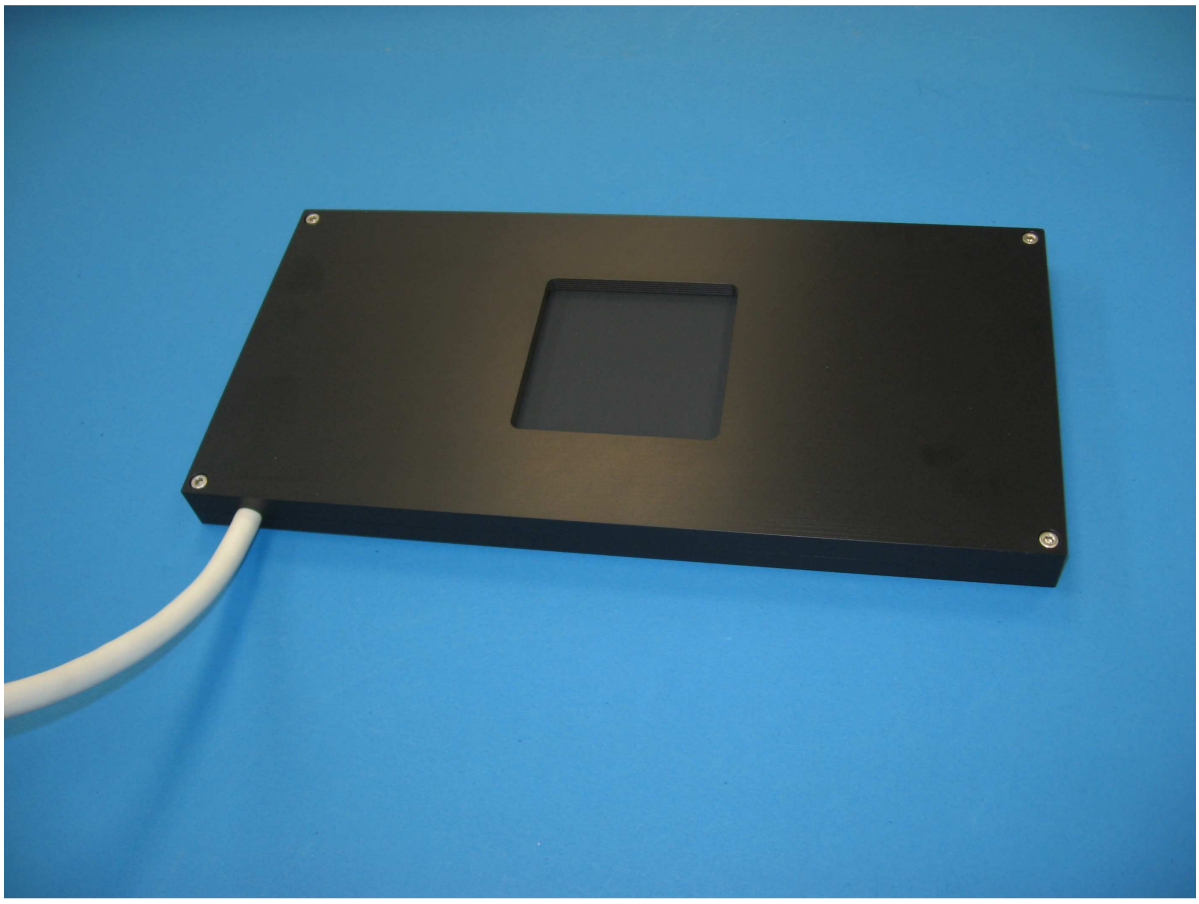
Bonn-Shutter 80mm



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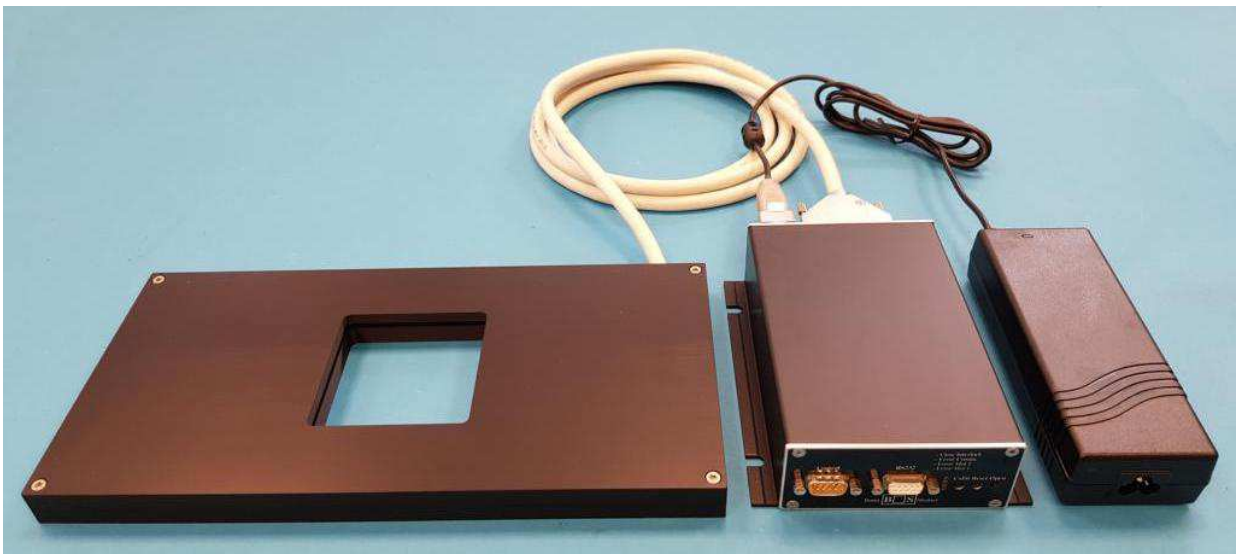

Fig. 1 The complete shutter assembly.

1 Abbreviations and Acronyms

µC	Micro Controller
ShMU	Shutter Mechanical Unit
ShCU	Shutter Control Unit

2 Quick Start

This is intended to test the basic shutter functions. See the following chapters for full details.

2.1 Make it run!

1. Connect the Shutter Mechanical Unit (ShutterMU) and the Shutter Control Unit (ShCU) with the shutter cable. All connector screws have to be tightened. These screws activate microswitches inside the ShCU which have an interlock function: Stepper motor drive stages are only enabled while these switches are activated. The yellow LED at the ShCU interface panel labelled ”Close interlock” is switched on as long as at least one screw is not tightened.

2. Plug in the power cord (no power switch). The position reset procedure starts. At the end of the reset procedure the shutter is closed.
3. Press/release the push button labeled ”Open” to open/close the shutter.

4. To test the shutter reset function press the ”Reset” button.

After reset blade ”A” is in the aperture (it’s the blade at the ”connector side” of the ShMU).

2.2 Make it talk to you!

The use of the RS232 connection is optional. The shutter is fully functional without it. Nevertheless it is useful for engineering and demonstration purposes and to get status information via a instrument control computer. To test it do the following: Connect a terminal to the ”RS232” connector and configure your terminal according to Table 6. Press the reset button. The ShCU sends a version string and the prompt c> appears. Try the following commands (always end with < CR >):

Command	Remark
ia 1	Switch to interactive mode: Answer prompts will be proceeded by a line break.
s?	Shows a list of all standard commands with a one line description.
os	Opens the shutter. *If opened by command the shutter can not be closed by the push button or external signals!* Therefore ...
cs	... closes the shutter.
sh	Shows an explanatory list of the velocity profile parameters for both blade A and blade B plus parameters of the reset procedure.
ex 1000	Perform a 1000msec exposure operation.
ss	Tells you which blade is in the shutter aperture.
ex 100	Perform a 100msec exposure operation.
ss	Tells you that now the other blade is in the shutter aperture.
vm 10000	Reduce the maximum speed to 10,000 steps/sec.
ex 100	Perform again a 100msec exposure operation and see that the slit is now narrower and moves slower.
fd	Reset all parameters to their factory default values. To make it active do a reset...
rs	Wait until the blades have reached their destination. Then try on your own.

Table 1

2.3 Make it fail!

This section is intended to demonstrate an error conditions and how to interpret status information. It would be helpful if the ”error status” signal at the ”Control” connector could be made visible (refer to Table 5 for pin assignments).

- Press the "Open" button. Put some soft tool in the shutter aperture (e.g. your fingers). Release the button. The blade movement will be blocked. An error LED and the "error status" will be on. Further exposure operations are not possible.
  When the time for the expected closing movement was over the firmware detected a mismatch between the commanded stepper motor position and the actual encoder value. Use sp 0, sp 1 to check positions of both blades. This mismatch is larger than the threshold of 24 steps. A threshold error was produced. Have a look at the status of blade A and B (just press < CR >).
  Do a shutter reset.

3 Shutter Specifications

In Table 2 the major shutter characteristics are given.

Table 2: Shutter Characteristics

Shutter type	Slit-type shutter with two independent blades driven by stepper motors.
Aperture size	80mm ×80mm
Minimum exposure time	≤1ms
Exposure time error	≤300µs
Exposure inhomogeneity	<1 msec over the full field of view.
Repetition rate	Minimum time interval between start of consecutive exposures is (exposure time + travel time + 1 msec).
Weight mechanical unit	1.5kg
Weight control unit	2kg

4 Part List

1. 1 Shutter Mechanical Unit
2. 1 Shutter cable
3. 1 Shutter Control Unit
4. 1 Power supply with cable
5. 1 Test connector for the control port
6. 1 Shutter Manual

5 Overview

The shutter is a slit type shutter with a square aperture of 80mm × 80mm. It consists of three main components, which play together to achieve the shutter performance: Timing accuracy of better than 1msec at any position across the aperture.

- The ShMU. The mechanics is based on two carbon fiber blades moving on a pair of linear ball bearings and driven by two stepper motors and toothed belts. The mechanical design is such that the shutter does not have a preferred direction of movement. Consequently for consecutive exposures the shutter blades move first from left to right and then from right to left.
- The ShCU — the microcontroller based control electronics. Four µCs are involved.
- The shutter control firmware — the software running on the microcontrollers. The
- firmware limits the shortest exposure pulse to about 300µsec.

A camera shutter has to guarantee precise exposure times. Moreover the exposure times have to be the same at each point in the focal plane, i.e. exposures have to be uniform.

The shutter like the other Bonn Shutters is an impact free, low acceleration (i.e. low power) device. Instead of driving the shutter blades at high speed/acceleration the <1msec timing accuracy is achieved by a simple yet very precise motion control of both blades: The generation of every single stepper motor micro-step (4413 for the 80mm aperture) follows exactly a time table which is derived from a given velocity profile. Both blades are driven with identical time tables (i.e. velocity profile), a prerequisite for uniform exposures. The velocity profile has a trapezoidal shape (see Fig. 5) and its parameters are programmable. The parameters of the “factory default” profile are stored with the code. These standard parameters are expected to be valid over the shutter lifetime. Nevertheless reprogramming may be necessary for technical or demonstration purposes (see Table 11). Factory defaults are recovered with a single command (fd).

6 Performance

The main performance issues are the exposure time accuracy and the uniformity of the exposure over the full shutter aperture. These parameters are listed in Table 3.

Table 3: Exposure time performance parameters

Exposure time error	≤300µs
Exposure inhomogeneity	<1ms over the full field of view.

6.1 Exposure time accuracy

As far as the ShCU is concerned the exposure time accuracy is primarily limited by the µC software. The open/close blade movements are started with a maximum delay of about 20±6µs after the CCD controller has set the appropriate signals.

The ShMU affects the exposure time accuracy as the two blade edges have a finite separation if in rest position. The width of this slit causes an additive amount of exposure time which in principle can lead to a shutter nonlinearity for very short exposures. Linearity measurements between 1ms and 100ms reveal that such an additive amount of the order of 0.3msec does exist. This corresponds to the chosen size of the slit of 0.1mm to 0.2mm.

6.2 Exposure Uniformity

Non uniform exposures occur, if the movements of both shutter blades are not exactly identical. Limitations are due to the stepper motor resolution and the tolerances of the mechanics. The effect becomes more and more important for shorter exposures. The exposure uniformity is of the order of 1ms across the full shutter aperture. This can be checked at any time by a very simple ”acoustic” homogeneity test. If irregularities of the blade motions of this order exist one would expect that collisions of the two blades occur at very short exposure times which are of the order of 1msec, i.e. when the two blades form a very narrow slit. These collisions should be visible and audible. But down to exposure times of 1msec collisions are not detected.

7 Shutter Mechanical Unit

The ShMU is a custom design. A drawing with all outer dimensions indicated is given in Figure 2 .

7.1 Description

Everything is mounted on a single aluminum base plate with the 80mm × 80mm aperture in the center. The two carbon fiber blades are guided by linear ball bearings. Micro switches are used for position reference, one for each blade. To calibrate the blade origin the blade is moved backward (away from the aperture) toward its reference switch until the switch opens (end switch condition). The point where the switch is closed during the following forward movement (towards the aperture) defines the zero position. A position reset procedure is initiated automatically after power on.

Stepper motors in micro stepping mode drive the blades by means of toothed belts (1600 micro-steps per revolution). The whole blade movement takes 4413 micro steps. Incremental encoders (1600 increments per revolution) are mounted on the motors shafts. Comparison of the number of commanded motor steps with the counted encoder increments provides the primary check of proper shutter operation. This check is done after each blade movement. If the position mismatch exceeds a given (programmable) threshold (see command ”th”) the error LED of the respective drive module in the front panel of the ShCU is switched on and the error status signal is activated.

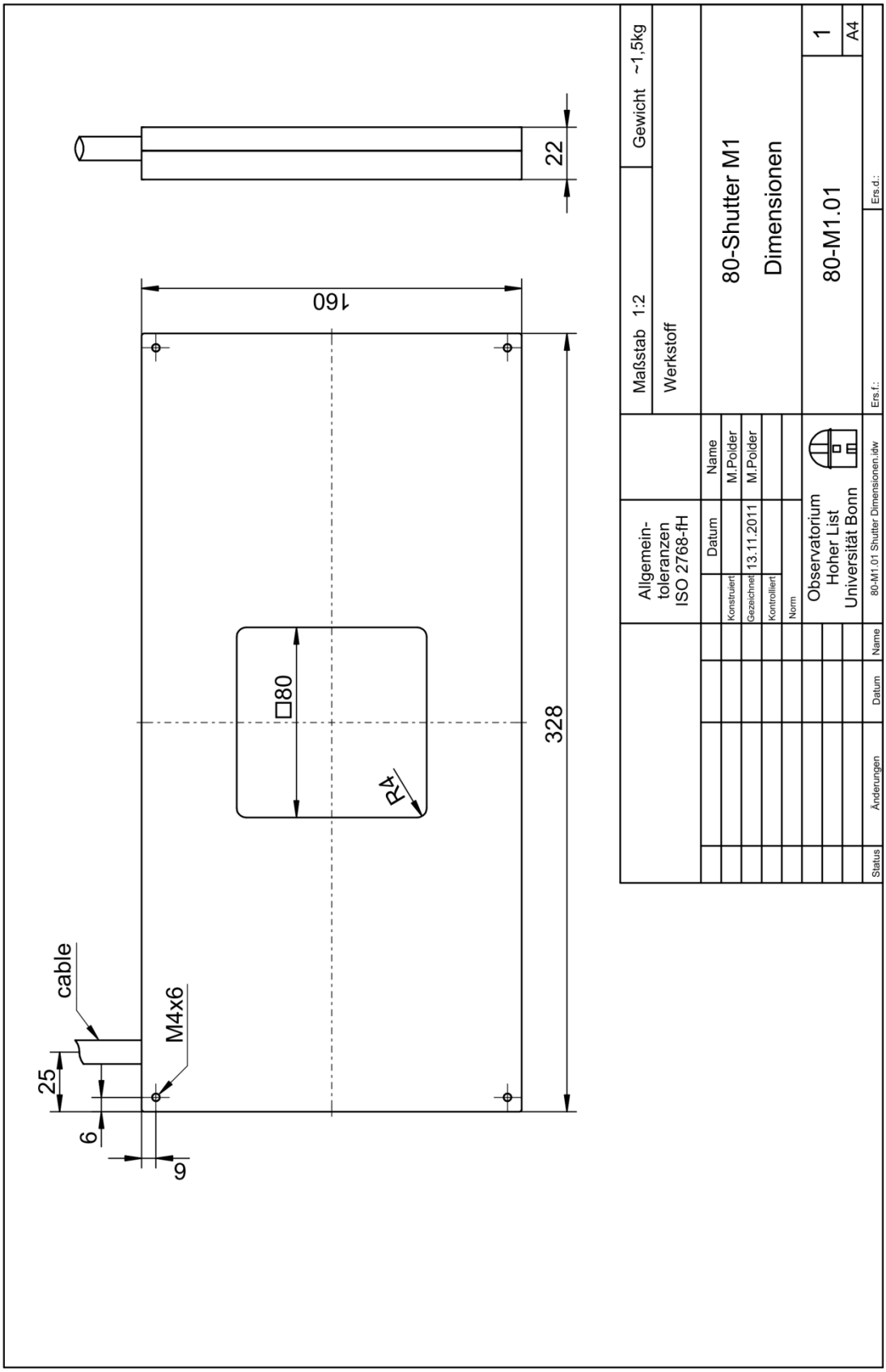

Fig. 2: shutter dimensions

Fig. 3: Front view of the Shutter Control Unit

8 Shutter Control Unit

The ShCU provides high precision control of the shutter blade movement. Software command and hardware signal interfaces exist to connect the system to the camera and/or instrument control H/W and S/W.

8.1 Description

The ShCU is based on four identical µCs with additional motor drive and encoder electronics - all on a single PCB with standard 160 mm × 100 mm Eurocard format.

The exposure start signal (falling edge) is continuously polled by software. The polling loop takes about 20µsec.

Table 4: Lay-out of the ShCU front panel (from top left to bottom right)

Label	Remark
Control	DSub9 connector (male) for control and status signals (see Table 5).
RS232	DSub9 connector (female) for RS232 connection (see Tables 6 and 7).
Close Interlock	If on indicates that the shutter cable connector screws are not in tightly.
Error Commun.	Indicates an error condition of the communication µC. For status information use the RS232 line.
Error Mot2	Indicates an error condition of the shutter blade B µC.
Error Mot1	Indicates an error condition of the shutter blade A µC.
Calib	Self adjustment button.
Reset	Reset button, for a hardware reset of the microcontrollers of the drive and communication modules.
Open	Shutter open button. The shutter stays open as long as this button is depressed.

Table 5: Hardware control lines (see Fig. 4)

Name	Pin	I/O	Definition	remark
Blade A closed	1	O	active low	Opto isolated (opto coupler collector, ILD213). Goes active when blade A is in the aperture and has reached its end position. Use pull-up resistor on the camera controller side.
Blade B closed	2	O	active low	Opto isolated (opto coupler collector, ILD213). Goes active when blade B is in the aperture and has reached its end position. Use pull-up resistor on the camera controller side.
Error	4	O	active low	Opto isolated (opto coupler collector, ILD213). Indicates a fatal shutter error. Use status bytes to get more information. After a reset (Reset button or ”rs” command) the shutter can be operated. Use pull- up resistor on the camera controller side.
Isolated 5V	6	O		May be used instead of an external voltage supply to drive the opto-couplers.
opto-coupler supply	7	I		Supply voltage for the opto coupler (5 - 12V) .
Shutter open/close	8	I	active low	Shutter stays open as long as the signal is kept low. This line connects to an opto coupler (LED with 2.7kΩ) which needs external 5V supply voltage (see below).
Ground	5, 9			Always connect (opto coupler emitter).

Table 6: RS232 setup

Baud rate	19200
Bits per byte	8
Stop bits	1
Parity	no
Protocol	none

Table 7: RS232 pin assignment

Pin number	assigned to
2	TX
3	RX
5	GND

8.2 Exposure control

The shutter can be operated in various ways

- **Manually:** Press/release the open button to open/close the shutter.
- **TTL compatible signal:** Falling edge opens, rising edge closes the shutter. There are two alternative inputs for this signal.

  – The main input is through the connector labelled “Control”. See Table 5 for details.
- **By command:** Use the “ex” command over the RS232 serial line to initiate a shutter operation (exposure time in msec). This is thought to be used for testing and demonstration only.

***IMPORTANT**: While after the end of an exposure the closing blade is still moving the open/close control line has to be quiet. The next shutter operation is of course only possible after the shutter is fully closed. Control signals appearing during this movement may disturb the ShCU. They are blocked by the signal filtering µC.*

8.3 Interfaces

The Interface to the camera/instrument control system is based on hardware control lines (see Table 5 and Fig. 4) and software command communication.

8.3.1 Hardware control lines

Four lines exist (i) for shutter open/close operation, (ii) to indicate the ”shutter closed” status for blade A and blade B respectively and (iii) any error condition. These lines are accessible through the SubD9 connector labeled ”Control”(see Table 5).

8.3.2 Serial command line

Through the RS232 line (SubD9 connector labeled ”RS2323”) a host can take control to get status information, to recover from error conditions and to redefine velocity profile parameters. The setup is specified in Table 6. Pin assignments are listed in Table 7.

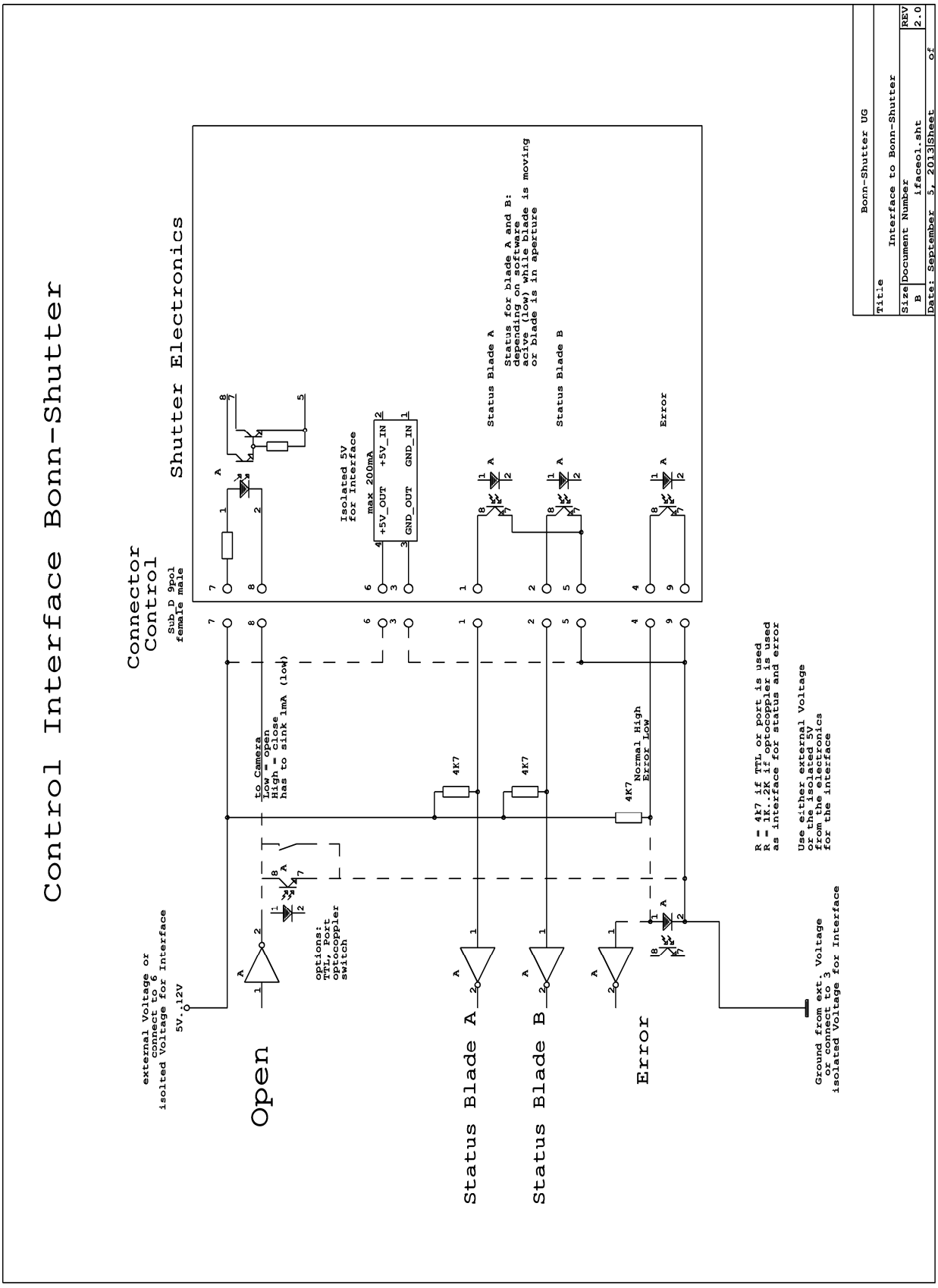

Fig. 4: Shutter control interface

9 ShCU firmware and control commands

The active set of programmable parameters is kept in µC internal EEPROM. The shutter is delivered with the factory defaults being the active set. Once parameters have been modified the factory defaults can safely be restored as the active parameter set with command ”fd”.

See Tables 8 and 9 for firmware version information and a list of factory default parameters respectively.

Table 8: Firmware Versions

µ-controller	Version
M1 (blade A)	no_ram_hen42_80-M1_r516
M2 (blade B)	no_ram_hen42_80-M1_r516
C	comodII hen4.2 Apr 24 2014@12:53:20
P	pshape 20071219 1105

Table 9: ShCU Parameter Defaults

Parameter	factory default value
blade A start position (steps)	4458
blade B start position (steps)	45
blade travel distance (steps)	4413
acceleration parameter	2
Max. velocity (steps/sec)	20000
mismatch threshold (steps)	24
reset timeout (msec)	5000
reset speed (steps/sec)	2000
resulting in a travel time of	0.27 sec

9.1 Initialization

At program start (power on or shutter reset) basic initializations (serial interface, timers, interrupt routines etc.) are performed. After the initialization of the communication module the prompt ”c>” indicates that the ShCU is ready for command input.

The drive modules are ready as soon as the position reset procedure and the calculation of the velocity profile is finished. This is indicated by the ”shutter close” status signal going active and by setting the S

blade A offline and S blade B offline status bits of the status byte #1 (check with the ”sv” or ”sb” command). Then the drive µCs start polling the ”shutter open/close” signal.

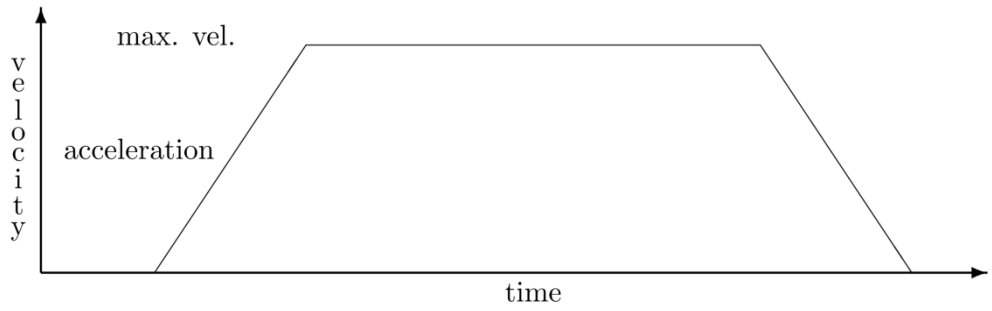

Fig. 5: Schematic velocity profile

9.2 Velocity profile

The shutter blade movements during open or close follow a velocity profile (see Fig. 5) which is identical for both blades and both movement directions. It is characterized by 3 parameters: Acceleration, maximum velocity and blade travel distance. The blade movement and movement control is then fully specified by 3 additional parameters: Start positions for blade A and B and the position threshold value. It is expected that the shutter will run with the factory default parameters over its lifetime.

If there seems to be a need for readjustment(-calibration) see the command ”nc” which runs a self adjustment procedure to find optimum values for the blade travel distance and start positions. The ”Calibrate” button on the interface module does exactly the same. This will not affect the factory defaults but only the active parameter set.

9.3 ShCU commands

For diagnostic, monitoring or parameter modification purposes a number of commands allow to communicate with the ShCU via the RS232 connection (see Tables 11 and 12).

9.3.1 Command usage

All commands consist of two lower case command characters and numerical parameters separated by blank spaces. Carriage return (0X0D) is recognized as end of command line. Each command sends its answer value (if defined) plus the prompt ”c>”.

The first two commands (s?, sh) shall only be used with terminal communication. All others are for terminal and host communication.

If an unknown command was detected the prompt changes to ”c?”.

9.3.2 Parameter value units and ranges

Units of positioning and movement control commands are based on stepper motor/encoder steps (50 steps/mm, identical for motor and encoder). Velocity: steps/sec. Acceleration: steps/sec/sec. Allowed parameter value ranges are listed in Table 10 or are indicated with the respective command.

Table 10 0: Parameter value ranges

Blade parameter bl	0, 1	0 for blade A, 1 for blade B (by default blade A is in the shutter aperture after reset).
Velocities	500<v<40000	(steps/sec) The max velocity can only be reached with an acceleration ramp like.
Positions	0≤x<4503	The maximum allowable position for a blade depends actually on the position of the other blade. To avoid collisions the sum of both position values must not exceed the indicated value of 4503.
Travel distance	0≤x<4503	Restrictions as above.

9.3.3 Command timing

All commands respond within less than one second. When parameters are modified (e.g. commands ”ac”, ”th”) wait at least 0.5sec between successive parameter modification commands. This time is needed to write safely to the EEPROM.

Table 11: Standard Commands

Command	**Param. range**	**Description**
<CR>		Full status information is listed. Equivalent to typing sv 0, sv 1, sv 2 in sequence.
s?		Show a list of available commands with a one line description.
sh		Show an explanatory list of the 7 current velocity profile parameters: Start positions for blade A and B, blade travel distance, start velocity, acceleration, max. velocity, threshold.
ma x pos bl	see Tab. 10	Absolute movement, move blade bl with velocity x to absolute position pos, ma 1000 0 1 (move blade B to origin).
mr x stp bl	see Tab. 10	Relative movement, move blade bl with velocity x by stp steps.
mq bl		Stop motor for blade bl.
sp bl		Get motor and encoder position for blade bl. Two numbers are written: The motor steps and the encoder value.
bs x bl	see Tab. 10	Velocity profile parameter. Set blade start position for blade bl to x steps. The blades are moved to their start positions during reset.

bd x	see Tab. 10	Velocity profile parameter. Set blade travel distance to x steps.
ac x	1≤x<10	Velocity profile parameter. Set acceleration parameter (1: lowest acceleration, 10: highest acceleration).
vm x	see Tab. 10	Velocity profile parameter. Set maximum velocity to x steps/sec.
th x	see Tab. 10	Velocity profile parameter. Set motor/encoder mismatch threshold to x steps. If the position mismatch between encoder and motor exceeds ”x” steps the error status signal is activated and the error LED of the respective drive module is switched on. Normal shutter operation is blocked. Commands ”sb”, ”sv” and ”sp” may be used to retrieve the shutter status. In any case a shutter reset is needed to resume normal operation.
ls x	see Tab. 10	Set position reset speed. During reset the blades are driven with speed x steps/sec.
lt x	0≤x<see	Set the reset timeout limit to x msec. If during reset the limit switch isn’t activated within the given timeout limit shutter operation stops and status bits are set accordingly.
fd		Reset the velocity profile parameters and reset parameters (speed, timeout) to their factory defaults.
pp		Get 8 velocity profile parameters. Start positions for blade A and B, blade travel distance, start velocity, acceleration, max. velocity, threshold, blade travel time.
sb x bl	1≤x≤6	Get status byte x. The byte is given in two representations: decimal ASCII, 8-digit binary ASCII (e.g.: ”5 00000101”)There are 6 status bytes, 2 for each of the three modules. Refer to section 9.4 for detailed information.
os		Open Shutter. *While opened by command external open/close signals are not recognized.*
cs		Close Shutter. External open/close signals are recognized.
rs		Shutter reset. A reset is performed by means of a program restart of all 3 microcontroller system.
ve		Version string. The version string is sent.
gv bl		Get the version of the motor firmware. Trafo 40%
vo		Shows the two adc voltage values of the electronics. The usual 5V and 36V needed for the motors. This could be used to check if motor voltages are ok.

For testing purposes during the development phase more functionality was implemented with the corresponding ”Special Commands”.

Table 12: Special Commands

s!		Show a list of special commands **with** a one line description.
ia x	(x=1/0)	Switch interactive mode on/off (for terminal use): if switched on a newline character is inserted before each prompt.
sv x	0≤x≤2	Get a verbose list of all status bits for the communication µC (x=0) and blade A and blade B µCs (x=1, x=2 respectively) (see also standard command sb). For full explanation refer to Section 9.4.
ss		Get the current open/close status. A number is returned with the following meanings: **0**: Status undefined. This may occur if after an error (e.g. blocking of blades) the shutter operation stops. **1**: Open. **2**: Closed (A). The shutter is closed with blade A in the aperture. **3**: Closed (B). The shutter is closed with blade B in the aperture.
po bl		Print port bytes 0, 1, 2 of the corresponding µC.
ex x		An exposure of x milliseconds is performed. While the exposure is running command communication may continue (e.g. to get status information).
xx x y z		A series of z exposures of x milliseconds each with a wait cycle of y milliseconds between exposures is performed. The wait cycle starts after the shutter is closed. For the timing precision see the ex command.
nc	[1]	Autonomous adjustment of blade start positions and travel distance. The procedure does consist basically in moving one blade towards the other until a contact is detected. Then from the sum of both encoder readings the new parameters are derived. The ”search for contact” is performed on both sides of the aperture. To allow a visual check of the result the blades are positioned finally such that a slit of 0.1mm to 0.2mm is formed right in the middle of the aperture. Few seconds later an automatic reset is performed. The newly determined parameters are stored in the EEPROM as the active set. Use commands ”sh” or ”pp” to get the parameter values. After a reset or power off-on the shutter can be used in the normal manner. Factory default parameters are not affected. With nc 1 the process is continuously monitored over the RS232 line.

9.4 ShCU status bits.

Status information is stored bitwise in status bytes. Two bytes are provided/foreseen for each of the three µCs. Use command sb to get an ASCII decimal and a 8-digit ASCII binary representation of individual bytes. In terminal mode special command sv may be used which lists the symbolic name of each status bit of the selected µC together with its status (ON=on, none=off).

Status byte #1 (sb 1) is generated by the command module.

Table 13: Status Byte #1

Bit	Symbolic name	Usage
0	S_blade_A_offline	Used and set during the start-up phase. Due to the profile calculation and the blade reset procedure the start-up of the drive modules takes several seconds. The command module checks continuously the status of the drive modules. The status bit is reset when the drive modue A is ready after completion of the startup.
1	S_blade_B_offline	Used and set during the start-up phase. Due to the profile calculation and the blade reset procedure the start-up of the drive modules takes several seconds. The command module checks continuously the status of the drive modules. The status bit is reset when the drive modue B is ready after completion of the startup.
4	S_error_interlock	Indicates that one of the drive modules has set the P_ERROR_INTERLOCK port bit because some error was detected.

Status byte #2 (sb 2) is reserved for future use.

(Error) status bytes #3 and #5 (sb 3, sb 5) are generated by blade ”A” (byte #3) and blade ”B” (byte #5) respectively. They are identically defined and status bits are set in case of error conditions.

Table 14: Status Byte #3 (blade ”A”) and #5 (blade ”B”)

Bit	Symbolic name	Usage
0	S_motor_to_origin_timeout	Is set if during the reset procedure the timeout limit is reached before the limit switch is activated. The timeout limit is given as firmware default or set by command ”lt” such that there is enough time to reach the limit switch with the given motor speed (firmware default or command ”ls”) under normal circumstances. Such an error may occur if one blade blocks during the reset movement.
1	S_threshold_error	Is set if a position mismatch is detected between the stepper motor steps and the encoder value. The threshold value is given as firmware default or set by command ”th”. Such an error may occur if one blade blocks during the open/close movement.
3	S_limit_switch	Indicates that the limit switch was activated unexpectedly. This may be due to a malfunction of the stepper motor control hardware. It could be due to a malfunction of the switch itself or if the cable connection to the switch brakes.
4	S_unknown_command	Is set if an unknown command was received over the RS232 line. This can only happen if a drive module gets its command directly through its own RS232 port.
5	S_collision	Is set if a blade receives a ”shutter close” signal while the P_BLADE_INTERLOCK port bit is switched active, i.e. while the other blade performs already a closing movement. This can occur in case of a false shutter open/close signal, e.g. if during a closing movement a (short) open/close signal was sent.

Status bytes #4 and #6 (sb 4, sb 6) are generated by blade ”A” (byte #4) and blade ”B” (byte #6) respectively. They are identically defined.

Table 15: Status Byte #4 (blade ”A”) and #6 (blade ”B”)

Bit	Symbolic name	Usage
0	S_blade_open	Indicates that the blade is in the open position (away from the aperture).
1	S_blade_closed	Indicates that the blade is in the closed position (covering the aperture).
2	S_error_LED	If an error is detected the error LED is switched on and this status bit is set.
3	S_error_interlock	Indicates that the P_ERROR_INTERLOCK port bit was set. The P_ERROR_INTERLOCK port output is used as a signal to communicate error conditions between the modules. The corresponding output lines of all modules are interconnected. If one drive module activates this signal exposure movements by the other drive module are prohibited by software.

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Prüfberichtnummer/Report No.: 0001/11
Seite/Page: 1/38

Prüfbericht über die Störaussendung und -beeinflussung elektronischer Geräte
Report on the Electromagnetic Emission and Immunity of electronic equipment

Prüfvorschriften: Test Specifications:	EN 61000-6-4:2007 Teile/Parts: EN 55011:2009, EN 61000-6-2:2005 Teile/Parts: EN 61000-4-3, EN 61000-4-4, EN 61000-4-5, EN 61000-4-6, EN 61000-4-8, EN 61000-4-11.
Auftraggeber: Customer:	Argelander Institut für Astronomie - Universität Bonn Auf dem Hügel 71 53121 Bonn
Prüfgegenstand: Equipment tested:	Bonn - Shutter System S/N: 1.7_033 consists of: • Shutter Mechanical Unit • Shutter Control Unit • Power supply
Eingangsdatum: Incoming Date:	06.01.2011
Prüfende Abteilung: Testing Department:	EMV-Zentrum EMC-Centre
Prüfer: Test Engineer:	Carkit
Prüfort: Test Location:	Bonn
Prüfdatum: Date of Test:	06.01.2011 to 07.01.2011
Bemerkungen: Remarks:	keine none
Prüfergebnis: Test Result:	Bestanden Approved

EMV-Zentrum
EMC-Centre

10.01.2011
Carkit, Prüfer

Qualitätssicherung
Quality Assurance

10. 01. 11