Multi-Aperture Scintillation Sensor. Engineer Guide.

Kornilov V., Potanin S., Shatsky N., Voziakova O., Zaitsev A.

February 28, 2002

Introduction

This document describes the preparation of the MASS device for measurements at the telescope. It is recommended to read first a document [3], since a number of references to it are used in the current document.

Chapter 1 contains information about an additional equipment (not delivered with the MASS device itself) which is needed for maintenance. Chapter 2 describes the procedure of disassembly and assembly of the device in order to do maintenance, alignment or reparation. A process of adjustment and alignment of the device using test bench is discussed in Chapter 3. Correct installation at the telescope, additional alignments and tests are described in Chapter 4.

In Chapter 5 auxiliary measurements for further determination of the main detector parameters are discussed. There are two procedures: choice of the optimal PMT usage and non-linearity and non-poisson factors evaluation. Chapter 6 is related to re-programming procedure which will be need in certain situations.

Bibliography

[1] Kornilov V., Potanin S., Shatsky N., Voziakova O., Zaitsev A. *Multi-Aperture Scintillation Sensor. Operation and User Manual.* February 28, 2002.

[2] Kornilov V., Potanin S., Shatsky N., Voziakova O., Zaitsev A. *Multi-Aperture Scintillation Sensor. Software Reference Manual.* February 28, 2002

[3] Kornilov V., Potanin S., Shatsky N., Voziakova O., Zaitsev A. *Multi-Aperture Scintillation Sensor. Final design document.* February 28, 2002

[4] Kornilov V., Potanin S., Shatsky N., Voziakova O., Zaitsev A. *Multi-Aperture Scintillation Sensor. Detailed Design.* February 28, 2002

Contents

Chapter 1

Additional equipment to operate

1.1 Requirements to power supply

As it is described in [3] Sec 2.3.5, MASS device is powered with +12 DC supply unit. This power supply may be either a battery or a line regulator or a switching converter. The maximal total MASS power consumption is 510 mA when high voltage 1250 V is on. The main requirements for the characteristics of the power supply are following:

- Output voltage: +12 V (Min +11.5 V, Max +13 V)
- Max output current: greater than 1 A
- Max output voltage pulsations: less than 100 mV
- Operating temperature from -10° to at least +35°.

A 2-wires cable which powers the MASS device, must have 0.5 mm^2 cross-section (AWG20) and the length no longer than 15 m. Voltage drop at the cable must be less than 0.2 V per one wire.

1.2 Interface board

MASS device data exchange is based on RS-485 interface. In principle, different interface boards supporting this interface can be used if they provide the following:

- Exchange rate up to 1 Mbaud
- PCI slot
- TL16C550C or fully compatible ACE chip.

In particular, the MOXA CP132 board was only tested. The board is recommended for a use with galvanic decoupling possibility (CP132I). The line cable is prepared for such a board. Circuit diagram of the line cable is shown in Fig. 1.7 of [4].

Install this board in the PC slot according to the MOXA Manual. Before this, set the jumper JP1 in a "short" position (using termination resistor 150Ω) and switch SW1 in the position "OFF" and SW2 in "ON".

1.3 Viewer TV camera

TV camera with the CS objective mount is attached at the focuser of the MASS viewer, without any additional adapter. Before this, the Koelner eyepiece must be removed with its adapter together. Any black/white TV camera with appropriate sensitivity, resolution and powering voltage can be used. The optimal choice is the TV camera WAT-505E (type 1/3) or WAT-902H (type 1/2) of the WATEC company. The used TV standard may be either CCIR or EIA, depending on the TV monitor specification.

A good idea is to put an elastic gasket (0.5 – 1 mm thickness) between the camera and the focuser. This permits to orient the TV camera in a usual way typical for astronomical observations: North to the top of the TV monitor screen. Correct orientation facilitates a star guiding.

The TV camera is powered via a short cable, which plugs in one of two sockets +12 DC at the MASS right side panel. The camera connection to TV monitor is done in accordance with its guide. Optimal camera exposure must be set before observations, using a star of 1.5 – 2 magnitude and illuminated work aperture. With an optimal exposure, the illuminated aperture edge must be seen clearly. To facilitate the camera focusing, it is useful to illuminate the field of aperture with help of any external light source.

TV camera installation is recommended to make after the complete MASS alignment and test observations with an eye-piece.

Chapter 2

Device disassembly and assembly

2.1 Detector modules (PM) exchange

2.1.1 Module removal

Warning! Close the PM shutters before detachment! Use a screwdriver to turn clockwise the axis of the shutter.

Afterward, detach the HV and RS-485 cables and untighten the washers from the back-side of the modules. Now it is free. Keep the rubber isolation between the PM and the base if not glued.

2.1.2 Module disassembly

In order to disassemble the module for PMT change, counter re-programming or repair, unscrew 2 screws above the line connector (see AS01) and 2 screws below the entrance window. Pull the panel PH01A and detach it. The main part of the module consisting the body PH01C and the back panel PH01B contains the PMT and all the electronics. Unscrew the screw fixing the connector TJ6 in the back panel, unscrew 2 screws fixing PH01C and PH01B together. Remove the body with care. Afterward, the PMT is accessible for maintenance of replacement. Assemble the module in an inverse order.

2.1.3 Module attachment

The PM is attached to the base with no ambiguity. Check the state of the elastic isolation at the front-end of the module. There must be nothing thick (like isolation band) on the side of PM which contacts another PM. Insert the PM in the base plug and turn and tighten the washer on the back-side. Ensure the straight position of the module and connect the cables.

2.1.4 Configuration file editing

Each PM (precisely, its counter) has its own number (an address in the RS-485 line) which is programmed in its micro-controller and normally marked on the module side. While changing the modules (setting the spare one, for example), set the proper counter numbers in the section `Devices` of the configuration file `turbina.cfg` for the channels A, B, C and D. The channel plugs are normally also marked on the side of the device and, for a standard segmentator alignment,

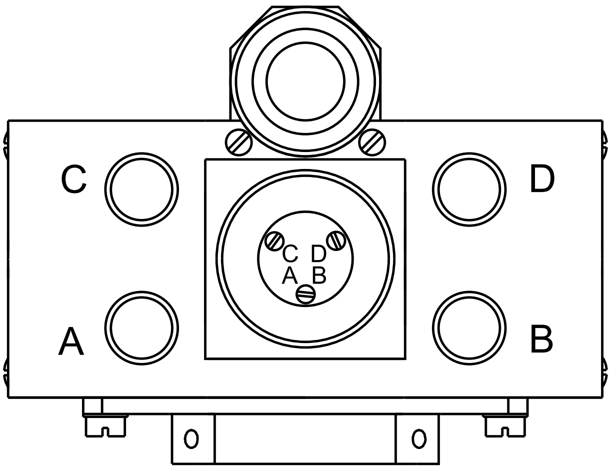

Figure 2.1: Back view of the MASS device with normal placement of channels.

follow the order shown in Fig. 2.1. It is a good habit to check the correct counters disposition and assignment in the configuration file by starting the Detector Test. The fluxes in channels must be approximately proportional to the areas of their segments (see respective Table 2.5 in [3]).

2.2 Disassembly sequence for alignment, maintenance or repair

Do not forget to close the PM shutters before disassembly of the device! (see Sec. 2.1.1). Disassemble the parts only to the state needed for the device maintenance or optics alignment. The part names mentioned below correspond to those given in drawings; their position is specified by assembly drawings (see [4]).

2.2.1 Covers removal

Follow the next sequence of the side panels removal. First, detach the front panel MC02C (4 screws). Then, unscrew 6 screws on the top panel MC02B and pull (slide) it in front direction (along Z-coordinate, opposite to the viewer direction).

In order to access the electronics or remove the Fabry lens unit or Focal plane unit supports, remove the side panels MC02D and MC02E.

2.2.2 Viewer removal

For detachment of the viewer, unscrew 2 screws from the side of the segmentator pit MC07A, which fix the viewer head MC09B to the PMT modules base MC01D and 4 screws on the viewer bear MC09A which fix it on the main beams MC01B and MC01C.

2.2.3 Blinds and Beam-splitter removal

Unscrew 4 screws and remove left and right baffles MC02G. Slide the beam-splitter in the segmentator pit and remove the blind MC08A (see AS08 drawing). Then slide the splitter back until the blind MC08D appears from the hole in the base MC01D and remove it.

2.2.4 Electronic modules detachment

For the further disassembly, detach (partially or completely) the electronic modules (see AS10 and AS11). Disconnect the Flat cable from the modules using a tweezer. Disconnect the power supply 12V from the motor controller board and the HV module board (Sockets X16 and X17 at SCH02B). Unscrew the washers screws and remove the PCB pawls MC01F and remove the boards. Avoid complete removal of the HV converter board PCB05B and of the Crossing board since in current design it demands to unsolder of the power supply wires W3 and W3. To access the screws behind the PCBs (fixing the Fabry lens support), just lift the PCB.

2.2.5 Fabry lens unit removal

In order to remove the Fabry lens unit (see AS06) assembled on its support MC05A, unscrew four screws fixing it to the main beams MC01B and MC01C. Simply pull the support top-wards after this.

2.2.6 Focal unit removal

Removal of the Focal unit (see AS04 and AS12) is made similarly to Fabry lens unit by unscrewing the four screws fixing its base MC03A to the main beams MC01B and MC01C. Meanwhile, in current design the connectors prevent sliding of the support. Removal of any of main beams allows to detach MC03A but is not recommended since this violates the rigid base of the device. That's why it is better to avoid the removal of the Focal unit and access it for maintenance from the side of the bottom plate MC02A.

2.2.7 Bottom plate removal

In order to detach the connecting flange MC01A together with bottom plate MC02A and the input door mechanism mounted on it, the four screws in corners of the flange and 2 additional screws on a plate must be unscrewed which fix the bottom plate to the main beams MC01B and MC01C. Detach the plate with an attention to the fine lever MC12D of the input door which is easy to damage.

2.2.8 Segmentator removal

To remove segmentator unit, PSU stopper MC07C must be screwed out. After this, the segmentator holder MC07B with the segmentator is removed by tweezer or fingers. Take care of the locking pin if it is not glued in the holder.

2.2.9 Further disassembly

Further disassembly is not recommended being needed in rare cases. See the drawings if needed.

2.3 Device assembly sequence

In general, the device assembly is done in an order inverse to described above. A few notes related to this process are specified below.

2.3.1 Segmentator installation

Pay attention to the special locking pin while inserting the segmentator in the pit. Rotate the holder until the pin finds its hole, then screw the PSU stopper MC07C tightly.

2.3.2 Focal unit mounting

In case the bottom panel is not removed, the installation of the Focal unit must be done with a care to the Hall sensor of the entrance door. It must fit the respective spacing on the entrance door cover fixed on the bottom panel. Setting the Focal unit support demands freeing of one of the beams MC01B or MC01C.

2.3.3 Bottom plate mounting

See 2.3.2 on the fitting of the Hall sensor to the spacing in entrance door cover on the bottom plate. Fix the flange with 4 screws and screw two additional ones on the bottom plate.

2.3.4 Fabry lens unit mounting

Mounting the Fabry lens unit is done after the assembly of the main base of the device. Just align the support to make the screw holes coincide. Pay attention to the power supply wires to enter the respective spacing in the bottom side of the Fabry lens support MC05A.

2.3.5 Electronic modules installation

Set the electronic boards (see AS10 and AS11) and tighten them with help of the PCB pawls MC01F with screws. Some of these small screws are made shorter so keep track of their disposition. While setting the boards PCB03A and PCB04A pay attention to connect them correctly to the boards PCB03C and PCB04C1, respectively. Install the board PCB04B on the board PCB04A. Connect the motor jack and power supply. Then attach the flat cable. Check that the device makes the correct motor initialization after this and before closing the electronics with side panels.

2.3.6 Beam-splitter unit installation

Beam-splitter unit is set to its base MC08E in such a way that the blind MC08D is inserted in the central hole of the PMT modules base MC01D. Slide it completely in this hole and set then the blind MC08A. Slide it back and check that the beam-splitter and the blind MC08A are connected. Otherwise, the viewer base cannot fix them correctly.

2.3.7 Blinds installation

See installation of the blind MC08A above. Set the baffles MC02G on their holders only if the final assembly is under way.

2.3.8 Viewer attachment

Setting the viewer, ensure the top of the beam-splitter unit to enter the respective spacing in the viewer bear MC09A. Fix the viewer bear with four screws to the main beams. Screw two additional screws from the side of the segmentator to the base MC01D.

2.3.9 Covers attachment

While putting on the right cover MC02D (with the openings for connectors) pay attention to the indicator LEDs on the crossing board PCB01A to enter their holes correctly. In case some hole for a fixing screw does not fit, free a bit the respective strut MC01E. After the side panels MC02D and MC02E, slide the top cover MC02B to the place and fix it with 6 screws. Finally, attach and screw the front panel MC02C.

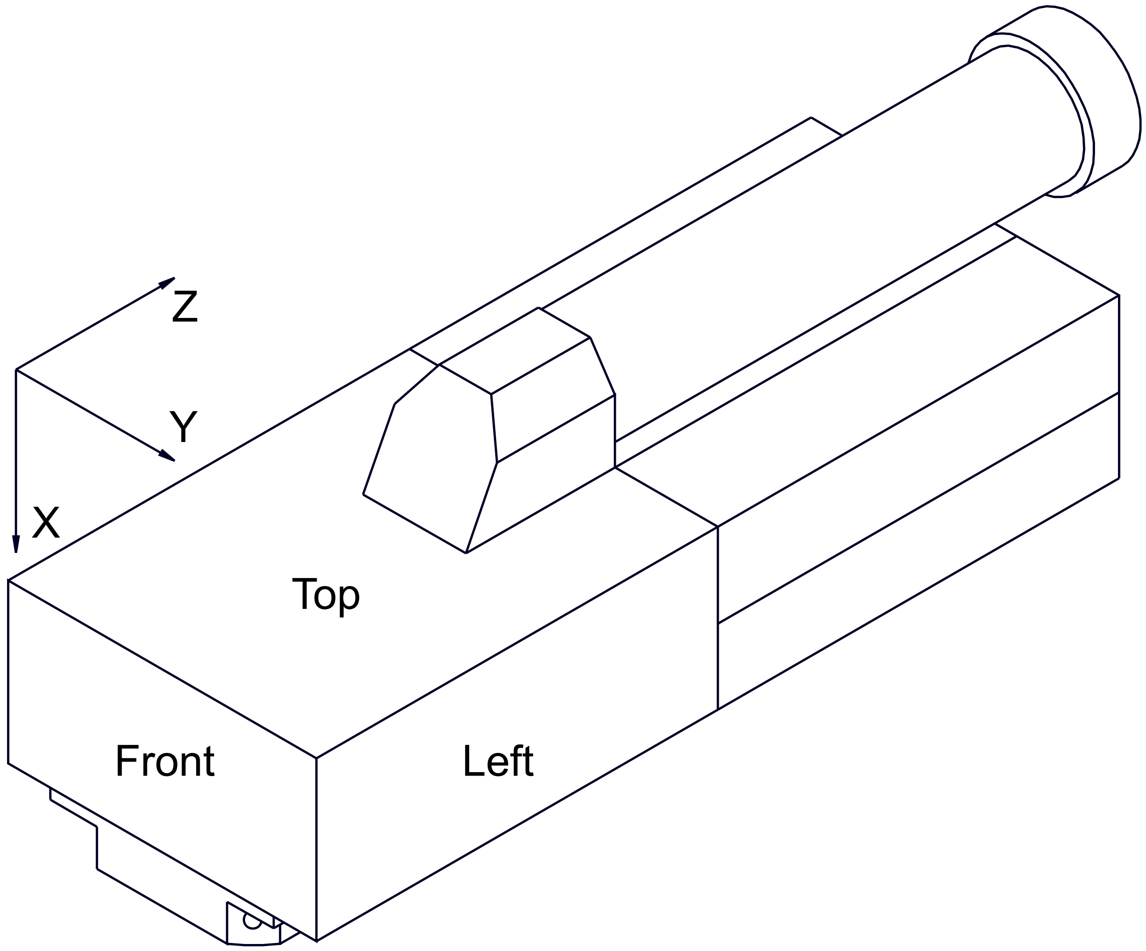

Figure 3.1: Coordinate systems used in the Document.

Chapter 3

Device alignment with test bench

3.1 Device preparation to alignment

3.1.1 Minimal requirement for test bench

The optics test bench may be arbitrary but providing enough rigidity and the source–MASS distance of the order of 1 meter. The attachment of the device to the bench must provide the possibility to adjust the position of the light source (laser beam) with respect to the device in two directions.

The semiconductor laser of no more than 3 mW power is set on the opposite end of the bench and can be fed from the +12 V DC plug of the MASS device. The resistor of 50-100 ohm is recommended to be connected sequentially with the laser. The laser support must also allow the slight corrections by angle putting the laser on the same height above the bench as the center of the MASS attachment flange.

In addition, one needs the weak negative lens to attack to the laser to make the slightly divergent beam. It is needed to illuminate homogeneously the entrance pupil of the model telescope. The latter is attached to the entrance flange of MASS and consists of the good-quality objective lens (focal length about 50–100 mm) and the pupil diaphragm of the size 2–4 mm set in front of the objective at the distance equal to the lens focal distance. Telescope focusing and the pupil diaphragm adjustment should be possible.

3.1.2 Adjusting tools

For the optics adjustment the following tools are needed:

1. Flat mirror or a flat glass plate of about 40–50 mm size
2. Targets from the Appx. 1 printed on the transparency in scale 1:1
3. A thin plate with parallel sides of the width 23.0 mm and length about 2 cm to check the position of apertures
4. The ocular adapter MC11G (Tool #2) for centering/focusing the exit pupil in the segmentator pit
5. An insert MC11A with a ground glass for the re-imaging mirrors adjustment (Tool #1)

6. Blue or neutral filter for fading the laser beam

7. Tweezers, screwdrivers

3.1.3 Device preparation for alignment

Disassemble the device to the state of the Sect. 2.2.5. Remove PMs, cables, the segmentator. Ensure the electronic boards to work with no danger of shortcuts. Set the front cover back if needed.

3.1.4 Installation of Device on Bench

Fix the device on the bench, switch on the laser. Insert the target #1 close to the MASS flange and tune the position of the beam until it

- Points to the center of the target #1
- goes back to the laser when the reflected beam obtained with a glass plate or mirror put on the flange

For this, either tune the angles of the MASS device and laser supports, or both the position and angle of the laser support only.

3.2 Alignment

3.2.1 Positional (angular) apertures adjustment

Switch the device on, open the entrance door and set the Work Aperture. Remove the target #1. The rotation of the aperture wheel affects the height of the aperture above the bottom plate internal surface. To tune the position of the work aperture, put the (clean) thin 23mm-plate on the top of the wheel in such a way that its side touches the bottom plate. In this case, another side is exactly at the height of 23 mm above the bottom plate. The exactly half of the aperture image seen through the segmentator pit must be hidden by the plate.

If the position is not equally divided by plate, use the micro-step tuning of the wheel stops position (green LED blinking mode of the buttons module or Aperture Adjustment mode of TURBINA). Count the steps ("+" when black button is used) in autonomous regime to write the corrections later in configuration file. Save the configuration file after tuning if the Aperture Adjustment mode of TURBINA was used. The precision of this alignment is better than 0.1 mm.

The same operation has to be done with Wide Aperture and Centering Hole apertures. Other apertures are adjusted in another way. When definite new corrections are obtained, they have to be set in the motor microprogram and reprogrammed in the memory of the module. Then the "corrections" in the configuration file `turbina.cfg` become zero and apertures are set exactly the same way in autonomous and program-driven modes of the device.

3.2.2 Folding mirror alignment

Set the Wide Aperture. Put the target #2 in the segmentator pit. Turning the screw # 1 (MC03D), which tilts the entrance mirror, adjust the position of the laser spot on the target in X-direction. Adjustment in perpendicular Y-direction is done with some thin spacers (0.1–0.3 mm) put near one of two screws which fix the mirror clamp MC03B to the focal section base MC03A. This will modify the other direction adjustment in some respect.

Set the Work aperture, ensure that the beam passes through it. Check the position of the beam on target #2 if something is wrong.

3.2.3 Fabry lens lateral alignment

Now we set the Fabry lens unit on place (taking care of hanging Crossing and HV boards, see Sect. 2.2.5 and 2.3.4). Normally, due to the unaligned position of the Fabry lens, the beam will shift from the central position on target #2.

Adjustment is made by two adjusting screws #2 to shift the beam back to the center. This ensures the on-axis position of the Fabry lens. The locking nut MC06C to fix the Fabry lens lateral adjustment.

3.2.4 Beam-splitter unit alignment

Assembled (glued) following the drawing OP09 beam-splitter with a filter is inserted with help of two rubber spacers (1mm thick, with 8mm holes for light) in the beam-splitter housing MC08B. Target #5 is fixed at the top side of the housing where the hole for the in-viewer-reflected light is located. One spacer is put first in the housing, then the splitter is put with filters atop of it and in such a way that the target #5 image is seen through it. Atop the splitter, the second rubber spacer is put and fixed with the cover plate MC08C.

The splitter is self-aligned along the optical axis by the spacers. Two other degrees of freedom are left: X-axis translation (in direction of the viewer-hole of the MC08B) and rotation around the main optical axis. The image of the target #5 helps to align the rotation. The correct position of the splitter may be checked with help of a laser beam which should cross the target #5 near the center. If not, untighten the cover plate MC08C and correct the splitter position or angle.

This operation may take up to 3–4 iterations. Remove target #5 after completion.

3.2.5 Viewer mirror alignment

Set the beam-splitter unit, the blind MC08A and the viewer head MC09B (see Sect. 2.3.6 and 2.3.8). Insert the target #6 in the head at the place of the removed viewer tube. The laser spot should cross the target near the center. If displaced, check the mirror fixation to the viewer mirror plate MC09C.

Remove the target #6 and insert the viewer tube with an eyepiece adapter MC10F. Ensure the tube to be parallel to the segmentator pit. Insert the target #7 in adapter. Displacement of the laser spot from the #7 center is corrected in narrow limits with the screws attaching the viewer mirror plate to the viewer head. If not enough, put thin spacers under the mirror. Remove the target #7 when finished.

3.2.6 Viewer focusing

Switch the laser off, set the eyepiece in viewer and illuminate the Work Aperture set with a diffused light. Sharpen its image in the viewer with help of the nut MC10E.

3.2.7 Exit pupil alignment

To proceed with further alignment, we need the exit pupil image to be formed in the segmentator place similarly to that formed when working with feeding optics. Insert the telescope model in the entrance flange (see above).

Attach the negative lens on the laser end to obtain the wide light spot at the telescope pupil diaphragm. Adjust the "telescope" in such a way that the point-like image of a laser "star" falls in the center of the Work Aperture. Note that this central position is critical for the Conjugating lenses radial alignment since the lens adjustment will co-align the lens center with the image of "star", *not* with the Work Aperture center.

Fade the laser light with a filter to avoid damage of eyes!

Then tune the position of the "entrance pupil" diaphragm in front of the "telescope" lens to get its centered image in the segmentator plane. Precise adjustment is possible with an eyepiece screwed-in the segmentator pit with the installed Tool #2 (MC11G) with a target #3 set.

3.2.8 Conjugating lenses radial alignment

The lenses in aperture wheel are fixed in slightly eccentric holders to allow their minor radial displacement. Set the ConjugLens1. Then the diffraction-distorted image of the entrance pupil should appear in the eyepiece.

By trial step-by-step rotation, determine the "radial" direction in the eyepiece field of view. Then, rotating the lens holder in its place of the wheel MC04A, set the center of the diffraction image to the axis X (along the tangential movement direction of the wheel). Then determine the correction value for the current aperture (ConjugLens1) with help of Aperture Adjust operation to center the image position in tangential direction.

Fix the lens holder position with some liquid glue. Repeat the procedure for another lens (ConjugLens2). Switching the wheel between the WorkAperture, ConjugLens1, and ConjugLens2 ensure that their centers fall always at the same place.

3.2.9 Segmentator alignment

Set the Work Aperture and remove the eyepiece with an insert from the pit. Insert the assembled segmentator on a holder into pocket of the pit MC07A, and orient it in angle correctly (see Fig. 2.1).

It may appear that the filter-faded laser beam will be too weak for a further optics adjustment. If so, remove temporary the beam-splitter.

The spots appear on the surfaces of re-imaging mirrors or near them created by segments of the segmentator. A piece of paper may help to locate them. Turn the segmentator until all the spots match the mirrors without vignetting. It is possible also to deviate the beams slightly with help of fixing screws on the back of the segmentator. Fix the segmentator temporary.

3.2.10 Re-imaging mirrors alignment

For adjusting the tilts of re-imaging mirrors the insert MC11A (Tool #1) is used. It is set on the place of the PMT module. Target #4 may be put atop the ground glass. The image of the segment corresponding to the given channel A, B, C or D should be seen on the glass. Access the three adjusting screws of the mirror support with a screwdriver and tune the tilt of the mirror to get the centered position of the segment image in target #4. **Take an immense care of not damaging the mirror surface with a screwdriver!**. The screws may be accessed from the top-cover side or through the adjacent holes of PMT modules. Remove the baffle struts MC02F for easier adjustment of two bottom-side mirrors.

After centering all four mirrors, slightly rotate the segmentator forward-backward and check the images on inserts. They should not change or be vignetted.

The last stage of alignment is pinning of the segmentator unit. For doing this, mark the hole position through one of the holes in the segmentator holder MC07B in the base. Then remove the segmentator, close the pit hole and make the 1.3mm diameter, 3mm depth hole with a hand-drill. Remove the metal powder thoroughly. Insert the segmentator and fix it position with a pin. Its length should be about 2 mm more than the thickness of the segmentator holder. Screw-in the PSU stopper MC07C which must fix the holder itself, not the pin. Check that the light beams on re-imaging mirrors are not displaced from their right positions.

3.2.11 Exit pupil check

After installation of the beam-splitter unit one needs to check the exit pupil position. If displaced, it should be compensated with a proper correction of the lateral position of the Fabry lens. Ensure again that the pupil image centers coincide with the target #3 center for WorkAperture, ConjugLens1, and ConjugLens2 set.

3.2.12 Fabry lens preliminary focusing

The Fabry lens must project the image of an object to the segmentator surface. This object is located at an (effective) distance of the system entrance pupil which is of order of one to few meters from the MASS entrance. If the diameter of the entrance aperture of the feeding optics is large enough, then it is the segmentator which works as a diaphragm. Then the position of the entrance pupil is determined by the whole optical system from the telescope objective to the segmentator, i.e. by the telescope parameters and the Fabry lens position and focal distance. From the calculations presented in Chapter 4 of [3] for the optimal feeding optics it follows that the *intermediate* entrance pupil (for the system with one Fabry lens and no telescope) is located at the distance of 1200 mm from the entrance flange of the MASS device. Note that the beam-splitter+filter is included in the optical system and should be set before focusing.

For the preliminary focusing of the Fabry lens, place the well-illuminated paper-printed target at the distance of 1200 mm from MASS. Screw-in tightly the eye-piece in the segmentator pit with a tool #2 inserted. The image of a cross (which is a target #3 located in the focal plane) should be sharp (for a normal eye). Then free well the locking nut MC06C and rotate the Fabry lens until the target image becomes sharp. Tighten the locking nut MC06C to fix the Fabry lens lateral adjustment and focus position.

The final focusing is done after the MASS is attached to the telescope, together with the determination of the system magnification. See Sect. 5.1.

Chapter 4

Installation of the device and start of the operation

4.1 Installation

4.1.1 Attachment to telescope

MASS instrument is attached to the feeding objective (telescope) using a special adapter (see [3], Fig. 4.3). Such an adapter (flange) is shaped at the attachment place of the off-axis feeding objective produced by Lytkarino factory. The adapter for other objectives should be made according to the specifications given in Fig. 4.3 and drawings of the attachment flange of the MASS device. On the attachment surface of the flange, it is desirable to make the "lowering" for the fixing screws to tighten the connection.

The device is set to the adapter tightly and fixed with four screws M4 with the rounded ends. Since a mismatch of the physical and optical axes of the off-axis objective is removed by the alignment of the MASS entrance mirror 1 (see scheme in [3], Fig. 2.9), it is needed to tune the position angle of the device relative to the objective for a correct projection of the output pupil to the MASS segmentator. For the off-axis telescope, the Viewer of the MASS device should lye in the symmetry plane of this telescope and point from its dovetail plate.

For the normal ("on-axis") telescope with no central obscuration (e.g. lens objective), the position angle of the device may be arbitrary and well suited for an ease of manipulations and guiding. If central obscuration is present, the tuning of the entrance mirror 1 of MASS must drive the part of the entrance aperture of the telescope in between the spider shades to the segmentator.

In any case after tuning, the position angle of the device with respect to the direction to North should be written in the configuration file for correct reporting of the star shifts by the program. Another parameter for this is the "mirror" factor which is "No" for the off-axis reflector.

It is recommended to attach the fully adjusted and ready-to-work MASS device to avoid problems. For more tight attachment, the device may be fixed also by the screws fixed at the segmentator pit side.

4.1.2 Cables attachment

Sequence of plugging the cables does not matter. Since the device does not have a power-on switch, it is switched on immediately with plugging the 12V DC socket in one of two plugs on the side. Power-on is indicated by the green LED near the sockets.

The PC connection cable is inserted in any of six telephone sockets on the same side of the device together with four jacks of photometric module cables. The DB9 connector on another end of the PC connection cable is inserted in the port 1 socket of the CP132 board (it is the second socket if counted from the PC motherboard side). There is no need to disconnect the cables in a day-time. For safety reasons it is better to attach the MASS-end of the PC connection cable to the telescope to avoid a casual destroy of the jack in the device plug.

4.2 Checks

4.2.1 Independent device checks

After the device power-on, the apertures motor tries to close the entrance door (if its Hall-effect sensor reports another state), then starts the search for the zero-point of the wheel and finally sets in its "initial" position.

The first check is that of the correct performance of the device electronics in autonomous regime. The initial state is: entrance door is closed, the aperture illumination is on. Plug the manual buttons if not yet attached.

Check the mode switching by these buttons. Pressing the *red* button switches the four modes in a cycle:

1 Apertures cyclic switching – green LED

2 Aperture illumination intensity tuning – red LED

3 Entrance door open/close – green and red LEDs

4 (Micro)step-by-step rotation of the apertures wheel – blinking green

The *black* button has a sense of "+", the *blue* one – of "−".

Set the mode 3 and open the entrance door (press the black button). Set the mode 1 and check the apertures changing checking them through the viewer. Increase the aperture illumination (black button in mode 2) if needed.

4.2.2 Viewer check

Set the Work Aperture. Its image should be clear and sharp if the viewer is well focused, otherwise correct the focus. If the viewer is aligned correctly, the aperture image is in the center of the eyepiece field of view. Set the Wide Aperture (two presses to the *blue* button in Mode 1) and point the telescope to the bright star using a finder. Correct the focus of the telescope if needed.

Setting the TV camera makes the viewer adjustment and focusing easier. The work aperture image has to be in the center of the monitor. The pointing and centering to the star is apparently easier with TV than with an eyepiece.

See the Sect. 3.1 in case of problems with viewer.

4.2.3 Exit pupil check

Since this check is relatively time-consuming and demands the (potentially dangerous) removal of the segmentator, it is recommended to make it only if the device was optically re-aligned or was displaced with respect to the telescope.

Checking of the position of the exit pupil is described in Sect. 4.3.

4.2.4 Normal operation checks and tests

After automatic checks made by the device on power-on, the TURBINA program has to be started (see User manual [1]). After the program start-up has run with no problems detected, select the menu item Tests and start all three tests (alternatively, they may be started as part of the Initial Scenario of the device specified in a section `Operations/Initialization` of `turbina.cfg`):

Exchange test. This test must be passed successfully. In principle, the normal MASS operation is possible with the exchange fault percentage up to 0.2% (the loss of one packet out of 500). In case of exchange faults detected, restart this test again.

Detector test. Checks for the correct performance of the photometric modules comparing the measured fluxes with those written in the configuration file. So, the invalid fluxes message may be encountered after changing the device alignment or the test settings in the configuration (these fluxes and non-Poisson parameters must meanwhile be more or less "plausible"). In this case, the tuning of these parameters is needed which must be done only after completion of all the optics alignments and the photomultipliers' working parameters fixation (HV and discrimination levels).

Statistic test. This test (see [1]) does not still have the formal success/not success verdict. One should compare the expected and measured scintillation indices by eye. Keep in mind that an intensive light-leaks in the device may violate them significantly (especially with luminary day-light lamps which give strongly fluctuating illumination).

Note that before two latter tests evaluation, the HV supply should be switched on and the photometric modules shutters must be open with a screwdriver if closed.

4.3 At telescope alignment

4.3.1 Finder alignment

First, the telescope finder should be co-aligned with the telescope field of view. Delivered with the Lytkarino off-axis objective, there is an adapter for the standard eyepiece of 11/4 inch diameter. Afterward, the MASS device should be attached to the telescope (see above). After pointing to the star and centering the star in Work Aperture, correct the direction of the telescope finder cross.

4.3.2 Folding mirror alignment for off-axis feeding optics

For Lytkarino off-axis telescope, the angle between the mechanical tube axis and the exit beam axis is 2.3 degrees. So, the MASS entrance mirror should be tilted with respect to the position adjusted on the bench.

Remove the segmentator and set the ocular with an insert (tool #2) as described in sections above. It is recommended to make these operations with the PMT modules cables disconnected. Keep segmentator in a safe place, ensure its fixing pin do not drop in the segmentator pit or lost.

Point the telescope to the bright star. The needed tilt of 2.3 degrees demands about 1 clockwise revolution of the mirror tilting screw. Control the position of the exit pupil relative to the cross on the target #3 seen in the eyepiece.

4.3.3 Additional alignment of exit pupil

In case the device position angle is not proper or by some other reasons, the exit pupil image may still be displaced from the target #3 center after fine tuning with the tilting screw of the MASS entrance mirror. In this case, remove the top cover of the device and adjust the lateral position of the Fabry lens (sec. 3.2.3). After the pupil centering, close the device top cover. Set the segmentator back not forgetting to insert the fixing pin correctly; screw and tighten the PSU stopper. Connect the PMT cables.

Chapter 5

Device parameters measurements

5.1 Fabry lens focusing and system magnification measurement

5.1.1 Fabry lens focusing

For focusing the Fabry lens, one needs to detach the upper cover of the device, disconnect the cables from the photometric modules and detach the module from the channel D. As with a preliminary focusing, remove the segmentator and insert an eye-piece with a Tool #2+Target #3 into the pocket of the segmentator pit MC07A. Open the entrance Door and set the Wide Aperture. Put some mask at the front end of the telescope which has sharp edges, illuminate with diffuse light.

Focus the Fabry lens as it was done preliminary (see Sect. 3.2.12), tighten it with the fixing nut MC06C.

If there is not enough freedom in shifting the lens (the least possible distance of Fabry lens to the aperture wheel is about 3 mm), then put the mask at the distance from the telescope where it becomes sharp. Measure the distance to the front end of the telescope. This will be the true entrance pupil position where the system magnification measurement should be done (see below).

5.1.2 Magnification adjustment

Remove the eye-piece and insert tightly the segmentator. Put some strong light source in front of the channel D hole in the plate MC01D to get the segmentator fully illuminated. The size of the source must be no less than 4 mm, which is the D-segment image size on the photocathode created by the re-imaging mirror **3D**. If the source is not large enough, displace it from the position of the D-channel photocathode.

The segment D image is built in the entrance pupil plane of the MASS+telescope system. It has blue-green color due to the presence of the filter in the system. The edges of the segment D image are easily examined with a looking glass. Put a transparent ruler or other precise measurement tool in the plane of the exit pupil located as described in a previous section. Use a magnifying lens to see simultaneously the D-segment image edges and the ruler clearly. This way measure the diameter of the image. The magnification of the system is obtained by division of this size by the physical size of the segment D of the segmentator (see [3], Table 2.6). If the image is well-focused, the precision of image size measurement of the order of 0.2–0.5 mm is easily achievable and is more than enough for our purpose.

While examining the edges of D–segment image, make sure that there is no vignetting in the system (edges are equally sharp, vertical size is equal to the horizontal size) and that the image is a bit smaller and more or less centered with respect to the entrance aperture of the telescope.

If there is some unavoidable vignetting in the system, one can measure the internal diameter of the D-segment image, or repeat the same procedure putting the light source in other channels. This can also help to control the magnification obtained by measuring D–segment. Note, nevertheless, that the less image size which is measured, the less relative precision of the magnification is obtained.

5.2 PMT optimal voltage and discrimination determination

In order to choose the working point (optimal HV level common for all PMTs, and individual discrimination levels), one needs to conduct the counting characteristics registration.

5.2.1 Counting functions measurements

Counting characteristics are recorded using the Detector Counting function of the TURBINA program (see [1]). Since the fluxes from the control light differ much in different channels, at least two levels of the control light are recommended to set in the sequence, to have the curves with the plateau fluxes from 300 to 1000 pulse/ms. With lower signal level, the precision of the non-Poisson parameter is degraded, with bright light, the strong non-linearity is already encountered. An additional control light level equal to zero (0) must be set in a sequence to get the dark current characteristics.

The grid of high voltage levels covers normally the range 800 to 1200 V with a 50 V step. While fine-tuning the settings subsequently, the step and range may be narrowed. The discrimination threshold level is tuned within a range from 0.6 to 1.2 mV with a step 0.2 mV.

The accumulation time of each point should be enough for the reliable estimate of non-poissonity. The estimate of the precision of its determinations is:

$$\epsilon_p^2 = \frac{2}{N}(1 + \frac{1}{F}), \qquad (1)$$

where N is a total number of microexposures, F is a mean count per microexposure. In reality, to achieve the relative precision of p about 0.5% one needs the accumulation time more than 100 s at high fluxes. This implies about 2–4 hours process for the total cycle of measurements.

5.2.2 Optimal characteristics determination

The dark current characteristics is aimed to determine the range of the HV level and discrimination thresholds where the dynode or pulse amplifier noise are negligible etc. An example of such parasitic phenomena revealed by the dark current characteristics is shown in Fig. 5.1.

It follows from the right figure that the power supply for such a PMT should be less than 1000 V if the threshold level is as low as 0.6 mV. For making the light characteristics, one needs to measure the relations of both flux and non-poisson parameter p on the HV level U. An example of such relations is given in Fig. 5.2.

From this figure it follows that the high voltage must be not lower than 1000 V. The counting characteristics become flat enough, fluxes depend weakly on the discrimination threshold and

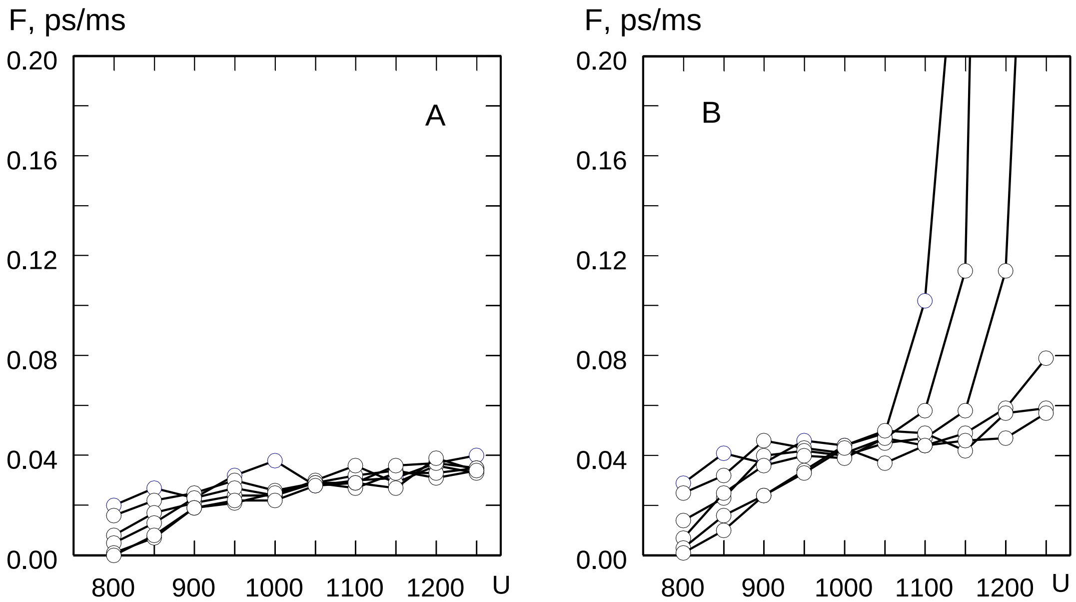

Figure 5.1: Dark counting functions for 2 PMTs. Left: without any adverse effects. Right: with large dynode current at low thresholds.

the non-Poisson parameter approaches the value about unity only above this value. Note, nevertheless, that for the threshold of 1.4 mV the HV has to be no less than 1050 V. On the other hand, the HV of 950 V is quite enough for the threshold of 0.8 mV.

A compromise which satisfies both the dark and light counting characteristics would be to set the threshold to 0.8 mV and the high voltage to 1000 V. If all the PMTs have the dark current behavior similar to that shown in Fig. 5.1 left, then the high voltage may be even higher. Note, nevertheless, that the upper limit for PMT R647 is 1250 V, the value which should not be selected for a long term usage.

An additional constraint is the overlight protection. Since the relation of an average anode current on the high voltage supply is quite steep, the safety limit of the overlight system (counted in pulses per second) at the limiting HV level becomes about 1.5 times lower.

While making such device tuning measurements, as well as while measuring the detectors non-linearity and non-Poissonity parameters, the thresholds are associated with no channels but with counters set in these channels. So, the determined thresholds are to be set in the file `device.cfg` in respective counter sections.

5.3 Non-linearity and Non-poissonity determination

In order to treat correctly the photon statistics and compute the correct scintillation indices at high fluxes (in C and D-channels especially), one has to know the non-linearity parameter τ and the non-poisson parameter p. Both these parameters are derived from the dependence of p on the light flux F which needs to be specially obtained.

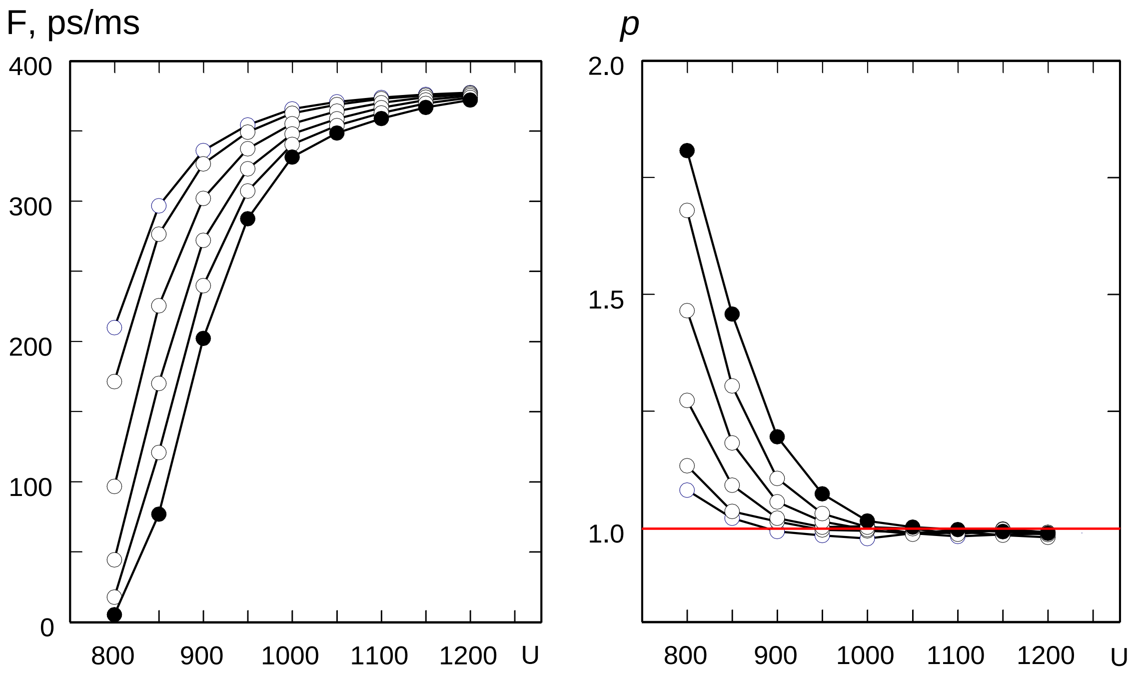

Figure 5.2: Light counting functions. Left: Flux dependence on high voltage for 6 threshold levels (0.5, 0.6, 0.8, 1.0, 1.2 and 1.4 mV). Right: Non-poisson parameter as function of Voltage for 6 threshold levels. Black points designate the curves with 1.4 mV threshold.

5.3.1 Statistical functions measurements

To get the p–F relation (see previous section), one can use the special function "Detector Statistics measurement" in the TURBINA program. The measurements of flux F and non-poisson p values are made with currently set values of the discrimination thresholds of counters and high voltage level. The grid of the control light relative intensities is supplied dense enough to get the needed precision of the output parameters. Some fifty values from 0.0 to 1.0 with a step 0.02 are recommended from practice. The duration of one point measurement is determined by the formula (1) and may be of the order of 30 sec or more.

It may be recommended to measure the detector statistics twice: with the usual counters placement and with A, B and C, D-counters exchanged. The reason is that in channels A and B the non-linearity is not that well determined due to the low count rate. It is not relevant unless the freedom of placement of counters by channels is desired. Note that the higher light flux the better precision of non-linearity parameter is demanded for correct scintillation calculations.

5.3.2 Non-linearity and Non-poissonity computing

The typical relation of the non-poissonity p on the average flux in channels C and D is shown in Fig. 5.3. It is clear that this relation is practically linear. It should be noticed meanwhile that the better fit is obtained with a quadratic approximation of the relation. This is essential for the channel D where the flux may be higher than 4000 pulses per millisecond.

Use the least-square method to get the linear or quadratic regression coefficients (the handy graph-plotting program `xmgrace` provides such a possibility as many others). The crossing point of a line fit with the p-axis (constant term in regression) determines the parameter p. The line slope in the point of zero flux is equal to $-3p\tau$ where the non-linearity τ is expressed in milliseconds if the flux F is counted in pulses per milliseconds.

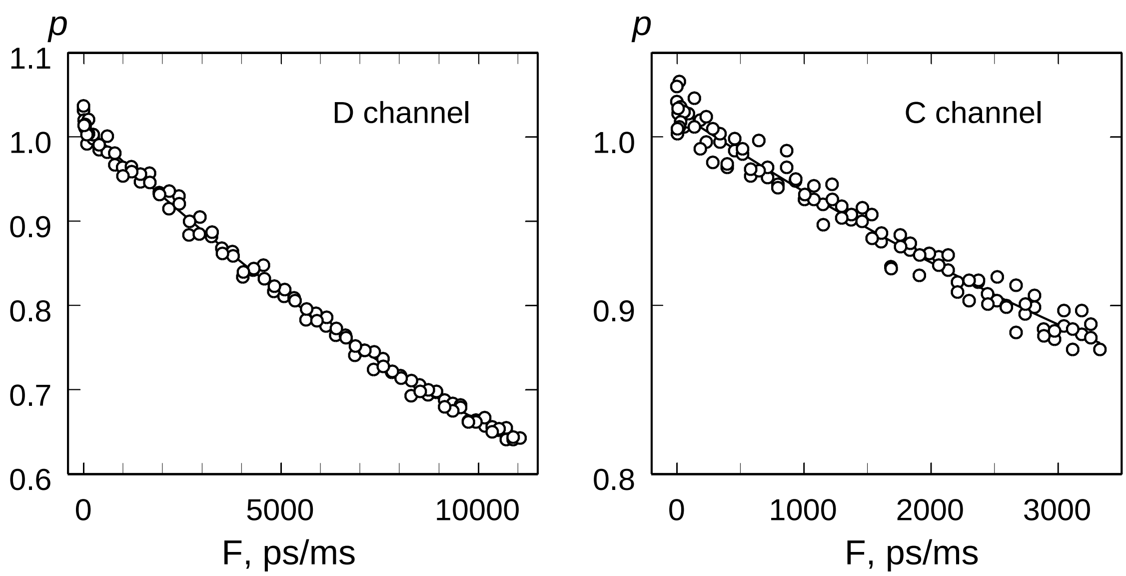

Figure 5.3: Dependence non-Poisson parameter p on flux F for D and C channels. Line is quadratic fitting of the measured points.

Chapter 6

Electronics reprogramming

6.1 General information

All the MASS electronics modules are controlled with the micro-controller AVR90S2313 produced by ATMEL company. See the documentation at the Internet site http://www.atmel.com. Micro-controller contains 2K Bytes of In-System Programmable Flash memory (endurance 1,000 Write/Erase cycles), 128 Bytes of SRAM, 128 Bytes of In-System Programmable EEPROM (endurance: 100,000 Write/Erase cycles).

In principle, the procedure of the controller re-programming is described in Manuals of the company. Here below we describe some particular means with which the MASS device electronics was programmed.

6.1.1 Tools for in-system programming

It is recommended to use the following software for reprogramming which works in Windows OS:

- AVR macro assembler — a separate (avrasm.exe, version 1.21) or an included in AVR Studio version 3.22 or later
- ATMEL AVR ISP version 2.65 or later (for ISP programmer from STK200 or STK300).
- AVR Studio version 3.22 or later for STK500.

Also needed are:

- the ISP programmer included in ATMEL STK300 or STK500
- an adapter for connection of the standard connector to the ISP connector used in MASS modules (see Fig. 6.1).

All the needed programs are located in the `AVR` directory as source codes. Below follows the list of files needed for reprogramming:

`2313def.inc` – general definitions for AVR 90S2313 device

`counter.inc` – definitions for Photometric module

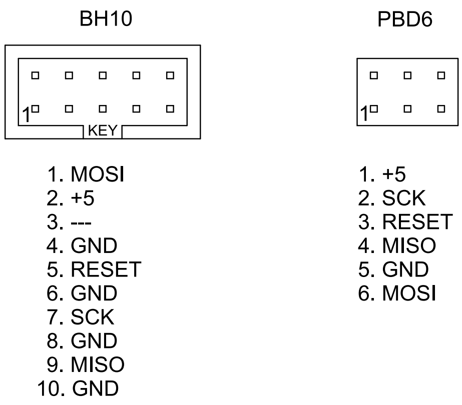

Figure 6.1: Diagram for an adapter between the standard 10-pin ISP connector and the used 6-pin connector.

`counter.asm` – assembler code for Photometric module

`counter.bat` – batch-file for compilation

`light.inc` – definitions for Light and Button controller

`light.asm` – assembler code for Light and Button controller

`light.bat` – batch-file for compilation

`motor.inc` – definitions for Stepper motor controller

`motor.asm` – assembler code for Stepper motor controller

`motor.bat` – batch-file for compilation

`power.inc` – definitions for HV module

`power.asm` – assembler code for HV module

`power.bat` – batch-file for compilation

Reprogramming is needed in case of any change of the program code. For compilation, start the respective batch-file `*.bat` or use the AVR Studio program means to obtain the files `*.rom` and `*.eep` which are used by a programmator. The *batch-files* are prepared for ATMEL AVR ISP and were used for programming.

The hexadecimal input data files are needed for the programmator in STK500. They may be produced changing the batch-file key `-g` to `-i` or specifying the needed format while compiling in AVR Studio. Before doing so, create the new MASS project add all `*.asm` files to it. To compile the needed program module, use Project setting to select it, afterward select the Assemble menu item.

Then one needs to :

- connect programmer to PC via the provided cable
- connect the re-programmable module to the programmator via an adapter

- start the program AVR ISP or AVR Studio
- load the needed files and ...
- start re-programming.

See the details of connection and file preparations in the sections below. For STK500, remove the jumper VTARGET (see AVR STK500 User Guide) before turning on. Before reprogramming, set the new date of reprogramming in the file `*.inc`. Then the first TURBINA start after reprogramming will give a message "Wrong Identification of ¡numbers¿" for reprogrammed moduli. These numbers must be copied in the configuration file `device.cfg` in respective section.

6.2 Modules re-programming

6.2.1 Re-programming of the detector modules

There are two features in re-programming the detector modules. First, the correct *address* of the re-programmed module must be set in `counter.inc`. Second is that the module itself should be disassembled to have access to the ISP connector. Disassembly of the detector module is described in Sect. 2.1.2.

After removal of the top board of the electronics PCB01B, connect it to the line and to the programmator connector. Switch the MASS 12V power on. Then start re-programming.

6.2.2 Re-programming of other modules

Other modules have fixed addresses and they do not need any change. For safety reason, disconnect all the modules from the flat cable except for the Crossing board and re-programmed module. No need is to remove the modules themselves.

For re-programming of the apertures module (stepper motor), disconnect the flat cable, detach the top board PCB04B, connect the flat cable back and the programmer adapter. The new wheel stop positions must be written in the file `motor.inc`. To calculate the new positions, add the corresponding corrections (determined during adjusting procedure) to the old positions in the file. For determination of the position of the closed (CL_POS) Door, close the Door. Then, using the function Tools/Talk (see [1]) and the low-level commands of the motor module SHIFT_AT and GET_POSITION, determine the absolute position of the disk with the finger position to the left and to the right of the shutter lever. CL_POS is computed as average of these positions. Similarly, determine the open Door position OP_POS.

The position `Stop7` is determined as an average of `Stop3` and `Stop4`, and the position `Stop0` corresponds to the position of the wheel finger to the left of the shutter lever with the closed Door (see above).

While re-programming the HV module, it is desirable to disconnect the power supply +12 V.

6.2.3 Final checks

Make the usual MASS operation test after completion of re-programming.