easy (and thus not cheap) to get high quality broadband AR coatings with well-defined reflection grades, while HR mirrors are more easy to get.

### 4.3.4 Setup 3: High Reflecting Mirror Acts as Beam Sampler

Because of these problems, it is usually better to use the transmission of a HR (high reflecting) mirror as a beam sampler. The transmissions are typically of the order of 1% down to 0.01%, which is by far enough in most cases.





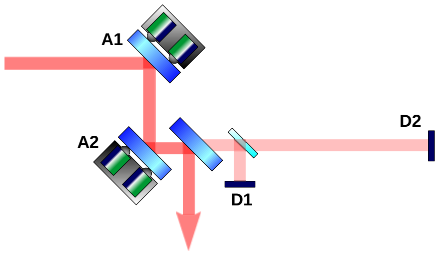
However, the polarization dependence of the transmitted beam can be large. Especially high-bred mirrors for high-power or high energy fs pulse lasers may have a polarization difference between s and p light by factor of 100 or even 1000.

(Often HR mirrors for the target wavelength, in contrast to AR coated substrates, are easier to get from stock.)

The distance between D1 and D2 defines the angle resolution.

In many applications, there are a lot of folding mirrors in the beam path.
One of the last mirrors before the experiment can be used as detection beam sampler for D2.

### 4.3.5 Setup 4: Only One Beam Sampler Mirror



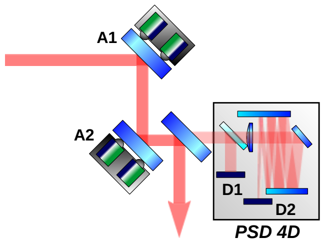

In a similar setup, a (nearly) non-polarizing 50% beam splitter (plate or cube) is introduced behind a non-moved high reflecting mirror, used for coupling out the test beam. This avoids the difficulty of using the mirror at A2 both as mirror AND as beam sampler. It leads to a smaller and more robust construction of A2. In addition, it gives the advantage that the ratio of the intensities of D1 and D2 only depends on the (known) properties of the detector beam splitter, not on different transmissions of two HR mirrors.

Most of the problems with a beam sampler plate described before are not important here, because the beam splitter is not located within the main beam path (dispersion, highest surface quality and flatness, HQ AR coatings,...). Interference between surfaces has to be considered, as well.

### 4.3.6 Setup 5: Compact 4D Sensor *"PSD 4D"*

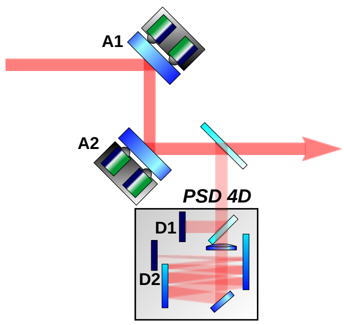
The distance between D1 and D2 determines the angle resolution. The introduction of optical elements can shrink down the necessary size of the detection setup:

1. A lens can create a far field image at the detector D2: If D2 is located in the focal plane of a lens; the detector is imaged to infinity. This detector will not register a (parallel) translation of the beam at all, as the lens laws show. It only registers angle movements. Therefore, this would be a pure angle detector, while detector D1 acts as a pure position detector. However, at a given detector size the angle resolution will increase with increasing the focal length. The optimum resolution is reached, if the focused spot diameter has nearly the detector size.
2. For getting a compact design the beam can be folded by mirrors back and forth, which leads to a very compact 4D detector, as realized in the ***"PSD 4D"*** detector box, which has the dimensions of only 80 x 80 x 40 mm.




The sketched setup here is the mostly used one with ***Aligna***® applications

### 4.3.7 Setup 6: "PSD 4D" with Beam Sampler Wedge Plate




Of course it is also possible to use a glass beam sampler for the creation of the test beam to be lead into ***PSD 4D***. The setup shown here is often used for testing purposes, because in many cases no change of a pre-existing optical setup is necessary. It has to be clarified that the beam sampler plate does not cause problems (too high losses, dependence on polarization, dispersion, interference).
Excessively high intensities at the detector have to be handled by optical filters.

**What is the Best Setup? Some Selection Rules**

All of the described setups can be realized with the ***Aligna® 4D*** (using PSD 2D or PSD 4D, different types of beam samplers). The user may decide which fits best to his application. However, there are some rules for selection:

## *4.3.8 Distance between A1 and A2*

The distance between A1 and A2 defines the possible compensation of the beam translation movement, while the possible rotation movement is independent on this distance.

Of course, in most cases a small and compact design is appreciated. What are the criteria?

If there is a large distance between the laser and the experiment, even small angle movements are translated into large transversal movements. In these cases, a large distance between the mirrors A1 and A2 is recommended. If the distance from the laser to the experiment is many meters, the optical path distance A1 to A2 should be 50 cm or more.

The standard actuators ***BeamScan 2D*** can move the mirror by an angle range of 2.3 mrad in X and Y direction. That means with a distance between A1 and A2 of 1 meter a beam displacement of up to over ± 2 mm can be compensated. This is quite sufficient for most applications.

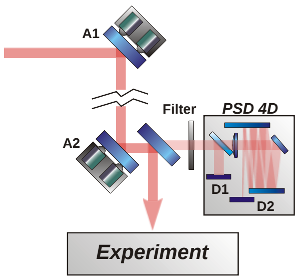
One mm or more will only be necessary with very long laser beam distances of over 5…10 meters, depending on environmental properties, or with the use of delay lines and other moving optics. In fact, it is not easy and takes some time to align a delay line to much better than some 100 microns of beam shift (depending on the moved rail length of course).

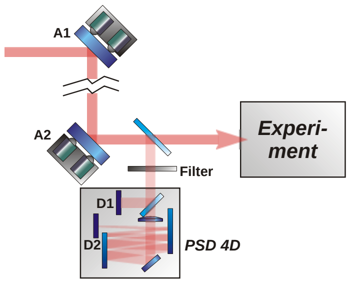
## *4.3.9 Position of the Detector(s)*

The 4D detection should be located close to the experiment, because only disturbances in the path BEFORE the detector can be detected, and thus can be eliminated.

Even if a large variety of positions and distances can be handled by ***Aligna® 4D*** <u>the best position of the 4D detector (or the first of the two ***PSD 2Ds***) is as close as possible behind the second actuator mirror A2.</u> (Of course, the necessary beam samplers/mirrors and maybe filters for adjusting the detection beam power have to be between A2 and the detector.)

In this case, the four servo loops can mostly be separated from each other. This leads to a more stable and robust locking behavior.



## 4.4 Beam Sampling

The sampling of the beam used for 4D measurement of the main beam is a fundamental issue, and very often, it is the limitation of the final precision. The beam will be stabilized related to the 4D detector. If the sampled beam does not exactly represent the main beam, the effective precision at the target will decrease.

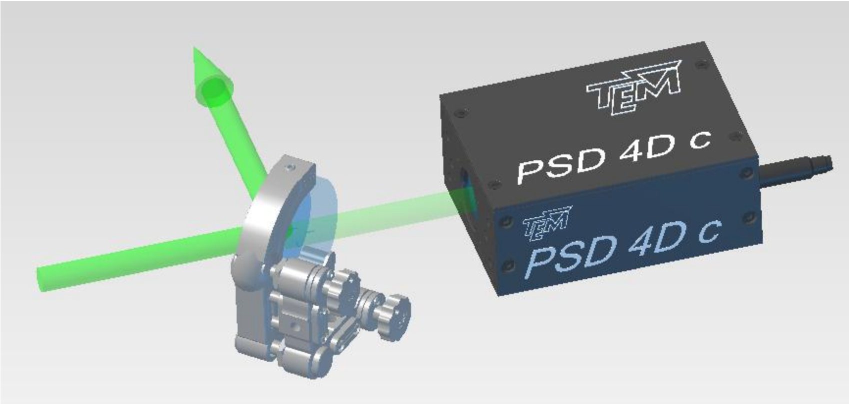
It is obvious that the detection of the beam movement has to be located BEHIND the actuators. (Otherwise, a movement of the actuators cannot be observed by the detectors for pointing correction in a closed servo loop.)

There are several methods creating the sampled beam from the main beam. All of them have advantages and disadvantages. Therefore, we will discuss the main methods in the follow up.

(In the pictures mostly the "PSD4Dc" is displayed. Of course it can be translated to the "PSD4De", "PSD4Di" and other variants as well.)

### 4.4.1 Leak of a HR Mirror

One of the simplest methods is using the leak transmission of a high reflecting mirror in the beam path (preferably the last mirror before the target).




One main advantage is that no additional optical components are inserted into the beam path. Especially with high power lasers or ultra-short-pulse lasers, this is the main reason to prefer this method.

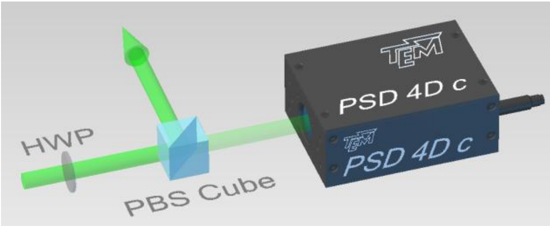
One problem is that often it is rather difficult to get exact properties regarding the leak of a HR coating. (The reflectivity may be specified as >99.7%, but the transmission may vary between 0.001% and 0.3% (which are 2.5 orders of magnitude!), depending on the complexity and the homogeneity of the coating, of polarization properties, of air temperature and humidity.

The transmission of a HR coating may differ by a factor of 200 or more for p- and s-polarized light. Thus if the laser is s-polarized, but p-light is transmitted 200-times stronger, the detector will see more or less the "dirt" (caused by birefringence in optical components, or un-polarized ASE), not the direct laser beam, which causes an incorrect stabilization result.

A half-wave plate may be used to vary the transmission by turning the polarization between s- and p-light.

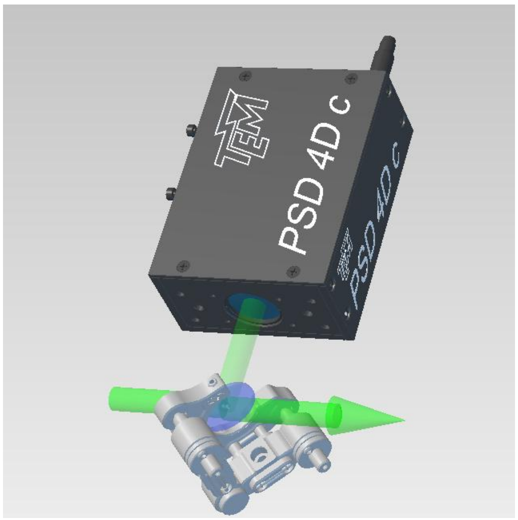
Other problems are interference effects, caused by Fresnel reflections of the back surface. So-called ghost reflexes may interfere with the main transmitted sampled beam. A wandering interference fringe, caused by small temperature changes of the mirror may be misinterpreted as beam position drifts.

(NOTE: When using ultra-short-pulse lasers with a pulse length much smaller than a few mm, interference is no longer a problem. Regarding problems of interference effects, see below.)




Alternatively, a Polarizing Beam Splitter (PBS) cube or plate can be used for folding the beam, and for creation of the sampled beam (in reflection or in transmission). In this case a half wave plate selects the necessary amount of sample intensity.

### 4.4.2 Uncoated or AR Coated Sampler Plates




A safer method in terms of predictable results and defined conditions is using a sampler plate (for example of fused silica, uncoated or AR coated).

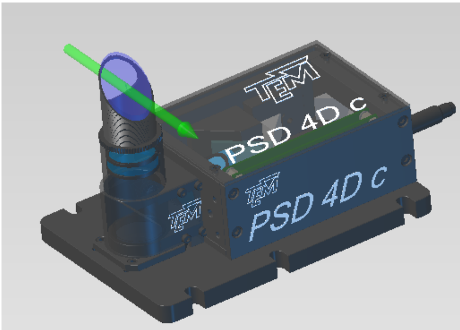
However, one has to be very careful with interference effects: front and back side surface reflections have nearly exactly the same intensity, and are normally extremely parallel. This leads to an interference contrast of nearly 100%. That means (with p-light at 45°, e.g.) the reflected light may vary between 0.9% per surface (at constructive interference) and 0 % (at destructive interference). This leads to a strong variation of the out-coupled intensity, by more than an order of magnitude!

Even more critical is that no parallel plate is absolute exactly parallel. There will be remaining interference patterns. If temperature changes, these interference fringes will wander over the beam diameter. Now the position detector cannot distinguish between a real (very small) movement of the beam, or a moved interference fringe.

(Again, interference is no problem with ultra fast lasers with coherence lengths under a few mm).

Often just a very small amount of the main laser beam is needed for measurement (1 mW average power or so for cw and high repeating lasers, or 100 nJ for slowly repeating lasers.)

Using the Fresnel reflection of an uncoated fused silica or BK7 substrate at 45° gives 0.9% per surface for p-light (close to Brewster's Angle), which is OK for lasers around 100 mW average power. If power is much higher, filters can be used to reduce the sampled power. (ND 1 filter for 1 W laser power, e.g.)

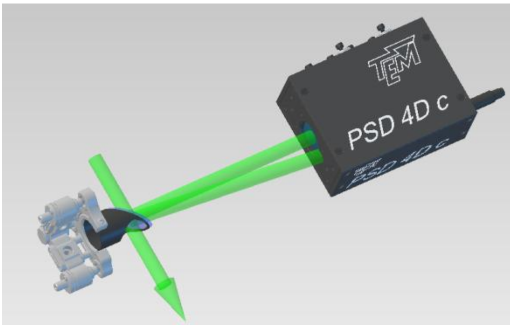



However, s-light would be reflected by 2 x 12% at 45°, which normally is a no-go, one does not want to lose 24% for the pointing measurement. (Only for very weak lasers in the range of 100 µW to few mW this might be a fitting solution.)

Therefore, for using uncoated sampler plates the laser beam has to be p-polarized.

If the laser happens to be vertically polarized, the sampler plate can be oriented in that way, that the sampled beam goes vertically down, and it is folded again to a horizontal detector.

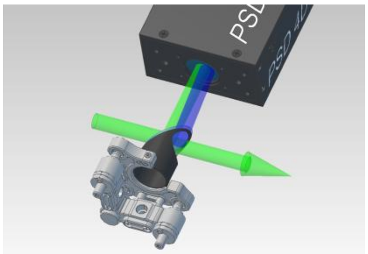
### 4.4.3 Wedge Plates



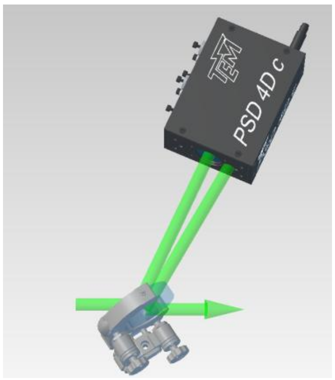

To avoid interference effects and ghost reflexes the use of a wedge plate (instead of a parallel plate) is strongly recommended.

For the experiment, the wedge angle should be rather small to avoid dispersion and to avoid an angle displacement of the beam. In this case, the PSD has to be located far enough from the sampler, so the part beams, created by both surfaces are separated sufficiently.
One of the beams is skipped.

#### 4.4.3.4 Short Distance Wedge Plate




If there is not enough space for this distance (especially, if the beam diameter is large), the wedge plate can be oriented vice versa, so the part beam from the front and from the back surface combine approximately the position detector chip. Of course, there will appear interference fringes at the detector chip. However due to the well-selected wedge angle these fringes are so narrow, that they wipe out by integration over very many fringes.

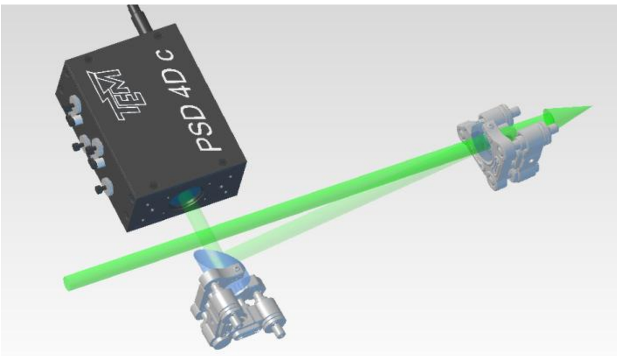



(In this case, the wedge angle has to be selected rather carefully: The focused spots at the angle detector chip have to be separated distinctly more than the A chip size, while both un-focused spots at the B chip should fit completely to the chip size.)

If the 2 x 0.9% reflectivity is too high (the 2% of power should not be lost, or the sampled beam becomes very strong because of high laser power) the sampler plate can be oriented at Brewster's Angle (about 57°) instead of 45°.

Because of the smaller angle, the demands on the surface quality of the sampler plate are higher, and the size of the plate must be larger, compared to 45°. In addition, the sampled beam comes out at a less convenient angle (compared to 90° with 45° plates).

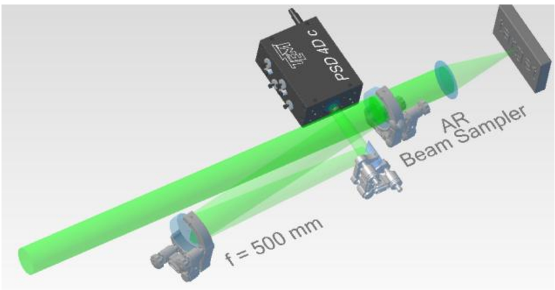
### 4.4.4 AR-Coated Windows at Small Angle




The wedge plates (or un-wedged plates with ultra-fast lasers) at 45° or larger angle have two draw-backs:
1. The sampling is strongly dependent on the polarization (p-light necessary!), and the out-coupling might be too strong for high power lasers.
2. AR coatings at 45° are difficult to get from stock and have much less assortment at most optics suppliers.

Custom-made AR coated wedge plates (at 45°) are a solution. They can reduce the reflectivity of the s-light from 12% down to 0.3% and of the p-light down to 0.1 % or so. However, they are difficult to get from stock. Thus, they have to be specially coated, and therefore are rather expensive and have a long lead-time.

Using commercially available AR coated windows (with or without wedge angle) are a practical solution. They can be (and have to be) operated close to 0° angle of incidence (AOI). Typically <12° is within the specs range of the coatings. An additional folding mirror helps avoiding too long distance from the sampler to the detector, and allows for a convenient sample beam alignment.

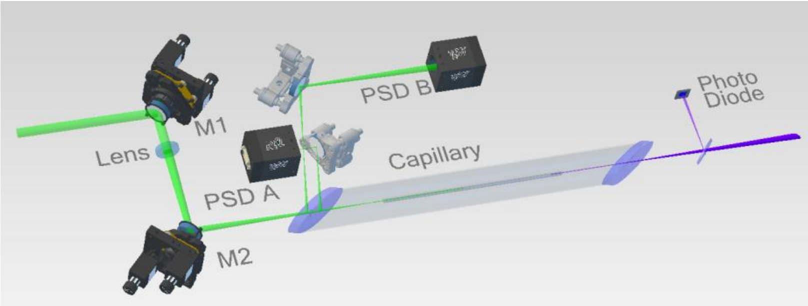



Due to the small AOI the polarization dependence is negligible, so this setup also works fine for un-polarized or randomly polarized lasers (for example some fiber lasers, or lasers which have been guided through a non-polarization-maintaining fiber, or lasers with rotating polarization, or lasers which have been combined via polarizing couplers..

In a variant for rather big beams, one folding mirror can be used as a concave focusing mirror. This replaces the PSD lens for the "far field" or "angle" detector "A". Here again a wedged or an un-wedged sampler plate may be used.

### 4.4.5 Focusing to a Capillary

One typical application for Aligna systems is stabilizing a beam, which is focused into a hollow fiber or capillary, by means of a lens with rather long focal length (f = 0.3 m … 2 m)



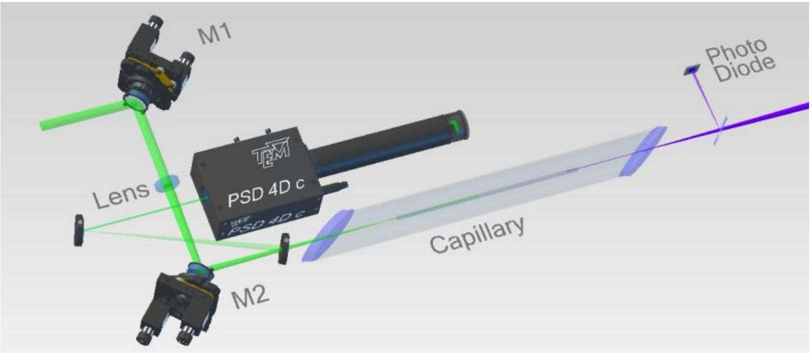

In this case it is recommended not to use the PSD-internal lens, but placing the A detector in the focal plane of the main lens. The B detector is located more down streams, distinctly behind the focus, when the beam diameter has expanded to a value, still smaller than the B detector chip size.

In this case thermal effects of the main lens are also detected, and thus corrected.

If the reflections of the entrance window of the vacuum chamber are available, these are good sampling surfaces. If these reflexes are not available, a separate Brewster's angled window, or an AR window can be used.

In this particular case, also a parallel window works fine, because the beam is convergent at the location of the beam sampling: in the near of the focus the two spots from both window surfaces are well-separated. (In opposite, if the beam sampler is located in the collimated beam, the two part beams from both surfaces cannot be separated by principle, if the surfaces are exactly parallel, and the sampler plate is not much thicker than the beam diameter.)

Alternatively, instead of the single 2D PSDs and external mirror mounts also the back-extended PSD4Dc can be used, without an own lens, using the main focusing lens as well.




The photo diode behind the fiber is used for automatic 4D optimization. (This is described in detail in another chapter.)

# 5 Some Typical Configurations

In the following, some typical 2D and 4D configurations are discussed. In particular, we think about rather long beam paths between the laser and the target.

In the examples, we will mostly use beam sampling mirrors (BSM). Alternatively, we can use wedged beam sampling plates (WBSP). (The advantages of the different beam sampling methods are described in a separate chapter.)

Following actuated mirrors can be used:

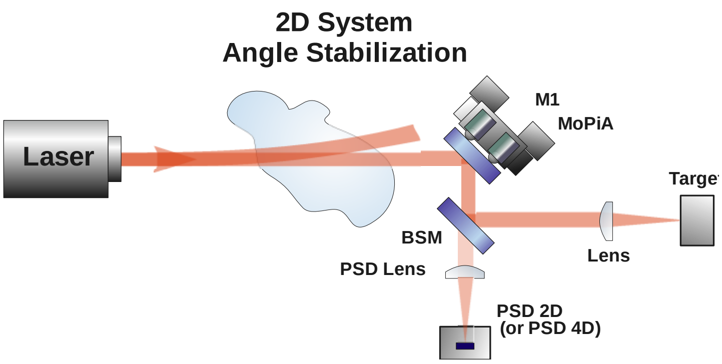
| | | |
|---|---|---|
| PiA: | Piezo Actuators | High resolution, high speed |
| MoA: | Motorized Actuators | Large Stroke, Auto-Alignment |
| MoPiA: | Combination of MoA and PiA | High resolution, high speed, large stroke, auto-align |

Following detectors are used::

| | |
|---|---|
| PSD 2D: | Position Sensitive Detector for measuring the Beam Position, OR (in combination with a detector lens) measuring the Beam Angle |
| PSD 4D: | Simultaneous and independent measurement of Beam Angle AND Beam Position |
| AimPD: | One or several photo detectors, located along the beam path at important optical components, for example at entrance of a beam line tube, before an amplifier stage, before mirrors, delay lines, SHG, … |

## 5.1 2D System (Angle Stabilization)

The 2D angle stabilization system is the simplest of systems discussed here. A laser is focused to a target by means of a lens (or objective). The spot position in the target plane has to be held stable. However, the target spot position is influenced by laser drifts, by thermal effects of mechanical and optical components, as well as air fluctuations, etc. These effects have to be compensated by the stabilization system, controlling the active mirror M1.




In this case, the laser beam is sampled by the leak of the beam sampler mirror BSM. The "PSD lens" is focusing the sampled beam onto a position sensitive detector (PSD 2D). If the spot position at the PSD2D is stabilized by movement of active mirror M1, also the spot position at the target will be stabilized.

(As explained before, in most cases the beam angle is much more sensitive, than the beam position: The angle represents the position of the spot at the target, while the beam position just influences the angle of incidence at the target, which is by far less sensitive in most cases, of course not in all.)

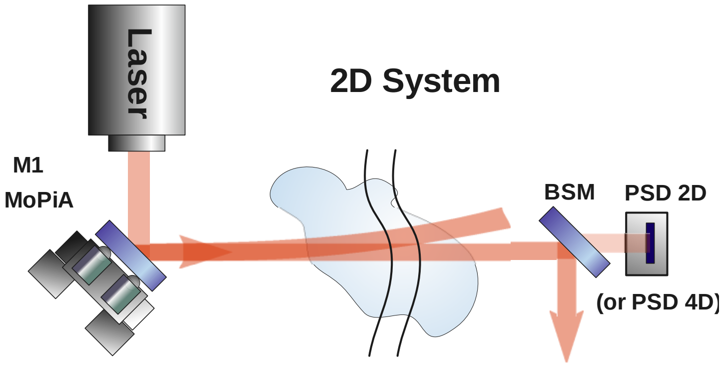
## 5.2 2D System (Long Path)

If the laser beam has to be guided over a more or less long beam path, in a simple 2D system the active mirror should be located near the laser, while the detector should be located close to the target.

(If the mirror was located far away from the laser -or the main source of drift, resp.- the beam might not hit the mirror due to even small miss-alignments or drifts.)

The laser itself may have pointing drifts. Additional drifts and fluctuations will appear along the long beam path.

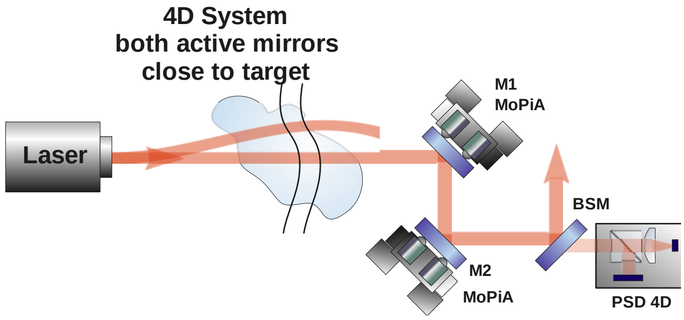
The angle of the target beam is given by the long distance and the position, stabilized at the PSD. Thus, the angle is not directly stabilized, but the beam position at the target table.




## 5.3 4D System

In many experiments and applications the target is both sensitive to angle AND position of the laser beam. In this case, a PSD4D can be used. (As discussed before the measurement of all four degrees of freedom, Angle X/Y and Position X/Y, INDEPENDET from each other results in a much better precision, than measurement of two positions along the beam path. Of course, the Aligna system also can be used measuring two positions, using two PSD2D. However, this normally is not recommended, only if other "far field" focusing is available and used for detection in the optical setup.)

Sometimes it is necessary to place the two active mirrors, used for correcting the 4D pointing, close to the target. However, this is not the best situation: In the case of a long beam path, rather high position fluctuations will occur.




(The position fluctuation and drifts are calculated by the angle fluctuations, and drifts at the laser position, multiplied with the beam path length, while the angle fluctuations are not directly scaling with the beam path length. Of course, additional angle fluctuations occur by air fluctuations along the beam path. But even these additional fluctuations are multiplied by the beam path length, depending on the position of their origin.

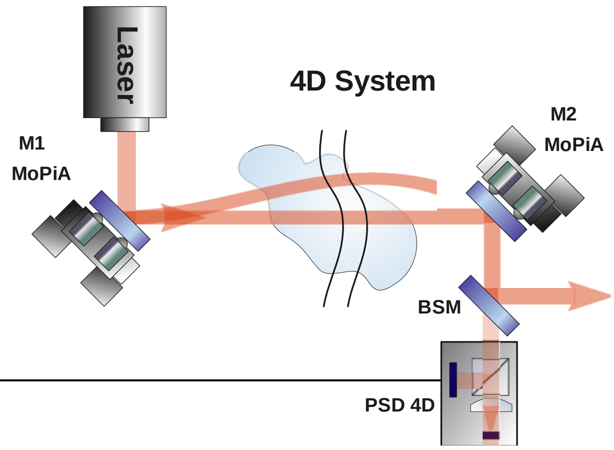
Therefore, in laser systems with long beam paths the ratio between position fluctuations against angle fluctuations is rather high.

For compensation of position fluctuations, both mirrors have to perform the same angle, however with different sign. The amount of mirror movement is reverse proportional to the mirror distance: <u>the longer the distance, the smaller the necessary movements</u>. However, the larger the absolute angle movement, the larger the absolute residual angle error of the servo loop will be (due to limited servo bandwidth). <u>Because of that a large distance between the active mirrors is recommended,</u>

## 5.4 4D System with Long Beam Path

As explained, a long distance between the mirrors leads to small residual angle errors, which corresponds to smallest possible target position errors.

As a result, for best dynamic performance <u>in setups with long laser beam paths one active mirror should be located near the laser, the other should be located close to the target.</u>



If the laser drifts or fluctuates, this setup gives an additional advantage: the whole beam path between the mirrors also benefits from the stabilization. (Often additional optical components, like telescopes, frequency doublers, etc. are located between the active mirrors. If in contrast both mirrors are located near the target (as mentioned in former chapter) the 4D pointing at the target will be stabilized as well, but the whole beam path before the second active mirror will "see" the full laser drift and fluctuation.

In more general: The first active mirror should be located near the main source of drift (may be located before or behind it). Thus, this drift is directly compensated near the source of drift, and the whole beam path will be more stable (not only in the target path).

In many cases, the laser itself is the main source of drifts. (Then the first actuator should be located close to the laser.). However sometimes another component may cause even larger disturbance: motorized zoom objectives, dynamic delay lines, portal sleighs, etc. In these cases the first active mirror should be located in the near of the strongest source of fluctuation.

The second active mirror and of course the detector should be located near the target.

## 5.5 Auto-Alignment and 2D stabilization

In laser systems with long paths, the beam often is guided in a beam line tube (BLT). The longer this beam line tube (and the thinner this tube is) the more difficult it is to align the beam manually through this tube. (The BLT may be several 10 meters or even 100s meters long.)

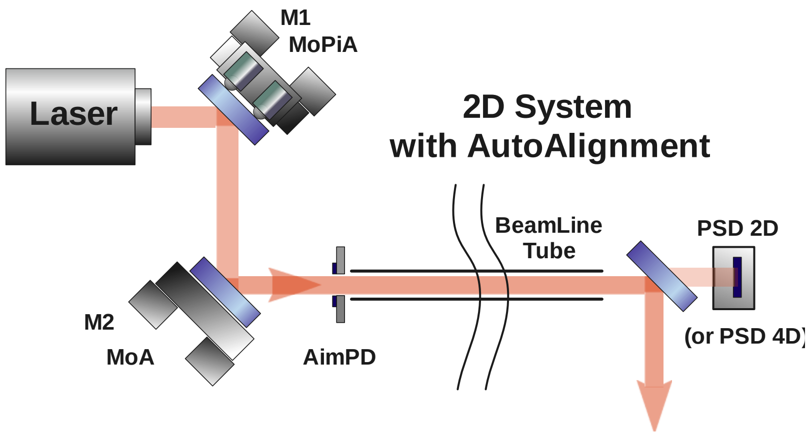
Sometimes this tube is evacuated. In this case, alignment is even more difficult, because the beam cannot be seen and manually aligned using paper screens or fluorescent plates.

In these cases, a fully automatical alignment through this beam line tube helps saving a lot of time.

(Auto-Alignment of these systems is described in detail in another chapter. Here just the basic principles are mentioned.)

For fulfilling this task, the Aligna system benefits from its matrix-based movements. By using linear combinations of four motors (two 2D active mirrors), the beam can be turned around any point along the beam path.

The basic steps are:




1. 2D-scanning of M2 (or M1), until the tube entrance has been hit.

2. The beam will be 2D angle-scanned around the mid position of the tube entrance aperture, while beam position at the tube entrance is held fixed. This is done, until the tube exit is hit, detected by the PSD (or another detector).

For hitting the tube entrance, a so-called "AimPD" is used. In principle this is a simple photo detector (PD), located at the tube entrance. (Normally this detector is not located in the center of the tube entrance, but at its border. However, it is also possible to use a motorized PD, which is driven by a small motor into the optical axis for this pre-alignment task. Alternatively, a flip mirror, or even a permanent beam sampling plate is inserted into the beam path at the entrance of the BLT, reflecting a part of the main beam to the detector. These "AimPDs" are described later in detail.)

If the beam now hits the AimPD, it automatically centers to this PD. Then the beam is moved from the border of the tube to the middle of the tube.

In the next step this tube entrance beam position is held fixed, and by means of a suitable OCL matrix the angle of the beam is scanned in X and Y (orthogonally or in a special search spiral shape), until a detector at the outlet of the tube is hit. This detector normally is a 2D or 4D PSD. (Alternatively, another AimPD of the next part beam is used. So many part beam sections can be aligned automatically, fully hands-off.)

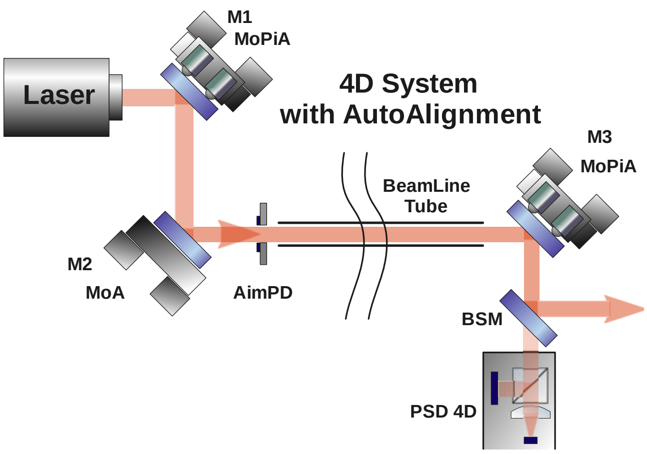
If this PSD is hit, M1 is stabilized with rather high servo bandwidth to the center of this PSD.

Due to the long BLT the mirrors at the laser hutch (or the laser table) do not really have an influence to the beam angle at the experimental hutch (or the experimental table), but just to the beam position in the experimental hutch. The angle is defined (and "fixed") by the axis of the BLT.

So the described stabilization is just a 2D stabilization. Only one of both motorized mirror mounts (MMM) has to be a fast 2D actuator (MoPiA). The second one is just used for "coarse" alignment (hitting the tube entrance). Therefore, requirements on speed and resolution are low. For the second actuator a motorized actuated MMM (MoA) is sufficient.

## 5.6 Auto-Alignment and 4D stabilization

In a large laser setup with long beam lines in reality often many more optical components (mirrors, lenses, telescopes,…) are in the optical path (for simplicity not sketched here). All of these components may drift, vibrate, fluctuate, move,…

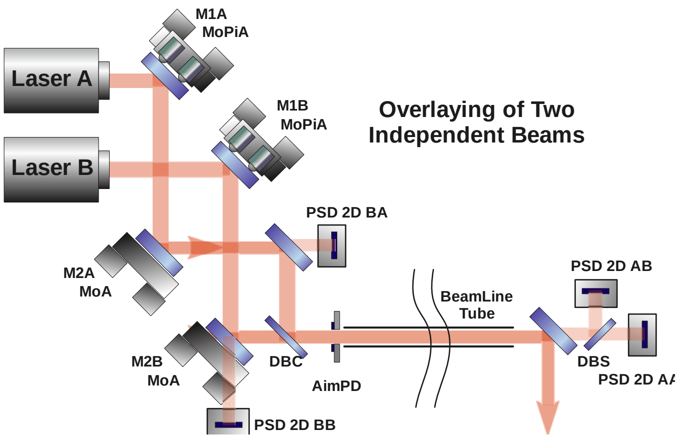



The beam position at the target table is aligned and stabilized by M1 and M2 in the manner, described in the former chapter. However also (or in particular) the beam angle, hitting the target (or the targeting objective) is very sensitive, and has to be stabilized as well.

In this case another active mirror (M3), located in the experimental hutch (at the experiment table) is used, as well as a 4D (instead of a 2D) detector, which measures simultaneously and independent from each other Angle X/Y and Position X/Y. Thus, the beam is automatically aligned and kept along the long beam line tube, position AND angle are stabilized with respect to the target. (This setup is one of the Aligna standard setups, it is described later in deeper detail.)

## 5.7 Overlaying Two or More Laser Beams Independently

In many experimental setups it is necessary to overlay two or more laser beams (with different wavelengths, sometimes with different polarization, with different pulse timing, maybe cw and pulsed, etc.) at exact one common optical axis. Sometimes all beams have to go through the same long beam line tube.




The beams are often combined by help of a dielectric beam combiner (DBC).

All methods, previously described, can be transferred to two or several beams. The additional task is to place the detectors and add some dielectric beam separators (DBS) in the detector path (or a polarization cube, interference filters, etc.), so each detector only observes the related laser beam.

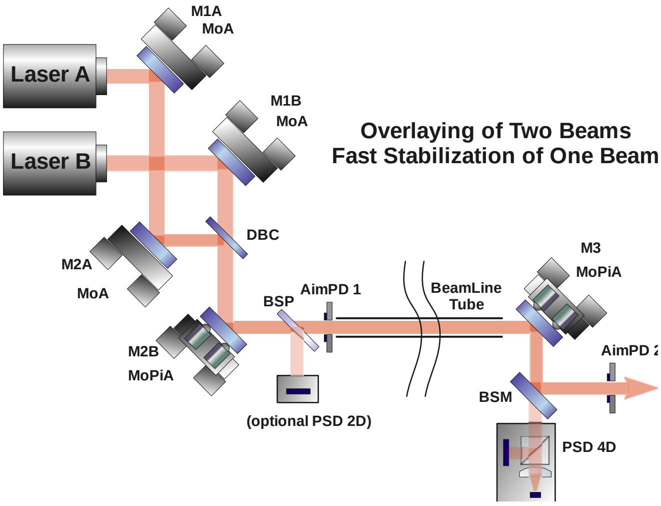
The "angle" detectors of beams "A" and "B", "PSD AA" and "PSD AB", will be located close to the target, while the "BeamPosition" detectors "PSD BA" and "PSD BB" are located near the lasers. They are also used for automatic combining alignment, in cooperation with an "AimPD", acting as a conjunct "electronical iris". If necessary, additional AimPDs can be inserted at critical points of the beam path, so all beams go exactly the same way.

## 5.8 Overlaying Two Laser Beams, Commonly Stabilized Path

Separating all beams and using complete independent detectors and motorized and piezo-actuators for all beam is a certain effort, especially for many beams. Often the relative drift of the lasers with respect to each other is small, compared to the beam pointing fluctuation caused by the long beam path. It is not always necessary, to stabilize all beams completely independently with full servo speed in 4D. Often it is sufficient to overlay all beams (just rather slowly) with the motorized mirror mounts, and stabilize the common beam path with help of (just two) fast piezo-based mirrors.

A certain problem when using several beams with very different wavelengths and/or very different power levels in one path is the beam sampling to observe all lasers simultaneously with one detector. Beam sampling due to leak of a HR mirror is rather difficult, because the leak of one mirror will be very different for the several wavelengths, also strongly dependent on polarization, etc.

We also can use motorized filter wheels and/or motorized flip mirrors to get suitable signal strengths using the same detector for all wavelengths (just one at a time).




Following tasks can be separated:

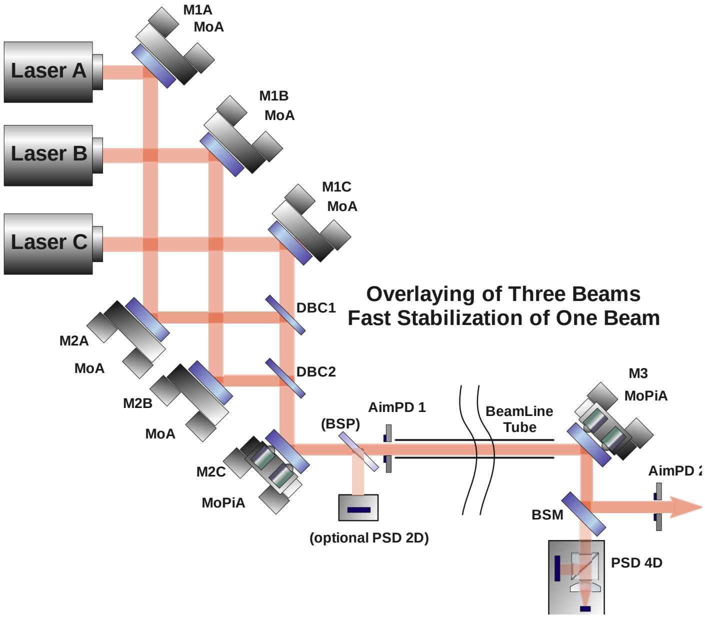
- Automatic overlaying the beams at the combining mirror (or at any other point close to the laser sources) (with motorized mirror mounts M1A, M2A and M1B, M2B, regarding a motorized electronic iris AimPD1, or the optional PSD 2D)
- Automatic overlaying the beams in the near of the target (with motorized mirror mounts M1A, M2B, M1B, M2B, regarding a motorized electronic iris AimPD2)
- 4D stabilizing just one beam, (with piezo actuators MoPiA M2B and M3) to avoid drifts and air fluctuations along the common beam path (using a PSD4D suitable to one of the wavelengths). All beams go the same path, so all beams will be stabilized regarding the drifts and disturbances at the common path.

The overlaying can be observed and -if necessary- repeated from time to time. This can be done automatically by help of one or several AimPDs ("electronical irises").

For this check of overlaying the beams are blocked (manually or by electrical shutters), just one beam is enabled at a time. The electronical irises (or wavelength-depending flip mirrors) in the common beam path close (depending on the former defined beam size). Each beam is automatically aligned regarding the irises. Then the irises are opened and all beams are enabled by the blocks or shutters. The fast 4D stabilization for one of the beams is enabled, the other beams are stabilized as well at the same path.

Optionally, a PSD (for one or several beams/wavelengths) and a beam sampler plate (BSP) can be installed at the laser table. In this case, a continuous observation (not from time to time) of the beam position at the laser table is possible.

## 5.9 Overlaying Three Laser Beams with Commonly Stabilized Path




In the following, the same procedure is sketched for three overlayed beams with a commonly stabilized long path.

All beams "A", "B", "C" are overlaid at the tube entrance, by help of dielectric beam combiners "DBC1" and "DBC2", regarding the "electronical iris" "AimPD1".

By help of matrix-4D-movement the beams are also overlaid at the target table, regarding "AimPD2".

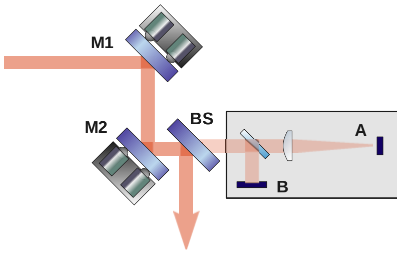
The common path is stabilized with full servo bandwidth regarding PSD 4D, which measures one of the beams (or an average of all).

If all wavelengths can be detected by the PSD4D, this detector can also overtake the task of "AimPD2". This however is only possible if all wavelengths are in the range of the same PSD (for example 350 nm…1100 nm).

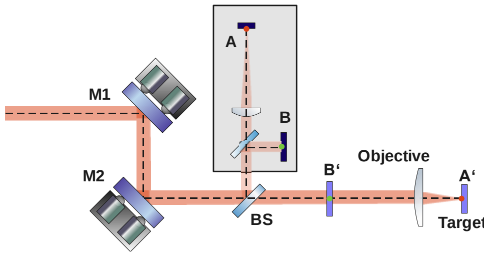
## 5.10 Comparison of some Setups

As a comparison, some basic setups are discussed now.

**Beam sampler types of 4D detector setups:**

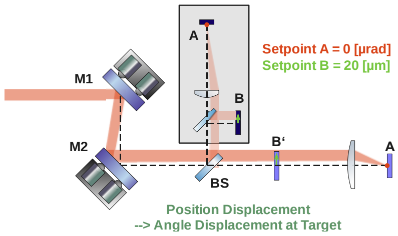



High reflecting mirror as beam sampler

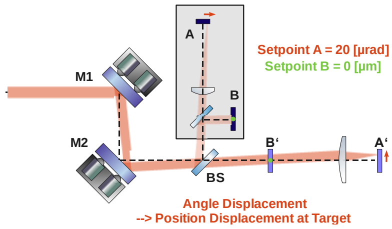



Weakly reflecting beam sampler plate

**Defined displacements** due to changing or scanning the angle or position servo setpoints; the beam is fixed at one detector, scanned relative to the other one.
(Here displayed with beam sampler plate, works with HR sampler mirror as well):




Position displacement



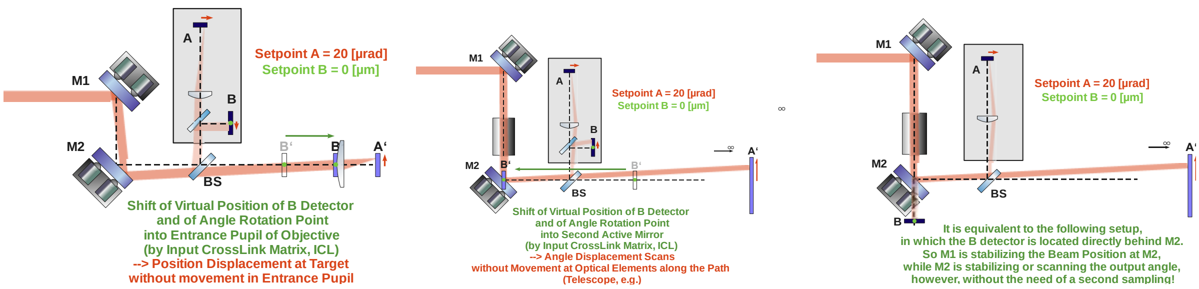

Angle displacement

In violet: virtual positions A' and B' of Angle detector A and BeamPosition detector B

**Shifting the virtual position of the B detector** due to the Input CrossLink Matrix (ICL):

This shifting of the virtual detector position, or the rotation point of angle movement is done by adding or subtracting an amount of angle signal Ax, Ay to position signals Bx, By in the ICL.)
It allows the scanning of the beam angle (and so the target spot position) without moving the beam position at sensitive optical elements, like objectives, telescopes, frequency doubler crystals, amplifiers, etc.

In the first example, the entrance pupil of an objective shall be hit exactly, while moving the target spot position. In the second example, the optical axis of a telescope (or crystal, amplifier, modulator,…) shall be hit, while stabilizing (or scanning) the output beam angle. (The green arrow indicates the shift of the virtual position of the B detector, which defines the rotation point of the angle scan.)




Fixing the beam position at an entrance pupil, or at a telescope axis for scanning the angle

# 6 Pulsed Lasers

***Aligna®*** can handle both cw (continuous wave) and pulsed lasers.

However, for best performance, pulsed lasers may need other detector electronics than cw lasers.

The standard actuators of an ***Aligna®*** system are piezo driven mirrors with first main resonances $f_R$ of 0.5 … 3 kHz. (We also offer Piezo actuators up to 40 kHz resonance frequency, working with a servo bandwidth up to 20 kHz) Thus, the closed servo loop bandwidth will be distinct below these first main resonances (0.3 … 2 kHz). The servo loop cannot compensate for disturbing frequencies above the servo loop bandwidth.

Pulsed lasers with repetition rates far above the servo loop bandwidth (>100 kHz) can be seen equivalent to CW lasers, while low repetition rates (< 3 kHz) are a bit more difficult to handle.

## 6.1 Repetition Rate Categories

We will subdivide the lasers into following categories (let us assume here the main piezo resonance $f_R$ to be 1 kHz; scale the named frequencies to other resonance frequencies):

1. CW lasers
2. CW lasers with laser intensity modulation (5 kHz to 200 kHz)
3. Pulsed Lasers with slow repetition rates (1 Hz … 3 kHz)
4. Pulsed Lasers with medium repetition rates (3 kHz … 15 kHz)
5. Pulsed Lasers with high repetition rates (> 15 kHz … > 1 GHz)

The servo signals are created from the momentary laser (periodically pulsing) intensities. Thus, the piezo signals will contain distinct components with the laser repetition frequency.

If the main resonance is assumed to be 1 kHz, the actuator will cut off frequencies above 1 kHz with approx. 40 dB per decade (system of 2$^{nd}$ order). That means the actuator will move at frequencies of 10 kHz with only 1% compared to low frequencies, but nevertheless these movements may cause acoustical noise with a periodic signal of the repetition frequency.

This will not disturb the beam pointing regulation: Laser pulses are typically very much shorter than the repetition time. The laser pulse will hit the moved mirror always at the same phase of the periodic movement. The laser pointing will not care about the movement of the mirror outside the very small time window of the laser pulse.

However, acoustical noise is not appreciated because of hearing a continuous beeping.

### 6.1.1 CW Lasers

Those lasers are the easiest to handle, because the detectors receive continuous information about the momentary beam pointing. Since the detector bandwidth is normally much higher than the bandwidth of the actuators, the actuator properties (resonance frequencies, resonance quality, mechanical crosstalk, etc.) will limit the regulation speed.

The smaller and lighter the mirrors are, the higher the servo bandwidth will be.

In many applications, however, there are no strong disturbances with some 100 Hz to some kHz. The strongest disturbances are slow or quasi-static (air density gradients and thermal drifts). No high servo bandwidth is necessary.

So only if higher frequencies have to be compensated small light-weighted mirrors are recommended (10 mm diameter, 2 mm thickness, depending on beam diameter). In most cases, standard 1 inch mirrors of 6.3 mm thickness are sufficient.

A 4D stabilization system is a rather complicated combination of four coupled servo loops. With CW lasers, however, the reaction is rather fast. Even if the servo parameters and the decoupling (➔ Orthogonalization) are not perfect the system is not critical.

### 6.1.2 CW Lasers with Intensity modulation (5 kHz to 200 kHz)

((Demodulation, PSD LID … Description in preparation))

### 6.1.3 Pulsed Lasers with Slow Repetition Rates (1 Hz … 3 kHz)

Those lasers are the most difficult to handle: The information of the momentary pointing is only available with the laser repetition rate. This is smaller than or around the servo bandwidth. Each amount of information should be used to achieve a servo bandwidth as high as possible, e.g. for compensating air fluctuations. However, the effective servo bandwidth will be smaller compared to CW lasers.

**Precision Measurement of Pulsed Signals**

It is much more complicated to measure position signals of short laser pulses with very high precision, compared to CW signals. Without compensation networks, the steep flanks of the laser light pulses drive the detector amplifiers into their non-linear "Slew Rate Limitation", even at small intensities. For creation of the position signals many signals have to be calculated by means of additions, subtractions and divisions. If this is done with signals that contain non-linearities, the residual precision decreases significantly.

To avoid (or reduce) these effects we introduce analog networks around the detector circuitry and we carefully match the time constants. However, this can only be done to a certain degree because of some position dependent asymmetries of time constants of the detector signals of the PSDs.

**Sample & Hold Stages**

A simple low pass filtering would cause unwanted phase shifts that lead to a servo loop band-width far beyond the repetition rate. In addition, a high residual amount of the repetition rate signal appears in the piezo signals; that leads to acoustical excitation of the mirror actuators.

For this reason, we use position sensitive detectors (PSDs) with a special differential three stage Sample & Hold circuitry (***PSD S&H***) for this category of lasers. (See detector description for more details). With these detectors, we get highest possible information speed with lowest possible phase shift and low residual repetition frequency amounts.

In addition the differential S&H offers the nearly perfect compensation of environmental light (daylight and 50/60, 100/120 Hz of artificial light sources,…), equivalent to a "Lock-In"-technique.

The repetition rates of course influences the following parameters, which have to be adapted to a changing repetition rate:

1. The filtering networks at the detectors and the transimpedance amplifiers (see description of PSD S&H)
2. The timing within the S&H logic circuitry (see description of PSD S&H)
3. The servo loop parameters of the four $PIDT_2$ Regulators in the ***Aligna® 4D*** electronics

Therefore, when ordering an ***Aligna®*** system, designated for pulsed lasers, you should tell us the target repetition rate and the possible variation range of the repetition rate. The detector and servo parameters will be pre-aligned to these frequencies before delivery.

### 6.1.4 Pulsed Lasers with medium repetition rates (3 kHz … 15 kHz)

The lasers of this category can be controlled similarly to CW lasers. However, the basic detec-tor signals are pulsed and residual amounts of the repetition frequency in the piezo signals will remain. They may lead to acoustical beeping of the actuators.

To reduce this effect we carefully match the time constants of the networks around the detector chip and the transimpedance amplifiers. However again, this can only be done to a certain extent because of some position depending asymmetries of time constants of the detector signals of the PSDs.

**Using Lock-In-Technique with medium repetition rates**

In principle, the described ***"PSD S&H"*** can be used in this frequency range, too. However, the switching times of the S&H circuitry are no longer negligible compared to the repetition period; thus the detection precision would decrease.

Equivalent to modulated CW lasers the pulsed detector signals can be demodulated and low-passed by a "Lock-In"-technique by help of the detector variant ***"PSD LID"***. This gives the advantage of the compensation of environmental light effects and electronic offsets (daylight, 50/60/100/120 Hz from artificial light sources, electronic humming,…) The necessary low pass cut-off frequency has to be selected beyond the repetition rate, but will be high enough not to decrease the servo bandwidth too much.

### 6.1.5 Pulsed Lasers with high repetition rates (>15 kHz … > 1 GHz)

This category of lasers (e.g. mode locked lasers) can be handled similarly to CW lasers, because the detectors or the ***Aligna®***-built-in filters will low-pass the AC amount of the light.

However, one has to be more careful not to destroy the detectors: Even if the average intensity at the detectors is low (let's say 100 µW) the peak intensity of a 100 MHz 20 fs laser is in the order of 50 Watts (!)

If 100 µW average power is applied to the detectors at a repetition rate of 1 kHz (measurement of amplified sliced 50 fs mode-locking lasers) the pulse peak power is unbelievable 5 MW (!!), the order of an energy power station! This power is focused onto the detector surface!

Up to now, we do not have too much experience with destroying levels of the detectors. (We have not destroyed detectors in a short pulse system yet ;-) BUT: In any case one should be very careful during the detector intensity alignment (with optical filters) not to apply much more laser power to the detectors than needed for operation.

((There is very little information from the detector chip manufacturers regarding short pulse destroying levels. In future time we will do some detector destroying experiments to get better values of the safe operating area. If you have knowledge or own experience about this topic, please let us know!))

# 7 Input CrossLink Matrix (ICL)

((Chapter and pictures on input orthogonalization, in preparation, see also chapter on "Learning OLCM" (Output CrossLink Matrix for Motors)))

# 8 Output CrossLink Matrix (OCL)

((Chapter and pictures on output orthogonalization, in preparation, see also chapter on "Learning OLCM" (Output CrossLink Matrix for Motors)))

# 9 Setting up an *Aligna*® Test System

The final laser system to be controlled by an *Aligna* device often involves complicated optical setups. Therefore, we **strongly recommend** using the simple test setup to become familiar with the *Aligna* parameters and their usage.

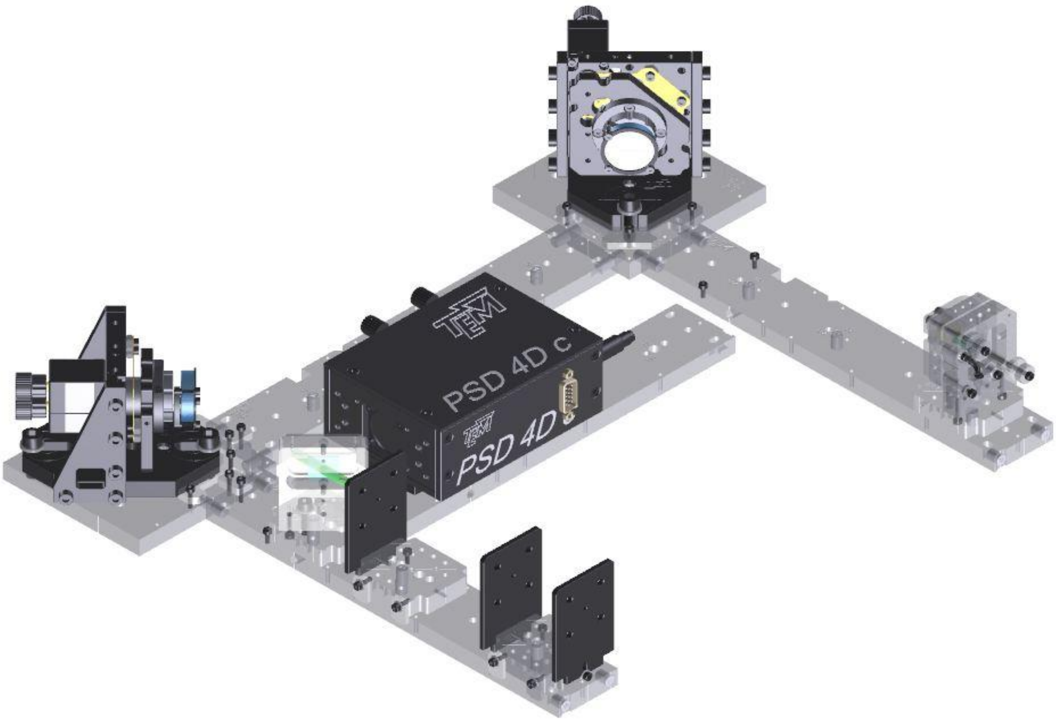
A typical test setup consists of the following items:

- a small laser (of visible (!) wavelength, e.g. a laser pointer)
- the two *Aligna* actuator mirrors (motorized and/or piezo driven)
- the PSD4D detector (or equivalent, depending on the ordered version: "PSD4D e", "PSD4D i", "PSD4D c",...)

Optionally, it also contains

- a beam sampler plate to couple out a test beam for pointing measurement
- two irises to define the target beam path

TEM offers the "*Aligna* Plug'n Play Kit", which is a test system as described above.




Aligna Plug'n Play Kit

The acrylic glass parts of the Plug’n Play Kit connect magnetically, and each connection is individually numbered, which makes the setup easy and fast. Once assembled, you can start working with the beam alignment and stabilization system. In a later step, you will transfer the *Aligna* components (without the acrylic base plates) to the final laser system.

**Setting up the test system is done in the following steps:**

- Cable Connections
- Installation and start of the visualization software "Kangoo"
- Setting and testing communication parameters between µC and PC
- Coarse pre-alignment of the opto-mechanical setup (already done if you got the Plug'nPlay Kit)

- Set detector sensitivity (PSD Gain parameters) (already done if you got the Plug'nPlay Kit)
- Switch on the regulator

Stabilization should work immediately, if the setup is similar to the setup used for setting the default parameters at TEM Messtechnik GmbH before delivery, or if you use the delivered Plug'n Play Kit.

If the setup is different, it will probably be necessary to modify some parameters:

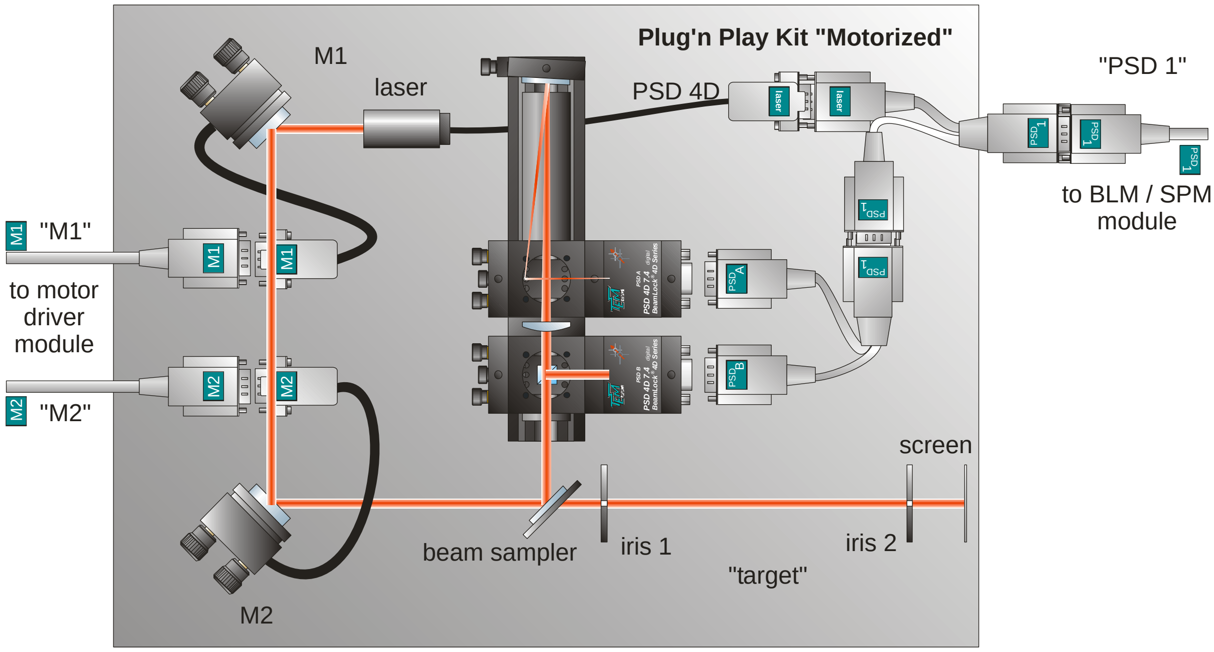
- Alignment of the OCLM Matrix (for Motorized Mirror Mounts) by automatic learning (or by manual setting)

If you have additional piezo actuators:

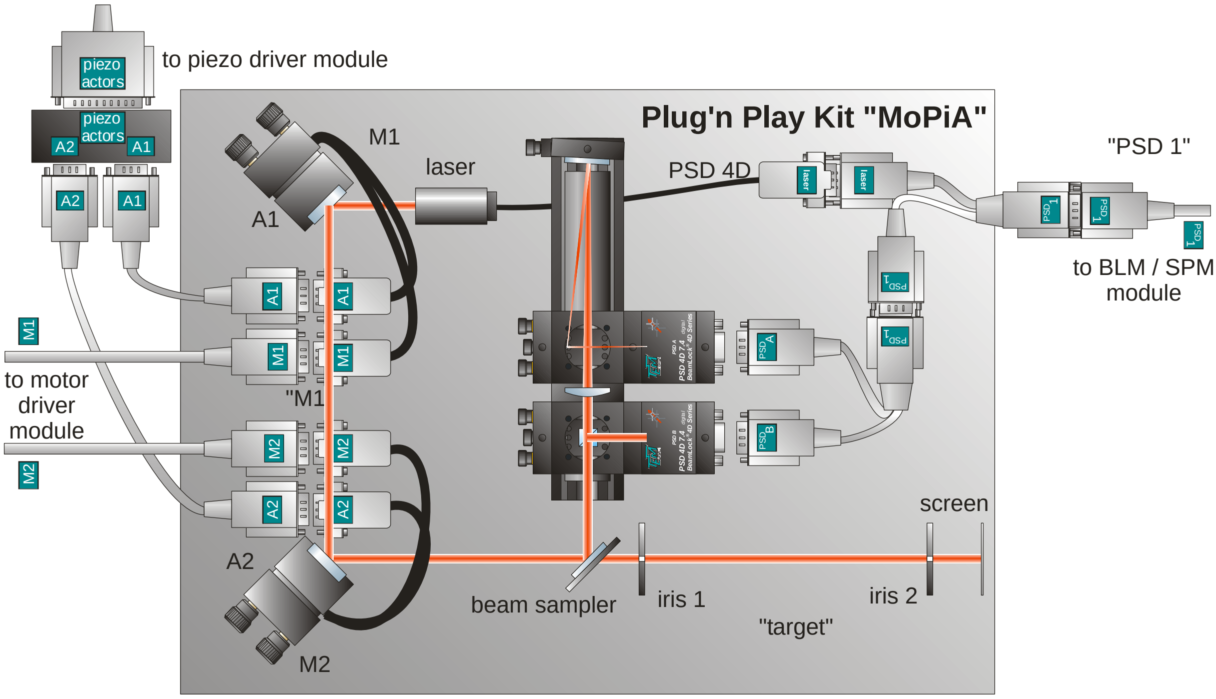
- Alignment of the OCL Matrix (for Piezo Actuators) by automatic learning (or by manual setting)
- Optimizing the servo parameters

These steps will we described now in more detail:

### 9.1.1 Cable Connections:




Cabeling a motorized system




Connecting a MoPiA system

- Power Cord to Control Rack (Module "PowerBlock" at the rear)
- “USB” at front to USB connection of computer (use always the same USB port, to avoid changing COM number at each connection)
  (Alternatively you can use the RS232 serial interface at the rear, connected with a standard 1:1 Sub-D9 cable)

- Connector “PSD 1” at rear → Y-shaped adapter “PSD1” → Detector: “PSD A” and “PSD B”
- If the laser is supplied by the *Aligna* rack case (laser has a HD15 pole cable): Use HD15 Y-Adapter for laser, and plug it in between one of the motor cables (M1, e.g.) or in between the PSD cable. (All HD 15 plugs lead supply voltage at pins 6,7,8)

If the laser has its own power supply: Connect laser power supply to the laser (laser should glow now).

In the case of a system, including Motorized Mirror Mounts (MMMs):

- “M1” connector at rear → “M1”cable → MMM “M1” (first actuator mirror in the beam path)
- “M2” connector at rear → “M2”cable → MMM “M2” (first actuator mirror in the beam path)

In the case of a system including piezo actuators

- "piezo actuators" connector at the rear → Y-cable (25pol SubD male "piezo actuators" → 2x HD15 female “A1”, “A2”) to Piezo Actuator “A1”, and Piezo Actuator “A2” (Or Y-shaped adapter SubD 25 → 2x HD15)

- **Installation and start of the visualization software "*Kangoo*"**
  - Install "*Kangoo*", following the instruction s of the "Install.exe" program of the installation CD (In case of problems see related chapter on "Kangoo Installation")

- **Setting and testing communication parameters between µC and PC**
  - Start „Kangoo.exe“. If communication window (terminal window) is off, switch it on: “Communication / display com window”
  - Switch on *Aligna* System. Communication, displayed in different colours should be seen at the COM window
    black: commands and requests of PC
    green: micro controller (not interpreted),
    red: micro controller, interpreted by PC)
    blue: manual user inputs
  - If this is not the case (only black words=PC requests, but now answers of the µC) the COM settings are wrong, mostly the COM number:
    Right mouse click to COM window, “COM Parameters”, “check!”. Now in the list all available COM numbers are listed. Select the one of the USB port, click “Open COM”. Click to COM window; hit the “Return” key. Answer should be “(no command)” (because you entered an empty line and <RETURN>.
    (If this is not successful: see chapter on setting up USB port)
  - Select configuration "Aligna Basic Use"
    (for more detail see chapter " Setting up the *Aligna*® System by Help of *Kangoo* ")

- **Coarse pre-alignment of the opto-mechanical test setup**

  For the Plug'n Play Kit the mechanical AND parameter pre-alignment is already done!

  - The intensity of the (cw) test beam, coupled out to the pointing detector, should be in the order of 200 µW to 2 mW. (For using pulsed lasers, see below!)
  - If irises are present: Pre-align laser beam to irises by means of the manual alignment screws to define the target beam path. Align the beam for best performance for your experiment.
    (If there is an iris BEFORE the detector beam sampler: Do not forget to open this iris finally!)
  - OR: Pre-align laser beam, so both detectors A and B are hit approximately in the mid. (You can open the detector covers to watch the spot positions.)
  - If no intensity is seen at one or both detectors, alignment of the detector and/or the beam sampler is necessary (depending on the type of pointing detector you ordered):

Open detector covers, align the two spots for hitting the detectors. If detectors are hit (intensity is seen) use scope dots at PC screen (green=beam position, red=beam angle) for finer alignment of the beam sampler or the mirrors inside the detector setup.

- **Set detector sensitivity**
  - Click button "AutoGain" to force an automatic detector gain setting, fitting to the actual test beam intensity. The PSD gain values are displayed in "%": 100% indicates typical test beam intensity. The values, found in "auto gain" procedure should be in the range of 10%...300%.
    If intensity is too high (gain < 15%) use neutral density filters in the test beam path!
    If intensity is too weak (gain > 1000 %) use other beam sampler or other mirror coatings (please refer to chapter on Beam Sampler Requirements)
  - When both intensity signals are in the recommended range of 1..5 Volts the main beam or just the test beam can be aligned for better hitting the mid of the detectors, observing the displayed 4D pointing

- **Switching on the Regulator ("RegOn" Button)**
  - If intensity is displayed at “A” AND “B” (red and green bar at the intensity devices "A" and "B"), LEDs “Intensity A” and “Intensity B” are lit, “IntensityOK” near “RegOn” button at screen), regulator can be switched on
  - If the setup in use is similar to that, which was used when setting the default parameters (at TEM Messtechnik GmbH before delivery) the system should stabilize now angle X/Y and position X/Y going to 0,0,0,0 positions at the X/Y scope screen.

In case the optical setup has changed (strong variations of the distances between the actuators and/or distance from second actuator to the detector, additional mirrors in the beam path, changing the direction of fold mirrors (exchange of X and Y, e.g.), a correction of signs and gains of the four servo loops may be necessary. This will be described in following chapters.

# 10 Setting up the *Aligna*® System by Help of *Kangoo*

The alignment of the parameters of an *Aligna*® system is performed by visualization, control and automatic alignment procedures in the *Kangoo* software.

(However you can control the system with other control software, like LabView, TestPoint, or other programs, written in VisualBasic, VisualC, C++, C#, ...)

## 10.1 Some basic *Kangoo* features

*"Kangoo"* is a comprehensive measurement and controlling software system, which can be adapted to control completely different applications. (Controlling an *Aligna*® system is just one of a long list). *Kangoo* will not be described in complete detail here; just the basic use and the configuration for use of *Aligna*® will be described.

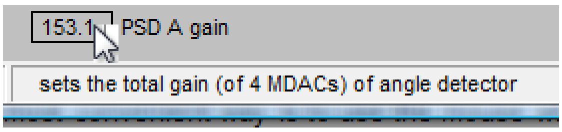
In this chapter, we will describe very briefly some basic features and the basic common usage of *Kangoo*. In a following chapter, we will describe the usage of configurations, related to *Aligna*® systems.

### 10.1.1 Installation of *Kangoo*

When you insert the *Kangoo* installation CD and start "Install.exe" (if it is not automatically started by the auto start option of your disk drive), follow the instructions. In most cases, *Kangoo* will be installed without problems. (In the case problems occur, please refer to the appendix "Installation of *Kangoo*")

### 10.1.2 Buttons and Devices

The interaction between the user and the program is (apart from the menu line) mainly realized by "buttons" and "devices". A short explanation ("ToolTip") of the meaning and sense of a button or device is displayed in the status line, when the mouse pointer is located over the button or device position.




A **"button"** forces an activity. This may be the

loading of another configuration (application-specific user surface) 

,

starting a measurement or analyzing process 

,

display a help text 

, and many more.

A **"device"** may represent a parameter, either of the *Kangoo* program, or of the control software inside the application's micro controller (µC) firmware.

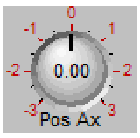
The appearance of a device can be very different:

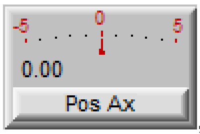
There are keys or LEDs 

,

numerical parameters, displayed as simple digital value 

,

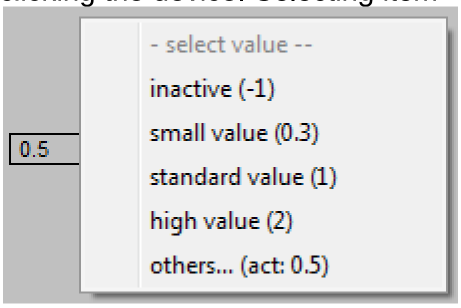
a digital and/or analog display 

, 

, and many more.

To **change the value** of these parameters there are different alternatives.

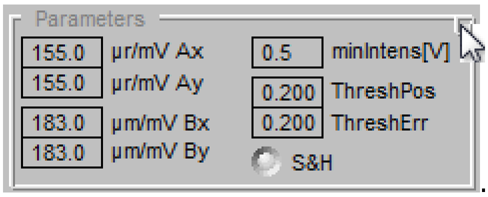
- The most convenient way is to use the **mouse wheel**, when the mouse is located at the device position (without clicking the left or right mouse button).
  **(It is strongly recommended to use a mouse with a mouse wheel, even at laptop computers with sense pad.)**
  Even very fine or coarse changes can be realized:
  The sensitivity of the mouse wheel can be controlled by pressing additional keyboard keys while mouse wheel movement
  - pressing the "shift" key: factor of 10 higher resolution
  - pressing the "ctrl" key: factor of 100 higher resolution
  - pressing the "alt" key: factor of 10 stronger variation.
  (The scaling of the variation can be additionally defined by a device's parameter, called "push factor", to any user-defined high or low sensitivity. This can be defined by editing the device object, selected by right mouse key, "edit object #xxx".)
- In the lack of a mouse wheel you can click at the device and push the value horizontally. Even here the "shift", "control" and "alt" keys will increase or decrease the sensitivity.
- Many devices have predefined values, which are displayed by a pull-up menu when left-clicking the device. Selecting item "others…" allows input of any user-defined value.




- A right-click to the device opens a pull-up menu, which also offers the ability of defining the value by selecting "set value" (even if no "toggle" pull-up menu is defined with this device.)

### 10.1.3 Sections

The configurations are usually separated into sections for more clearness and convenience. Some sections contain parameters, which are not needed all the time, just for setting once, or which are used rather seldom. By clicking the upper right "close" button, the section window will be shrunk to a small button at the bottom line of the user screen. The section window can be re-sized by clicking to the shrunk button.





### 10.1.4 Hotkeys

Most of the hotkeys are defined in the menu definition (which can be modified by the user.)

A list of the actual hotkeys is given in the menu item "Help / Kangoo / show common hotkeys".

Some of the hotkeys are described later, for explaining device control (like "Ctrl D" for switching on and off device activity), "r" for "redraw", "a" for "rescale all coordinate frames", etc.

### 10.1.5 Further Kangoo Functions

There are thousands of additional features of the *Kangoo* program, like calculations, analyzing measured data, import and export of data, creating own configurations, etc.

However, in this manual we concentrate just on the description of the configurations, which are needed for the use of the *Aligna*® system.

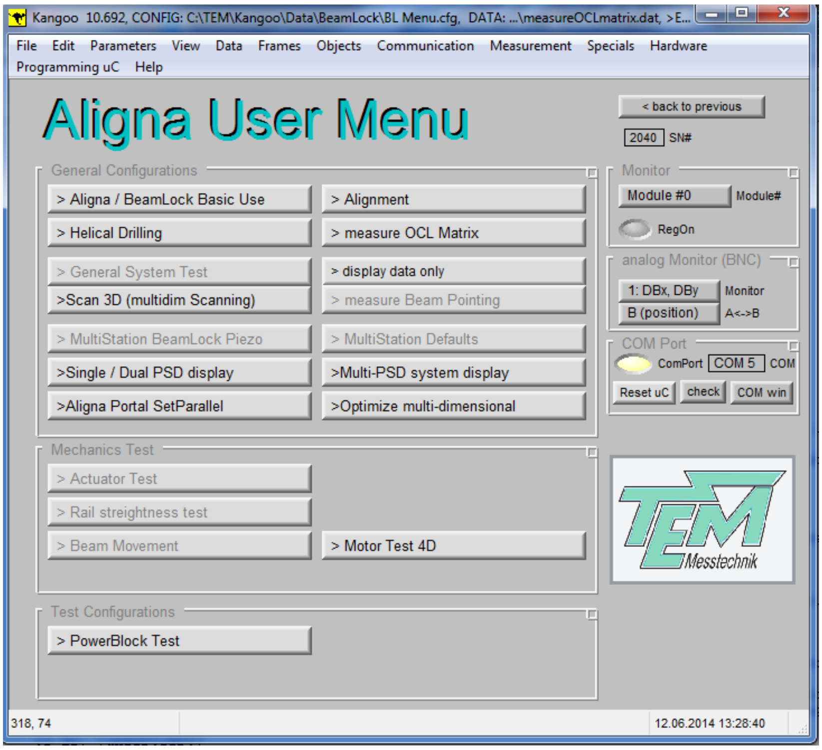
Many of the features are described by HelpFiles, available by the menu items "Help / ...".

(If you have questions regarding further use of Kangoo, please don't hesitate to ask TEM for additional information!)

## 10.2 Main *Aligna*® Configurations

In the following, we will describe some of the main configurations, useful for *Aligna*® systems. Depending on the individual hardware, there are special configurations, which control and visualize the different features. (Thus, some of the described configurations will not fit to your individual hardware combination.)

### 10.2.1 Configuration "Aligna User Menu" ("BL Menu")



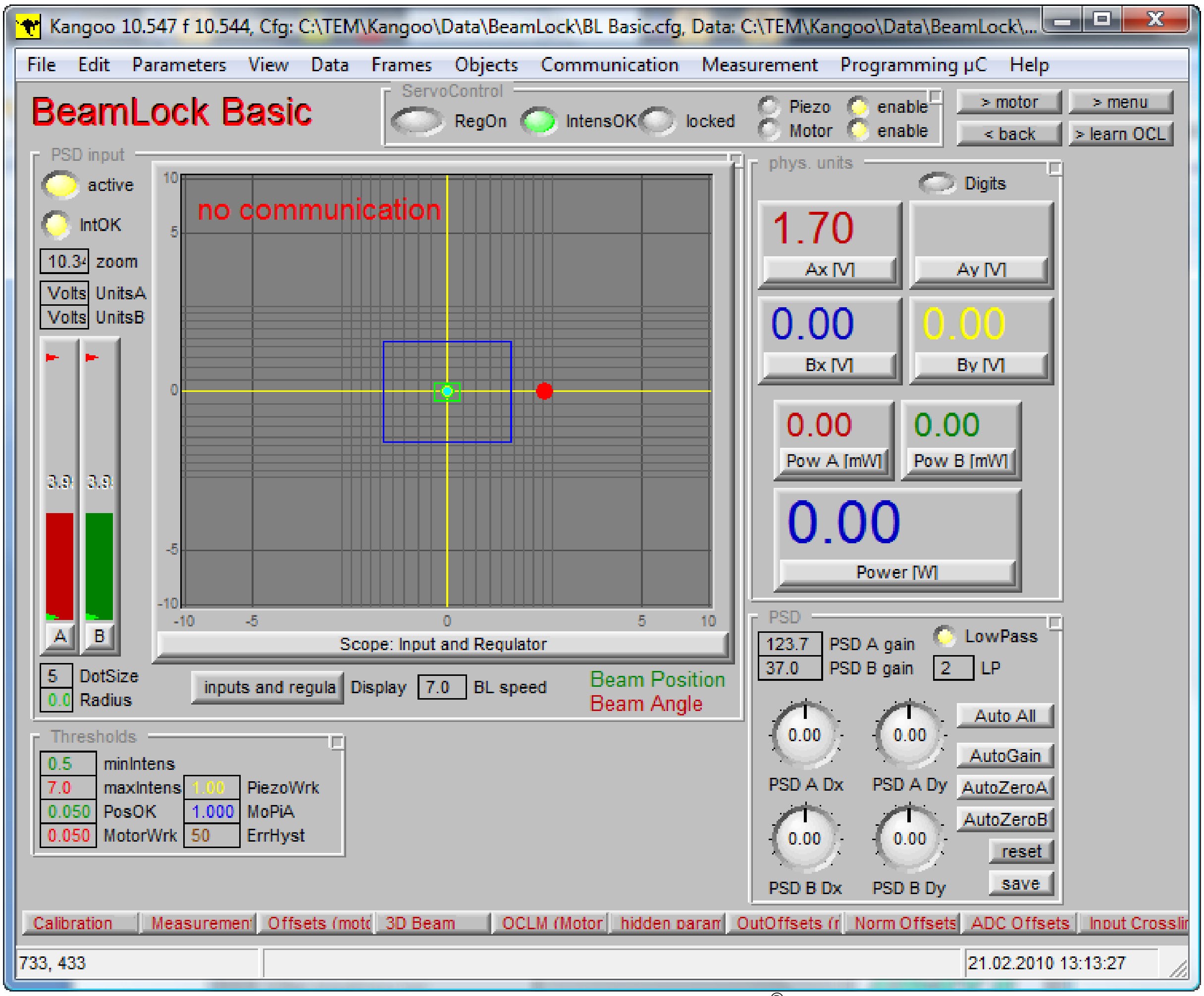

The configuration "Aligna User Menu" leads to different user configurations.

A short explanation of each button (and the corresponding configuration) is given in the status line, when the mouse pointer is located over the button. Some of the individual configurations will be described in following sub-chapters.

- BeamLock Basic use: General use of *Aligna*® systems or even PSD systems (without actuator control or servo loops)
- Grey buttons are pointing to a configuration which is not enabled with your software or hardware version.

(Regarding the configurations, please refer to the individual sub-chapters!)

### 10.2.2 Configuration "BeamLock Basic"




Configuration "BeamLock Basic" is for general use of *Aligna*® systems or even PSD systems (without actor control or servo loops)

The following sections are mainly used: (unneeded sections are "shrunk", indicated as a button at the window bottom)

- The section "PSD input" shows the actual position and intensity values (and other values, like regulator outputs, e.g., if selected.)
- The section "PSD" controls the **sensitivity of the transimpedance amplifiers** (located in the PSD housings). They correspond to the applied detector intensity at the angle detector (PSD A) and the beam position detector (PSD B). The eight amplifiers (four for each PSD) are controlled by multiplying DACs (MDACs) (For details see below.).
- The exact **fine X/Y position of the detectors** is not aligned by mechanical micrometer screws, but by “virtual micrometer screws”, namely the relative sensitivities of the quadruple transimpedance amplifiers of each PSD. These "virtual micrometer screws" (it is not the same as a simple offset, as explained in the PSD description!) are called "PSD A Dx"..."PSD B Dy")
- The **Input CrossLink Matrix (ICL**) aligns the “virtual position” of the detectors: A pure angle detector, e.g., has to be positioned exactly in the focal plane of an optical lens, for being insensitive to XY parallel translation beam movements). This requires precise mechanical alignment components and a sensitive alignment procedure. If, however, two PSDs are present, one mostly watching angle, one mostly watching position, by help of mixing the signals a pure angle and a pure position signal can be calculated without the need of mechanical alignment. This is done by the ICL Matrix.

- The **Output CrossLink Matrix (OCL)** allows the actuators to achieve a nearly pure angle or position movement of the beam. A parallel beam movement, e.g., is achieved by an angle displacement of the first actuator and an angle displacement by exactly the negative value of the first. Thus the resulting angle movement will be compensated and a pure parallel (position) movement results. Therefore, a position movement requires a combination movement of both actuator mirrors.

  In extension, a combination movement of both mirrors can act as a beam angle movement around any arbitrary point of the beam.

  Due to properties of the opto-mechanical setup a movement of one piezo (let's say the X piezo of actuator 1) may cause a combination movement even (more or less) also in Y direction. This can be compensated by suitable combination steering signals to all four piezo actuators. Thus the four regulator channel signals (angle x,y and position x,y) are transformed into four actuator signals by the 4x4 Output CrossLink Matrix OLC.

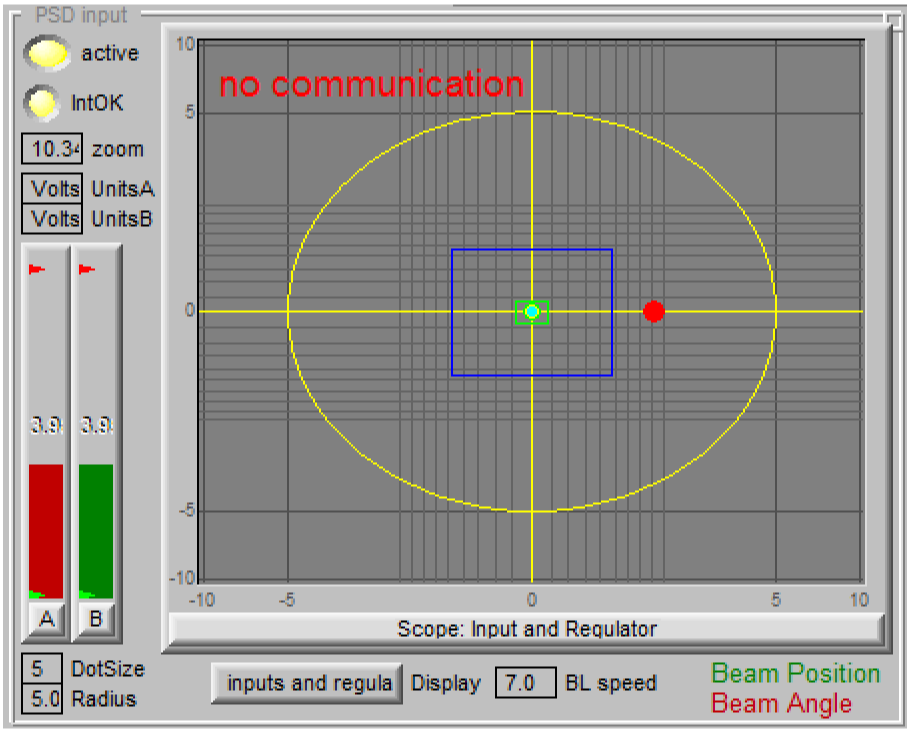
  There is one OCL related to the motorized actuators (called OCLM) and a second one, related to the piezo actuators (OCLP or simply OCL). Both are independent from each other, because even the motor and piezo actuators can be separated completely: In some applications the piezo actuators ("BeamScan OneInch") are located in the vacuum chamber, close to the target, while the motorized actuators ("Aligna60", e.g.) are located at the laser table.

- The **regulator parameters** of the four servo loops (of each beam) have to be aligned fitting to the mechanical setup to achieve a fast and precise servo loop operation. By applying test signals to the output channels, and analyzing the system response by recording the input signals an optimization of the regulator parameters P, I, D, and $f_0$ is achieved, individually for each of the four channels.

## 10.3 Some Common Sections

In many application-specific configurations (graphical user interface), there will be identical or at least similar sections, as shown in the "Basic" configuration; some of them are described now:

### 10.3.1 PSD Input Section




The **"active"** switch enables or disables the background requests of the actual position and intensity values. It should be switched ON (yellow) normally. It is switched OFF for some measurement procedures to avoide information collision. In most cases this is done automatically, thus this switch may be hidden in some configurations.

**"zoom"** defines the displayed range. Depending on the displayed units (see below), standard is +/- 10 Volts, which is the range of the basic PSD and servo signals.

**"UnitsA"** and **"UnitsB"** define the displayed units for the angle detector "A" and for the beam position detector (B). This may be "Volts" (basic signals), calculated physical units like "mm" (used for position and angle detector), "mrad", "deg" (=degree) "arc min", "arc sec", (normally used for angle detector), "mmTarget" (mm at Target position, also used for angle detector). In some applications, both detectors A and B are used for position or for angle measurement. Thus, all combinations are possible. (For calculation of these units, some parameters are needed, defined in section "calibration", like focal length of the PSD lens, of the target focusing lens, etc.)

**"IntOK"** (Intensity OK) indicates valid intensity levels at all used detectors. (Regulation can only be switched on, if intensity is in the OK range (yellow). Normally the OK range is defined being between 0.5 Volts ("min Intens") and 5 Volts ("max Intens"). These min/max values are indicated as small green and red arrows in the intensity bars. They are defined in the "Thresh-olds" section. If intensity is above "max Intens", lamp IntOK will be red. In this case an overrid-ing of the internal signal amplifiers may lead to incorrect position measurements. (A damage of the PSD chips will occur much (many orders of magnitude) later, depending on the pulse duration and of the focusing. See PSD description.)

Bar graphs **"A"** and **"B"** display signal strength at the position sensitive detectors (PSD) in use. The intensity signals are influenced by the PSD gain values (see section "PSD"). The units are Volts. The intensity signals do not directly influence the position measurement. However, too low signals (< 0.5 Volts, e.g) will degrade the precision (due to offsets, noise, etc.). Excessively high intensity leads to non-linearities, and incorrect position measurement. (For displaying the intensity in physical units (like mW, Watt, etc.) see below!)

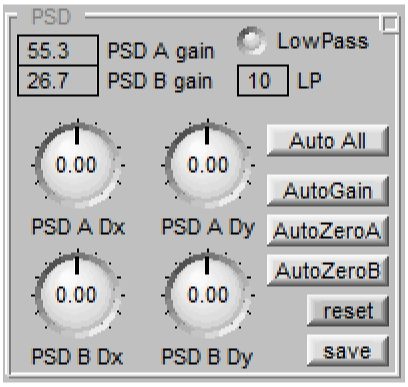
**"Dot Size"** defines the size of the display dots at the XY scope. (Large dot sizes are used when the computer screen is rather far away in the case of manual alignment at the experimental table.)

**"Radius"** defines the radius of the displayed circle. This circle is used for different purposes, displaying regulator ranges, target ranges for manual alignment, etc.

**"Display"** defines the displayed values. In many cases, this will be the position and angle signals of the detectors. However, you can also observe the regulator outputs, the servo set point values, and other variables (also depending on the hardware in use).

**"BL speed"** controls the request frequency of Kangoo for visualization of the displayed values. It does not influence the (background) processing speed inside the µC! However, a too high visualization speed will slow down the PC and the µC foreground speed (reaction to user requests, etc.). Values between 3 Hz and 10 Hz are typical. (The maximum real request speed also depends on the computer's speed and on the kind of values to be transmitted.)

### 10.3.2 PSD Input Section




**"PSD A gain"** and **"PSD B gain"** control the programmable gain values of the 8 transimpedance amplifiers inside the PSD 4D detectors.

The PSD gain values are displayed in "%": 100% indicates a typical test beam intensity. The necessary values should be in the range of 10%...300%. However, values up to 10000% are possible (depending on the µC type). The higher the gain, the stronger the sensitivity against environment light!

If the intensity is too high (gain < 10%) use neutral density filters in the test beam path. (Otherwise, nonlinearities can influence the measurement precision.)

If intensity is too weak, use a different beam sampler or different mirror coatings (please refer to chapter on Beam Sampler Requirements, discussing possible problems of beam samplers and filters, as interference effects and ghost reflexions.)

**PLEASE NOTE**: The PSD gain can be controlled over a very wide range of 1:4000! However, if the test beam intensity is very high or very low, the system may even work properly, but the performance and precision may be reduced.

The PSD offset values **"PSD A Dx"**, **"PSD A Dy"**, **"PSD B Dx"**, **"PSD B Dy"**, define the position at the detectors, displayed as "0 / 0". If the offsets are "0" the mid position of the detectors will be displayed as "0, 0, 0, 0".

This offset shift is achieved by different transimpedance gains of the quadruple amplifiers of each detector (not by addition of an offset value. This leads to a much better linearity and normalization precision). Therefore, the offset alignment is (nearly) equivalent to a mechanical alignment of the detector positions ("virtual micrometer screws"), as long as the spot is not cut by the detector's dimensions. (For the angle detector, which is (approx.) in the focus of a lens, the spot at the detector ("A") will always be small. However, the position detector size ("B") should not clip the (unfocused or partially focused) test beam too much. A little clipping is OK in most cases: It leads to a non-linearity of the position measurement, which is not important in most cases, because the beam is 4D stabilized to one fixed pointing. If however the spot size fluctuates, the clipped amount of light will vary, which leads to an apparent position fluctuation. This will be (wrongly) compensated for by the servos due to a position correction.

**"AutoGain"** forces an automatic setting of the PSD gain values, so the measured intensity values are in a valid range (e.g. 1 Volt ... 5 Volts). (Normally the target intensity is in the middle of "min Intens" and "max Intens")

**"AutoZeroA"** forces an automatic PSD offset setting of angle detector "A", so the actual beam angle position is defined to be the "0,0"-Position.

**"AutoZeroB"**, same for detector B.

**"Auto All"** is the same as clicking "AutoGain", "AutoZeroA", and "AutoZeroB"

**"reset"** sets all four PSD offset values to "0". (→ thus the mid of the detectors are displayed as "0,0,0,0")

(The gain values are not influenced by "reset".)

**"save"** writes a text file, including the actually set PSD gain and offset values (as well as some other parameters). This can be inserted into the "User Script" file, which defines the device-specific parameters. They are used as "Default Values" (when "Default" key is held while booting. Watch LCD while booting)

**Explanation**: The **PSD offset** values define the (4D) precise target pointing for the stabilized beam. There is no need to align the test beam exactly to the PSD centers (of PSD A and PSD B). The PSD offsets have to be saved to stabilize exactly to the wanted 4D position, even after selecting "Default values".

The **PSD gain** values also depend on the individual optical setup (beam sampler) and laser property (intensity, polarization,...). If the PSD gain values are saved in the "User Script" the system will start (even after selecting "Default values") with the correct fitting PSD gain values without the need of setting these parameters.

**Note:** Of course the test beam spots should hit the detectors without clipping distinct parts of the spot (otherwise the measured position is incorrect). The PSD offset values are given in % of the detector area. "+/- 50%" is the total detector area in X and Y direction. If an X=0 / Y=0 position is achieved only with an offset value of 40%, that means the detector is hit very close (10%) to its border, and parts of the test beam will not hit the detector (especially for the position detector B, which is normally not focussed on).

With small beam diameters (compared to the detector size of, e.g., std. 9x9 mm), the offset values should be smaller than +/- 30%, with large beam diameters (6 mm at a 9x9 mm detector, e.g.) the offset values should be within +/- 10%, which requires a better mechanical pre-alignment, for hitting the detectors better in its mid region.

**"LowPass"** switches on and off a low passing of the position measurement: Especially in the case of low repetition rate pulsed lasers, but also in the case of noisy cw lasers there are pointing fluctuations, which cannot be compensated for:

<u>Shot-to-shot fluctuations cannot be compensated by principle</u>, because the laser pulse is much shorter than every mechanical servo reaction time, by many orders of magnitude. Thus, the servos can only adjust the mirror positions for SUBSEQUENT laser pulses, never for the actual one. Thus, the shot-to-shot noise will remain by principle.

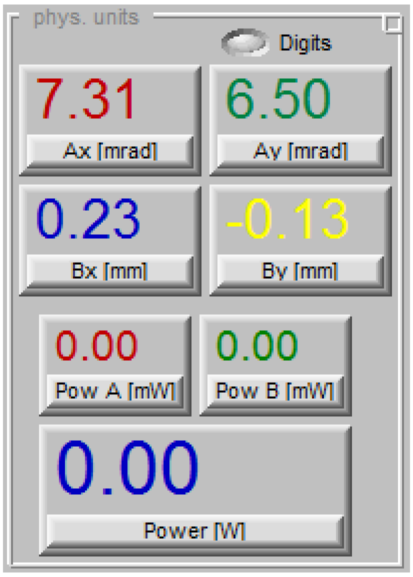
Even in cw systems, there may be fluctuations or vibrations, faster than the servo bandwidth, so it cannot be compensated for.

In this case, the motors will work continuously, trying to compensate for the noise, which is not possible. Therefore, it is better to filter out these fast contributions by the Low Pass Filter, which gives two main advantages: 1. The display is less confusing. You can observe the real drift, which might be small compared to the shot-to-shot noise.

2. The motors will remain at rest if the AVERAGE pointing stays in rest. This leads to a better beam stability (see below: MotorWork Threshold).

**"LP"** defines the low pass strength (up to now in seconds, the higher the value, the slower, the stronger the filtering, the slower the observed movement.

### 10.3.3 "Physical Units" Section




This section displays the measured pointing values as physical units (in mm, µm, mrad, µrad, mW, Watts, etc.) in numerical displays.

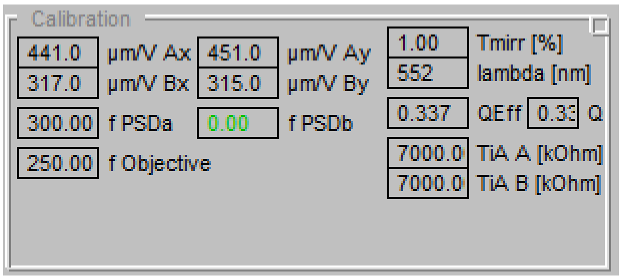
The display depends on the selected units (see Section "PSD input"). The angle values may be displayed in [mrad] (0.001 mrad means 1 µrad), the position values are displayed in [mm] (0.001 mm = 1 µm, 0.0001 mm = 100 nm, depending on the selected resolution.)

The measured angle of the beam can also be displayed as µm spot translation in the target plane, depending on the focal length of the focusing optics in use. (For instance, an angle displacement of 10 µrad, using a focusing optics of 250 mm, will cause a spot displacement of 2.5 µm in the target plane.)

These parameters are defined in section "Calibration"

The switch **"Digits"** defines the displayed number of digits. If the spot-to spot fluctuations of a pulsed laser (which cannot be compensated for by principle) will fluctuate by 10 µm, for example, the display is less confusing if the displayed values are rounded to 10 µm. (Depending on the application the display will be switched between 2 and 3 decimal digits. Higher resolution is possible, even using short focal lengths of the target objective.)

### 10.3.4 "Calibration" Section




This section contains the calibration parameters of the individual opto-mechanical setup. (These parameters have to be set ONCE. They should be stored in the individual "User Script" for being present even after choosing "Default Values". After the correct setting, this section will be shrunk, because it is no longer needed).

**"µm/V Ax"** ... **"µm/V By"** define the translation between measured Volts to mm at the detector. These values can be trimmed easily, if the detector or the beam is shifted by a known displacement (position and angle). Then the parameters are scrolled, until the correct physical value (in [mm], or [mrad]) is displayed in the "physical units" section.

For this procedure, TEM provides calibrated elements (40x40x40 mm cubes including glass plates). The "Position Calibration Cube" contains a (very parallel) glass plate at an aligned angle, which introduces a well defined position displacement (for example 2 mm).

The "Angle Calibration Cube" contains a wedged glass plate, which introduces a well defined angle displacement (for example 1 mrad).

However, the user can realize own calibration tools. The detector can be set to a calibrated (manual or motorized) translation stage. The real displacement can be taken from a micrometer screw, or from the motorized stage.

A (small) angle displacement can be realized by moving a conventional mirror mount, watching the spot at a long distance (many meters at the wall).

**"f PSD A"** and **"f PSD B"** are used to calculate the measured angle movement from the measured position movement at an angle detector. (For example: an angle movement of 1 mrad will cause a spot movement of 300 µm at the angle detector chip in the focal plane of a 300 mm lens). (A value of "0" indicates "no lens", which is typical for the position detector "B", using "UnitsB = mm".) In some applications, however, both detectors A and B are used for angle measurement. In this case, "f PSDb" has to be set to the correct focal length of lens B.

**"f Objective"** corresponds to the focal length of the target focusing objective. Thus, the measured angle movement will be transformed into a spot movement in the target plane. Displaying the angle is often less intuitive than the spot movement in the target plane.

The following parameters are used to calculate the real laser power (for monitoring/logging purposes).

**"Tmirr [%]"** is used to calculate the laser power from the measured test beam power. It defines the part of light put from the main beam into the test beam. This may be the transmission of a highly reflecting mirror (typ. 0.1%), or the reflectivity of a beam sampling plate (typ. 0.2...4%) or even a beam splitting cube (typ. 50%). If "Tmirr" is chosen as 100% "Power" will display the test beam power.

PLEASE NOTE: The transmission or the reflection of optical components can be STRONGLY dependent on the polarization angle between the laser beam and the optical component's orientation.

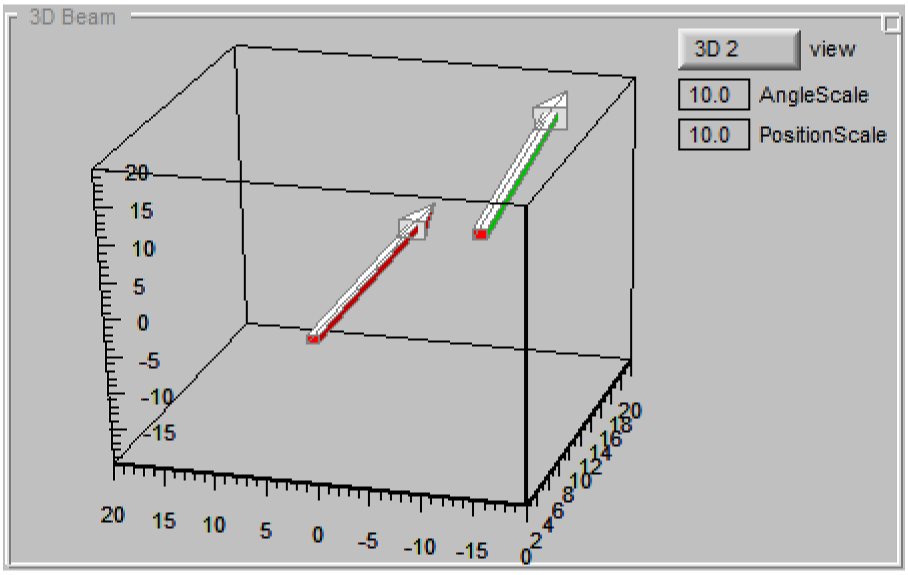
**"lambda [nm]"** defines the used laser wavelength. From this the calibration curve device **"QEff"** calculates the actual quantum efficiency of the PSD in use.
By means of the transimpedance gain factors **"TiA A"** and "**TiA B"** and the chosen PSD gain settings, the microcontroller can calculate the test beam power at both detectors.

In most cases, you will align **"Tmirr"** as follows:

Align "PSD gains" so both intensities are OK (some Volts). Measure the real laser power with a suitable power meter. Select the wavelength "lambda [nm]" correctly.

Turn "Tmirr" (with the mouse wheel) until the correct laser power is displayed at the device "Power".

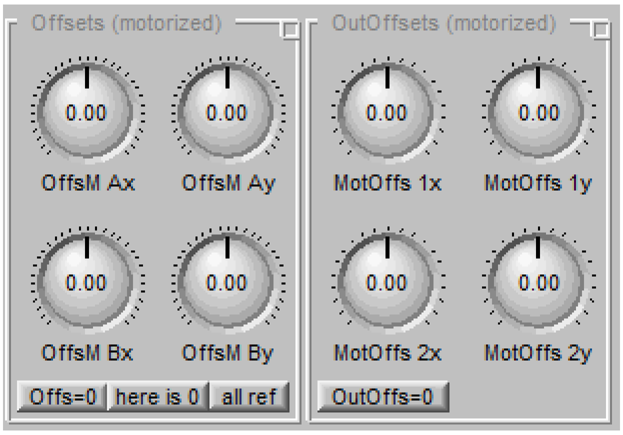
### 10.3.5 "3D Beam" Section




In the section "3D Beam" you can watch the beam pointing in a 3D frame. You can rotate the frame or choose predefined points of view to get the best overview of the beam movement. (The red arrow indicates the "reference beam", normally position X/Y = 0/0, angle X/Y= 0/0)

By means of the scaling parameters, both angle and position can be "blown up" for best view.

### 10.3.6 "3D Beam" Section

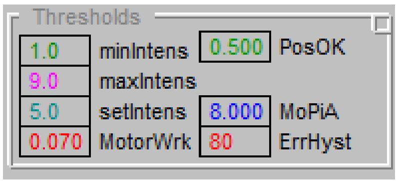



With the help of the "OutOffsets (motorized)" you can turn the four actuators of the two MMMs (motorized mirror mounts), like you would do manually (but much finer) (Please remember: You can scroll the values with the mouse wheel. Using the Shift, the Control and the Alt key the scrolling can be done much finer or more coarsely. The main scrolling scale is predefined by the "push factor", which can be adapted regarding your requirements.

The "Offsets (motorized)" also turn the four actuators. However, the turning is calculated via the OCLM (Output CrossLink Matrix of the Motors). Thus if you turn "OffsM Bx", for example, the mirrors will perform a combination movement, so (nearly) exactly a pure parallel beam movement ("Bx" = "Beam Position x") is achieved. So (if the OCLM is set correctly), the four degrees of freedom are independent, and the alignment is MUCH easier and convenient.

Thus, in normal cases, you will no longer turn the individual four knobs ("MotOffs 1x".."Mot Offs2y"), but just the four orthogonalized knobs ("OffsM Ax" .. "OffsM By"). So you can shrink section "OutOffsets". This section is only used for demo (to show the difference between both handlings), and for debugging (you can turn each of the four motors independently, and watch if it is really turning).

### 10.3.7 "Thresholds" Section




In section "Thresholds" some threshold parameters are defined, mainly used for servo control purposes. The threshold values are also indicated (when used in the chosen servo mode) in the XY-display, and in the sum bar meters.

**"minIntens"** and **"maxIntens"** have been explained earlier: They define the threshold for "IntOK" (Intensity OK) LED indicator. If intensity is not OK, the servos will no longer work to avoid wrong movement, caused by incorrect position measurement. (These thresholds are indicated in the SumA and SumB intensity bar meters as small green and red arrow markers.)

**"PosOK"** threshold defines whether the actually detected 4D pointing is OK. On the one hand this is used for the "locked" indication. On the other hand it is used, when the (motorized) servo is switched off: When all four positions (Ax ... By) and both intensities (A and B) are OK when the (motorized) servos are switched off, the actual position will be defined as 0,0,0,0 position. The motors will remain exactly at this position.

If, however, the position (when switching servos off) is "not OK", the motors will go back to the last known "OK" position.

The "PosOK" threshold is indicated as a green rectangle in the XY display.

Note: The "PosOK" threshold is given in the unit "Volts". Thus if the displayed units in the XY display is "mm" or anything different from "Volts", and the scaling of detector A and B are different, "PosOK" will be displayed as TWO rectangles (of two different green colours), corresponding to the two different scaling values of A and B.

**"MotorWrk"** defines the threshold for activating motor servo work. (It is used when only motorized actuators are enabled.)

If the (four) error values (Ax, Ay, Bx, By) are below this threshold, the motors will stay at rest. The reason is: Very small or very fast pointing fluctuations cannot be compensated for by the motors (which have a very small, but not infinite fine mechanical resolution, hysteresis, etc.) (See explanation of "LowPass"!)

The "Motor Work" threshold is indicated in the XY display as a red rectangle.

**"ErrHyst"** (Error Hysteresis [%]) is an extension of "MotorWrk": If this hysteresis is set to 0 (inactive), the motors will work if one of the errors is above "MotorWrk" threshold. The motors will not work if all are within the given value. However, this leads to following behavior: Sometimes this "MotorWrk" threshold has to be selected rather high (at high shot-to-shot noise, e.g.). Well, if the servo starts movement to the target position, but it will stop, when the threshold is reached, it will not reach the really target position, but remains at the border of the threshold. It starts working very soon, if the border is overcome by any small noise peak.

If the hysteresis value is chosen as "90%", e.g. the servos will work until all errors are within 10% of the MotorWork threshold (thus much closer to the target position). Then the motors remain in rest, until the (100%) threshold has overcome.

This leads to a closer pointing to the target pointing without permanently switching the motors on and off.

In the XY display the inner hysteresis MotorWork threshold is displayed as a dark red rectangle, the outer hysteresis (which IS the MotorWork) is indicated as a red rectangle, as explained before.)

**"MoPiA"** Threshold is used in "MoPiA mode" (motorized AND piezo actuators). The piezo servos are always working (even at infinitely small errors), because the servos have an "infinitely" high resolution. They will work with rather high speed for compensation of fluctuations and mechanical vibrations. However, the piezos have a limited, small stroke. Even rather small drifts will drive the piezos to their limits. Thus, the motorized servos will keep the piezo outputs close to their mid positions. If the piezos remain in their mid positions, the motorized actuators will keep in rest to achieve less noise by moving the mirrors.

The "MoPiA" threshold defines the piezo servo output values (deviation from zero), when the motor servos will start working.

The "MoPiA" threshold is indicated in the XY display as a blue rectangle

### 10.3.8 "Hidden Parameters" Section

In section "hidden parameters" are some parameters which are not normally used, or which are set automatically. They are available for debugging purposes.

((They will be described in a later version of this manual.))

### 10.3.9 "OCLM" (Motors Output Crosslink Matrix) Section

As discussed in the general description of 4D beam pointing stabilization the de-coupling of the four degrees of freedom is done by the so-called "output crosslink matrix" (OCL matrix). It defines the combination movements of the four output actuators, which has to be done, if one of the fundamental movements (for example a position movement in X direction, or an angle movement in Y direction) shall be performed.

Example of a position movement 100 µm to the right: In the ideal case, the X actuator of mirror #1 has to do an angle movement, which causes a beam translation of 100 µm at the second mirror (depending on the distance between the two moved mirrors M1 and M2). The second mirror, however, has to do an angle movement into the opposite direction to compensate for the beam angle, this way the wanted pure parallel position shift is performed.

**Note:** To achieve a simple position shift a combination movement of at least two actuators is necessary.

In real systems even more complicated combinations are necessary:

- If one additional (fixed) mirror is located between the two moved mirrors, it changes left and right. So the necessary relative movement of the two actuator mirrors will be reversed. (Same with 3, 5, ... reflexions, e.g. in case of a delay line.)
- Often in a real setup, the beam path is reflected upwards and then aside again. This will change X and Y of the relative movement.
- Assume a Y shift of the beam is wanted to correct or perform a Y position drift of the laser beam. Nearly all mirror mounts (and the *Aligna* mirror mounts as well) do not turn the mirror exactly around the point of incidence at the mirror surface (gimbal). If a Y screw is moved, this leads to the wanted Y beam angle variation, BUT it also leads to an additional X-shift of the beam. This again has to be compensated for by both X screws.
- If the beam leaves the horizontal plane, this leads to X/Y-coupling.
- In real systems there may be even more effects of coupling between X and Y (lenses in the beam path, non-ideal collimated beams, non-planar beam path, etc...), which will not be discussed here.

As a result: All of the four basic beam movements (beam angle shift in X and Y "Ax", "Ay", beam position shift in X and Y, "Bx", "By") need linear combination movements of the four actuators "1x", "1y", "2x", "2y" at the two moved mirrors "M1" and "M2".

These linear combinations are described by the 4x4 "Output Cross-Link" matrix with 16 elements. It contains the information of the distance between the mirrors and to the detector unit, as well as the relative mirror arrangement, properties of the motorized mirror mounts, etc.

**Note:** In *Aligna* systems with both, motors AND piezo actuators, there are two independent OCL matrixes, OCL (piezo) and OCLM (motors).

As an example element “Ax1xM” defines the amount of movement from channel Ax (Angle x direction) to actuator 1xM (actuator in x direction of motorized mirror mount #1).

“Ax1x” (without “M”) represents the same matrix coefficient, but of the piezo OCL (not of the motor-related “OCLM”).

#### 10.3.9.5 Scaling factors for each motorized actuator

For each motorized actuator (1x, 1y, 2x, 2y) there exists a scaling factor (“Scal1x”, “Scal1y”, ...), which transforms the output of the OCL matrix to motor units.

In principle there is no need for these additional scaling factors; they could be part of the OCL matrix coefficients. However, it helps for better clearness: For example, if Aligna 60 or Aligna

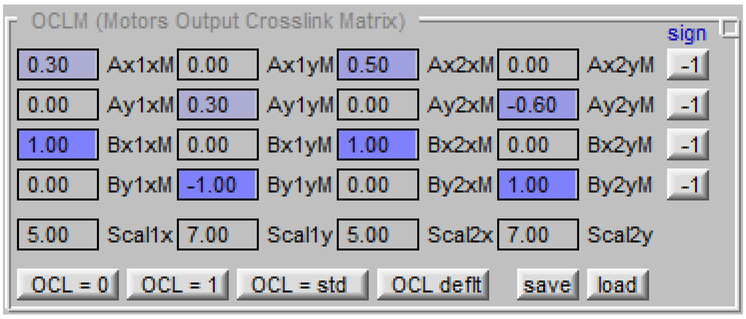
40 mirror mounts are used, the transformation of motor units to mirror angle movement will differ by a factor of two, because of different dimensions.

It depends on the orientation of the mirror mount, whether a positive x (or y) motor movement will cause a positive or negative beam angle movement.

In addition, if 45° mirror blocks or 45° piezo mounts are used, the scaling will differ by a factor of sqrt(2) from the situation without these 45° mounts. These actuator-specific parameters can be pulled out of the matrix to the motor-specific scaling parameters. Thus, the remaining OCL is more or less a description of the optical setup and coupling effects, while the motor scale values represent properties of the mirror mounts and of the motors. This simplifies the interpretation of the OCL values.

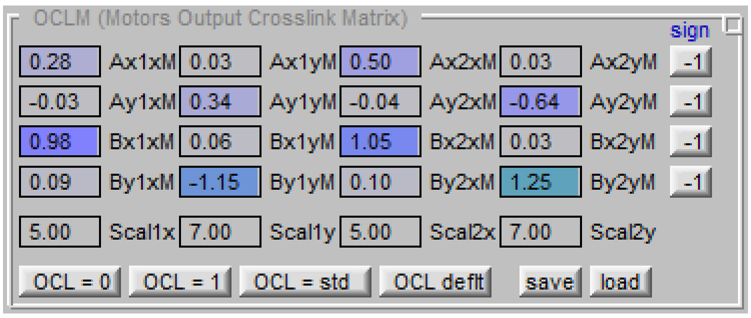
In the example OCL these 45° mirror mounts are represented by the scaling values of “5.0” and “7.0”, which approximately differ by sqrt(2).

A default matrix of the sketched test setup may look as follows:




For example a beam position shift in x direction (“Bx”) will be performed by the same amounts of motor 1x (coefficient “Bx1xM”=1) and motor 2x (coefficient “Bx2xM”=1). In this case, the angle shift of both mirrors will cancel each other, which results in a position shift (without angle movement).

After “Learning” of the matrix, it looks as follows:

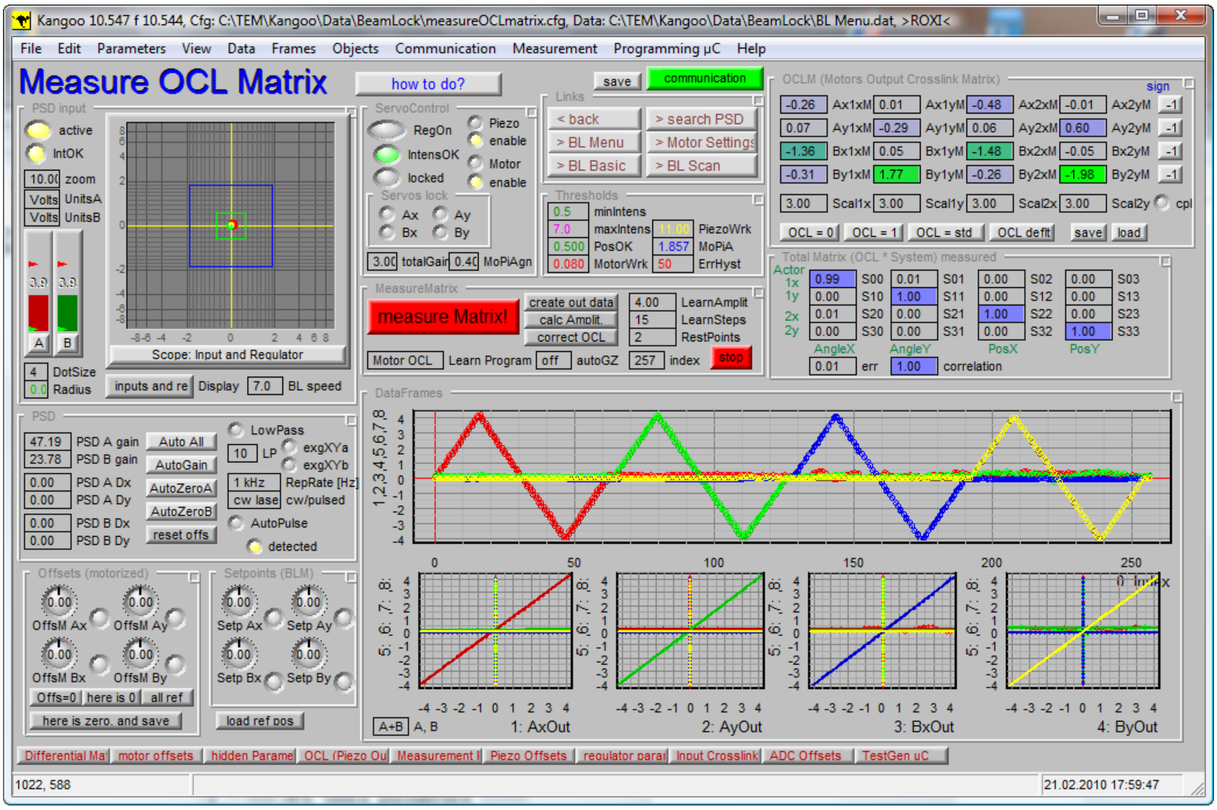



You can see small deviations from the default matrix, and X/Y-coupling elements, which represent the deviation from “ideal” gimbal mounts, and other coupling and scaling effects.

### 10.3.10 Alignment of the "OCLM" Matrix (Output CrossLink Matrix of Motorized Actuators)

The OCL matrix (both OCLP for piezos and OCLM for motors) can be aligned manually (by changing the matrix elements) or -much more convenient and more precise- by automatic OCL learning procedures.

Go to configuration “Measure OCL Matrix” (e.g. from the “BeamLock Menu” configuration)



This configuration gives you access to most of *Aligna's* parameters.

In the following, we will describe the basic steps:

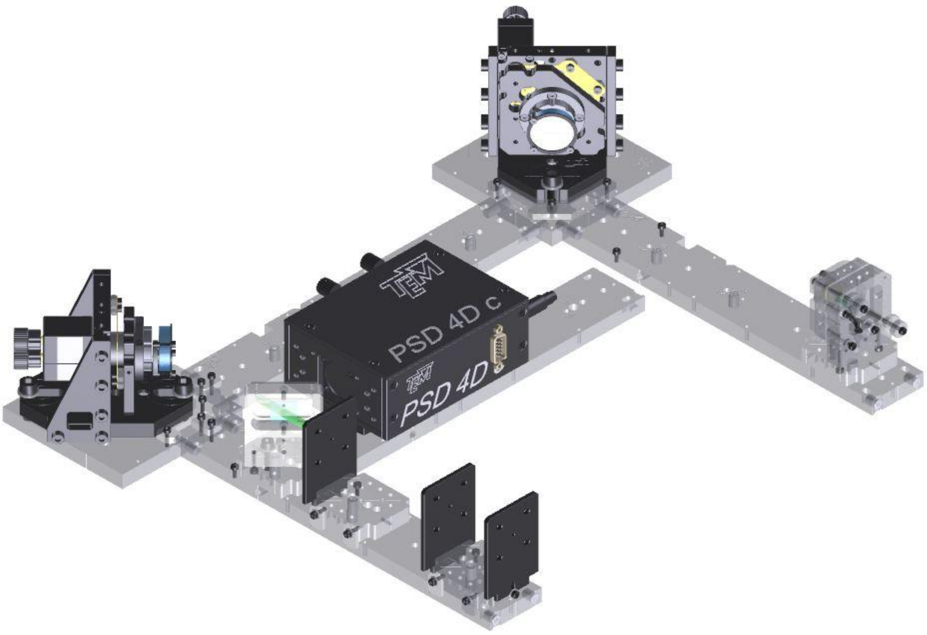
- coarse manual alignment of the opto-mechanical setup
- learning the motor's OCL ("OCLM")
- starting the motor servos, optimizing the motor servo "total gain"

If you have a system including motorized AND piezo servos, now

- learning the piezo OCL ("OCLP")
- starting the piezo servos
- optional: optimizing the piezo servo parameters

As mentioned before, it is STRONGLY RECOMMENDED to start with a simple test setup (visible (!) laser pointer, the two actuator mirrors, the 4D detector) for learning the usage, to play with the parameters, and to get some experience with the signals and the system behavior.

Normally your system has been delivered with the "Plug'n Play Kit", which includes all *Aligna* components at acrylic base plates, a laser, the mirror mounts with actuators (motorized and/or piezo), including mirrors (aluminium coating for testing purposes only), the 4D detector (different types possible), a beam sampler plate (for testing only!), two apertures, representing your experimental setup.




Aligna Plug'n Play Kit

Prepare the system as described in "Setting-up a Test System"

- Cable Connections
- Switch on the *Aligna*® rack case
- If your test laser can be switched between cw and pulsed, start with cw mode
- Installation and start of the visualization software "Kangoo"; start Kangoo, choose configuration "Aligna / BeamLock Basic Use"
- Check communication between the PC and the Aligna microcontroller (simplest way: use a serial interface, COM1. In the case of USB you have to check the "virtual COM port" number, see USB description)
- Coarse pre-alignment of the opto-mechanical setup (is done, if you got the Plug'nPlay Kit)
- Set detector sensitivity (manually turning "PSD A gain", "PSD B gain", or by clicking "auto-Gain")

Normally we deliver your system with pre-aligned parameters. Therefore, the OCLs will fit for the test setup as displayed. If you have got the "Plug'n Play Kit", even the laser dependent parameters (PSD gain A and B) will fit.

If you start from scratch, you can choose button “OCL dflt” (“set OCL matrix to default values”). This will set all values valid for a typical setup (distance of mirrors M1-M2 approx 22 cm, distance M2 to detector “PSDi 4D” approx 10 cm). However, it depends on the type of actuators (Aligna 40, Aligna 60, Aligna AddOns,...) and type of PSD. Thus, sign and gain values may be wrong.

If your system is completely different from the test setup you can also start with the unity matrix (“OCL = 1”), that means Ax goes to motor 1x, Ay goes to motor 1y, Bx goes to 2x, By to 2y. This is a completely wrong matrix, but the system will learn from it rather easily.

IMPORTANT: If the laser in use is a cw laser (or the Plug'nPlay-Kit test laser in cw mode) or a pulsed laser (or the test laser in pulsed mode) the parameter "cw/pulsed" (section PSD") has to be selected correctly as "cw" or "pulsed", and the (approx) RepRate [Hz] has to be set. Otherwise, a correct position and intensity measurement is not possible!

- Choose "Learn Program: Motor OCL" (The system will learn the OCL for the motor servos) (Section "OCLM (Motors Output CrollLink Matrix" will be visible)
- Click “measure Matrix!”, which starts the learning procedure:

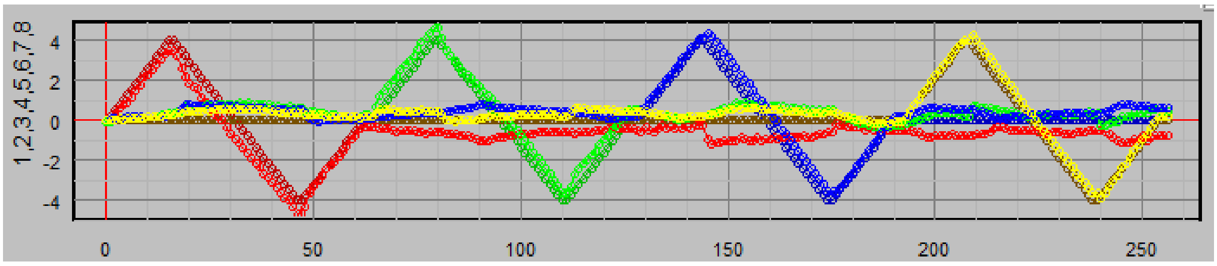
If "autoGZ" is set to "Z+G autoZero and autoGain before learning" is set, first the system will perform a “PSD AutoAll” procedure (automatic alignment of PSD gains and alignment of the offsets), to see the actual beam pointing approx. at the position 0,0,0,0.

Then all four channels (Ax, Ay, Bx, By) will scan all actuators, using the actual OCLM matrix. You can watch the red and the green dot. The better the OCL fits to the real setup, the more independent the dots will move (to the right, to the left, up, and down, back again to the mid position, both for channels A and B).

The goal is to find an OCL(M) matrix, so the Total Loop Matrix (behavior of the opto-mechanical setup "System Matrix", multiplied with the OCL Matrix) will be the unity matrix. That means:

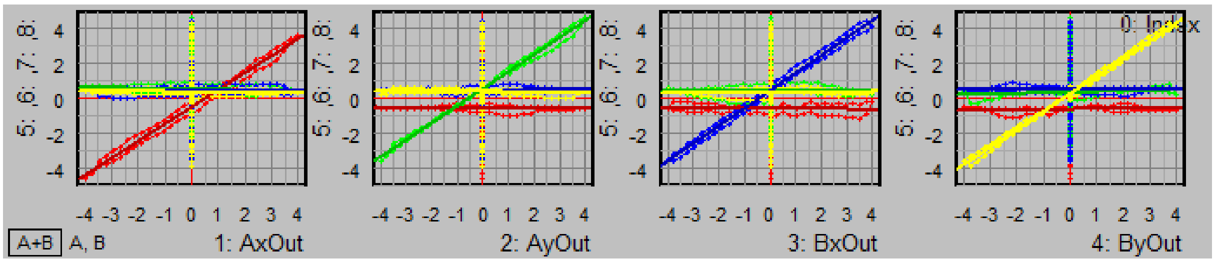
For example: Changing of the parameter “Bx” (beam position x) is seen at the detectors as “Bx” movement only, no other movements (no position Y, no angle X, no angle Y). Similarly for the other parameters “Ax, Ay, By”. This means, all channels are (as good as possible) independent from each other, they do not influence each other, and a fast and safe servo work is possible. The creation of this independency is called “orthogonalization”.

In the measurement data coordinate systems you will see four coloured traces with the (triangle shaped) set values (Ax: red, Ay: green, Bx: blue, By: yellow), and four traces with the measured values (Ax: dark red, Ay: dark green, Bx: dark blue, By: brown=dark yellow)




Set values and measured values

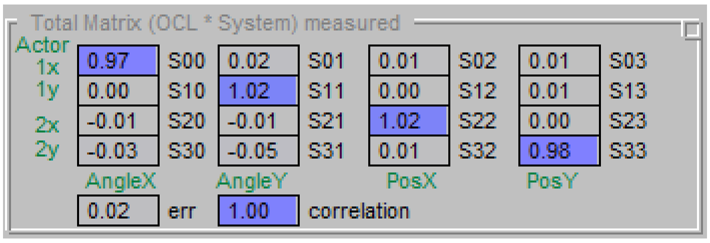
You can also see the same data in the correlation data frames: The goal is to reach a diagonal (red, green, blue, yellow) in each four correlation coordinate systems (Set values Ax, are identical with measured values Ax, etc.). The other traces should be horizontal or vertical lines, close to the axes (no influence of Ax to Ay, Bx, By, etc.)




Four diagonals: red (Ax), green (Ay), blue (Bx), yellow (By)

If you look precisely, you can also observe the mechanical hysteresis between the up-scan and the down-scan. If this hysteresis is much larger than displayed here (>10%) there is something wrong with the mechanics: Mirror mounts at the mechanical limits, or cables touch actuator knobs, or similar.

After the measurement, the Total Matrix is calculated and displayed:



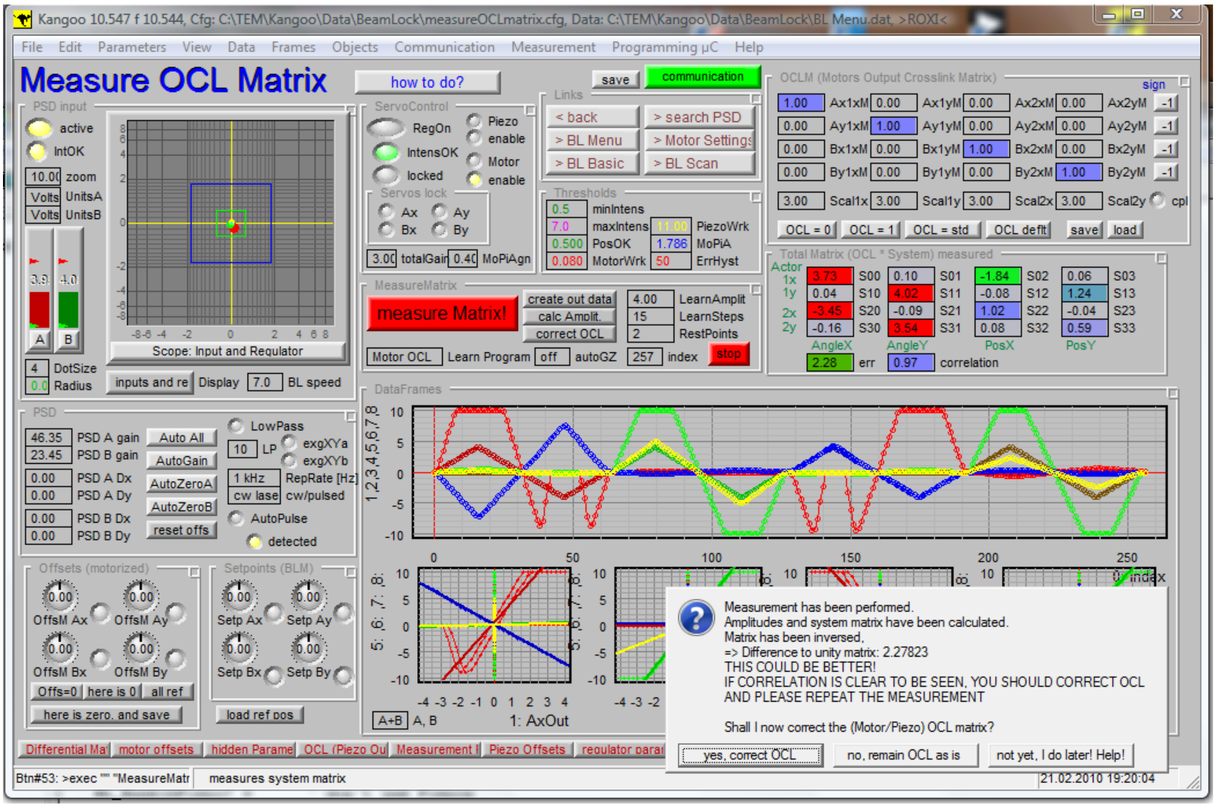

Measured Total Matrix, is close to Unity Matrix

The measured Total Matrix shown here is close to a unity matrix (close to "1" in the diagonals, close to "0" in the off-diagonals). (Normally the section "Total Matrix" is hidden, it can be un-shrinked for observation.)

The average deviation of the measured total matrix from the aspired unity matrix is displayed.

### 10.3.10.6 Measurement, starting with misaligned Matrix

In the following example we start with (a completely wrong) OCL matrix: We select "OCL=1", so the OCL is set to unity matrix: Ax turns Motor 1x, Ay turns 1y, Bx turns 2x, By turns motor 2y. The measurement looks as follows:

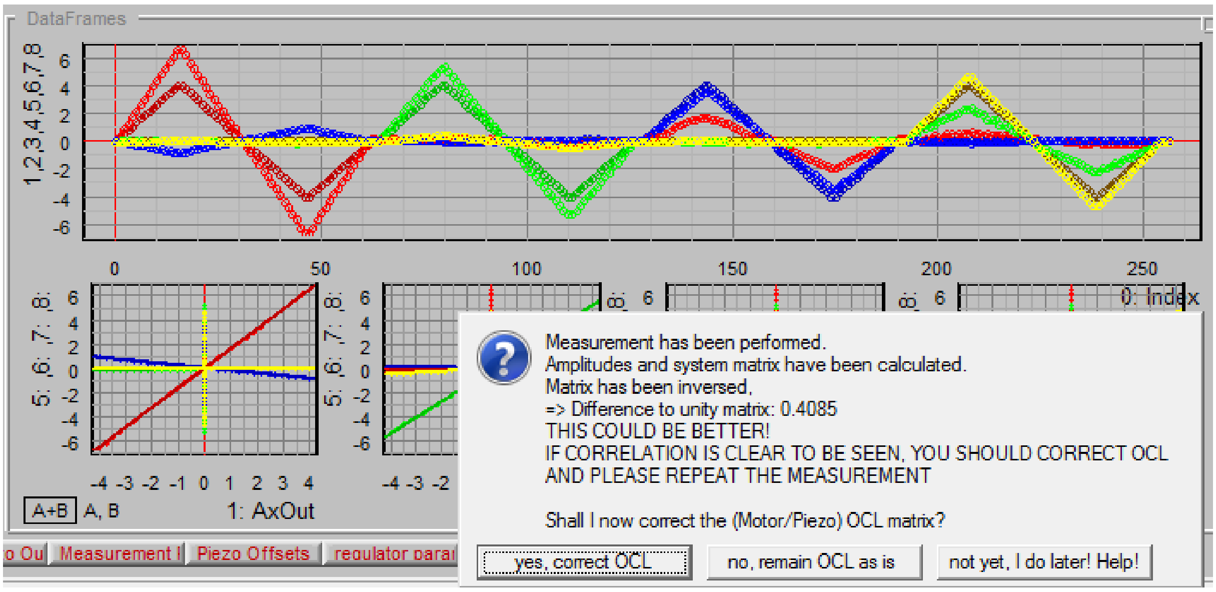



You can see a clear correlation between set values (red, green, blue, yellow) to the measured values (dark red, dark blue, dark green, brown), but the sign and the gain factors are completely wrong. The calculated remaining error is large. Many of the measurement points are clipped, or even gone back to zero, because one of the detectors was no longer hit. (Even if most points cannot be used, the system can usually calculate a better OCL matrix.)

The system now proposes the correction of the OCL.

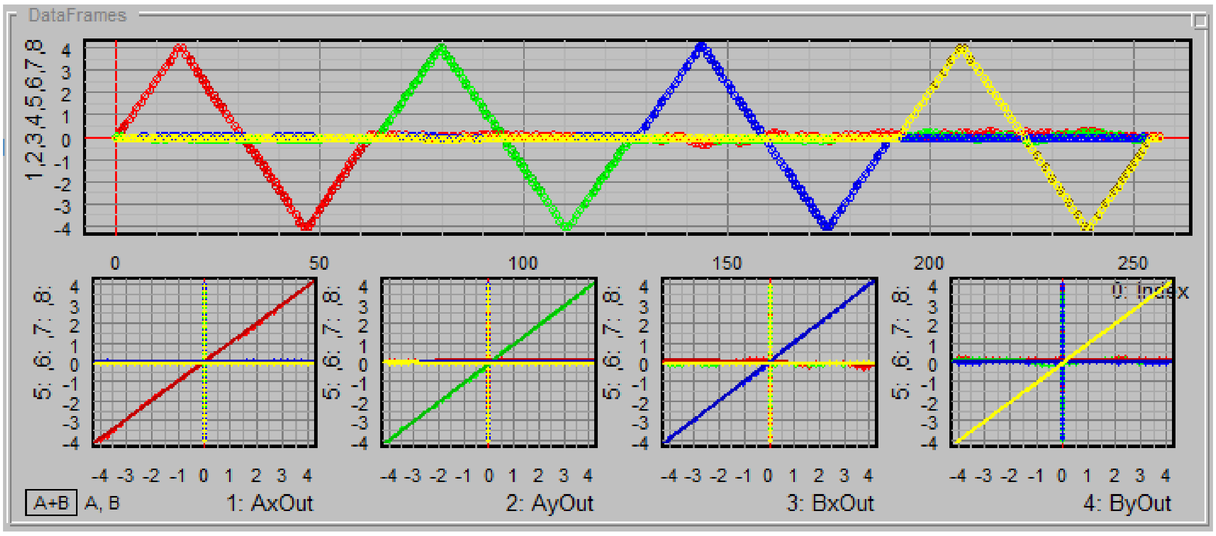
If you agree, the system will calculate/accept a corrected OCL matrix.

When you repeat the measurement now, you get a much better result:




The signs are correct now; however, there are remaining errors in the gain values. The system will calculate an improved OCL, again.

In the next measurement, you get a nearly perfect result:



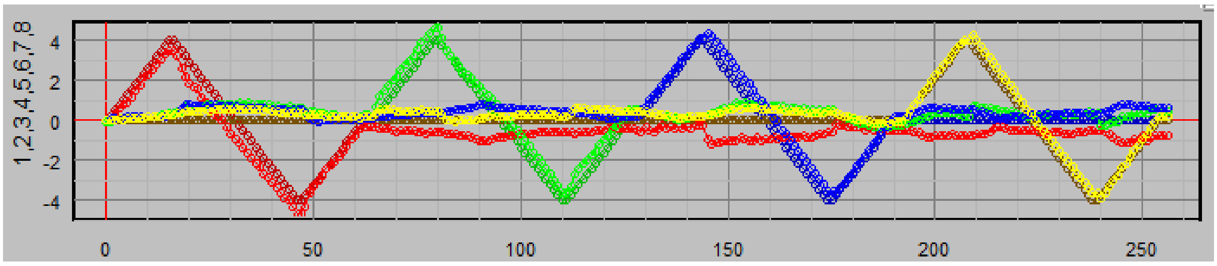

The measured values (dark) are nearly identical with the set values (bright).

> NOTE: This movement is done WITHOUT the servo loops! This is called "feed-forward". If the servos ("feed-back") will be switched on later, they will compensate for the (very small) residual errors. That means: The feed-forward will compensate 90%...99% of the 4D error by the matrix calculation, due to the "knowledge" of the opto-mechanical system. You can say: "by the experience with the setup". As a result, the feed-back loop is just responsible for a very small amount, let's say 5%. Thus, the system will be 20-times faster, compared to the situation, that the feed-back loop has to do the whole job!

The matrix now contains the information on the mirror motor properties, in scaling and sign of movement, distances between the mirrors and the detector, properties of the detectors like sensitivity, scaling, focusing, coupling of X and Y, or sign changes, by inserted mirrors, telescopes, non-planar beam path, etc.

> NOTE: The examples here are achieved with a simple system (cw laser pointer with small fluctuations, short distances, enough test beam intensity, Aligna 60 mirror mounts, which have high mechanical resolution etc.) If conditions are worse (laser with large pointing fluctuation, large distances, etc., the curves may be much noisier. However, it can work as well (not as fast as with an "ideal" system), because the OCL only defines the "feed-

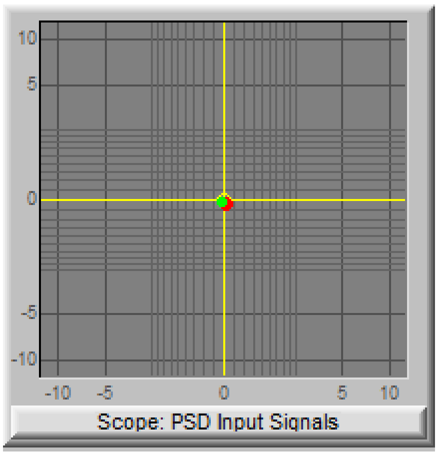
forward" control. The "feed-back" loop, performed by the servos, is responsible for the residual errors of the feed-forward control.

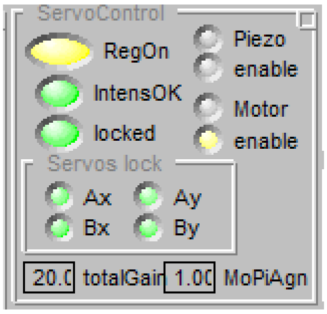



Measurement with larger distances:
Higher deviation from ideal curves, but nevertheless working well.

### 10.3.10.7 Switching on the (Four) Motorized Servos

Now the system "learned" the properties of your opto-mechanical setup (including distances between the mirrors, distances to the PSDs, orientation of the mirrors and detectors, etc.), and you can switch on the regulation (click the "RegOn" button). The red and the green spot (angle and position) of the X/Y scope will immediately go the center, which means, the beam is 4D stabilized to the beam path, given by the optical axis of the 4D detector.




Note: The matrix is stored inside the micro controller. It can now work as a stabilization system in an autarkic way, without the need of a connected PC. The PC is just needed for "learning", for visualization, for error message display, for scanning, etc.

The servos need enough intensity ("IntensOK" lamp is lit green).

Depending on the "quality" of the OCL learning, it may be necessary to reduce the "total gain" value in the case the motors are oscillating, moving permanently, and maybe even enlarging their movement. In this case, switch off the regulator, select a distinct smaller "total gain" by a factor of 3 or 10 or so, and try again.

For testing the stabilization function, you can bend the laser mount or any of the mirror mounts with your finger tips and observe the servos working, putting both angle (red dot) and position (green dot) back to the 0,0,0,0 4D pointing position.

### 10.3.10.8 Optimization of Servo Gain and other Servo Parameters

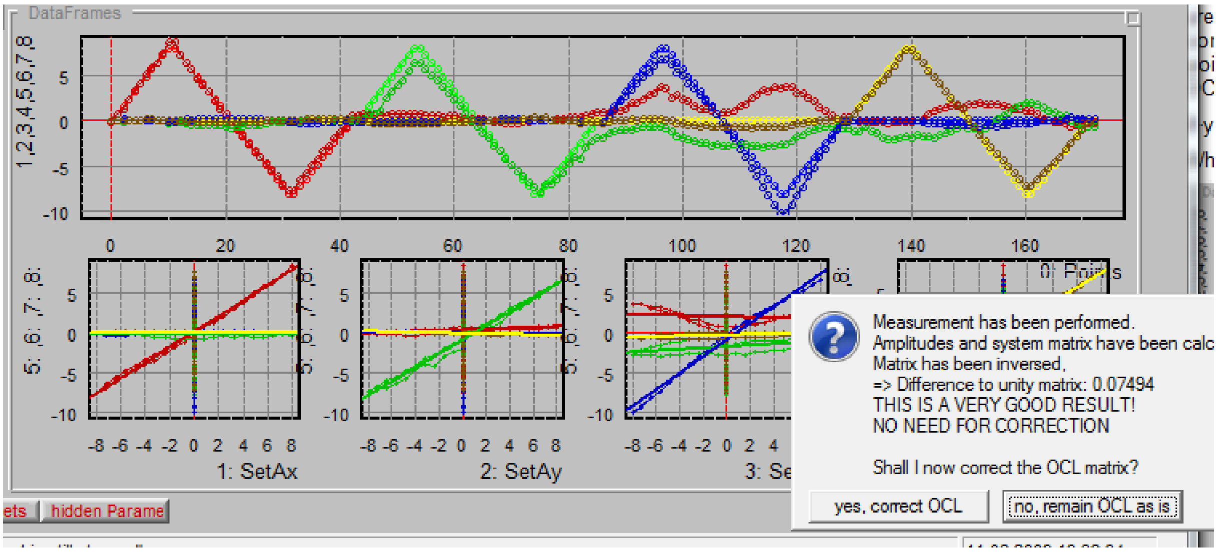
Increase parameter "totalGain" to make the servo loop faster. Decrease the parameter to avoid oscillations or overshoots.

(A more detailed description of manual and automatic optimizing of the total gain and other servo parameters is in preparation...)

### 10.3.10.9 Comments on some Effects:

Some effects, which lead to a non-ideal behaviour, are described now:

#### 10.3.10.9.1 Residual angle movement while position movement




As you see in the example OCL measurements above (marked as “very good result”) you see remaining measured angle values (red and green), even if only position is scanned (blue and yellow).

This can be quite normal, especially with small actuators, which have a lower mechanical resolution: A beam shift is performed by a (large) angle movement of the first actuator, and compensated for by a (large) angle movement of the second mirror. A relatively small beam position movement (to be corrected or scanned) is performed by the difference of two large (angle) movements, which have effects like mechanical hysteresis, adhesion, etc. Even if these effects are small (in the case of good mirror mounts, with polished tap surfaces, like *Aligna* mirror mounts, which use extremely hard sapphire plates, special position mounting elements,...) they are “blown up” significantly in this measurement. In the closed servo loops they will be compensated nearly completely.

This effect is larger, if the distance between the mirrors is smaller. (More mirror movement is necessary to reach the same position shift.)

In addition, if a motor/piezo actuator combination (MoPiA) is used, the piezo will give extremely high resolution. Therefore, even if the mechanical resolution of small motorized actuators (Aligna 40) is limited, it will not limit the final resolution.

#### 10.3.10.9.2 Offset Shifts

In the example measurement, you see a shift between the green and the dark green trace (set and measured angle Ay). This is an effect of mechanical hysteresis. At the start of the measurement, the PSD offset was automatically aligned to the actual beam pointing, to be displayed as 0,0,0,0.

When the Ax scan has been performed, the motors will not be exactly at the start position because of mechanical hysteresis. Thus, the measured Ay curve is shifted against the set curve.

However, this will be neglected, only the slope (calculated by least square fit of the measured data against the set values), not the absolute position, is used for calculation of the matrix elements. Because of this, these offset shifts are not important.

### 10.3.10.9.3 Nonlinearities

In the example measurement, you see a difference between the blue and the dark blue trace (set and measured position Bx). In this setup, it is a property of inserted lenses, which are not hit exactly in the center. However, this is a small effect of some percent; so it has no influence to the servo loop performance.

## 10.3.11 Alignment of the Piezo OCL Matrix OCLP (Piezo's Output Crosslink Matrix)

This chapter is only important for you, if you got a piezo actuator-based (PiA) or a motor AND piezo based Aligna system (MoPiA).

In principle, the learning of the piezo OCL ("OCLP") is rather equivalent to the motor's OCL ("OCLM"). However, there are distinct differences, because the hardware behind it is quite different: The motorized orthogonalization and the motor servo loops are completely done by software in the microcontroller, while the piezo servo and the piezo OCL are made by hardware in the BLM servo modules. (This is done for speed and precision issues, the servos can go in principle up to MHz regions with extremely high resolution and low noise, better than digital servos. However, this is only used and needed in very special applications.)

So one main difference is, that the matrix and servo coefficients are not just calculated numbers (with a very large dynamic range), but all these parameters are realized by MDACs (multiplying Digital Analog Converters), which are controlled by the microcontroller. They act like digitally controlled potentiometers. (There are approximately 60(!) MDACs per BLM module, up to 240(!) per Aligna rack.)

Even if the signals themselves have an "infinite" (analog, just noise limited) resolution, the MDAC-controlled coefficients have a resolution of 14 bit (1:16192). There are a lot of sums, differences, multiplications and divisions in the signal path. Thus, the signal heights have to be well adapted all along the signal path, not to be too large (being clipped at the analog voltage limits), and not too small (competing against analog offsets and noise).

Even if the piezos have a nearly infinite resolution, they have a rather small stroke, and a rather large hysteresis of approx 5%...10% of its stroke. This makes well-defined combination movements MUCH MORE complicated.

We offer different types and sizes of piezo actuator-based XY-scanners: The standard is the OneInch MoPiA actuator, a compact combination of the Aligna 40 motorized mirror mount and a 1 inch piezo-based XY actuator. In addition, there are 2 inch piezo actuators (for handling rather heavy 2 inch mirrors of 12 mm thickness. For getting a good dynamical performance, the 2 inch piezo actuators have an even much smaller angle stroke compared to the 1 inch piezo actuators.

### 10.3.11.10 Learning of the Piezo "OCL" Matrix

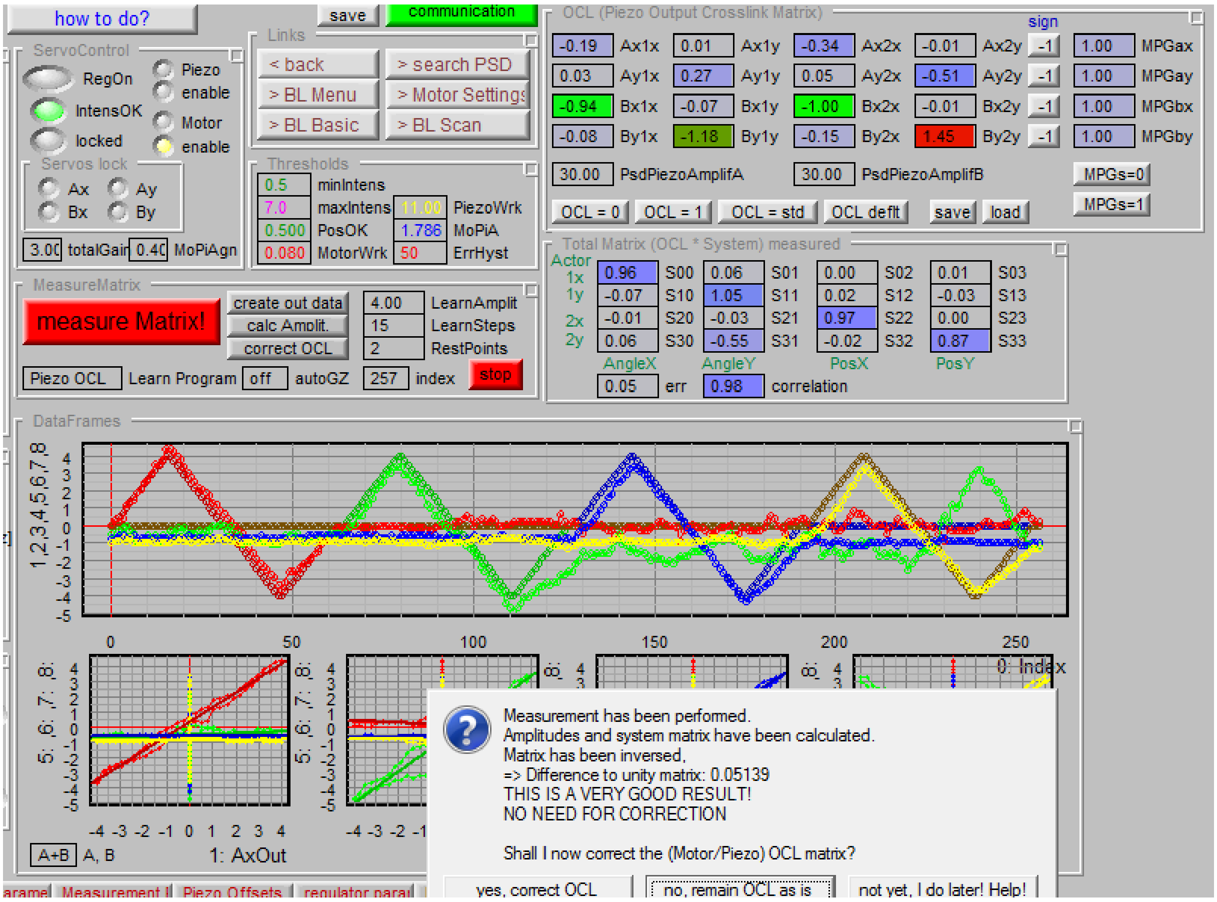
The procedure is rather equivalent to the one described for the motors:

- Choose "Learn Program: Piezo OCL" (The system will learn the OCL for the piezo servos) (When you select "Learn Program: Piezo OCL", Kangoo shrinks down the motor OCL section, and rescales the piezo OCL section.)
- Click “measure Matrix!”, which starts the learning procedure:

In addition, the scaling units of the displayed position values have been blown up by selecting "UnitsA" and "UnitsB" to "Volts, amplified for piezo". The factor is given by the parameter "PsdPiezoAmplifA" and "...B". This is necessary to achieve a Total Matrix being the unity matrix: The opto-mechanical system has a very small reaction (dues to small stroke of the piezos). Thus, we need an additional gain to get the same total scaling of approx "1".

In the case of 2 inch piezo actuators this "blow-up" amplification is of the order of 30...60. (Thus, the PSD signals seem to be very noisy and fluctuating. But this is just seemly due to the "blown-up" measured position signals, just for the OCLP learning procedure. If you touch the mirror mounts with your finger tips the position and angle dot will go out of the display range immediately.)

After one or two learning cycles, you will get a result as shown below:




Compared to the motorized learning the signals (of the feed-forward measurement) are noisier and have larger offsets. The reasons are the blown-up scale, but particularly the piezo hysteresis. Especially the position movement (blue and yellow) looks much worse.

NOTE: For position movement the angle movements have to counterbalance each other exactly. If the hysteresis of the actuators of mirror mount 1 and 2 are not exactly the same (they never are), there will be residual angle movements. (You can see the green (angle Y) movements in the last quarter, in which only position Y movement is expected, but no angle Y movement.)

Nevertheless, the orthogonalization works well, the 4 degrees of freedom are independent enough from each other, and the 4D piezo servo loops should have an easy job.

If one of the OCL elements exceeds +/- 1.49 (which is the hardware limitation of the "electronic potentiometers, the MDACs) you should increase "PsdPiezoAmplifA" and/or "...AmplifB". (Normally you can change both values synchronously. For individual alignment: If the red limitation numbers are in line Ay or Ay lines, 1st or 2nd, AmplifA should be increased, if the red numbers are in Bx or By lines, 3rd or 4th, AmplifB should be increased).

If, on the other hand, none of the elements is larger than +/- 1 you should decrease the "AmplifA/B" values. (If maximum value in one line pair is 0.5, e.g., you should decrease the AmplifA/B by factor of 2. Then in the next iterative cycle the max value should be around 1).

If the learning was more or less OK, you can use the actual OCL for learning of next optimization cycle. If, however, one or more of the OCL coefficients are at their limits (+/-1.49), the movements (given to the actuators) can be partially "wrong". They can even have opposite signs, or the measured matrix becomes no longer "linearly independent". Therefore, it is better not to use the actual matrix for the next measurement, but to start with the unity OCL matrix. (Click button "OCL=1".) Increase " PsdPiezoAmplifA " and "...B", and start a new measurement.

After learning the Piezo OCL switch back "UnitsA" and "UnitsB" to "Volts", "mm", "mrad", or so.

(In near future we will supply you with an even more automated procedure, which does these corrections on its own.)

### 10.3.11.11 Switching on the Piezo Servo

Switch the XY "Display" to "inputs and regulator".

When you switch on the regulation (only motors are enabled up to now), you see the red and green dots (representing angle and position) going to the XY center. When enabling the Piezo Servo, the red and green dot shout remain in the center, and a cyan and a yellow dot are walking around: These are the piezo regulator outputs. You can observe the servos working if you touch the mirror mounts slightly with your finger tip.

If the cyan and yellow dot exceed the blue rectangle (MoPiA threshold), the motor servo will "help" the piezo servo, until the piezo servo outputs are again inside the blue "MoPiA threshold" square.

### 10.3.11.12 Optimizing the Piezo Servo Parameters

In the case of oscillations or too slow piezo servo performance, the piezo servo parameters have to be aligned.

((This procedure will be described in the next version of this manual.))

## 10.4 Storing and Recall of the Individual Parameters

You are able to select, whether the actual parameters are saved in a battery-buffered CMOS RAM (which keeps the parameters for several years,) when the rack case is switched off and on, or in contrast the actual parameters will be taken from "default values", when the rack case is switched off and on (this is actually the standard).

However, the actual values can be defined as "default values", which is described now.

Therefore, in case of strong misalignment of some parameters (and the system does not work any longer) you can simply go back to "default values" by simply switching off and on the rack case.

These default values (OCLM and OCLP coefficients, PSD gain and offset values, properties of the laser, etc.) have to be correct to allow valid working at all. However, these values depend on your personal individual optical setup, on your laser and on your application. Therefore, you should store the valid parameters from time to time into the EEPROM of the *Aligna's* microController, especially after a processing a learning procedure of the OCL.

> NOTE: When you have spent (maybe a lot of) time for learning OCLs, optimizing the servo parameters, etc., please do not forget to save the gathered parameters as default values. It just takes a few seconds. When you have lost valid parameters for any reason, you will be glad not to start from scratch again.

The operating system ("firmware") of the 32 bit microController MOTOROLA 68332 is stored in 1 MB EEPROM, organized in eight blocks, 128 kB each.

One of these blocks (block #7) contains script procedures, which set all user-specific parameters and script commands. This block (in contrast to all other blocks) contains clear text commands, which can be edited by the user. (Menu item "programming uC / edit uC Scripts"). It is stored in a file "TEM / UserData / <UserNameDataFolder> / uC Scripts".

This file contains a script procedure named "Intro", and a second one, which is called "Defaults". The "Intro" script is executed at each booting; the "Defaults" script is executed when booting is completed (and automatic default values are selected, as standard).

The main task of the "Intro" script is, to define the available hardware (quantity and type of beams, PSDs, motors, piezos, other detectors, laser parameters like wavelength, repetition rate, cw or pulsed, etc.) (see below "Defining Hardware-Specific Parameters").

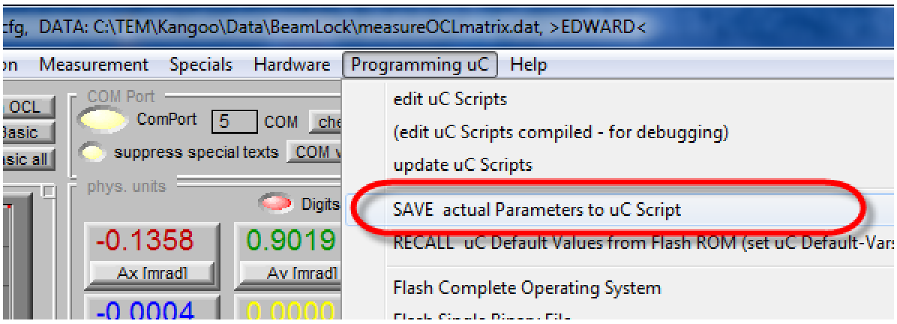
The "Defaults" script sets all user-specific parameters of the individual setup, (PSD gain values, PSD offsets, servo parameters, learned matrix elements, etc.).

### 10.4.1 Recall of the (User-Specific) Default Parameters

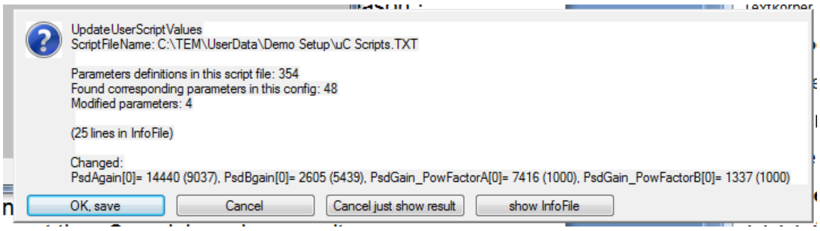
If you switch on the *Aligna* rack case or if a reset is performed, the system will reboot. (You can switch on the system by use of the key switch at the front or by use of the main power switch at the rear side, close to the power cord connector. A hardware reset while power is on is done either by hitting the small black "reset" key at the µC module, or by menu item "programming µC/reset uC"). When the system reboots, (in standard configuration) it will take the default parameters, indicated by a beb beeep sound.

### 10.4.2 Storing the actually defined Parameters as Default Parameters (into the µC's FlashEEPROM)

When you click "SAVE actual Parameters to uC Script" the actually defined parameters are compared to the default parameters in the "uC Scripts" file.



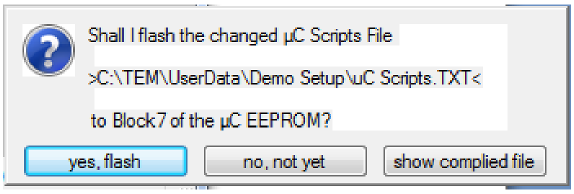

All changed parameters will be prompted:



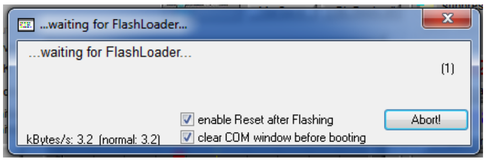

If very many parameters are changed, not all are listed. However, you can observe the complete list by button "show InfoFile".

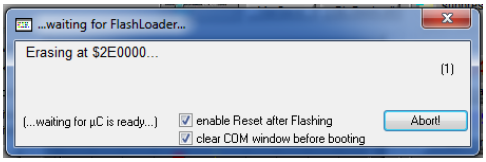
Usually you will confirm: "OK, save". Now the changes parameter values will be updated in the "uC Scripts" file.

Now the actual parameters are saved to the scripts file (located in the TEM / UserData folder in the PC), and you are asked, if you want to flash the data permanently to the uC:

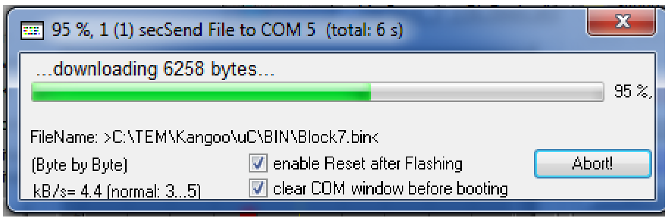



If you confirm, the FlashLoader is started, EEPROM block #7 will be erased




and block #7 (containing all individual parameters) is flashed to the EEPROM.




Then the uC reboots with the new values. Now it can work autarky from the PC.

### 10.4.3 Defining the Hardware-Specific Parameters

For some convenience, the script file can be automatically pre-processed, before it is sent to the µC FlashROM. This pre-compilation can be controlled by "compiler directives" (starting with a dot "."), and "compiler flags", for example "`.Beams= 2`". Therefore, the pre-compiler can set many parameters automatically without the need of editing all related parameters manually. (For example: The number of beams defines the number of motors, detectors, etc.

Because of that, normally it is not necessary to define all of the parameters, but just set the main flags, like number of beams, PSD version, etc.)

As an example, the following "UserScript" is seen in the editor:

```
' -------------------------------------------------------
'     Script File for Aligna Standard Demo Setup
' -------------------------------------------------------

' Use of Compiler-Directives, Flags and If statements:


' ******************************************************************************************
' Procedure Intro is called when uC has booted (every time, not only at "default settings")
' ******************************************************************************************
Intro:

  SerialNumber= 2167

  ' --- front panel LCD ------

  LCD_Line1$=   "   Aligna 5.2       "
  LCD_Line2$=   "TEM Messtechnik GmbH"
  SN_Customer$= "SN 2167 Demo TEM III"
  Release$=     "Release 02.03.2013  "


' --- some Flags for controlling actual configuration (without need to change the complete script) ---

.Beams= 1        ' actual Configuration for OneBeam (1) or TwoBeam (2) system
.RefDetectors= 0 ' 0: no Reference detectors, 1: 1x 4D or 2x 2D, 2: 2x 4D or 4x 2D
.AimPDs= 0       ' AimPDs available? (special photo detectors for auto-alignment systems)
.ADDA= 0         ' with ADDA module             (Analog/Digital-Digital/Analog module available
.PSDversion= 7.5 ' PSD-Type

  ' --- definition of available hardware components ----

  BL_BeamOn[0]= 1            ' Beam 0 is on

  ModuleAvailable[0]= 1      ' Module #0 is SPM  (0= not available, 1= SPM, 2= ADDA)
  PiezoAvailable[0]= 1       ' Piezo Servo Board 0: not available, 1: available
  SnH_available[0]=  1       ' Sample&Hold Board 0: not available, 1: available
  BL_AvailableAB[0]= 3       ' 1: A only, 2: B only, 3: A+B available



' ******************************************************************************************
' Procedure Defaults is called when uC has booted,
'  AND the "DefaultParameters" are initiated by pressing a key while booting
'  or when the "DefaultParameters" command was chosen
' ******************************************************************************************
Defaults:
  Tadaa                   ' make some noise: I take default parameters

  BL_EnableMotor= 1       ' Motors are active
  BL_EnablePiezo= 0       ' Piezos are NOT active

' --- Laser properties ---

  LaserCwPulsed= 0        ' 1: pulsed 0: cw
  LaserRepRate= 4000      ' 4 kHz Reprate    low Reprate
  AutoPulseDetection= 0   ' no auto-pulse detection

' --- individual Piezo OCLP ---

  Ax1x= 1322     : Ax1y= 122      : Ax2x= -2717    : Ax2y= -313
  Ay1x= 0        : Ay1y= -2050    : Ay2x= -131     : Ay2y= -4170
  Bx1x= 3543     : Bx1y= 463      : Bx2x= -3618    : Bx2y= -270
  By1x= 58       : By1y= 4604     : By2x= 188      : By2y= 5420

…etc…
```

When you save the changed script to the hard disk, *Kangoo* observes this file, and asks you, if you want to "flash" the changed script file to µC's EEPROM now. If you confirm, the script with the actual parameters is pre-compiled and is written to the Flash ROM (EEPROM). From now on the new parameters are "burned" into the µC, so it is autarky from the PC and can do its stabilization work.

#### 10.4.3.13 Manual edition of the Script "Default"

You can also edit all relevant parameters manually.

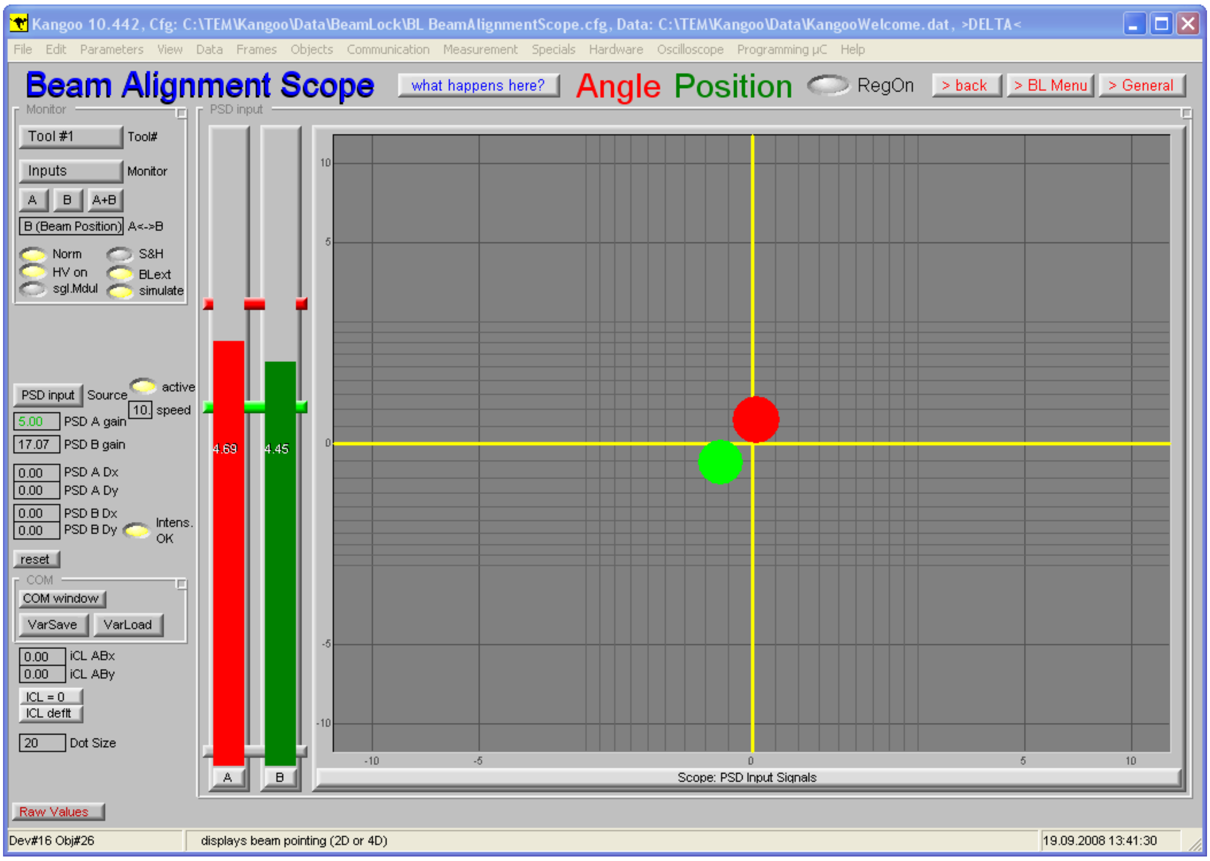
> NOTE: Most of the numerical parameters inside the µC are handled as integer values. Even if the display in *Kangoo* might be in decimal values (displayed Value "PSD A gain" is 12.34 [%]) the command to the µC is given as integer ("PsdAgain= 1234"). (The scaling factor between the displayed *Kangoo* device value (12.34) and the sent µC command value (1234) is defined in the device's "gain" property, "0.01" in this case.)

If you want to see the correct syntax (including the correct variable name and the number of digits or scaling resp.), switch on the COM terminal (menu item "Communication / display COM window (F6)"), scroll the wanted parameter, e.g., with the mouse wheel and watch the communication. ("\PsdAgain= 1234". The backlash "\" suppresses the µC echo. It should NOT be used in the script commands ("PsdAgain= 1234"), because you want the µC to echo these commands. Thus, *Kangoo* can update its displayed devices, receiving these echoes during boot process.

When you save the modified script file, *Kangoo* observes this file, and when it is changed, *Kangoo* will ask you, whether you want to flash it to the µC's EEPROM now.

Now you are able to set any changed value as default value and you can restore whenever you want.

## 10.5 Configuration "Beam Alignment Scope"




… ((Setup procedure description will follow…))

# 11 Safety Instructions

The device is manufactured according to the International Laser Safety Standard IEC 825-1:1993 and complies with US laws FDA 21 CFR §1040.10 und §1040.11.

**DANGER!** The device should only be opened by appropriately trained personnel. Before opening, the supply cable must be disconnected from the mains.

**DANGER!** For safe operation, use the provided supply cables. Improper or missing connection to protective ground can lead to serious injury.

**CAUTION!** Laser light is potentially harmful to the human eye.

**CAUTION!** Apply the legally specified protective measures for lasers. In particular, make sure that it is not possible to look into the laser beam under conditions, which exceed the limits specified by the United States Food and Drug Administration. If in doubt, avoid exposure to a direct or reflected beam.

**NOTICE!** The device has been designed for operation in laboratory environment with a temperature range between +15 °C and + 45 °C. The system is not to be operated in a hazardous environment. Avoid exposure to heat, or to emissions of other electric equipment. Protect the system against humidity, dust, aggressive fluids, or vapors.

**NOTICE!** For connection of the components use no other cable than the one delivered with your device.
Using standard cables like those used for personal computers can lead to malfunction or damage of electronic components.

Store the manual at a place where it is easily accessible in order to secure that you can get quick access to it whenever you need it and that you can quickly refer to it.

Add this guide if you hand over your device to any other person.

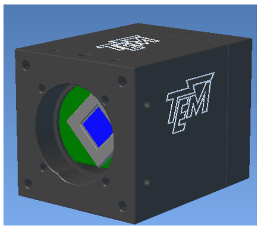
# 12 Delivery content

Please check the ***Aligna***® system on delivery for damaged or missing items.

## 12.1 Delivery content *Aligna*® :

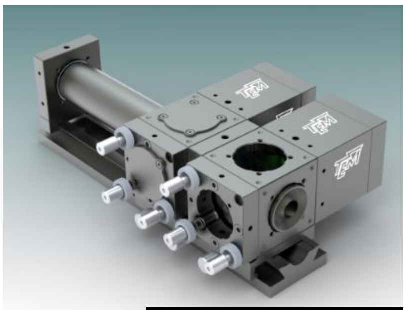
- ***Aligna***® Control unit
- ***Aligna***® User Manual
- If a piezo-based system was ordered (PiA or MoPiA):
  SubD25 ← → 2x HD 15 (labeled as “piezo actuators”, "A1", "A2")
  additional ones, if more than two piezo drivers are ordered
- in the case of In/Out Modules: HD15 male/male cable for Motors, “Inputs", "Outputs"
- power supply cord (European, American version, others on demand)

## 12.2 Delivery content *PSD 2D*:



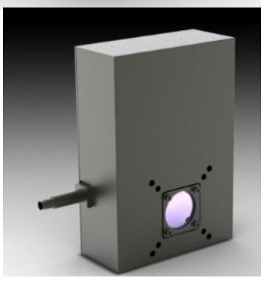
- ***PSD 2D*** Detector box (different types of detector sizes and properties)
  Regarding PSD type with or without mechanical alignment possibilities
- HD15 male/male cable for PSD (labeled as “PSD 1”)
- (power supply is overtaken by ***Aligna***® ***4D*** or ***µAligna***®)

## 12.3 Delivery content *PSD 4D e*:



- ***PSD 4D e*** Detector system
- HD15 cable male/female, labeled as "PSD 1" (or PSD 2, 3,…)
- Y adapter (labeled as “PSD 1”←→ "PSD A", "PSD B")
- (power supply is overtaken by ***Aligna***® ***4D*** or ***µAligna***®)

## 12.4 Delivery content *PSD 4D i*:



- ***PSD 4D i*** Detector system
- HD15 male/male cable for PSD (labeled as “PSD 1”)
- (power supply is overtaken by ***Aligna***® ***4D*** )

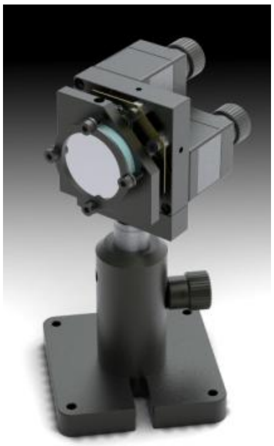
## 12.5 Delivery content *BeamScan OneInch*:

- ***BeamScan 2D*** or ***BeamScan 2D One Inch*** or ***BeamScan 2D 4M***
  (depending on order: with or without mirrors)
- HD15 male/male cable (labeled as “A1” or "A2", "A3", A4" for second beam, etc.)

- Unless otherwise agreed, and MoPiA (Motorizes AND Piezo Actuators) are ordered, the *BeamScan OneInch* are mounted onto the *Aligna60* Motorized Mirror Mounts.

## 12.6 Delivery content *Motorized Mirror Mounts (MMMs)*:

Depending on the ordered system, you have got following items



- 2 x *Aligna 40* MMMs
- 2 x *Aligna 60* MMMs
- 2 x *Aligna 40* MoPiA MMMs
- optional linear actuators, like *AlignaLin*, ...

- HD15 male/female cable for Motors, “M1", "M2",…

It is strongly recommended to keep the packaging material for future storage and transportation.

# 13 Technical Data

(Data may change related to new developments)

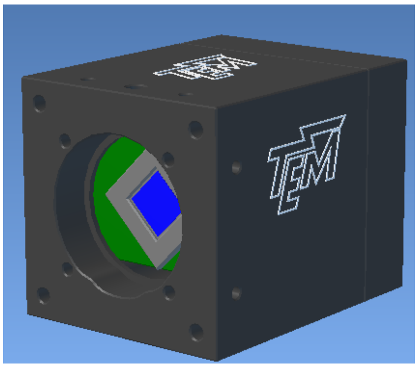
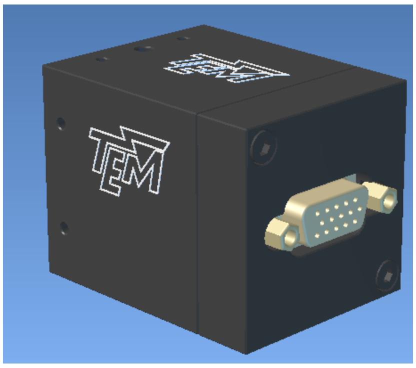
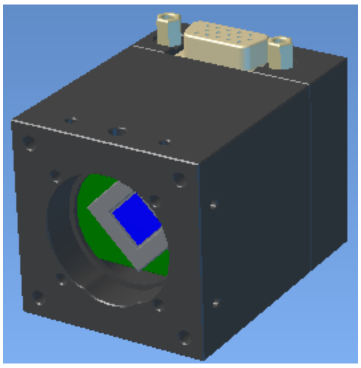
## 13.1 Environmental conditions:

The ***Aligna®*** system has been designed for operation in laboratory environment with a temperature range between +15 °C and + 45 °C. The system is not to be operated in a hazardous environment. Avoid exposure to heat, or to emissions of other electric equipment. Protect the system against humidity, dust, aggressive fluids, or vapors.

## 13.2 *Aligna®* 4D Module Rack Case Properties


| | |
|---|---|
| Dimensions (excl. handles and pedestal): | 450 x 280 x 133 mm |
| (incl. handles, fixing angles and pedestal): | 484 x 333 x 144 mm |
| Regulation bandwidth: | selectable by filters and software, 0.1 Hz...20 kHz |
| Number of Calculation Modules "BLM": | 1 … 4 (for use of up to 8 PSD2Ds or 4 PSD4D |
| Number of piezo amplifier modules: | 1 or 2 (8 or 12 HV ch per each → 24 HV ch max) |
| Number of motor driver modules: | 1 or 2 (4 motors per each → 8 motors, 4 MMMs) |
| Output voltage of piezo amps: | standard 0…150 Volt, active limitation<br>(max.: -10 …270)<br>0…500 Volts or 0…95 V on request |
| Line voltage: | 200…240 VAC 50…60 Hz<br>100…120 VAC 50…60 Hz<br>automatically switching between Line Voltages |
| Power consumption: | < 95 Watts (typ. 70 W) |
| Interfaces: | USB (front), RS232 (rear)<br>USB (fast, rear, optional), Ethernet (optional) |

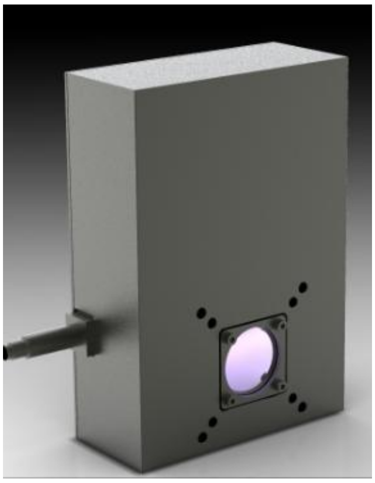
## 13.3 Detector properties *PSD 2D (Detector A, or Detector B)*

| | |
|---|---|
| Resolution of the detectors: | 10 nm … 200 nm, only noise limited,<br>no quantization (like CCD/CMOS)<br>(depending on measurement bandwidth,<br>selected gain, environment light,…) |
| Signal to Noise Ration: | < 0.1 mV rms at +/-10 Volts voltage range ($10^{-4}$) |
| Detector area: | Standard Position Detector: 9mm x 9mm<br>Standard Angle Detector: 4mm x 4mm,<br>in focus of a lens, f = 300 mm |
| (other detector areas: | 2mm x 2mm, 12mm x 12mm, others on request |
| Rise time of the detectors | 10 µs, or filtered, regarding ordered laser rep rate |
| (of other detector variants: | 1 µs, 2 µs, please contact TEM Messtechnik) |
| Filter bandwidth limitation: | 10 kHz, selectable |
| detector case size: | 40 x 40 x 52 mm |
| connector: | HD15 (VGA) male (at rear or at any side) |
| | (Pinning: see "Connectors and Cables") |

## 13.4 Detector properties *PSD 4D i*

(same as before)

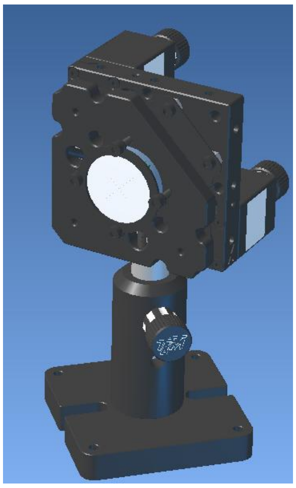


## 13.5 Actuator properties *BeamScan 2D One Inch*

| | |
|---|---|
| Dimensions: | 30 mm length, 25 mm diameter in the front part<br>20 mm diameter in the rear part<br>fitting into most 1 " mirror holders |

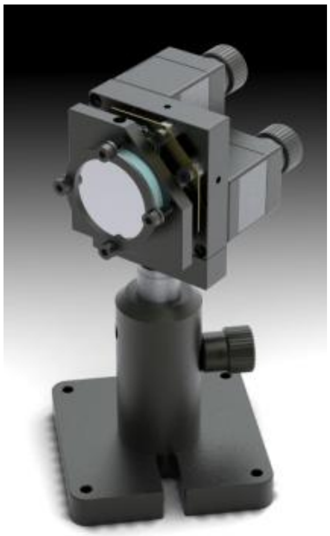
| | |
|---|---|
| Angular beam displacement: | X-direction: 4.8 mrad (>4.8 mm at a dist. of 1 m)<br>Y-direction: 4.8 mrad (>4.8 mm at a dist. of 1 m) |
| Mirror size: | 1 inch diameter (24.0 … 25.8 mm)<br>thickness: 2 … 10 mm |
| other mirrors: | on demand |
| Free aperture (max beam diameter): | 15 mm (1" mirror at 45°)<br>or 22 mm (elliptical mirror)<br>or 11 mm (1/2 inch mirr.) |
| Fixing of the mirror: | 3 or 4 screws M 2.5 mm<br>or M2<br>alternatively glued |
| First main resonance: | 1.3 kHz,<br>including mirror 1 inch diameter, 6 mm thickness<br>(other actuators with different displacements<br>and other speed on request) |

## 13.6 Aligna 60 Motorized Mirror Mount



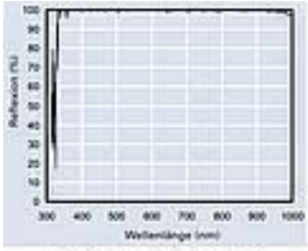
| | |
|---|---|
| Dimensions (excl. post, carrier,…): | 60 x 60 x 63 mm |
| Angular beam displacement: | X-direction: 5 deg<br>Y-direction: 5 deg |
| Mirror size: | 1 inch diameter (std)<br>thickness: 2 … 10 mm |
| | 2 inch (with adapter)<br>thickness 6…15 mm |
| Reference switches: | optical X and Y |

## 13.7 Aligna 40 Motorized Mirror Mount



| | |
|---|---|
| Dimensions (excl. post, carrier,…): | 40 x 40 x 63 mm |
| Angular beam displacement: | X-direction: 8 deg<br>Y-direction: 8 deg |
| Mirror size: | 1 inch diameter (std)<br>thickness: 2 … 10 mm |
| Reference switches: | optical X and Y |

## 13.8 Used Mirrors



DLB 350-950 nm / 45° Einfallswinkel

The user may use any own mirrors. For standard applications we recommend (and deliver) mirrors with QI/LINOS dielectric super broad band coating DLB 350-950

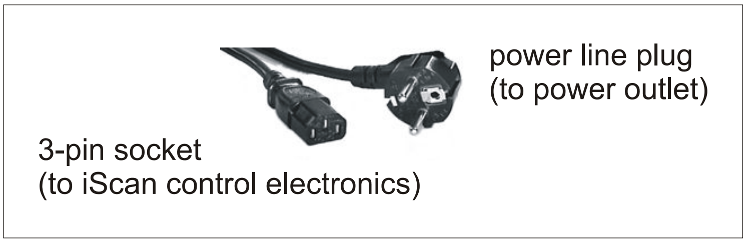
| | |
|---|---|
| Wavelength range: | 350 … 950 nm > 99%<br>at 45° AOI<br>400 … 950 nm > 99 %<br>at 0°…45° AOI |
| Dimensions (for different applications): | round, D=10 mm, T=2mm<br>rectangular 20 x 15 mm, T=2.5 mm<br>ellipse 22 x 32 mm, T=5 mm |

(Other mirrors, coatings and mirror sizes on request)

# 14 Connectors and Cables

### 14.1.1 Mains power cable

Use the included power supply cable that provides proper grounding contact.

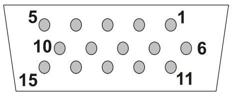



(The system may be delivered with country-specific mains power cables.)

### 14.1.2 Connection of the Detectors and Actuators

**Notice!** Only use the cable delivered with your system. Using standard cables like those that are used for personal computers can lead to malfunction or DAMAGE of electronic components: Many available cables have internal connections (common shielding of R,G,B) or some pins are not connected.

NEVER use so-called VGA cables, they are not connected 1:1, and they miss pins, especially pin 9, which is not used in VGA monitors.




HD15 socket

#### 14.1.2.14 PSD4D Connector ("PSD 1", "PSD 2",…):

| | | | | | |
|---|---|---|---|---|---|
| 1 | diff Ax | 6 | +Usupp (+15 V) | 11 | sum Ax |
| 2 | diff Ay | 7 | -Usupp (-15 V) | 12 | sum Ay |
| 3 | diff Bx | 8 | System Ground (0 V) | 13 | sum Bx |
| 4 | diff By | 9 | $I^2C$ SCL | 14 | sum By |
| 5 | analog ground in for differential inputs | 10 | $I^2C$ Data | 15 | $I^2C$ CLK |

Cable requirements: >= 0.09 $mm^2$, >= 20 V

#### 14.1.2.15 Motor Actuator Connector ("M1", "M2", "M3", "M4"):

| | | | | | |
|---|---|---|---|---|---|
| 1 | Motor X A | 6 | +Usupp (+15 V) | 11 | Motor Y A |
| 2 | Motor X -A | 7 | -Usupp (-15 V) | 12 | Motor Y -A |
| 3 | Motor X B | 8 | System Ground (0 V) | 13 | Motor Y B |
| 4 | Motor X -B | 9 | Switch X 1 | 14 | Motor Y -B |
| 5 | Switch X 0 | 10 | Switch Y 1 | 15 | Switch Y 0 |

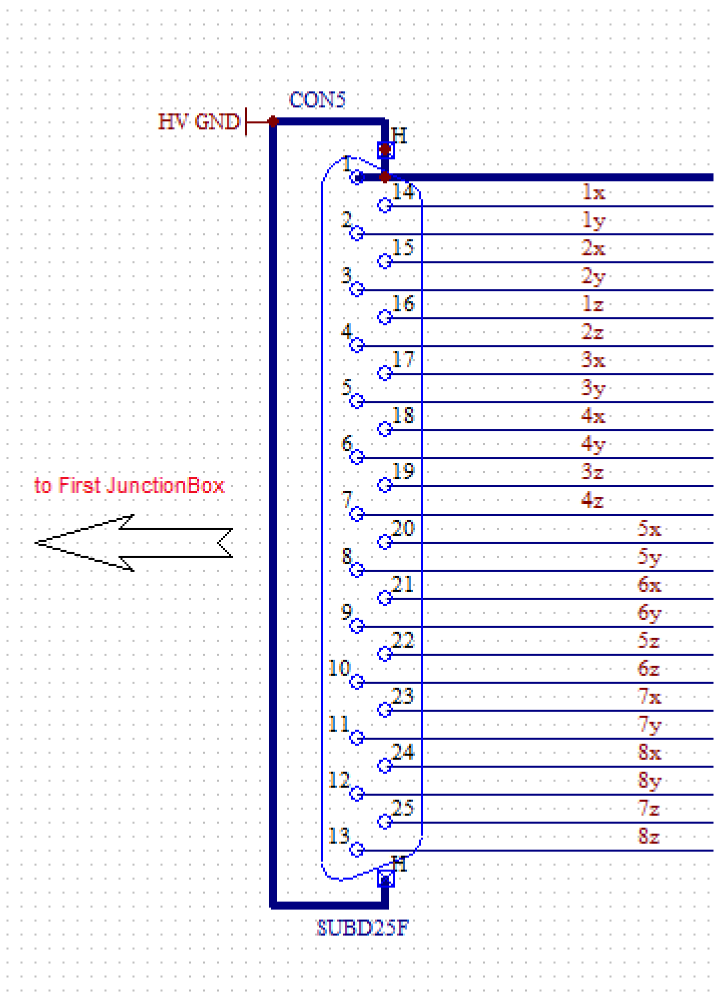
Cable requirements: >= 0.09 mm², >= 20 V

### 14.1.2.16 Piezo Actuator Connectors ("A1", "A2", "A3", "A4"):

| | | | | | |
|---|---|---|---|---|---|
| 1 | | 6 | | 11 | Piezo X |
| 2 | | 7 | | 12 | Piezo Y |
| 3 | | 8 | | 13 | (Piezo Z, 3D actuator)<br>(Piezo X2, 4D actuator) |
| 4 | | 9 | | 14 | (Piezo Y2, 4D actuator) |
| 5 | | 10 | Piezo GND | 15 | |

Cable requirements: >= 0.09 mm², >= 150 V

### 14.1.2.17 Piezo Driver



### 14.1.2.18 Cable Extensions

As mentioned before, DO NOT USE standard VGA cables as cable extensions!

(They are NOT connected 1:1, the shielding is different, and at least 3, mostly 4 shield pins are shortened, which may destroy components in the power supply. At least it will cause malfunction of the TEM device because of missing signals.)

We offer HD15 1:1 extension cables male/female in many variants, all compatible against each other. (Additionally we offer 1:1 connected 25 pole cables for the multi-channel piezo drivers.)

The cables have high quality gold-plated contacts. Therefore, even if you use several cable extensions in a sequence to achieve a long cable path, there is no increase of noise, electrical offsets by contact resistance, reduction of performance, caused by the additional connections.

Very often, it is easier, more convenient and safer, to use several short cables, instead of laying one very long cable through several cable channels from one lab into another, or even one floor to another, or from one building into another .

The only important thing: You should connect the cables mechanically properly by UNC hex bolts (which you get in combination with the cables), or by wire straps (see pictures below).

Up to about 30...50 meters path length it works fine without any change. If longer cables are used (100 meters or even more is no problem), we normally reduce the communication speed. (There are different variants, please contact us in this case.)

We offer (amongst other cables) following HD15 and SUB-D 25 variants and cable sets:

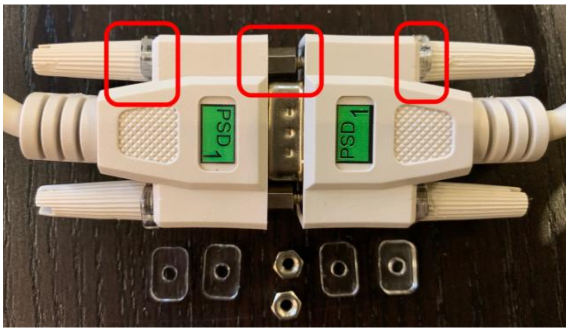
| | |
|---|---|
| cable HD15 m/f 5 m | extension cable 5 m for PSDs, motorized and piezo actuators |
| HD15-Y | HD15 Y-shaped adapter, male-female-female |
| cable Set | std cable set (2x MMM, 2+1 Piezo, 1x PSD+Y, 1x USB) |
| cable HD15 (m/f) 1 m | extension cable 1 m for PSDs, motorized and piezo actuators |
| cable HD15 (m/f) 2 m | extension cable 2 m for PSDs, motorized and piezo actuators |
| cable HD15 (m/m) 2 m | male/male cable 2 m |
| cable HD15 (m/f) 3 m | male/male cable 3 m |
| cable HD15 (m/f) 5 m | male/male cable 5 m |
| cable HD15 (m/f) 10 m | male/male cable 10 m |
| cable HD15 m/f 25 m | extension cable 25 m for PSDs, motorized and piezo actuators |
| cable HD15 m/f 35 m | extension cable 35 m for PSDs, motorized and piezo actuators |
| cable HD15 m/f 60 m | extension cable 60 m for PSDs, motorized and piezo actuators |
| cable SubD25 m/f 5 m | extension cable SunD25, 5 m for Piezo Actuators |
| cable SubD25 m/f 10 m | extension cable SunD25, 10 m for Piezo Actuators |
| cable SubD25 m/f 25 m | extension cable SunD25, 25 m for Piezo Actuators |
| cableSet M | cable set Motorized Actors |
| cableSet P | cable set Piezo Actors |
| trailing cable per meter | trailing cable per meter |
| trailing cable per piece | trailing cable per piece |

(Halogene-free trailing cables are used in material processing machines or other applications, in which the cables are moved or are exposed to harsh environment condition, like strong electromagnetic noise, UV or gamma radiation, mechanical stress, fire restrictions, etc.)

### 14.1.3 Fixing the cable handles

It is important to connect the cable handles properly to avoid loosening due to vibrations or unwanted pulling the cables.

With the cables, you get delivered fitting UNC 4-40 hex-bolts (which are usual with computer cables), and acrylic spacers. You should remove the knurled screw heads by simple screwing out, and screw the acrylic spacers between knurled screw heads and connector handle.)

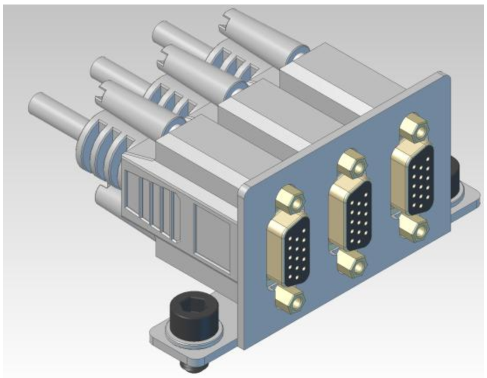



left: Connected HD 15 cables with spacers and hex-bolts, right: WITHOUT spacers: no good contact !!!

You can see the reason here: The screws are foreseen for connection into a device, not cable-to-cable. So the screws are too long, they touch each other and avoid a proper traction force. If you insert the acrylic spacers (or any other fitting spacers, like a stack of washers) the cables are fixed safely.


The bolts and spacers are also used to fix the handle-pairs to a mounting metal angle.

Alternatively, you can also use a pair of simple wire straps for fixing:




# 15Customer service

In case of service needs, general questions related to the ***Aligna***® system, need of repair, or warranty claims you will get quick and effective support at:


**TEM Messtechnik GmbH**

Grosser Hillen 38

D-30559 Hannover

Germany

Phone: +49 (0)511 51 08 96 -30

Fax: +49 (0)511 51 08 96 -38

E-mail: info@TEM-Messtechnik.de

WWW: www.TEM-Messtechnik.de