PLUTO-2.1

Phase Only Spatial Light Modulators

Device Operating Instructions
SLM Software Instructions

HOLOEYE **Pioneers in Photonic Technology**

Note

This Instruction explains the correct usage of the device and serves prevention of danger. All persons who apply or use, care of, maintain and control the device have to read and follow it. It is part of the device and should always be at the user's disposal.

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Copyright notice

Technical specifications given in this document are subject to change without notification.

1 Device Manual

1.1 Introduction

Figure 1: PLUTO-2.1 phase modulator

The PLUTO-2.1 device is a phase only Spatial Light Modulator (SLM) and consists of a driver unit with standard digital video interface (HDMI) and a phase only LCoS (Liquid Crystal on Silicon) microdisplay with full HD resolution (1920 x 1080 pixel) and 8 µm pixel pitch leading to an active area diagonal of 0.7" with aspect ratio of 16:9.

HOLOEYE offers different phase panel versions that can be driven with the PLUTO-2.1 driver unit. The different panel versions are optimized for the use at different wavelength ranges. All versions use fast full digital addressing which assures high reliability and a compact driver unit as basically only two voltages need to be generated.

To reduce the drawback of super posed phase fluctuation, that can reduce efficiency for some applications, high retardation phase display versions are available as well. The high retardation enables driving with low voltages for 2π modulation, which enhances phase stability as the ability of the LC to follow voltage pulses is reduced. This leads to a better averaging of the applied pulse code. High retardation models can also enable mod 4π or even mod 6π modulation, which can be of benefit for e.g. wave front applications.

The chapter "PLUTO-2.1 Phase Modulator Versions" of this user manual contains the parameter range for the available phase display versions and gives rough guideline which model suits best for an application with specific requirements. Further help will be given by the technical sales team: slm@holoeye.com

The PLUTO-2.1 SLM is a plug & play phase modulator and can be addressed with phase functions via standard graphics cards as extended monitor device. Typically the green color channel of the video signal is used for addressing 8 bit gray level patterns (the SLM's native resolution need to be addressed). Addressing can be done using the supplied "Pattern Generator", the "SLM Slideshow Player" software or standard image viewer software.

A certain gray level represents a defined average voltage across the LC cell. This voltage leads to a variable tilt of the LC molecules due to their electrical anisotropy. As LC molecules also show optical anisotropy this tilt changes the refractive index of the LC molecules (for incident polarization along the long display axis) which causes a modified optical path length within the LC cell. The addressed gray level is converted into a phase level.

The PLUTO-2.1 driver unit is equipped with an USB interface that allows changing the voltage vs. gray level distribution (gamma control) and dynamic range (voltage across the LC cell) in order to calibrate the SLM for different wavelengths. This will be explained in the chapter "Configuration Manager" of the user manual and in the separate document SLM-calibration.pdf.

1.2 Deliverables

- High resolution (full HD) phase display incl. flex cable
- Driver unit
- 12 V Power supply + cable
- USB cable
- HDMI-cable
- Magnetic display mount
- Device mount
- Safety instructions & quick-start guide (test polarizer inside)
- USB flash drive with software package and documentation

Figure 2: PLUTO-2.1 deliverables

1.3 General Usage Guidelines & Safety Instructions

Important safety instructions! Read this section carefully before initial operation!

This instruction provides information for a safe operation of your HOLOEYE Spatial Light Modulator. Please follow and retain all information included.

Please note: Power cables, power supplies and other components could bear safety risks, which especially at improper use could lead to personal injury or property damage. To lower the risks, please follow all safety instructions and note all warnings on the product itself and within the user manuals.

For a long lifetime of the SLM device please follow these general handling instructions:

- All plugs of electrical interfaces especially the display to drive board connection has to be done without applied voltage.
- Do not use the kit outside buildings and in humid or dusty places and keep the kit away from extreme heat and coldness.
- Avoid touching the LCoS display because this might cause damages or reduce its optical quality.
- If you plan to illuminate the kit with powerful light sources, we strongly recommend consulting HOLOEYE services.

The LCoS display and the flex cable are electrostatic-sensitive parts. To prevent electrostatic discharge (ESD) to cause malfunction of the SLM avoid touching these parts with a finger or other conductor.
Do not touch pins and leads. Set up and handle the display in a static controlled location and be properly grounded, e.g. wearing an ESD wrist strap.

The SLM (driver unit and microdisplay) and the power supply induce heat while operation. Please be careful touching these components and avoid keeping them in your hand for a longer period.
Do not cover the components or block the heat transfer to surrounding air in any other ways.

If you detect any signs of overheating or if you have any other safety concerns regarding the device, please interrupt the power supply connection and stop using the device until you are able to get in contact with HOLOEYE support.

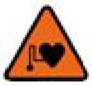
Avoid shocks and shaking of the device (especially the microdisplay) and protect the device from strong mechanical force and scratches.

Only use power supplies and power cables recommended by HOLOEYE. Never use power supplies and power cables which show signs of damage!
Before you connect or disconnect the microdisplay to/from the driver unit make sure to interrupt the power connection.

Remark regarding LC microdisplays: The microdisplay contains a cover glass which could break by mishandling. If the display glass or other parts are broken and the included liquid crystal material gets in contact with skin or eyes, flush out the affected areas for at least 15 minutes with clear water and consult a doctor.

Please check the SLM and the included parts for damages, traces of wear or other signs of safety risks on a regular base. Do not use the device if you have any concerns about the proper condition of any part. In such cases please get in contact with HOLOEYE support!

The display base plate or the display mount contain NEODYMIUM magnets. Magnets produce a far-reaching, strong magnetic field. They could damage TVs and laptops, computer hard drives, credit and ATM cards, data storage media, mechanical watches, hearing aids and speakers. Please keep the related parts away from devices and objects that could be damaged by strong magnetic fields.



Magnets could also affect the functioning of pacemakers and implanted heart defibrillators.

Magnets may contain nickel. Some people have an allergic reaction when they come into contact with nickel. Nickel allergies could develop from perpetual contact with nickel-plated objects.

- Avoid perpetual skin contact with magnets.
- Avoid contact with magnets if you already have nickel allergy.

In order to ensure the conformity with the essential requirements of the EMC directive (Electromagnetic Compatibility - DIRECTIVE 2014/30/EU) the SLM or the apparatus it is incorporated into, needs to be shielded by an appropriate EMC housing. Please contact HOLOEYE if you need support on this topic for appropriate solutions.

Contact information regarding service and support can be found at the HOLOEYE website at https://holoeye.com/contact/.

1.4 Phase Display Specifications

1.4.1 Display Parameter

Part No.:	HED 6010 xxx
Type:	LCoS (reflective),
Drive Scheme:	Digital (pulse code modulation)
Mode:	PAN (Parallel Aligned Nematic) or VAN (Vertically Aligned Nematic)
Phase Levels:	256 (8-bit) phase levels
Active Area:	15.36 mm x 8.64 mm
Display Diagonal:	0.7”
Resolution Nominal:	1920 x 1080 pixels
Resolution Total:	1952 x 1088 pixels
Pixel Pitch:	8 µm
Fill Factor:	93 %
Input Frame Rate:	60 Hz
Reflectivity f(λ):	65 % - 95 %
Illumination (max.)	~ 2 W/cm² for standard versions up to multiple 10s of W/cm² (CW laser) for dielectric mirror versions. For high power and pulsed laser applications, and for wavelengths below 450nm, please contact HOLOEYE.
Operating Temp.:	+10°C to +70°C
Waveband:	Model dependent.

Figure 3: HED 6010 phase display

⚠ **UV irradiation below 405 nm shall be blocked via an absorption filter.**

1.4.2 Connecting the Display

At first the driver unit and the display flex cable have to be connected. This has to be done under antistatic conditions and without applied voltage. Also note that the ZIF connector is limited in the contact durability for which reason frequent connection cycles should be avoided!

Release the two screws on top of the driver unit and remove the cover. Open the brown connector flap by pulling it up (e.g. using plastics tweezers) until it is perpendicular to the driver board as shown on the left side of figure 4.

Take the display with face and golden pins up and align the flex straight to the connector. Insert the flex cable straight into the connector with low force. Now fix the connector by pressing down the brown plastic flap, while holding the flex cable in place. If the display is connected correctly, the interface stopper on both sides of the display flex will be interlocked by two small white plastic spikes. Finally close the cover of the housing and fix it with the two screws.

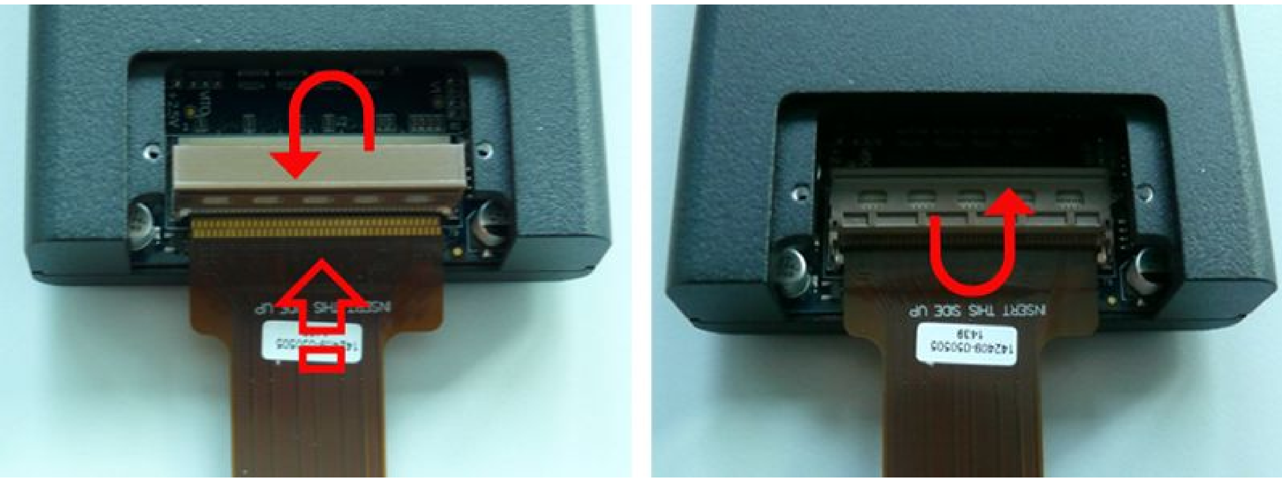


Figure 4: Connecting the display

You can verify if the display is connected properly by performing the µLCD bus test using the Configuration Manager software (LCD data bus check).

> **NOTE**
> The lifetime of the ZIF connector and of the pins on the flex cable is limited and frequent connection and disconnection should be avoided.

1.4.3 PLUTO-2.1 Microdisplay Dimensions

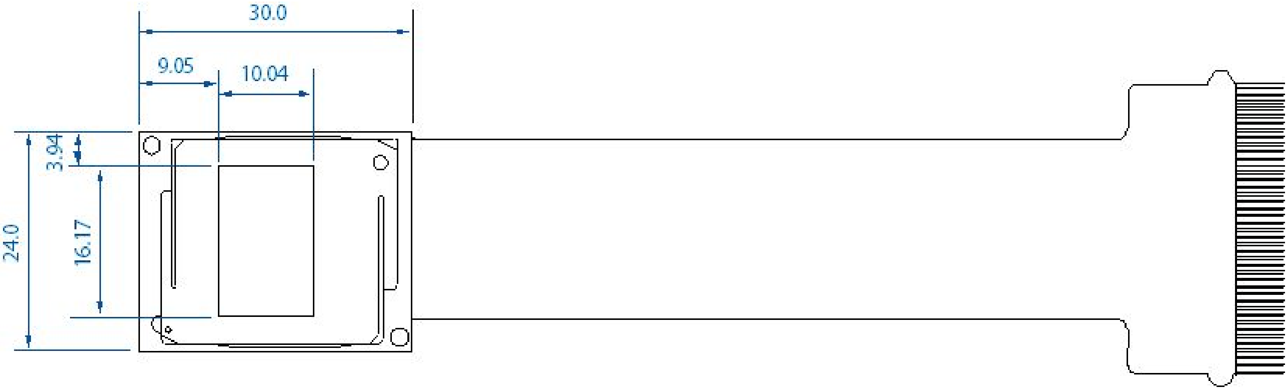


Figure 5: Display dimensions metal packaging (unit: mm)

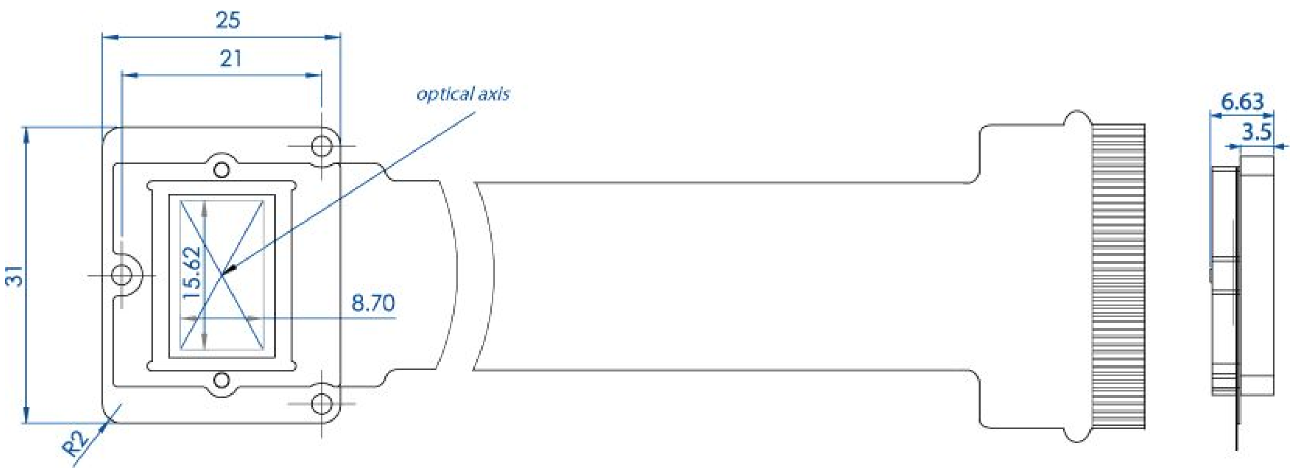


Figure 6: Display dimensions ceramic packaging (unit: mm)

1.4.4 Mounting the Display

For mounting the display of the SLM it is recommended to use the supplied magnetic display mount. Please avoid forces to the flex cable to assure stable mounting conditions.

For display versions with ceramic base plate (ceramic packaging) a different display mount is delivered as for the versions with metallic base plate (metal packaging).

Figure 7: Display Mount (metal packaging)

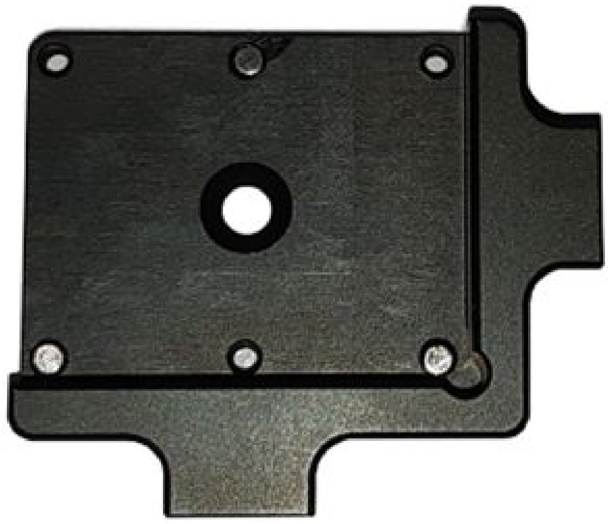


Figure 8: Display Mount (ceramic packaging)

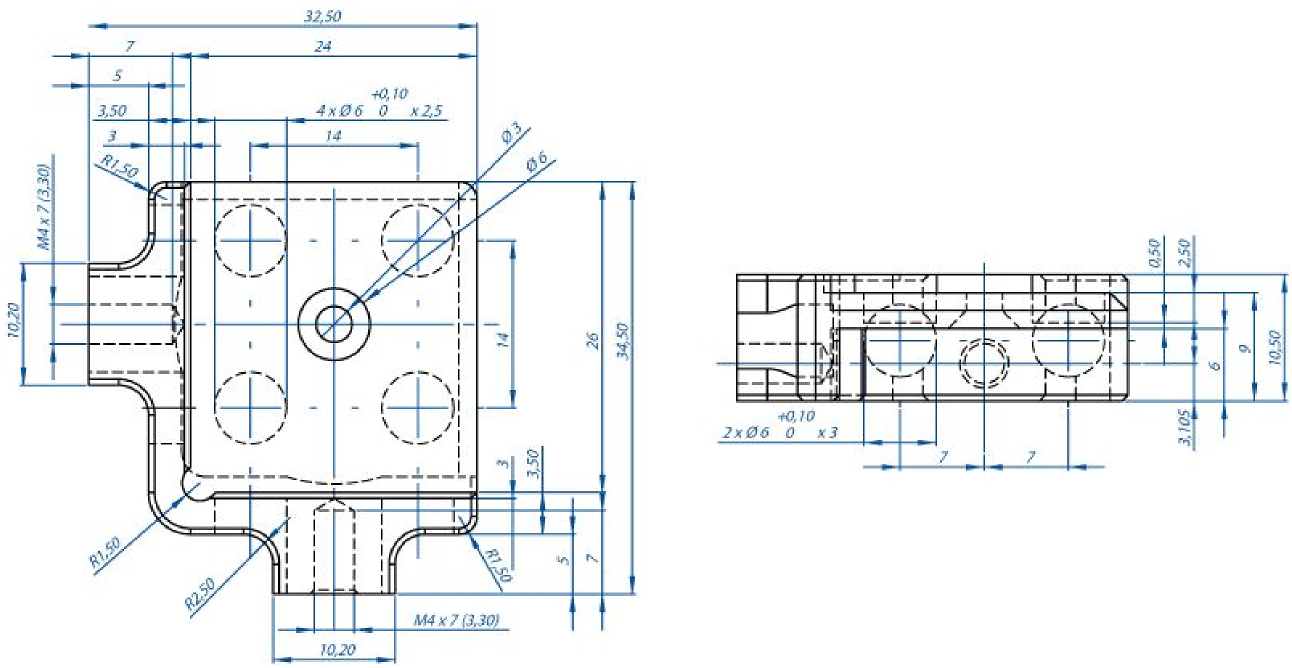


Figure 9: Display mount dimensions for metal packaging versions (unit: mm)

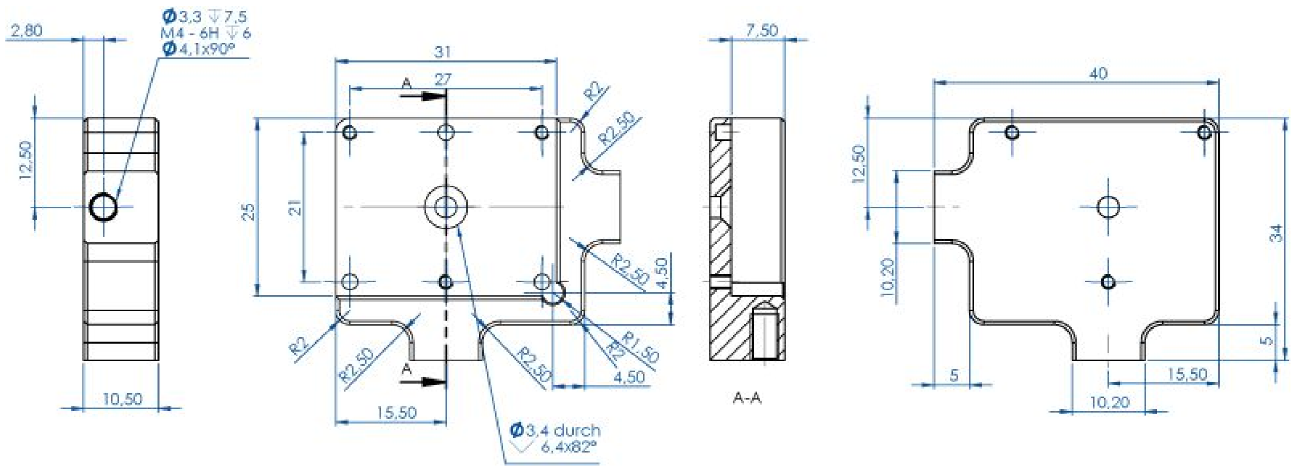


Figure 10: Display mount dimensions for ceramic packaging versions (unit: mm)

1.5 PLUTO-2.1 Driver Unit

Figure 11: PLUTO-2.1 Driver

The PLUTO-2.1 driver uses an HDMI interface for addressing phase functions and an USB connection for advanced calibrations. Via the USB connection (UART USB slot) the user can perform various display adjustments like gamma correction, geometrical settings and different sequences can be loaded to the driver (also see "Configuration Manager"). Besides this the driver features a trigger sync output to synchronize the device with external devices.

The PLUTO-2.1 driver also features a dual-core ARM® Cortex™-A9 processor. This enables the user to program additional functionality, which is directly processed on the PLUTO-2.1 device (e.g. loading image files from a USB drive or generated internally). The dual-core system runs an embedded Linux™ SMP operating system. The PLUTO-2 provides access through Serial and Ethernet-over- USB2 (RNDIS) interfaces and can be programmed using standard Ubuntu™ cross compile GCC toolchain.

1.5.1 Dimensions of the Driver Unit

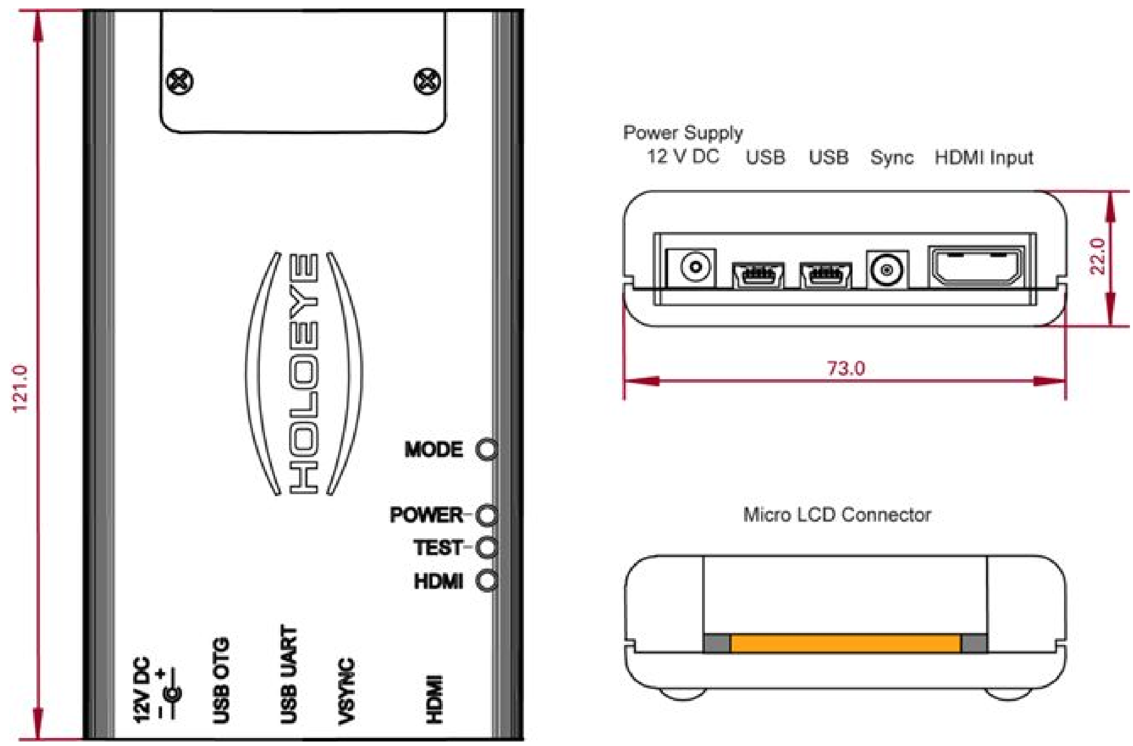


Figure 12: Driver interfaces and dimensions

1.5.2 Mounting the Driver Unit

For mounting the driver unit on an optical table please use the delivered device mount. Please always use the delivered screws as the drive board can be damaged if screws are too long. Thread options see figure 13.

Figure 13: Device mount

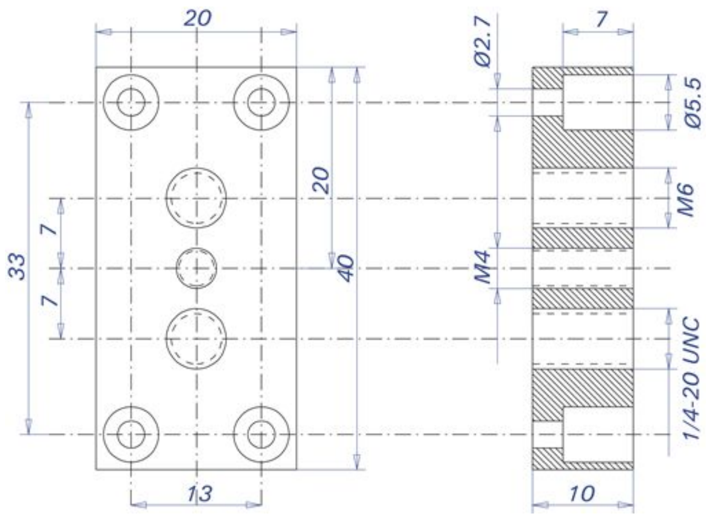


Figure 14: Device mount dimensions (unit: mm)

Figure 15: Left image : Device mount attached to device driver. Right image : Complete setup with device mount and display mount on posts.

1.5.3 Connectors of the Driver Unit

Back Side

12V DC	Connection of power supply
USB OTG	USB connection to use embedded Linux system via using Ethernet over USB.
USB UART	USB connection to virtual com port (via USB) of the computer. Used for calibration of the device (with Configuration Manager).
VSYNC	Connection of v-sync trigger cable (RG174 MCX PLG-PLG,1M from Farnell / Newark)
HDMI	Connection to computer via HDMI

1.5.4 Power Supply

Switching Power Supply

Input:	100-240 V AC 50-60 Hz ~0.5 A
Output:	12 V --- 2.5 A

Power applies directly by plugging the power supply cable into the driver unit.

1.5.5 LED Status Notifications

LED	Color	Status	Indication
HDMI	Yellow	LED is off if HDMI connection failed or is interrupted	Check of HDMI connection
TEST	Green	LED is on if µLCD test is passed	On startup a µLCD bus test is performed (display connection)
POWER	Green	LED is blinking every second when power is connected	Check if microcontroller is running
MODE	Green	OFF: Linux system is not started or not fully initialized. ON: Linux system is started and fully initialized.	This led is controlled by integrated ARM/Linux applications. User controllable.

Table 1: LED status notifications

1.5.6 Video Sync Signal

This connector provides a synchronization signal, which can be used to trigger a camera, with the input video signal.

The plug is compatible with lead RG174 MCX PLG-PLG,1M from Farnell / Newark.

The v-sync itself has 3.3V signal-level.

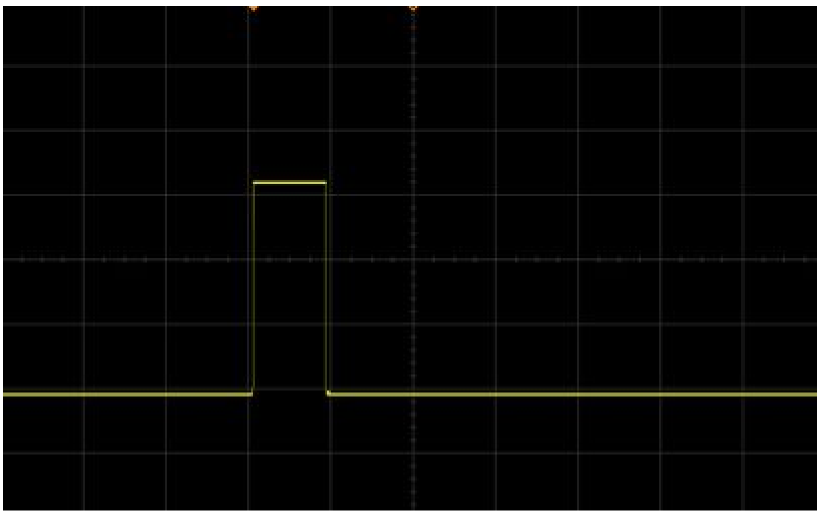
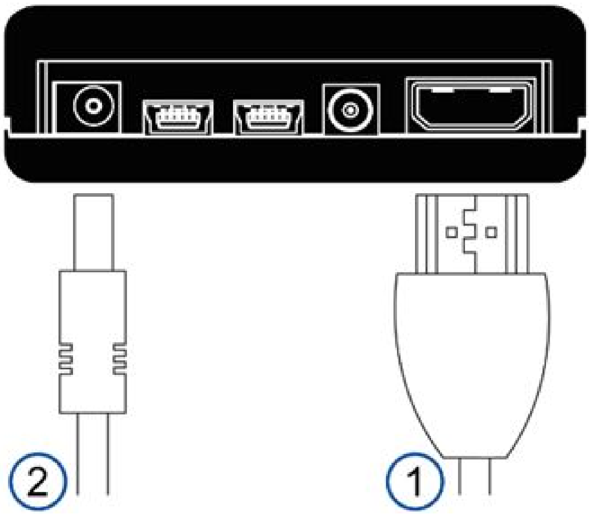


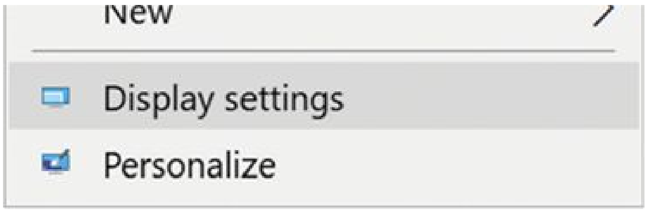
Figure 16: V-sync signal

1.6 Quick-Start Guide

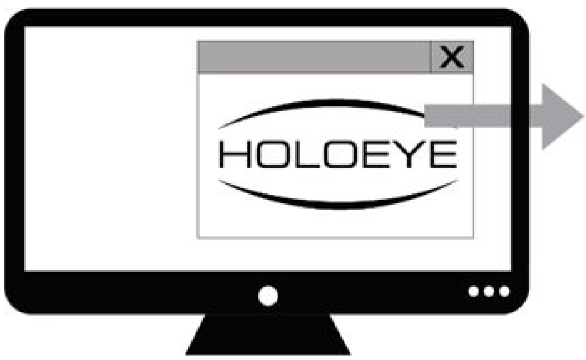
1 After booting your computer, establish the HDMI connection to the SLM. Now connect the power supply.



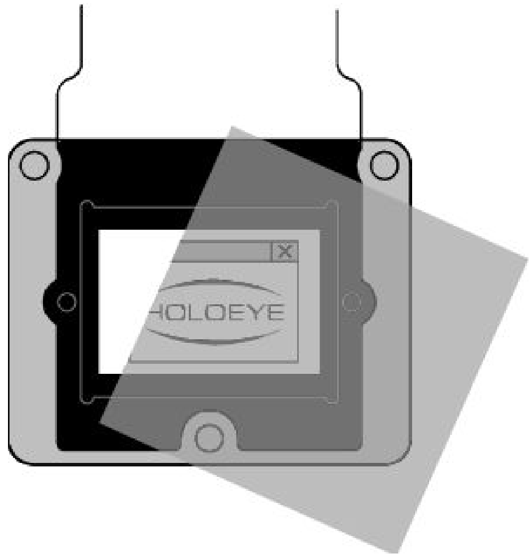
2 Right click on the desktop and select “Display Settings“. Set the device in extended desktop mode by selecting “extend these displays“ at the “Multiple Displays“ selectbox. Make sure the night light mode is not activated.



3 Open an image file in any image viewer software (e.g. Windows image viewer or IrfanView) and drag the image window to the second monitor (which is the SLM).



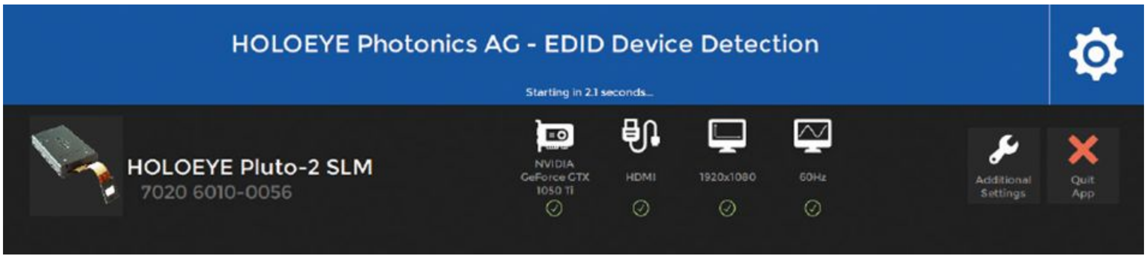
4 To finally check if all settings are correct and if the SLM works properly, place a polarizer (test polarizer included in printed quick start instruction) on the display and turn it until you see the image.



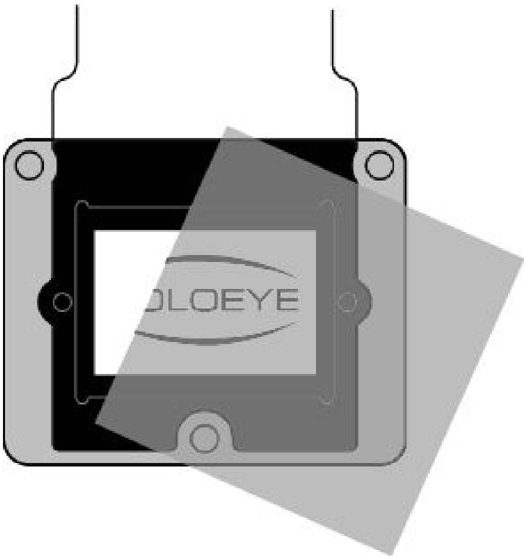
Alternatively you can use to HOLOEYE SLM Pattern Generator software or the Slideshow Player software to check your settings and to guide you through a proper configuration.

2a Install the HOLOEYE Slideshow Player software or the Pattern Generator software, which are included on the delivered USB drive and start the software.

3a The HOLOEYE SLM software features a SLM device detection. The device detection checks graphics card settings, the HDMI connection and SLM configurations. If anything is not configured correctly a dialog will lead you through a proper configuration.



4a To finally check if all settings are correct, you can address any image on the SLM using the HOLOEYE SLM software (please refer to the detailed manuals which are included on the USB drive or are available by the "Help" function of the software) and place a polarizer on the display and turn it until you see the image.



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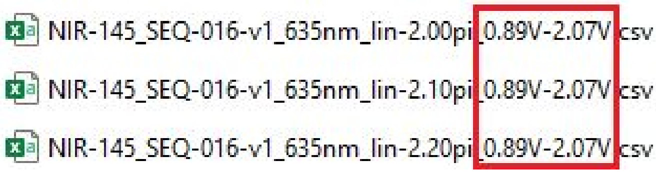
5 On the supplied USB drive you find 2 sets of configuration files for different wavelength ranges. A recommended standard configuration and another configuration optimized for either lowest phase flicker or faster response. Start the HOLOEYE Configuration Manager software and chose the "Color Look-Up Table" tab. Load the proper configuration file for the used wavelength. Use the file for linear 2 π phase response. You may achieve better results with slightly adjusted configurations if you e.g use a slightly varied wavelength and/or address high spatial frequencies (e.g. 2.1π or 2.2 π for longer wavelength).

Make sure to adjust the voltage setting at the "Voltages" tab according to the values mentioned in the file name.



The first value stands for the “low level pixel voltage“ and the second value for the “high level pixel voltage“.

Slight changes of the voltages while observing the device response can be used for fine tuning.

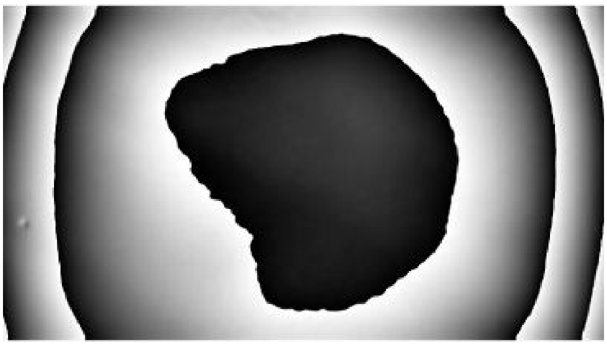
The device is now configured properly and ready for use.

6

Wavefront compensation (optional):

On the supplied USB drive you find a wavefront compensation file (*.h5 file). This wavefront compensation file can be loaded as background compensation using the Pattern Generator software or the SLM Display SDK to compensate wavefront distortions of the display itself.

You can find more detailed information at the chapters "Optical Flatness" and "Wavefront Compensation Overlay".



1.7 PLUTO-2.1 Phase Modulator Versions

HOLOEYE provides several versions of the PLUTO-2.1 SLM for different wavelength ranges and applications. Differences are within anti reflection coatings, dielectric mirror coatings, cell thickness for adapted phase retardation depth, as well as used LC material. The phase modulation for characteristic wavelengths will be shown in this section for all currently available versions. The measurement results were obtained using a common-path interferometer setup, depicted below, with measurements taken at small angles of incidence. For angles of incidence greater than 15 degrees, the values may deviate from those reported here.

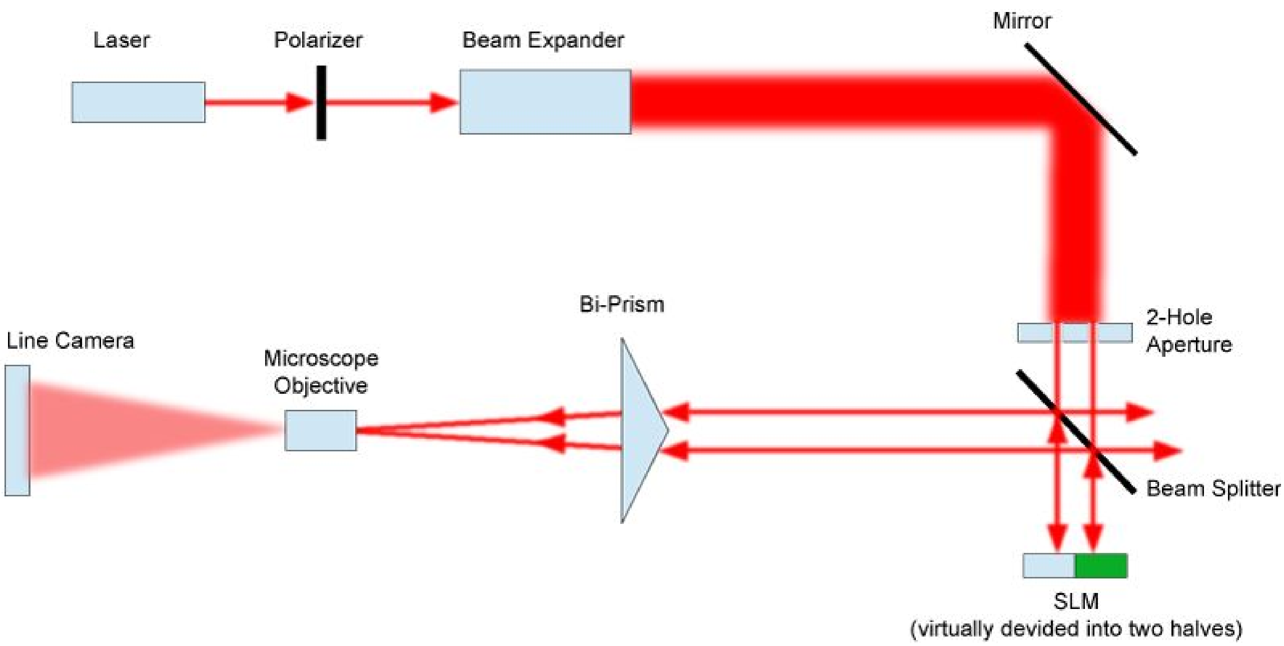


Figure 17: Experimental setup for phase modulation measurements

NOTE

- The incident polarization for PAN (Parallel Aligned Nematic) display versions for phase only modulation is along the long display axis!
- VAN (Vertically Aligned Nematic) display versions might use a 90° rotated alignment layer and incident polarization is along the short axis.

1.7.1 Overview PLUTO-2.1 Versions

Device	Wavelength Range	Reflectivity	Comment
PLUTO-2.1-UV-099	350 – 500 nm	>90 %	Dielectric Mirror
PLUTO-2.1-VIS-014	420 – 650 nm	65 %	
PLUTO-2.1-VIS-016	420 – 700 nm	67 %	High Retardation Version
PLUTO-2.1-VIS-130	500 – 660 nm	94 % average	Dielectric Mirror
PLUTO-2.1-NIR-145	420 – 1064 nm	82 % average	
PLUTO-2.1-NIR-015	650 – 1100 nm	65-73 %	High Retardation Version
PLUTO-2.1-NIR-113	730 – 940 nm	95 % average	Dielectric Mirror

Device	Wavelength Range	Reflectivity	Comment
PLUTO-2.1-NIR-149	1000 – 1100 nm	93 %	Dielectric Mirror
PLUTO-2.1-NIRO-024	1064 – 1400 nm	82 %	
PLUTO-2.1-TELCO-013	1400 – 1700 nm	80 %	
PLUTO-2.1-TELCO-142	1400 – 1700 nm	93 % typical	Dielectric Mirror
PLUTO-2.1-SWIR-157	1700 – 2500 nm	85 %	Short Wavelength Infrared

Table 2: Overview PLUTO SLM versions

Besides the standard PLUTO-VIS and PLUTO-NIR versions there are special high retardation versions available (-HR versions) which show a considerably higher phase retardation compared to the standard panels which enables more stable addressing or mod 4π respectively mod 6π phase functions to be addressed.

This can be beneficial for wave front functions as this enables higher slopes and can reduce transition points in the addressed function compared to mod 2π encoding.

The pulse code modulation for digitally addressed devices leads to a slight phase flicker. For some applications a more stable phase response is required. This can be accomplished driving the high retardation panels with low voltage settings for 2π phase retardation, however compromising the response time.

In the following the main parameter for the different PLUTO-2.1 versions are shown including phase stability/flicker data. To measure the phase flicker with sub frame resolution, a common path interferometer combined with a fast line camera has been used. The camera resolves up to 20 kHz signals what is considerably faster than the maximal possible pulse addressing frequency of ~5.3 kHz. Measurements were performed at ~30°C display temperature. To illustrate the phase flicker reasonably, each graph includes minimal and maximal phase values per frame for each phase level as well as mean value, peak to peak and standard deviation. The table for each panel version includes representative values (*) for the maximal flicker amplitude - peak to peak (PP) and more interestingly for the mean standard deviation (mSD) over all phase level.

The provided measurements are made for a linearized phase distribution.

The response time depends on the configuration of the PLUTO-2.1 SLM (drive sequence and DVR voltage settings). In the following measurement tables for each PLUTO version we indicate the response time (rise and fall time) for a typical 2π phase response configuration for a certain wavelength.

Some PLUTO SLM display versions are equipped with a dielectric mirror coating to increase the reflectivity. Due to the increased reflectivity less absorption occurs and these display versions can be used with higher incident laser power compared to the standard versions.

For the PLUTO-2.1 devices we provide 2 different sets of configurations. A recommended standard configuration and another configuration optimized for either lowest phase flicker or faster response. The values stated on the sections below relate to the standard configuration.

(*) *Exemplary for one respectively two wavelengths. Shorter working wavelengths usually lead to better phase stability, as driving voltages can (not must) be lower for 2p modulation, at the cost of slower switching speed. For further questions, please contact SLM@holoeye.com*

1.7.2 PLUTO-2.1-UV-099 (350nm-500nm)

Part no.:	HES 7020-1 6010-UV-099
Wavelength Range:	350 – 500 nm
Active Area:	15.36 mm x 8.64 mm
Pixel Pitch:	8 µm
Fill Factor:	93%
Reflectivity:	90%
Display Mode:	VAN (Vertically Aligned Nematic)

The PLUTO-2.1-UV-099 version can be used between 350 nm and 500 nm. The display has an AR coating that gives a front reflection less than 0.5% in this range.

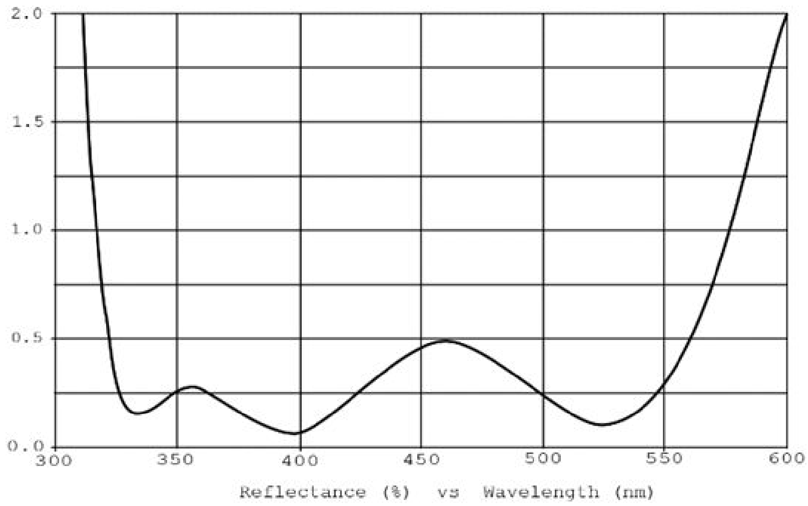


Figure 18: AR coating of the PLUTO-2.1-UV-099 panel

The PLUTO-2.1-UV-099 display is equipped with a dielectric mirror to enhance reflectivity. This also reduces absorption which enables the use of higher power sources compared to the standard PLUTO-2.1 versions.

NOTE
For phase only modulation with this display version the incident polarization has to be vertical (along the short display axis)!

Wavelength	Maximum Phase Shift	Average Reflectivity
355 nm	5.2 π	>90 %
405 nm	4.9 π	>90 %
450 nm	4.0 π	88 %
480 nm	3.5 π	91 %

Wavelength	Maximum Phase Shift	Average Reflectivity
520 nm	3.2 π	80 %

Table 3: Maximum phase shift for PLUTO-2.1-UV-099

1.7.2.1 Phase Flicker & Response Time @ 405 nm

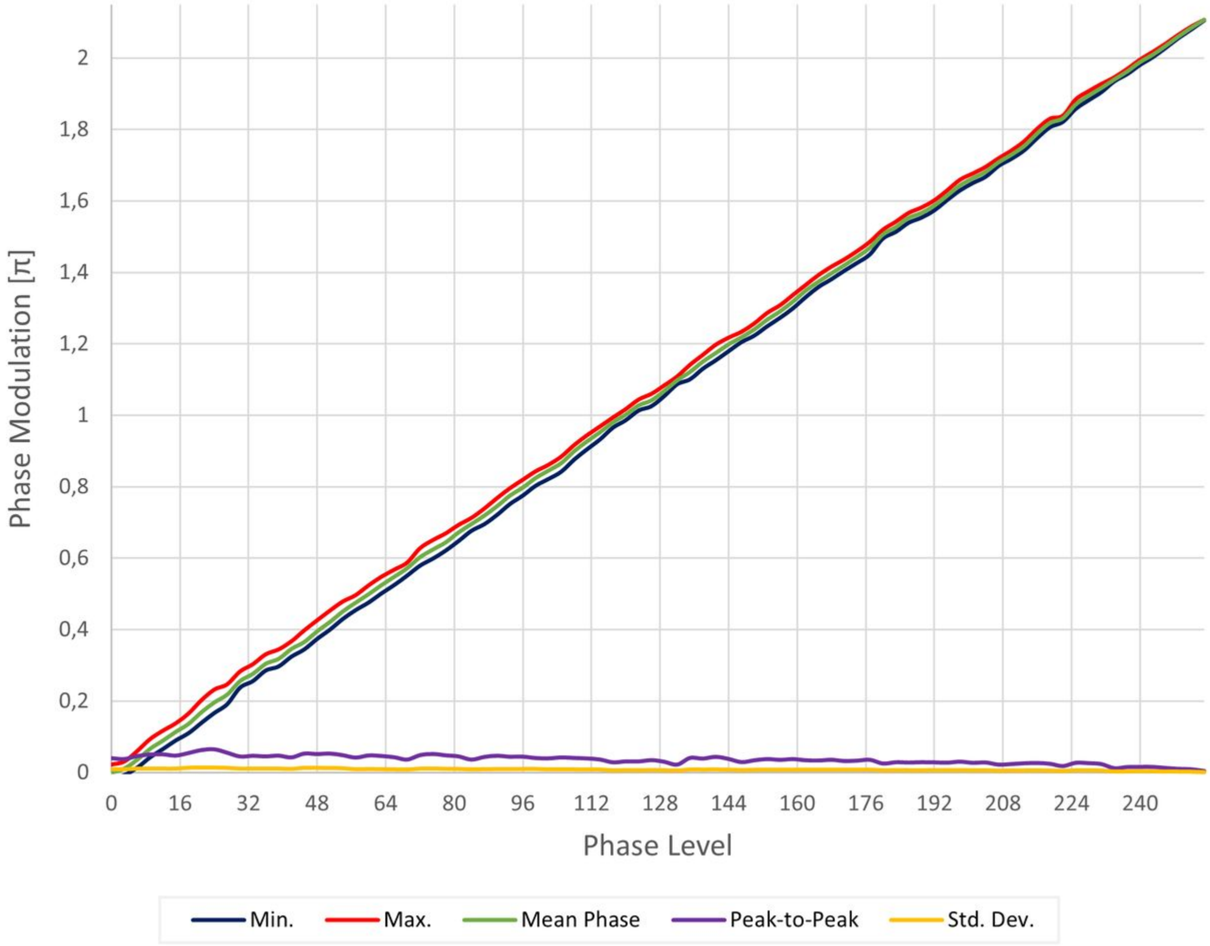


Figure 19: Phase flicker measurements @ 405 nm with PLUTO-2.1-UV-099

Panel Version	PLUTO-2.1-UV-099
Max. phase shift @ 405 nm	4.9 π
Flicker Std. Deviation: 2π @ 405 nm	0.008 π
Flicker max. Peak-to-Peak: 2π @ 405 nm	2.9 %
Response time: 2π @ 405 nm (rise + fall)	37 ms + 44 ms

1.7.2.2 Phase Flicker & Response Time @ 450 nm

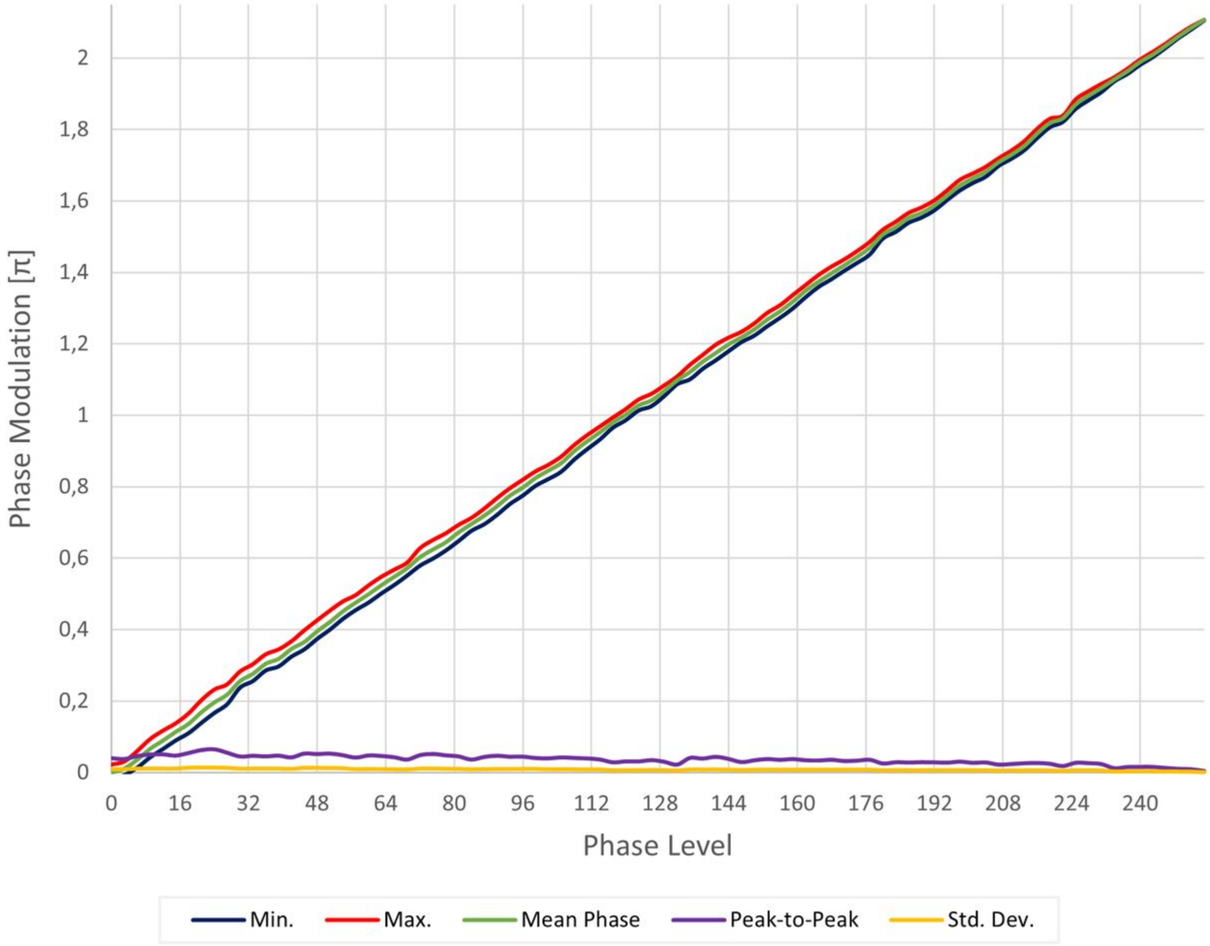


Figure 20: Phase flicker measurements @ 450 nm with PLUTO-2.1-UV-099

Panel Version	PLUTO-2.1-UV-099
Max. phase shift @ 450 nm	4.0 π
Flicker Std. Deviation: 2π @ 450 nm	0.008 π
Flicker max. Peak-to-Peak: 2π @ 450 nm	3.1 %
Response time: 2π @ 450 nm (rise + fall)	35 ms + 41 ms

1.7.3 PLUTO-2.1-VIS-014 (420nm-650nm)

Part no.:	HES 7020-1 6010-VIS-014
Wavelength Range:	420 – 650 nm
Active Area:	15.36 mm x 8.64 mm
Pixel Pitch:	8 µm
Fill Factor:	93%
Reflectivity:	65%
Display Mode:	PAN (Parallel Aligned Nematic)

The PLUTO-2.1-VIS-014 version can be used between 420 nm and 650 nm. The display is equipped with an AR coating that gives a front reflection less than 0.5% in this range.

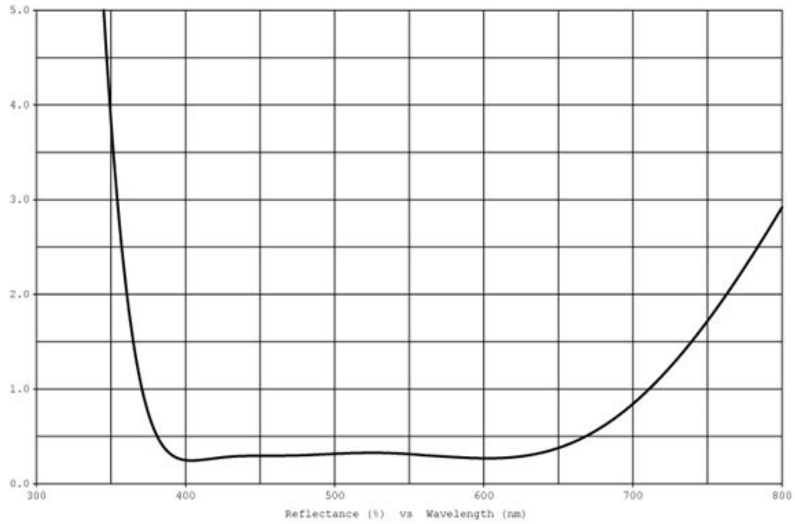


Figure 21: AR coating of the PLUTO-2.1-VIS-014 panel

The LC cell enables at least 2π phase retardation up to 650 nm.

NOTE
For phase only modulation with this display version the incident polarization has to be along the long display axis!

Wavelength	Maximum Phase Shift	Average Reflectivity
450 nm	5.6 π	65 %
532 nm	4.2 π	65 %
635 nm	3.1 π	65 %

Table 4: Maximum phase shift for PLUTO-2.1-VIS-014

1.7.3.1 Phase Flicker & Response Time @ 450 nm

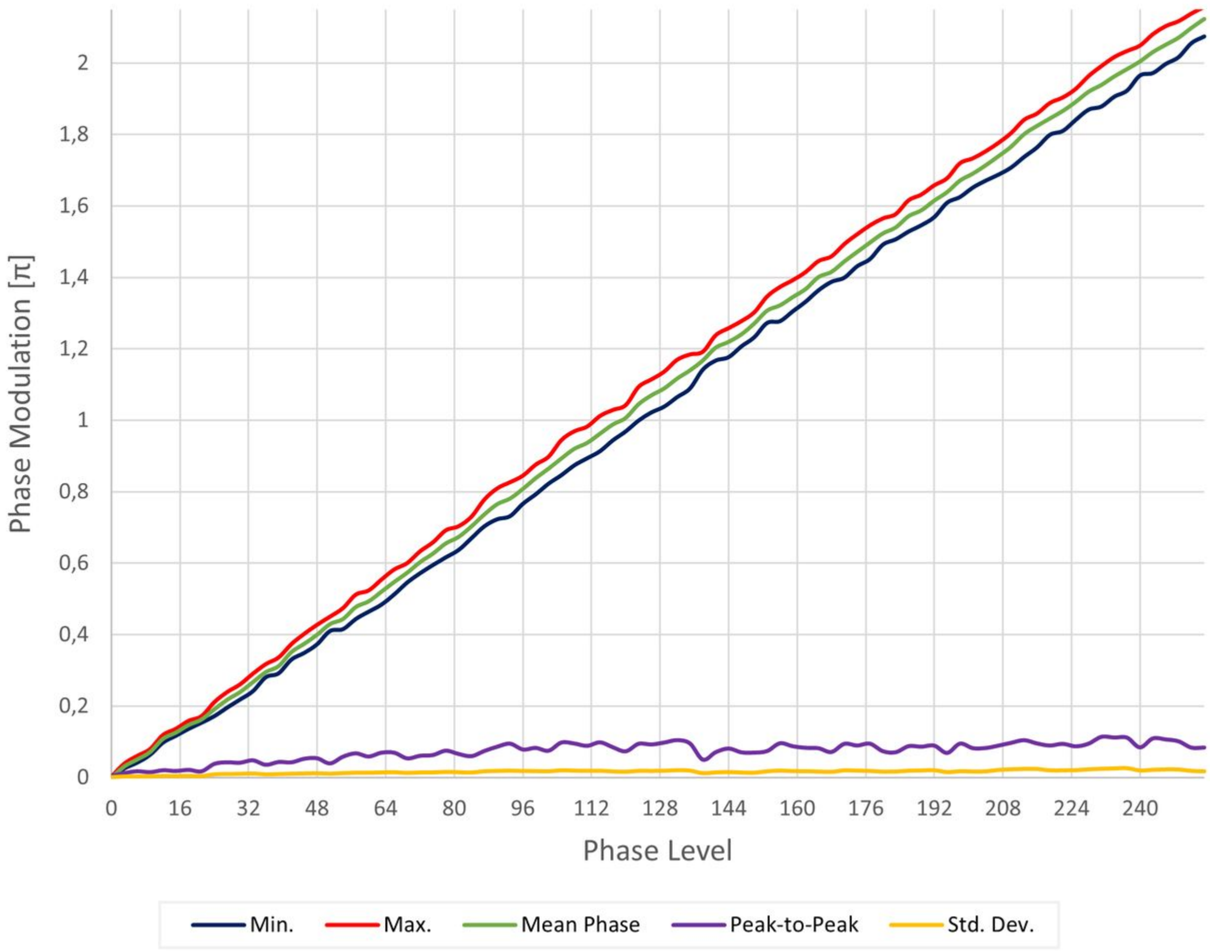


Figure 22: Phase flicker measurements @ 450 nm with PLUTO-2.1-VIS-014

Panel Version	PLUTO-2.1-VIS-014
Max. phase shift @ 450 nm	5.6 π
Flicker Std. Deviation: 2π @ 450 nm	0.016 π
Flicker max. Peak-to-Peak: 2π @ 450 nm	5.8 %
Response time: 2π @ 450 nm (rise + fall)	16 ms + 24 ms

1.7.3.2 Phase Flicker & Response Time @ 520 nm

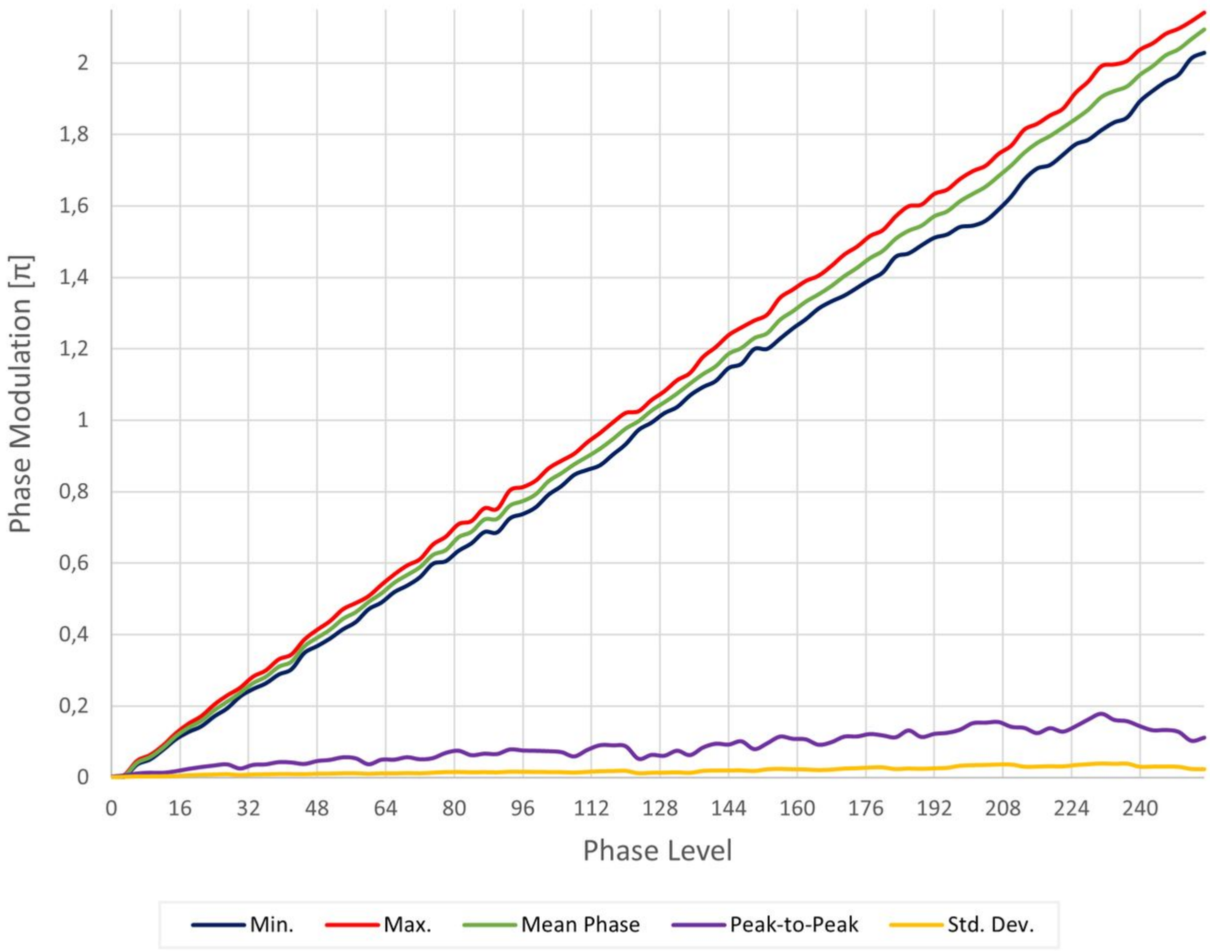


Figure 23: Phase flicker measurements @ 520 nm with PLUTO-2.1-VIS-014

Panel Version	PLUTO-2.1-VIS-014
Max. phase shift @ 520 nm	4.2 π
Flicker Std. Deviation: 2π @ 520 nm	0.02 π
Flicker max. Peak-to-Peak: 2π @ 520 nm	8 %
Response time: 2π @ 520 nm (rise + fall)	15 ms + 23 ms

1.7.3.3 Phase Flicker & Response Time @ 635 nm

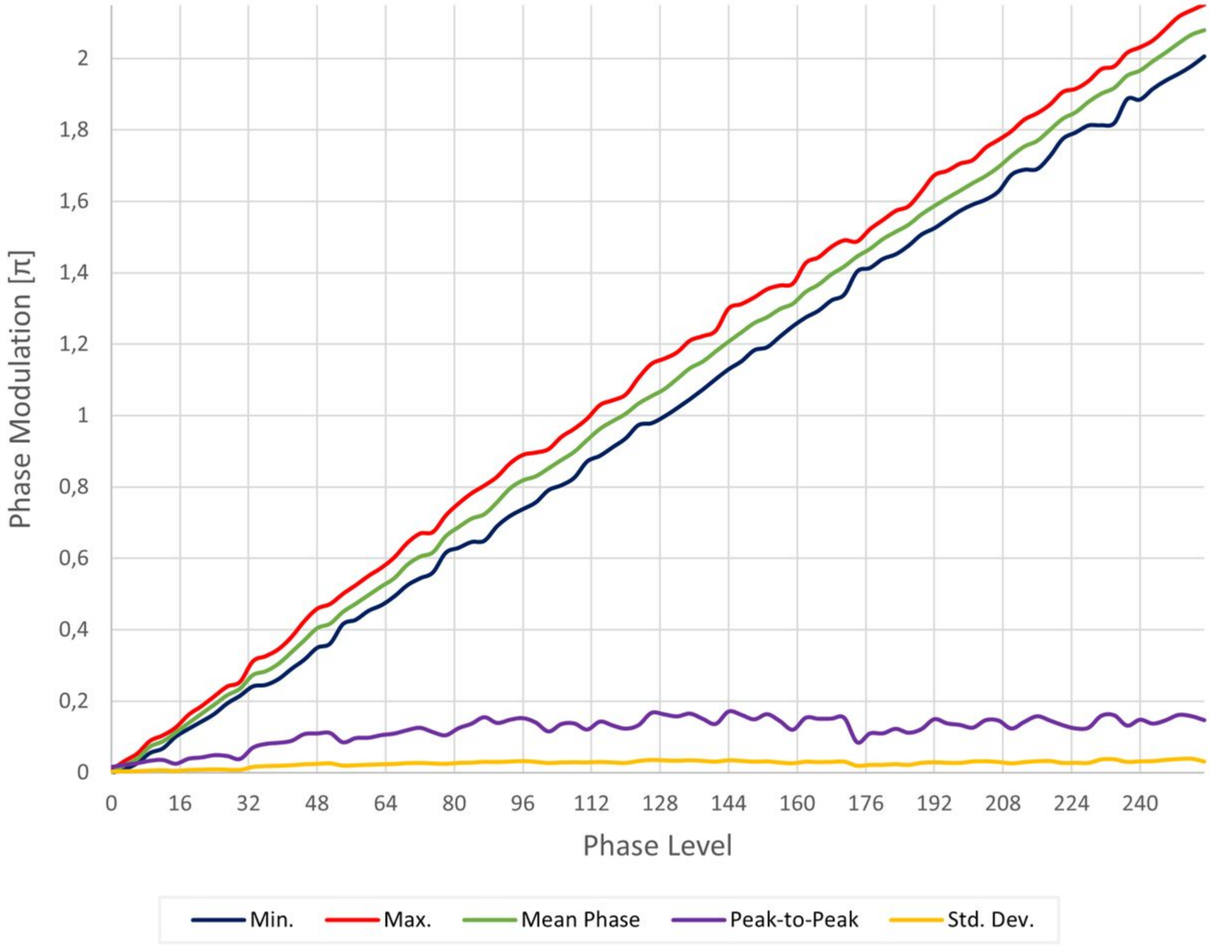


Figure 24: Phase flicker measurements @ 635 nm with PLUTO-2.1-VIS-014

Panel Version	PLUTO-2.1-VIS-014
Max. phase shift @ 635 nm	3.1 π
Flicker Std. Deviation: 2π @ 635 nm	0.026 π
Flicker max. Peak-to-Peak: 2π @ 635 nm	8.7 %
Response time: 2π @ 635 nm (rise + fall)	7 ms + 20 ms

1.7.4 PLUTO-2.1-VIS-016 (420nm - 650nm) HR Version

Part no.:	HES 7020-1 6010-VIS-016
Wavelength Range:	420 – 650 nm
Active Area:	15.36 mm x 8.64 mm
Pixel Pitch:	8 µm
Fill Factor:	93%
Reflectivity:	67%
Display Mode:	PAN (Parallel Aligned Nematic)

The PLUTO-2.1-VIS-016 version features an AR coating with front reflection less than 0.5% in the 420 – 650 nm range. Using high retardation LC material the PLUTO-2.1-VIS-016 provides a max. phase shift up to ~ 9 π (dependent on wavelength).

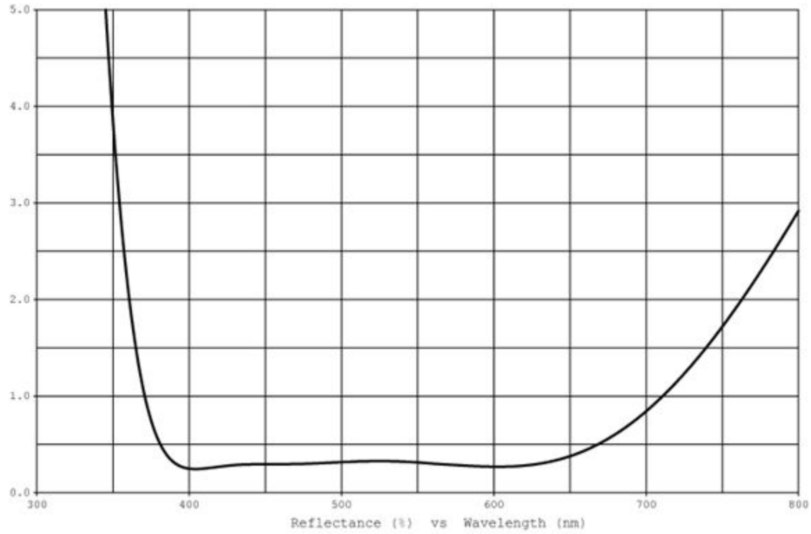


Figure 25: AR coating of the PLUTO-2.1-VIS-016 panel

Using an adapted gamma curve for 2 π phase shift at a certain wavelength, this version also can be used to significantly reduce phase flicker effects.

NOTE
For phase only modulation with this display version the incident polarization has to be along the long display axis!

Wavelength	Maximum Phase Shift	Average Reflectivity
450 nm	9.1 π	66 %
532 nm	6.9 π	66 %
635 nm	5.2 π	67 %

Table 5: Maximum phase shift for PLUTO-2.1-VIS-016

1.7.4.1 Phase Flicker & Response Time @ 450 nm

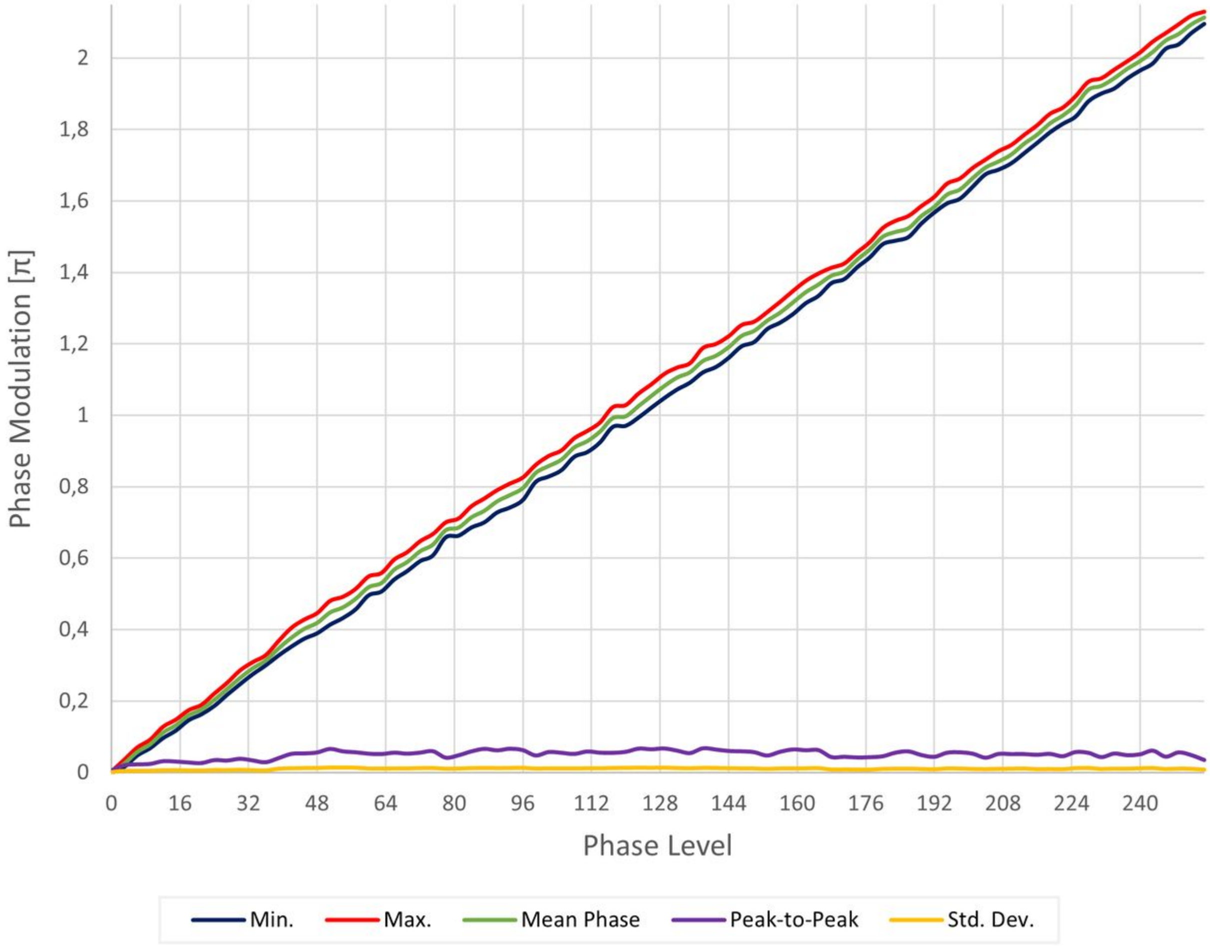


Figure 26: Phase flicker measurements @ 450 nm with PLUTO-2.1-VIS-016

Panel Version	PLUTO-2.1-VIS-016
Max. phase shift @ 450 nm	9.1 π
Flicker Std. Deviation: 2π @ 450 nm	0.01 π, *0.003 π
Flicker max. Peak-to-Peak: 2π @ 450 nm	3.3 %, *1.4 %
Response time: 2π @ 450 nm (rise + fall)	21 ms + 38 ms
	*in low-flicker configuration

1.7.4.2 Phase Flicker & Response Time @ 520 nm

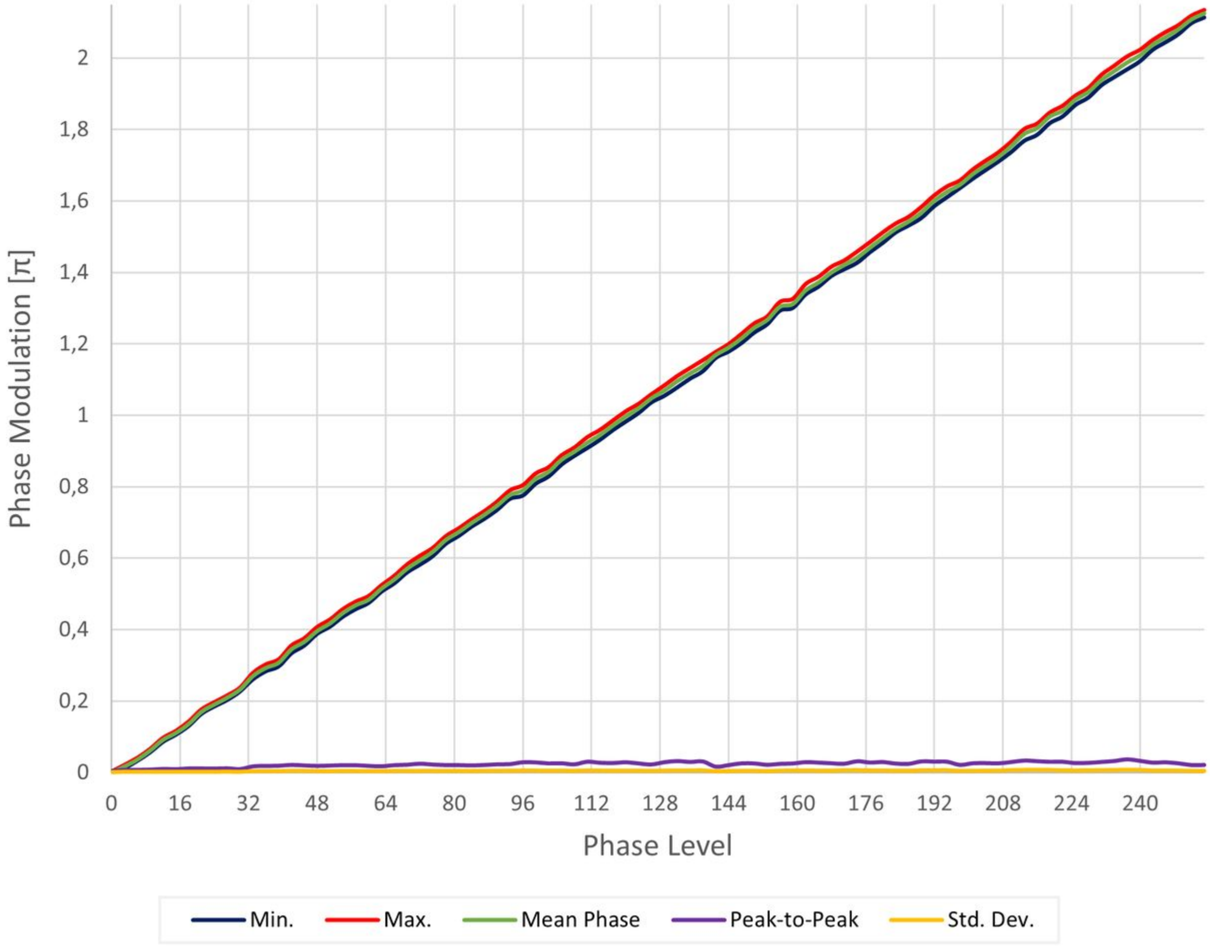


Figure 27: Phase flicker measurements @ 520 nm with PLUTO-2.1-VIS-016

Panel Version	PLUTO-2.1-VIS-016
Max. phase shift @ 520 nm	6.9 π
Flicker Std. Deviation: 2π @ 520 nm	0.005 π, *0.003 π
Flicker max. Peak-to-Peak: 2π @ 520 nm	1.7 %, *1.3 %
Response time: 2π @ 520 nm (rise + fall)	43 ms + 71 ms
	*in low-flicker configuration

1.7.4.3 Phase Flicker & Response Time @ 635 nm

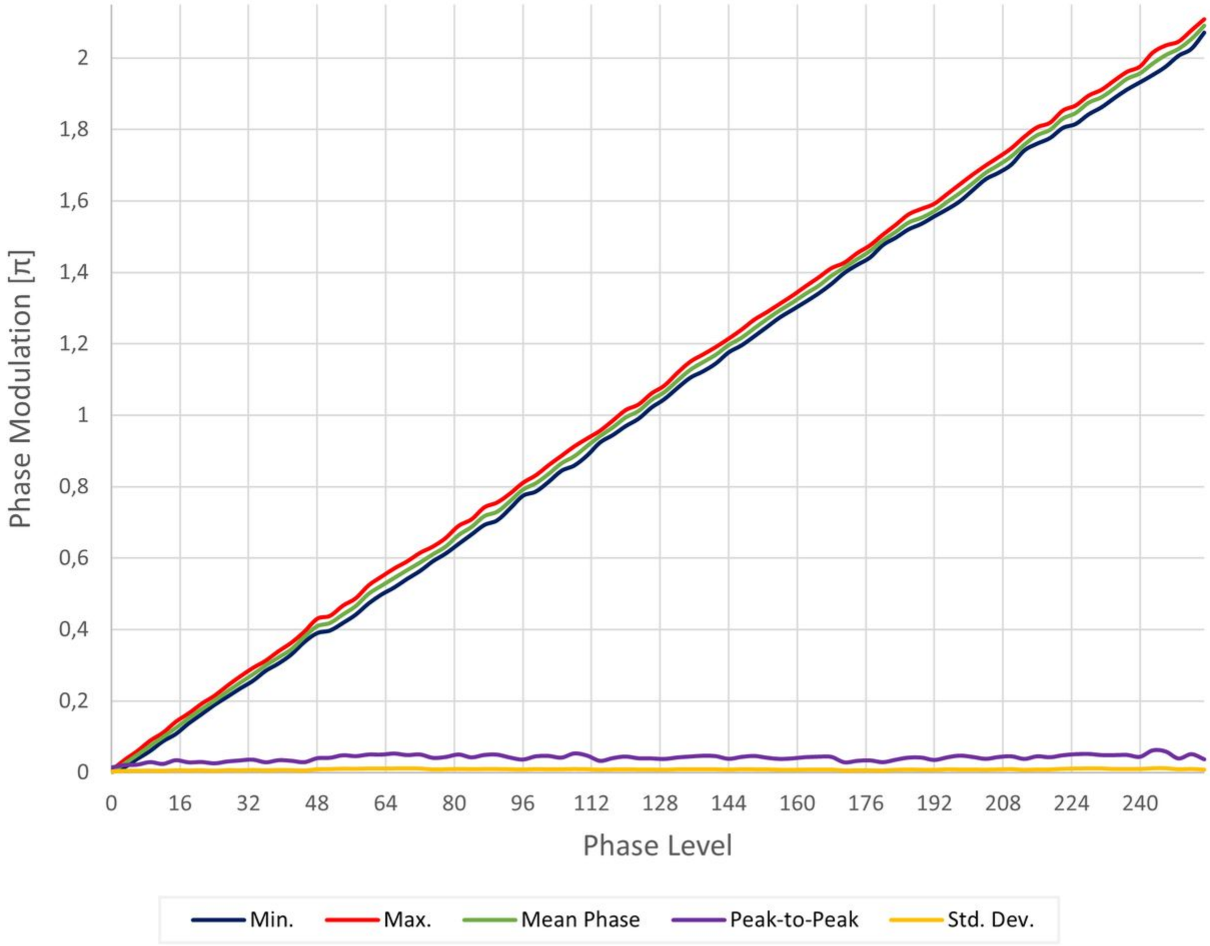


Figure 28: Phase flicker measurements @ 635 nm with PLUTO-2.1-VIS-016

Panel Version	PLUTO-2.1-VIS-016
Max. phase shift @ 635 nm	5.2 π
Flicker Std. Deviation: 2π @ 635 nm	0.008 π, *0.004 π
Flicker max. Peak-to-Peak: 2π @ 635 nm	2.7 %, *2.0 %
Response time: 2π @ 635 nm (rise + fall)	25 ms + 61 ms
	*in low-flicker configuration

1.7.5 PLUTO-2.1-VIS-130 (500nm - 660nm)

Part no.:	HES 7020-1 6010-VIS-130
Wavelength Range:	500 – 660 nm
Active Area:	15.36 mm x 8.64 mm
Pixel Pitch:	8 µm
Fill Factor:	93%
Reflectivity:	94% (average)
Display Mode:	VAN (Vertically Aligned Nematic)

The PLUTO-2.1-VIS-130 version can be used between 500 nm and 660 nm. This version features an AR coating with front reflection less than 0.5% in the 420 – 1000 nm range.

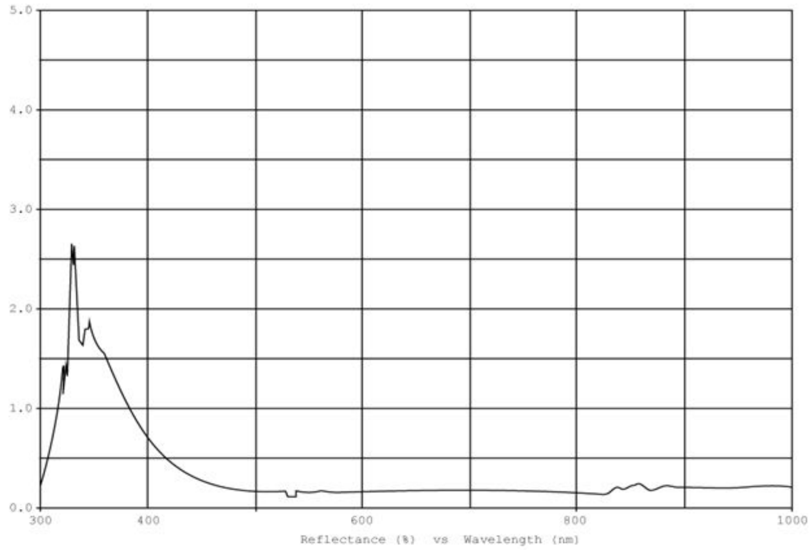


Figure 29: AR coating of the PLUTO-2.1-VIS-130

The display is equipped with a dielectric mirror to enhance reflectivity in the range of 500 – 660 nm. This also reduces absorption which enables the use of higher power sources compared to the standard PLUTO-2.1 versions.

NOTE
For phase only modulation with this display version the incident polarization has to be along the long display axis!

Wavelength	Maximum Phase Shift	Average Reflectivity
450 nm	4.2 π	80 %
520 nm	3.3 π	93 %
633 nm	2.5 π	96 %

Table 6: Maximum phase shift for PLUTO-2.1-VIS-130

1.7.5.1 Phase Flicker & Response Time @ 520 nm

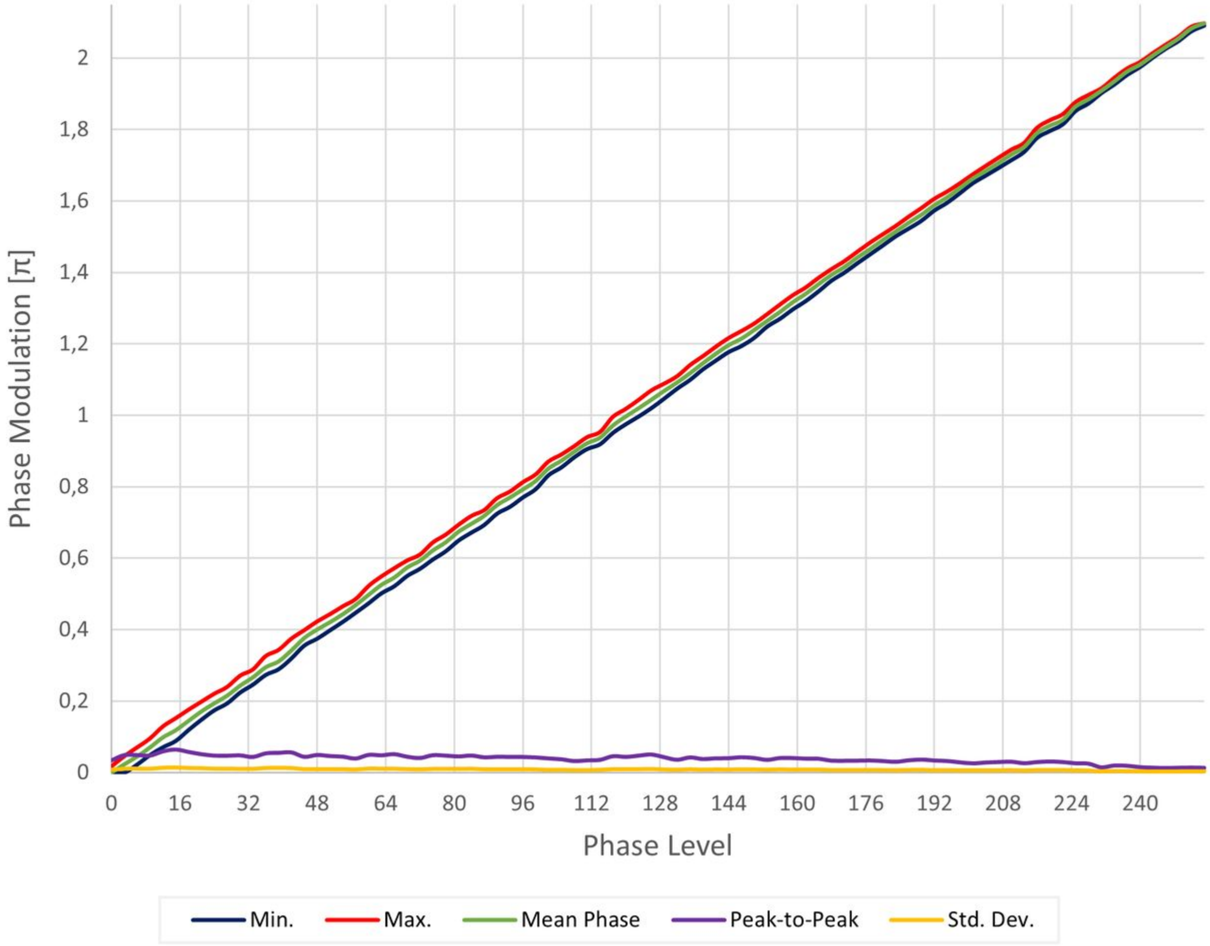


Figure 30: Phase flicker measurements @ 520nm with PLUTO-2.1-VIS-130

Panel Version	PLUTO-2.1-VIS-130
Max. phase shift @ 520 nm	3.3 π
Flicker Std. Deviation: 2π @ 520 nm	0.014 π
Flicker max. Peak-to-Peak: 2π @ 520 nm	3.1 %
Response time: 2π @ 520 nm (rise + fall)	31 ms + 47 ms

1.7.5.2 Phase Flicker & Response Time @ 635 nm

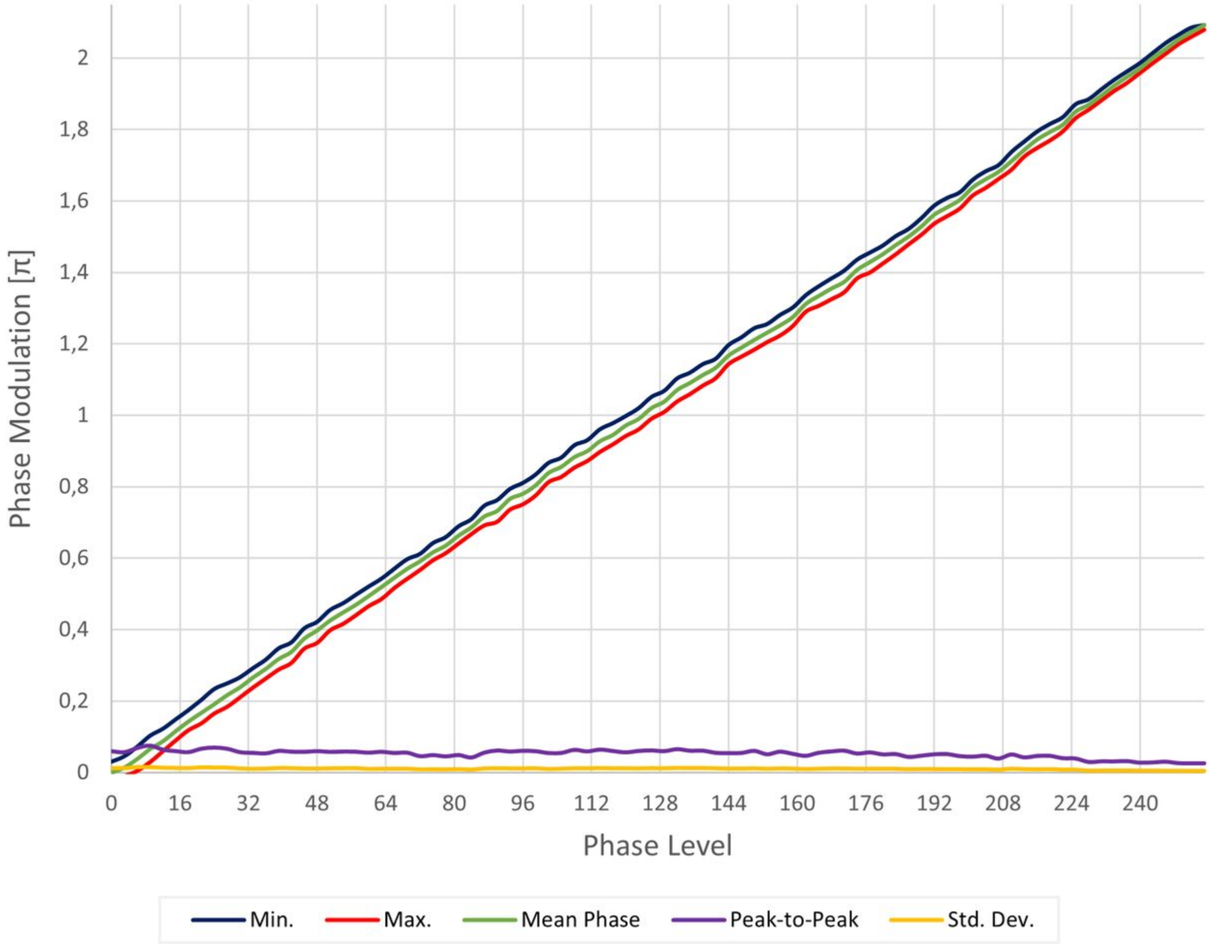


Figure 31: Phase flicker measurements @ 635 nm with PLUTO-2.1-VIS-130

Panel Version	PLUTO-2.1-VIS-130
Max. phase shift @ 633 nm	2.5 π
Flicker Std. Deviation: 2π @ 633 nm	0.015 π
Flicker max. Peak-to-Peak: 2π @ 633 nm	3.5 %
Response time: 2π @ 633 nm (rise + fall)	23 ms + 44 ms

1.7.6 PLUTO-2.1-NIR-145 (420nm – 1064nm)

Part no.:	HES 7020-1 6010-NIR-145
Wavelength Range:	420 – 1064 nm
Active Area:	15.36 mm x 8.64 mm
Pixel Pitch:	8 µm
Fill Factor:	93%
Reflectivity:	65% – 87% (80% average)
Display Mode:	PAN (Parallel Aligned Nematic)

The PLUTO-2.1-NIR-145 version enables at least 2 π phase retardation in the 420 nm - 1064 nm range. The display is equipped with a broad band AR coating that enables low front reflection in this broad wavelength range (see coating specs in figure 32).

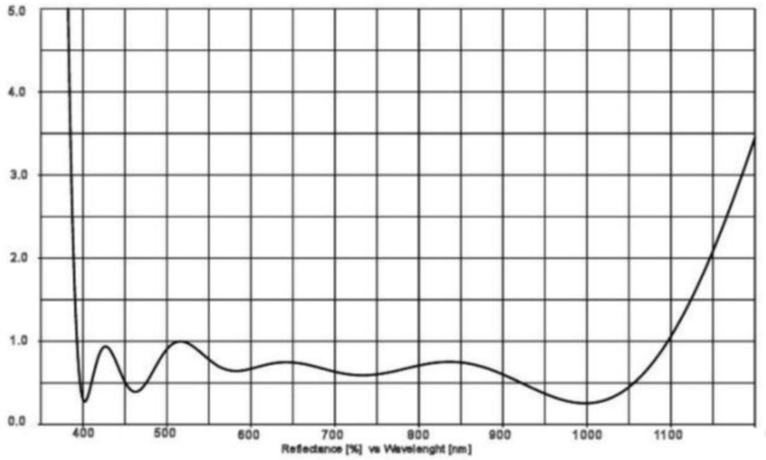


Figure 32: AR coating of the PLUTO-2.1-NIR-145

Even though the PLUTO-2.1-NIR-145 can be used from 420 nm to 1064 nm it is recommended to use the VIS versions in the visible range as the AR coating and response times are better.

NOTE
For phase only modulation with this display version the incident polarization has to be along the long display axis!

Wavelength	Maximum Phase Shift	Average Reflectivity
450 nm	7.1 π	78 %
520 nm	5.5 π	80 %
633 nm	4.1 π	80 %
800 nm	3.1 π	85 %
1064 nm	2.2 π	70 %

Table 7: Maximum phase shift for PLUTO-2.1-NIR-145

1.7.6.1 Phase Flicker & Response Time @ 450 nm

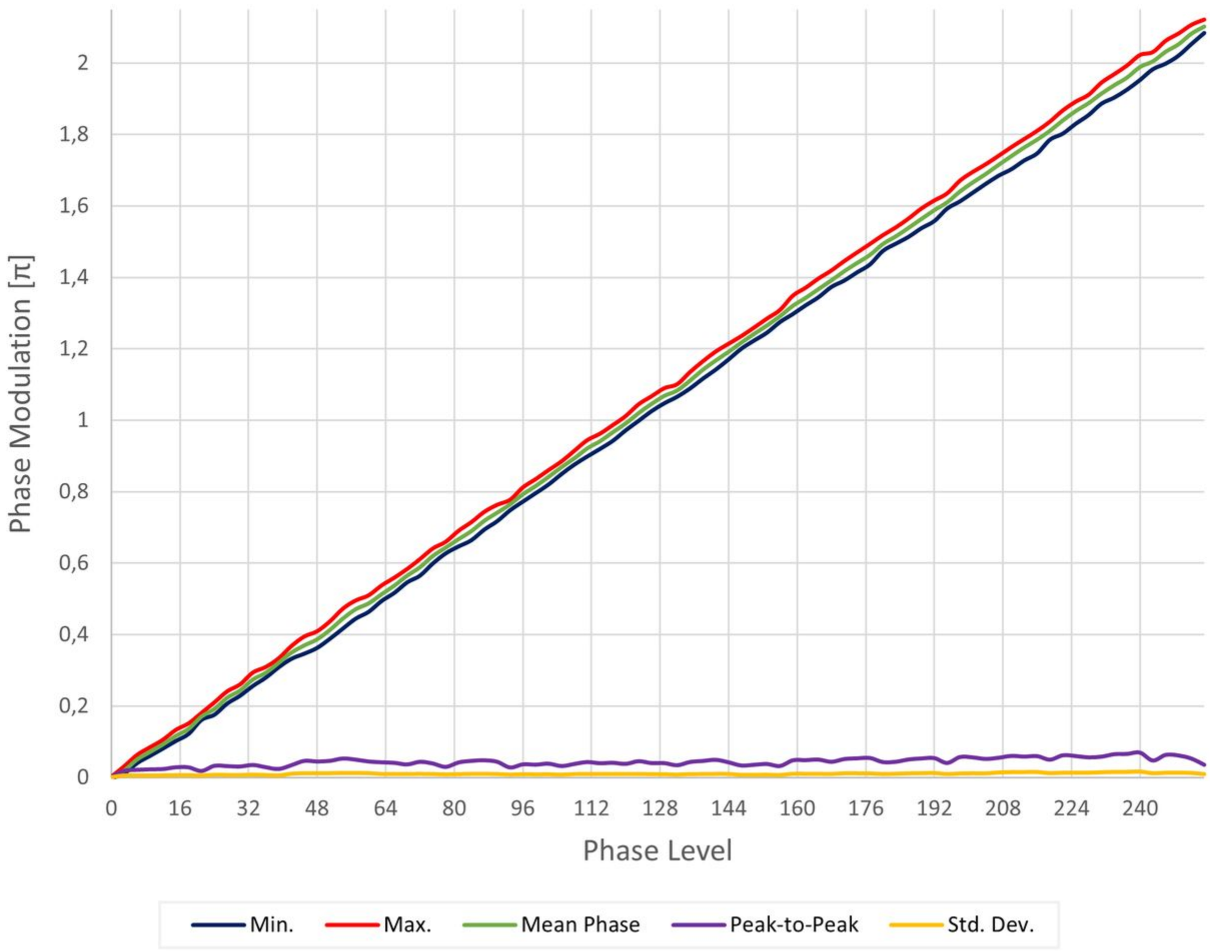


Figure 33: Phase flicker measurements @ 450 nm with PLUTO-2.1-NIR-145

Panel Version	PLUTO-2.1-NIR-145
Max. phase shift @ 450 nm	7.1 π
Flicker Std. Deviation: 2π @ 450 nm	0.010 π
Flicker max. Peak-to-Peak: 2π @ 450 nm	3.3 %
Response time: 2π @ 450 nm (rise + fall)	26 ms + 42 ms

1.7.6.2 Phase Flicker & Response Time @ 520 nm

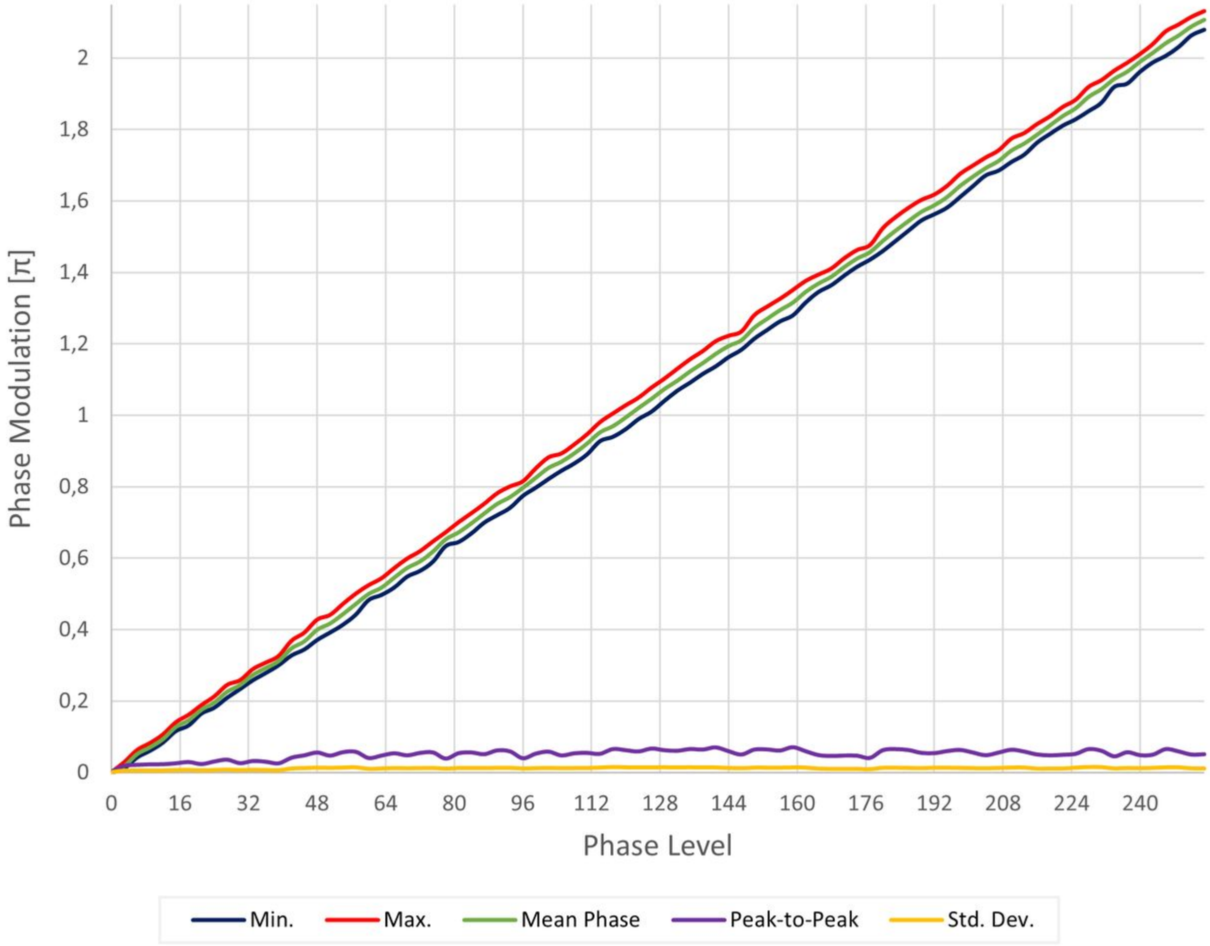


Figure 34: Phase flicker measurements @ 520 nm with PLUTO-2.1-NIR-145

Panel Version	PLUTO-2.1-NIR-145
Max. phase shift @ 520 nm	5.5 π
Flicker Std. Deviation: 2π @ 520 nm	0.011 π
Flicker max. Peak-to-Peak: 2π @ 520 nm	3.4 %
Response time: 2π @ 520 nm (rise + fall)	19 ms + 36 ms

1.7.6.3 Phase Flicker & Response Time @ 635 nm

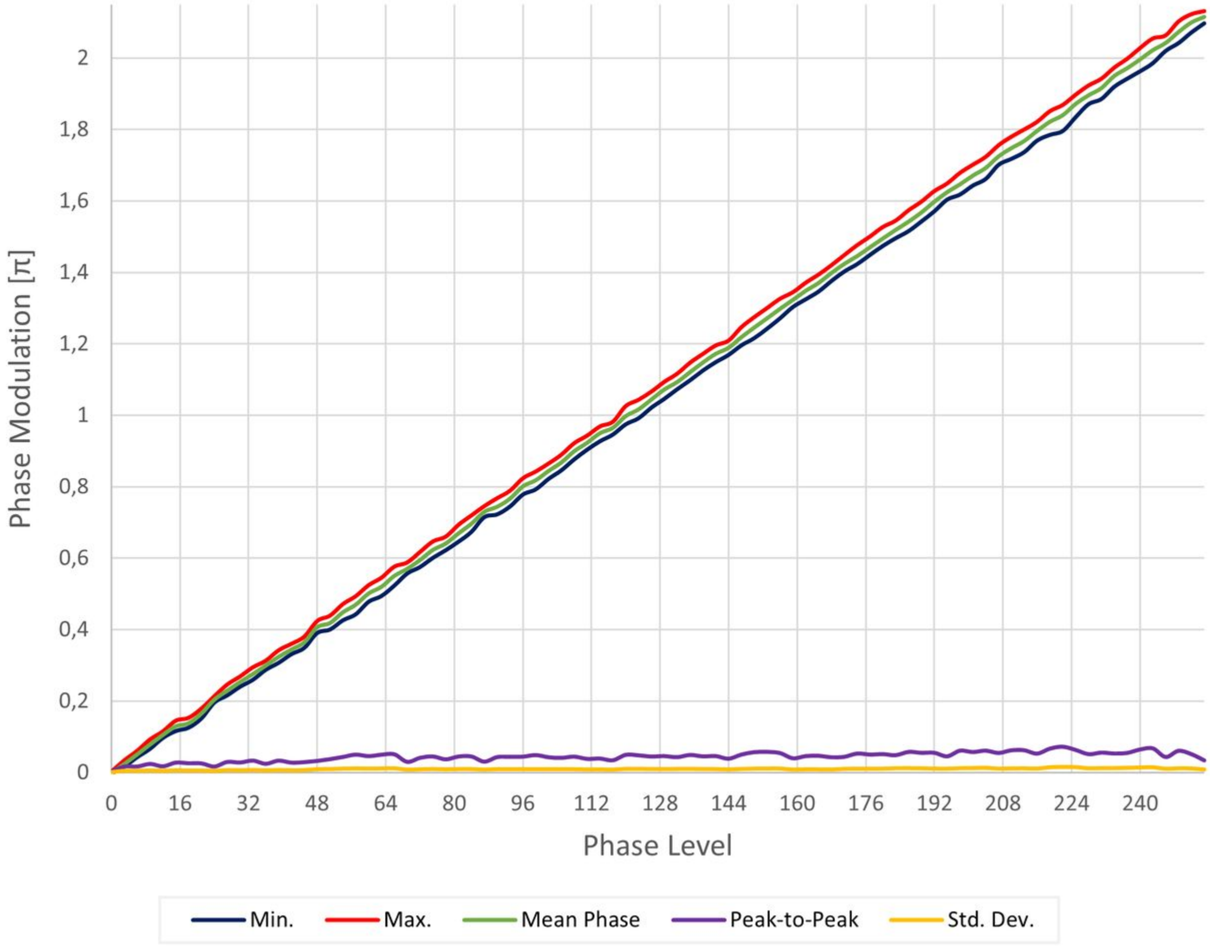


Figure 35: Phase flicker measurements @ 635 nm with PLUTO-2.1-NIR-145

Panel Version	PLUTO-2.1-NIR-145
Max. phase shift @ 635 nm	4.0 π
Flicker Std. Deviation: 2π @ 635 nm	0.010 π
Flicker max. Peak-to-Peak: 2π @ 635 nm	3.4 %
Response time: 2π @ 635 nm (rise + fall)	21 ms + 48 ms

1.7.6.4 Phase Flicker & Response Time @ 800 nm

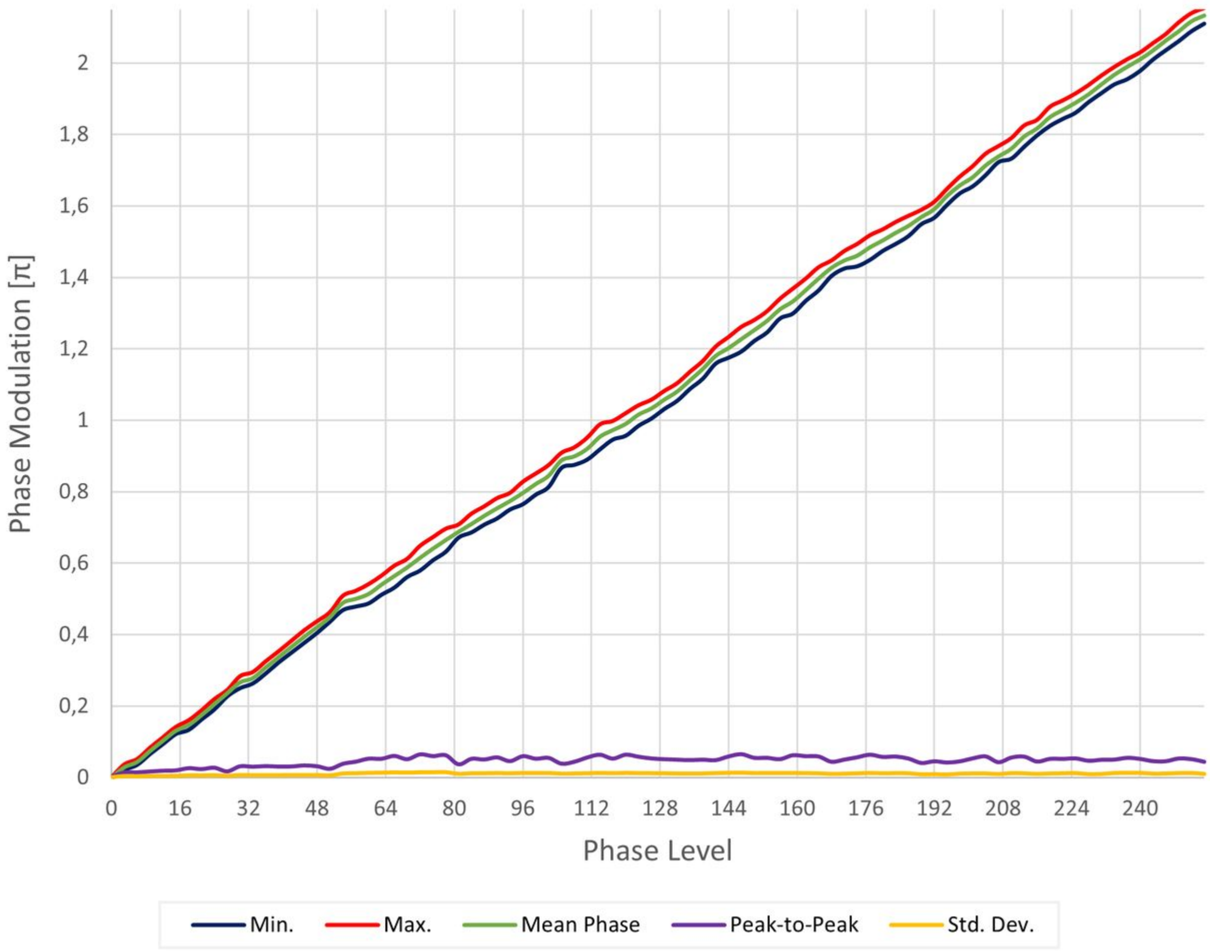


Figure 36: Phase flicker measurements @ 800 nm with PLUTO-2.1-NIR-145

Panel Version	PLUTO-2.1-NIR-145
Max. phase shift @ 800 nm	3.1 π
Flicker Std. Deviation: 2π @ 800 nm	0.01 π
Flicker max. Peak-to-Peak: 2π @ 800 nm	3.3 %
Response time: 2π @ 800 nm (rise + fall)	16 ms + 50 ms

1.7.6.5 Phase Flicker & Response Time @ 1064 nm

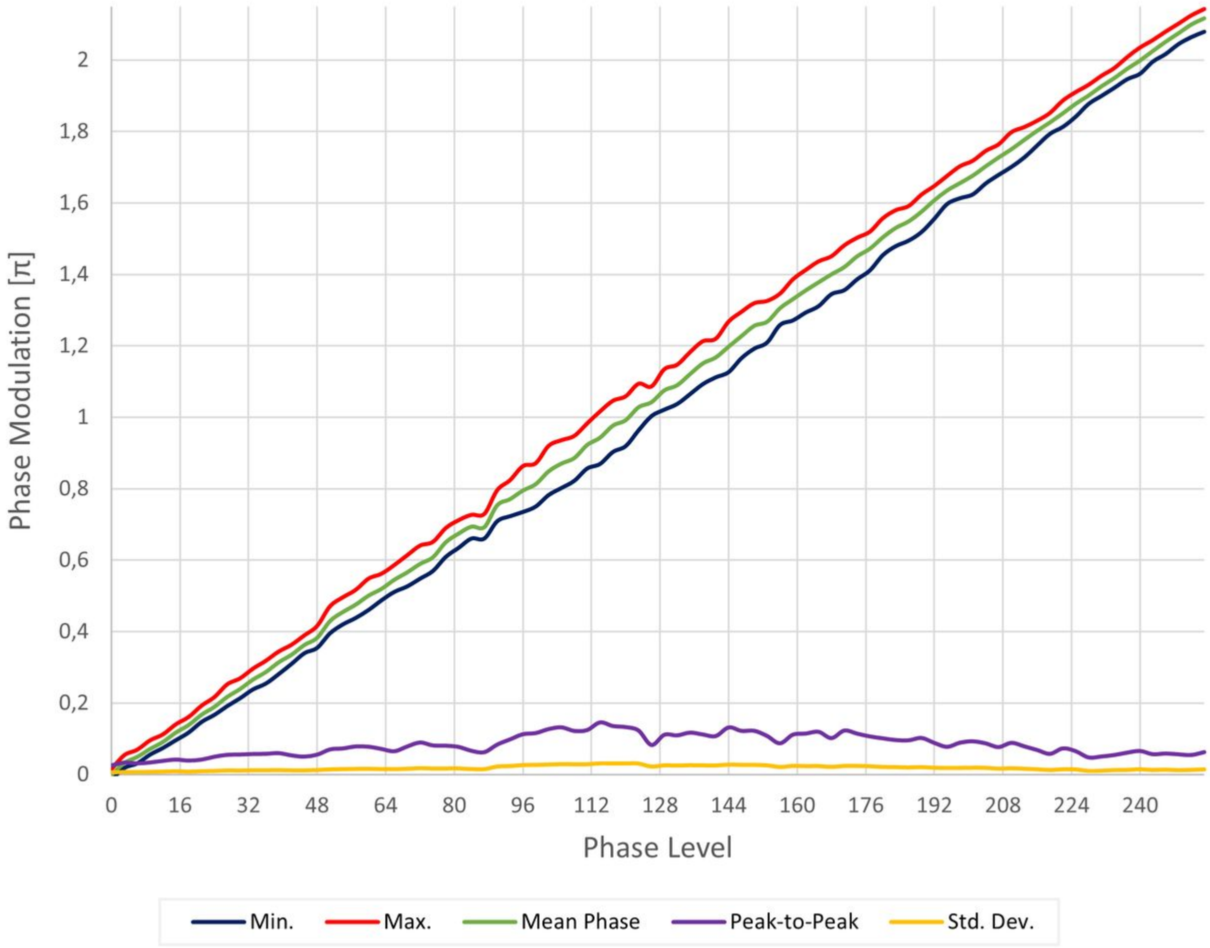


Figure 37: Phase flicker measurements @ 1064 nm with PLUTO-2.1-NIR-145

Panel Version	PLUTO-2.1-NIR-145
Max. phase shift @ 1064 nm	2.2 π
Flicker Std. Deviation: 2π @ 1064 nm	0.018 π
Flicker max. Peak-to-Peak: 2π @ 1064 nm	7.0 %
Response time: 2π @ 1064 nm (rise + fall)	7 ms + 49 ms

1.7.7 PLUTO-2.1-NIR-015 (650nm-1100nm) HR Version

Part no.:	HES 7020-1 6010-NIR-015
Wavelength Range:	650 – 1100 nm
Active Area:	15.36 mm x 8.64 mm
Pixel Pitch:	8 µm
Fill Factor:	93%
Reflectivity:	65% – 73%
Display Mode:	PAN (Parallel Aligned Nematic)

The PLUTO-2.1-NIR-015 version is equipped with an AR coating for the range of 650 nm to 1100 nm.

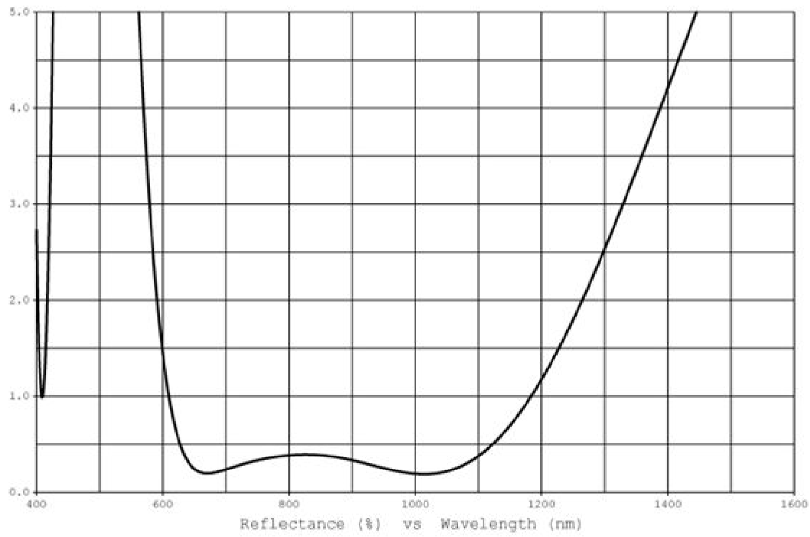


Figure 38: AR coating of the PLUTO-2.1-NIR-015

Using high retardation LC material the PLUTO-2.1-NIR-015 provides a high phase shift enabling mod 4π or even mod 6π phase functions (dependent on wavelength). Using an adapted gamma curve for 2π phase shift, this version also can be used to significantly reduce phase fluctuations.

NOTE
For phase only modulation with this display version the incident polarization has to be along the long display axis!

Wavelength	Maximum Phase Shift	Average Reflectivity
635 nm	6.8 π	68 %
800 nm	5.4 π	65 %
1064 nm	3.6 π	73 %

Table 8: Maximum phase shift for PLUTO-2.1-NIR-015

1.7.7.1 Phase Flicker & Response Time @ 635 nm

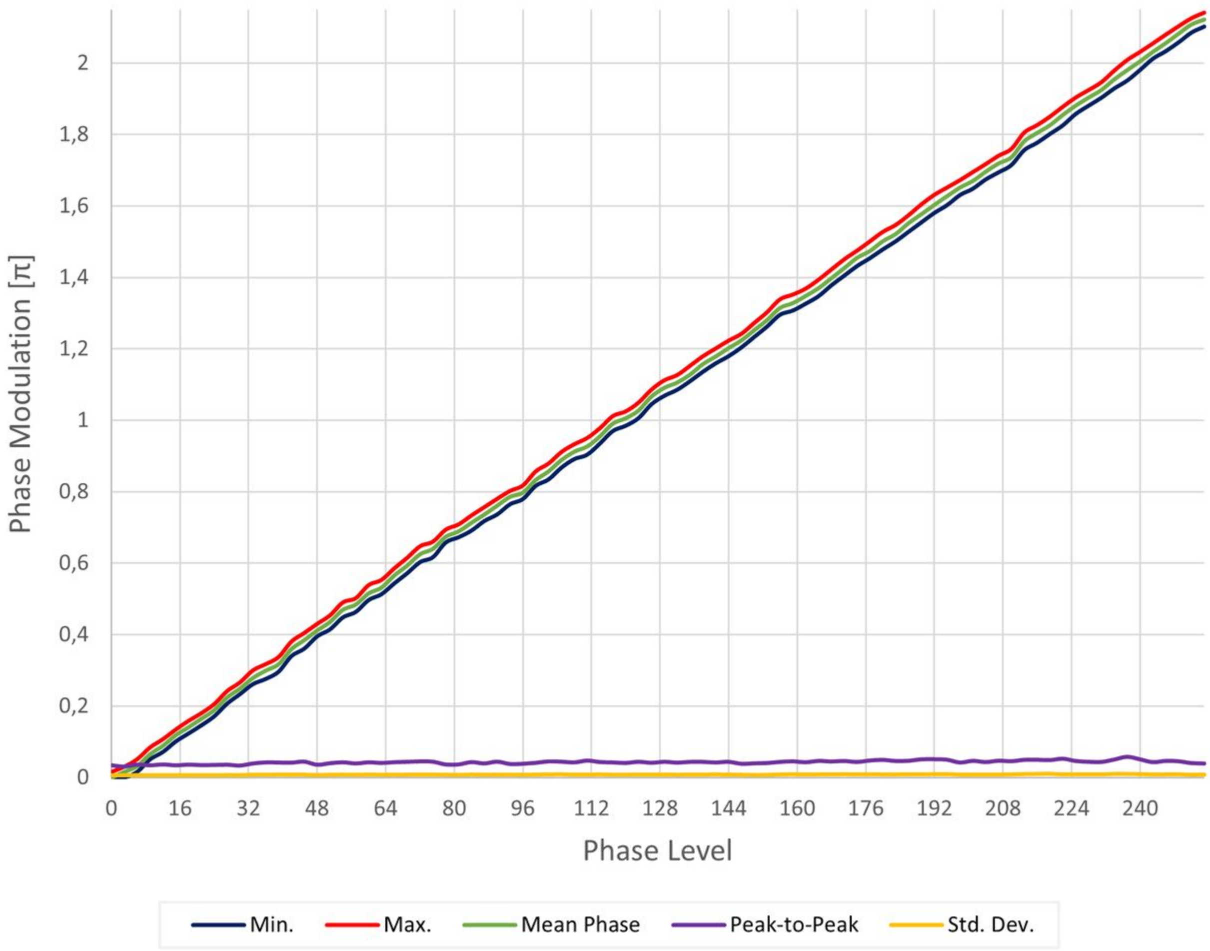


Figure 39: Phase flicker measurements @ 635 nm with PLUTO-2.1-NIR-015

Panel Version	PLUTO-2.1-NIR-015
Max. phase shift @ 635 nm	6.8 π
Flicker Std. Deviation: 2π @ 635 nm	0.008 π, *0.005 π
Flicker max. Peak-to-Peak: 2π @ 635 nm	2.7 %, *1.4 %
Response time: 2π @ 635 nm (rise + fall)	52 ms + 81 ms
	*in low-flicker configuration

1.7.7.2 Phase Flicker & Response Time @ 800 nm

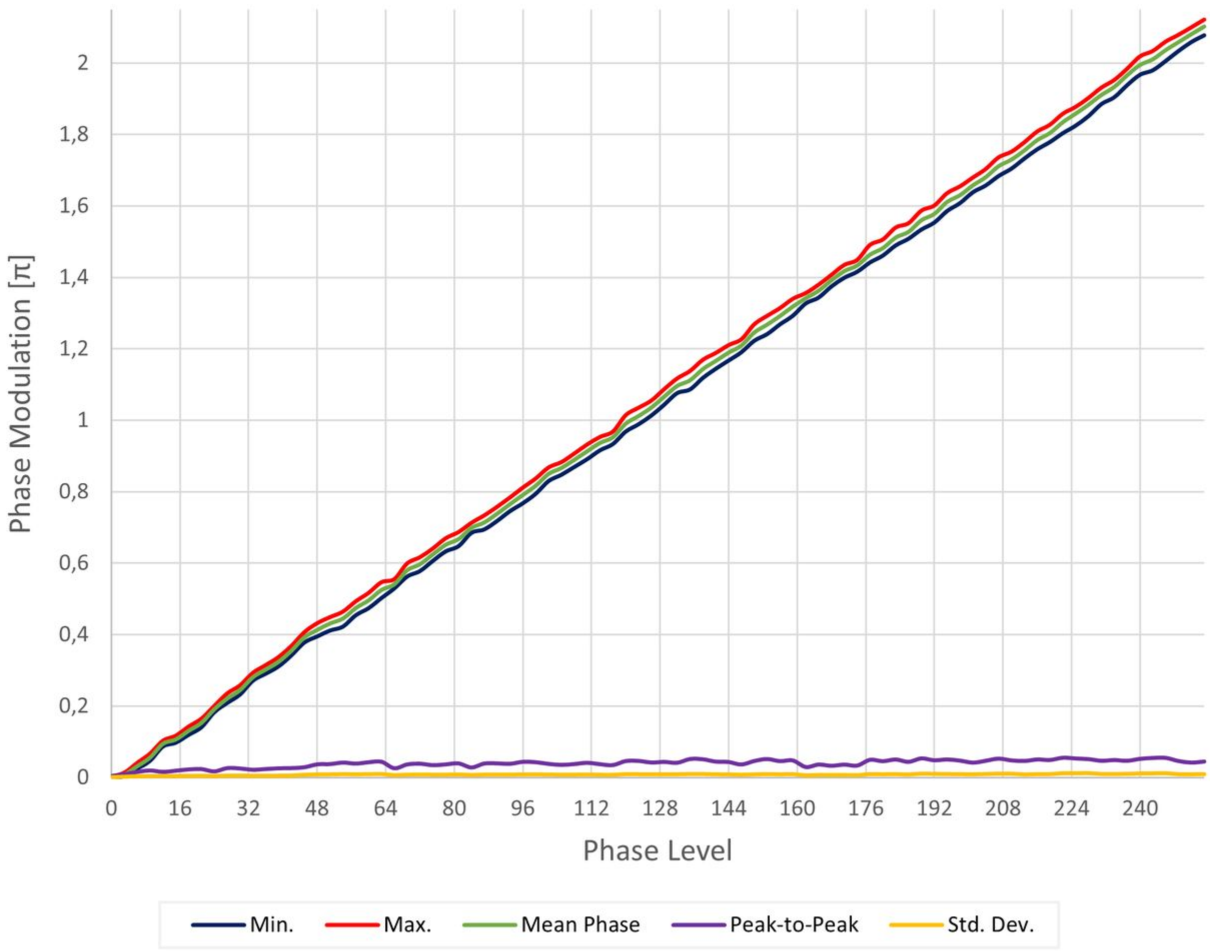


Figure 40: Phase flicker measurements @ 800 nm with PLUTO-2.1-NIR-015

Panel Version	PLUTO-2.1-NIR-015
Max. phase shift @ 800 nm	5.4 π
Flicker Std. Deviation: 2π @ 800 nm	0.008 π, *0.004 π
Flicker max. Peak-to-Peak: 2π @ 800 nm	2.6 %, *1.4 %
Response time: 2π @ 800 nm (rise + fall)	24 ms + 57 ms
	*in low-flicker configuration

1.7.7.3 Phase Flicker & Response Time @ 1064 nm

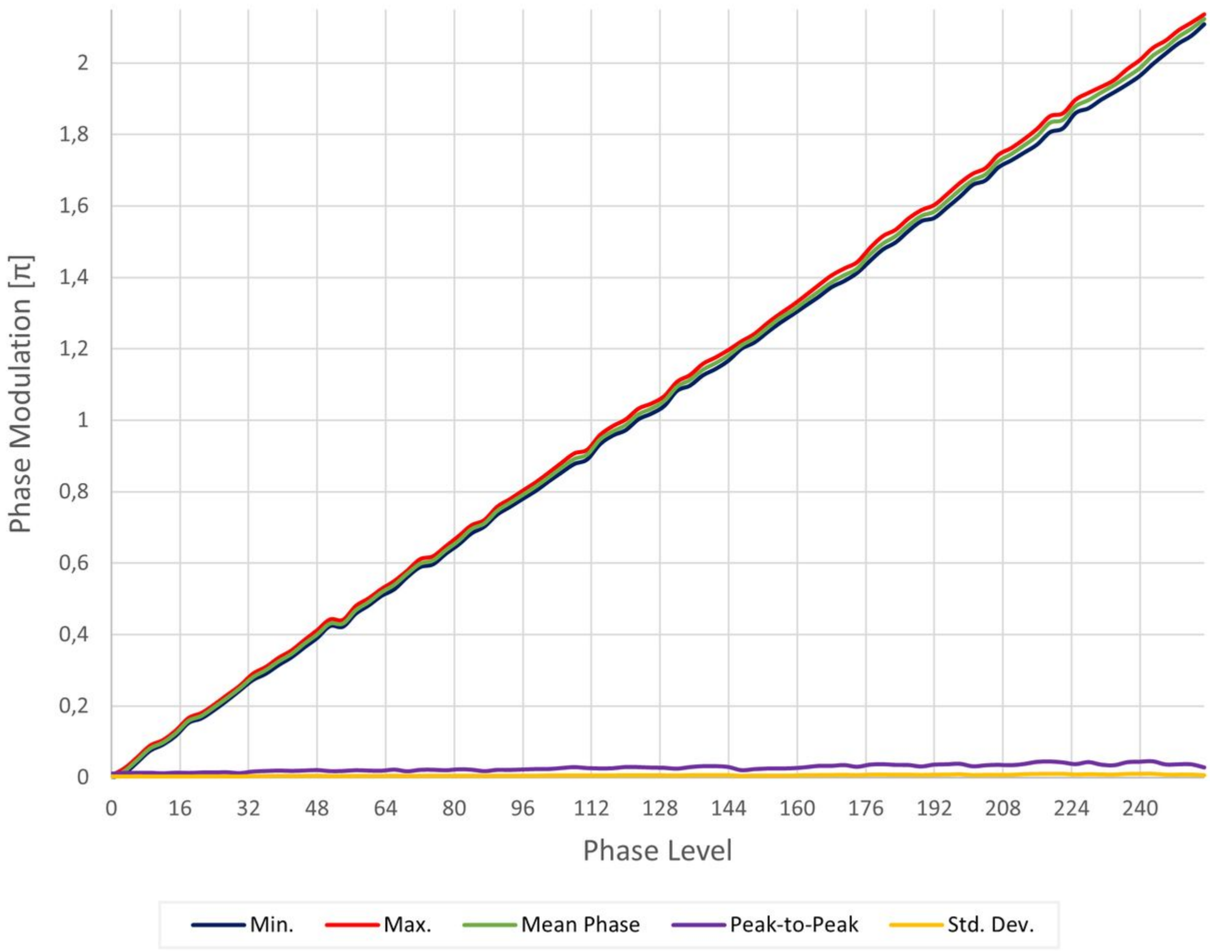


Figure 41: Phase flicker measurements @ 1064 nm with PLUTO-2.1-NIR-015

Panel Version	PLUTO-2.1-NIR-015
Max. phase shift @ 1064 nm	3.6 π
Flicker Std. Deviation: 2π @ 1064 nm	0.005 π
Flicker max. Peak-to-Peak: 2π @ 1064 nm	2.1 %
Response time: 2π @ 1064 nm (rise + fall)	43 ms + 95 ms

1.7.8 PLUTO-2.1-NIR-113 (730nm-940nm)

Part no.:	HES 7020-1 6010-NIR-113
Wavelength Range:	730 – 940 nm
Active Area:	15.36 mm x 8.64 mm
Pixel Pitch:	8 µm
Fill Factor:	93%
Reflectivity:	95%
Display Mode:	VAN (Vertically Aligned Nematic)

The PLUTO-2.1-NIR-113 version can be used between 730 nm and 940 nm. This version uses the same broadband AR coating as the PLUTO-2.1-NIR-015 version.

The display is equipped with a dielectric mirror to enhance reflectivity in the range of 730 – 940 nm. This also reduces absorption which enables the use of higher power sources compared to the standard PLUTO-2.1 versions.

NOTE
For phase only modulation with this display version the incident polarization has to be along the long display axis!

Wavelength	Maximum Phase Shift	Average Reflectivity
800 nm	2.5 π	95 %

Table 9: Maximum phase shift for PLUTO-2.1-NIR-113

1.7.8.1 Phase Flicker & Response Time @ 800 nm

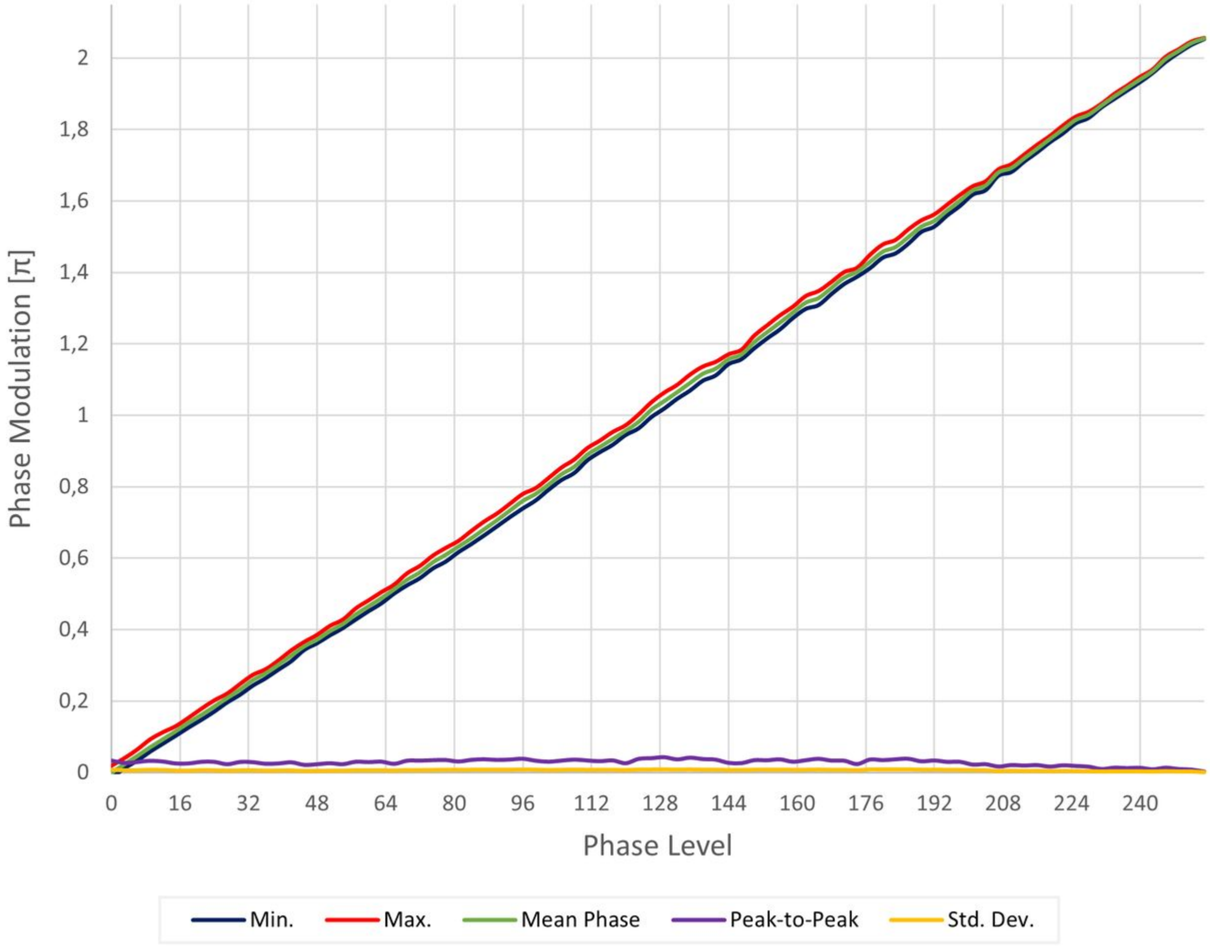


Figure 42: Phase flicker measurements @ 800 nm with PLUTO-2.1-NIR-113

Panel Version	PLUTO-2.1-NIR-113
Max. phase shift @ 800 nm	2.5 π
Flicker Std. Deviation: 2π @ 800 nm	0.006 π, *0.005 π
Flicker max. Peak-to-Peak: 2π @ 800 nm	2.1 %, *1.5 %
Response time: 2π @ 800 nm (rise + fall)	31 ms + 94 ms
	*in low-flicker configuration

1.7.9 PLUTO-2.1-NIR-149 (1000nm-1100nm)

Part no.:	HES 7020-1 6010-NIR-149
Wavelength Range:	1000 – 1100 nm
Active Area:	15.36 mm x 8.64 mm
Pixel Pitch:	8 µm
Fill Factor:	93%
Reflectivity:	93%
Display Mode:	PAN (Parallel Aligned Nematic)

The PLUTO-2.1-NIR-149 version can be used between 1000 nm and 1100 nm. This version uses the same broadband AR coating as the PLUTO-2.1-NIR-015 version.

The display is equipped with a dielectric mirror to enhance reflectivity in the range of 1000 – 1100 nm. This also reduces absorption which enables the use of higher power sources compared to the standard PLUTO-2.1 versions.

NOTE
For phase only modulation with this display version the incident polarization has to be along the long display axis!

Wavelength	Maximum Phase Shift	Average Reflectivity
1064 nm	2.9 π	93 %

Table 10: Maximum phase shift for PLUTO-2.1-NIR-149

1.7.9.1 Phase Flicker & Response Time @ 1064 nm

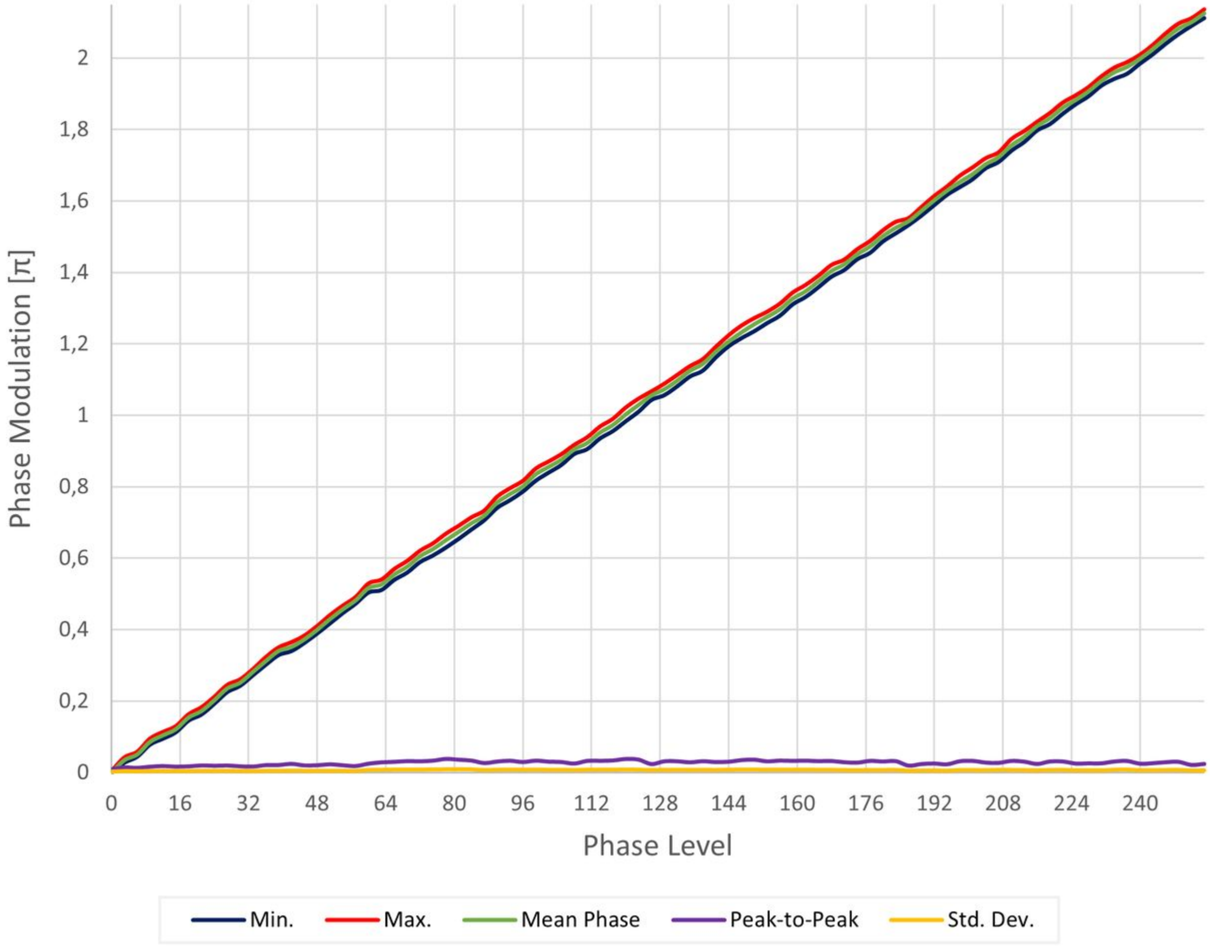


Figure 43: Phase flicker measurements @ 1064 nm with PLUTO-2.1-NIR-149

Panel Version	PLUTO-2.1-NIR-149
Max. phase shift @ 1064 nm	2.9 π
Flicker Std. Deviation: 2π @ 1064 nm	0.006 π, *0.005 π
Flicker max. Peak-to-Peak: 2π @ 1064 nm	1.9 %, *1.6 %
Response time: 2π @ 1064 nm (rise + fall)	30 ms + 97 ms

*in low-flicker configuration

1.7.10 PLUTO-2.1-NIRO-024 (1064nm-1400nm)

Part no.:	HES 7020-1 6010-NIRO-024
Wavelength Range:	1064 – 1400 nm
Active Area:	15.36 mm x 8.64 mm
Pixel Pitch:	8 µm
Fill Factor:	93%
Reflectivity:	82%
Display Mode:	PAN (Parallel Aligned Nematic)

The PLUTO-2.1-NIRO-024 version features an AR coating which assures a front reflection of less than 0.2% between 1064 nm and 1400 nm. The display enables 2π phase retardation up to 1400 nm.

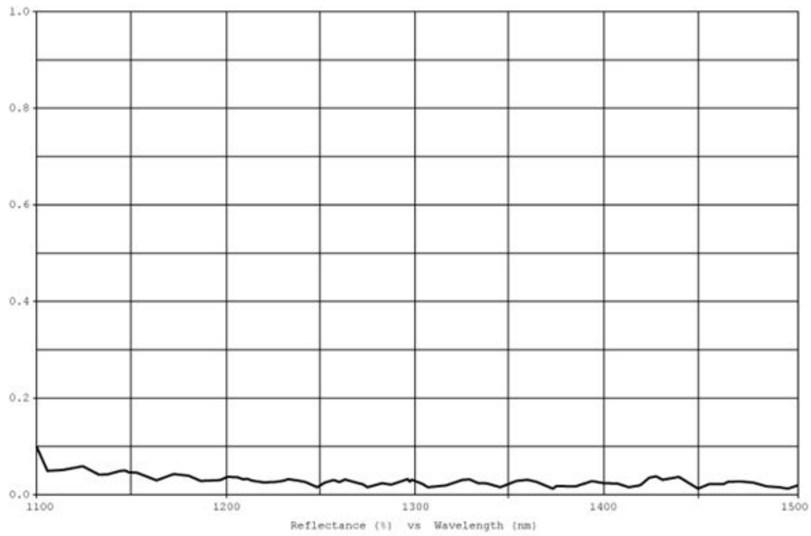


Figure 44: AR coating of the PLUTO-2.1-NIRO-024 panel

NOTE
For phase only modulation with this display version the incident polarization has to be along the long display axis!

Wavelength	Maximum Phase Shift	Average Reflectivity
1064 nm	5.4 π	84 %
1300 nm	4.2 π	82 %

Table 11: Maximum phase shift for PLUTO-2.1-NIRO-024

1.7.10.1 Phase Flicker & Response Time @ 1064 nm

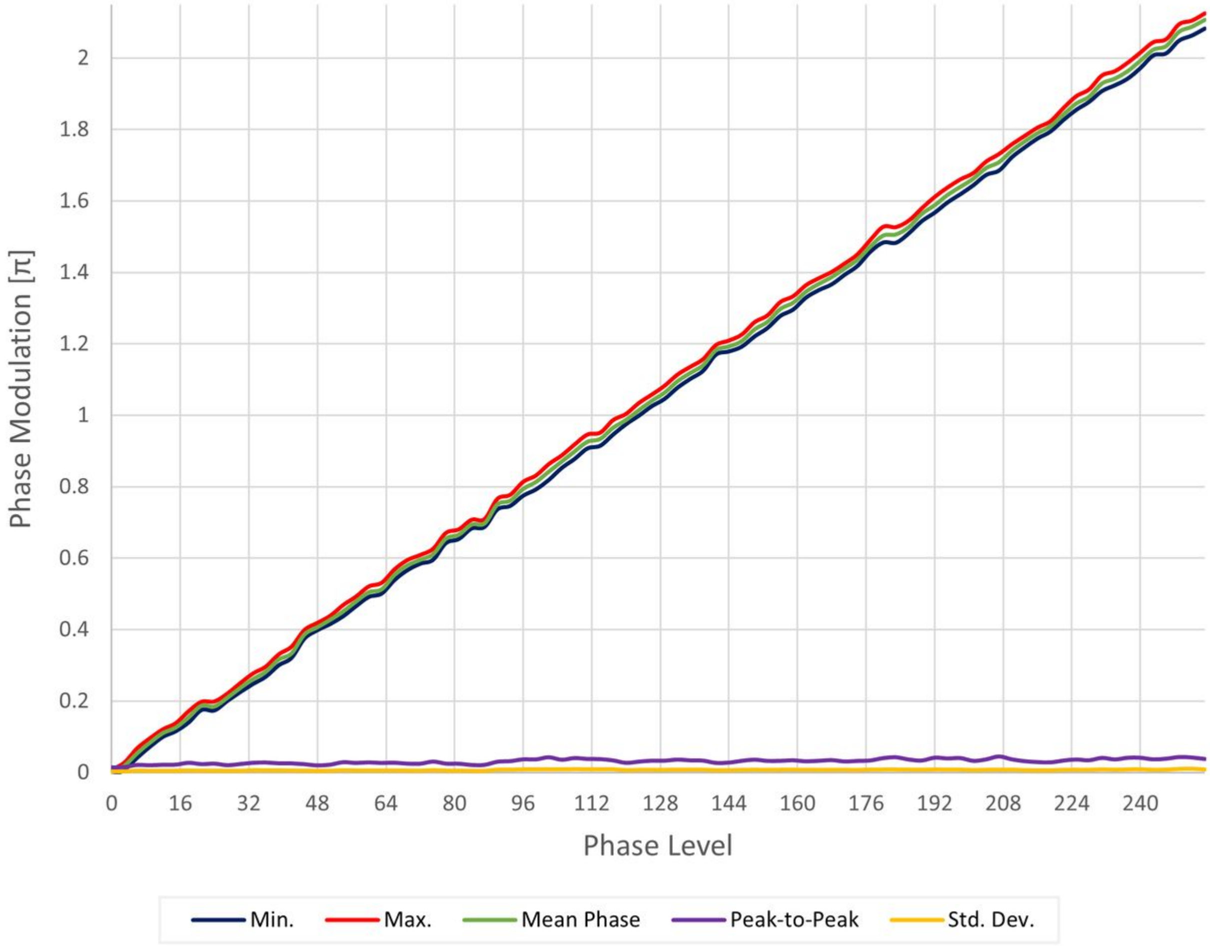


Figure 45: Phase flicker measured at 1064 nm with PLUTO-2.1-NIRO-024

Panel Version	PLUTO-2.1-NIRO-024
Max. phase shift @ 1064 nm	5.4 π
Flicker Std. Deviation: 2π @ 1064 nm	0.003 π, *0.002 π
Flicker max. Peak-to-Peak: 2π @ 1064 nm	0.9 %, *0.8 %
Response time: 2π @ 1064 nm (rise + fall)	135 ms + 256 ms
	*in low-flicker configuration

1.7.10.2 Phase Flicker & Response Time @ 1300 nm

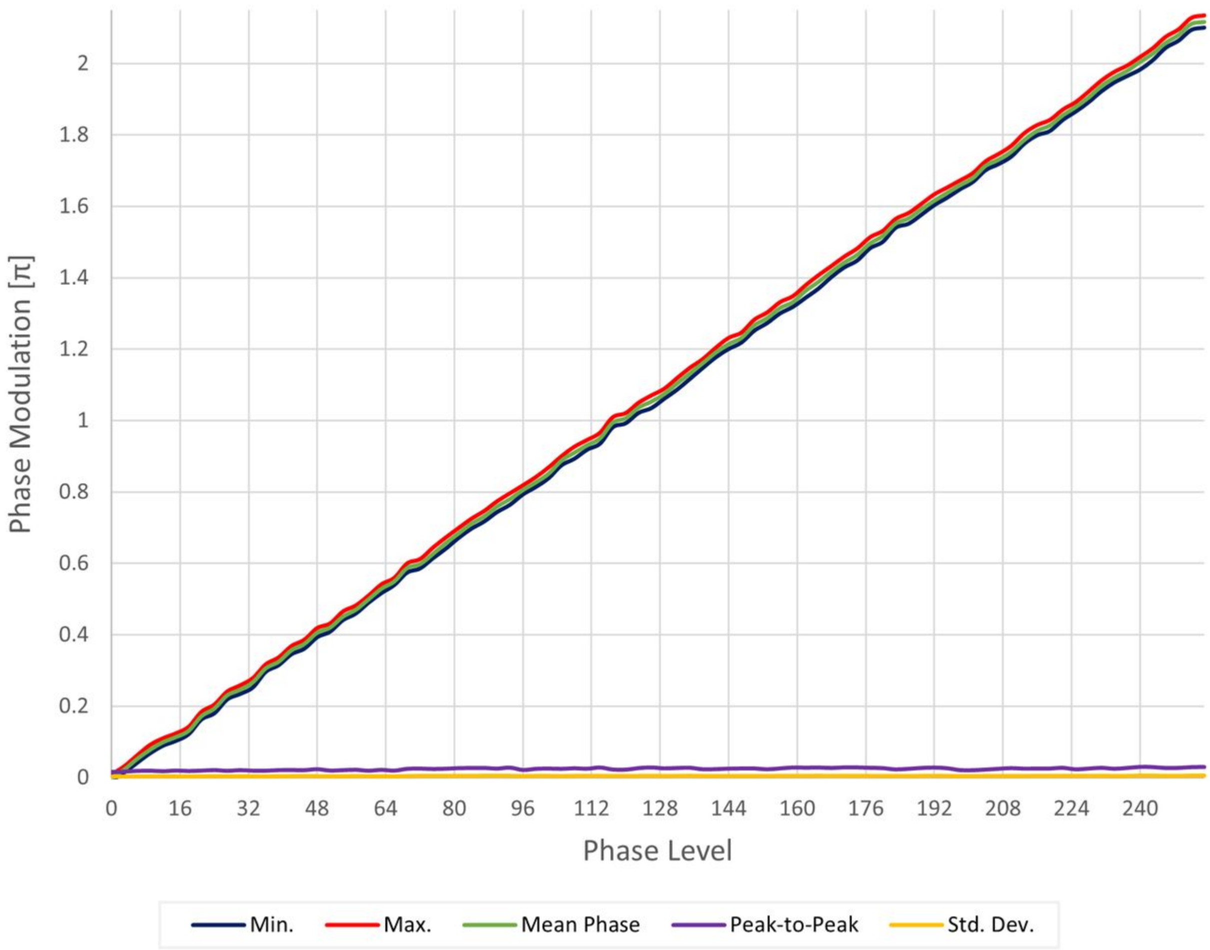


Figure 46: Phase flicker measured at 1300 nm with PLUTO-2.1-NIRO-024

Panel Version	PLUTO-2.1-NIRO-024
Max. phase shift @ 1300 nm	4.2 π
Flicker Std. Deviation: 2π @ 1300 nm	0.003 π, *0.002 π
Flicker max. Peak-to-Peak: 2π @ 1300 nm	1.1 %, *0.8 %
Response time: 2π @ 1300 nm (rise + fall)	112 ms + 250 ms
	*in low-flicker configuration

1.7.11 PLUTO-2.1-TELCO-013 (1400nm-1700nm)

Part no.:	HES 7020-1 6010-TELCO-013
Wavelength Range:	1400 – 1700 nm
Active Area:	15.36 mm x 8.64 mm
Pixel Pitch:	8 µm
Fill Factor:	93%
Reflectivity:	80%
Display Mode:	PAN (Parallel Aligned Nematic)

The PLUTO-2.1-TELCO-013 version features an AR coating which assures a front reflection of less than 0.5% between 1400 and 1700 nm. The display enables at least 2π phase retardation up to 1700 nm.

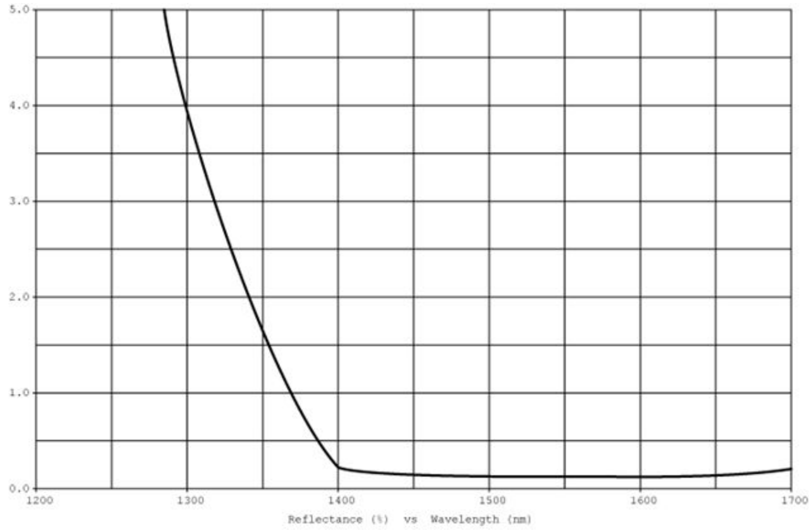


Figure 47: AR coating of the PLUTO-2.1-TELCO-013 panel

NOTE
For phase only modulation with this display version the incident polarization has to be along the long display axis!

Wavelength	Maximum Phase Shift	Average Reflectivity
1400 nm	4.2 π	80 %
1550 nm	3.9 π	80 %
1625 nm	3.6 π	80 %
1700 nm	3.4 π	80 %

Table 12: Maximum phase shift for PLUTO-2.1-TELCO-013

1.7.11.1 Phase Flicker & Response Time @ 1550 nm

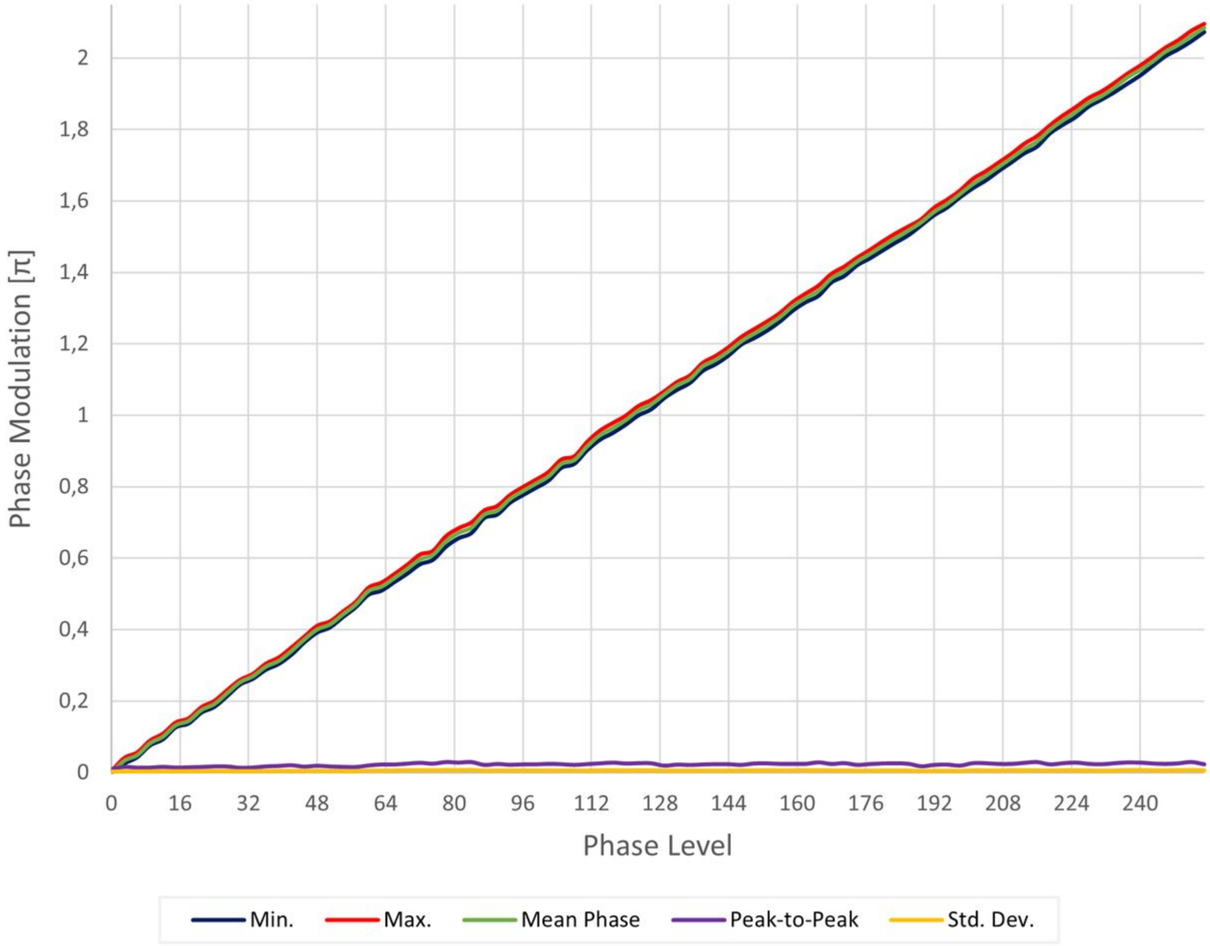


Figure 48: Phase flicker measured at 1550 nm with PLUTO-2.1-TELCO-013

Panel Version	PLUTO-2.1-TELCO-013
Max. phase shift @ 1550 nm	3.9 π
Flicker Std. Deviation: 2π @ 1550 nm	0.004 π, *0.003 π
Flicker max. Peak-to-Peak: 2π @ 1550 nm	1.4 %, *1.1 %
Response time: 2π @ 1550 nm (rise + fall)	37 ms + 133 ms

*in low-flicker configuration

1.7.12 PLUTO-2.1-TELCO-142 (1500nm-1600nm)

Part no.:	HES 7020-1 6010-TELCO-142
Wavelength Range:	1400 – 1700 nm
Active Area:	15.36 mm x 8.64 mm
Pixel Pitch:	8 µm
Fill Factor:	93%
Reflectivity:	93%
Display Mode:	PAN (Parallel Aligned Nematic)

The PLUTO-2.1-TELCO-142 version features an AR coating which assures a front reflection of less than 0.5% between 1400 and 1700 nm. The display enables at least 2π phase retardation up to 1700 nm.

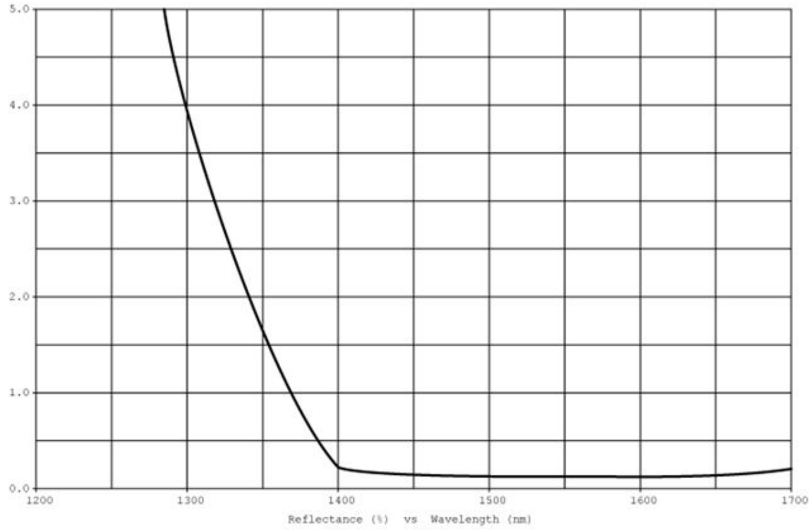


Figure 49: AR coating of the PLUTO-2.1-TELCO-142 panel

The display is equipped with a dielectric mirror to enhance reflectivity in the range of 1500 – 1600 nm. This also reduces absorption which enables the use of higher power sources compared to the standard PLUTO-2.1 versions.

NOTE
For phase only modulation with this display version the incident polarization has to be along the long display axis!

Wavelength	Maximum Phase Shift	Reflectivity
1550nm	3.4 π	93 %

Table 13: Maximum phase shift for PLUTO-2.1-TELCO-142

1.7.12.1 Phase Flicker & Response Time @ 1550 nm

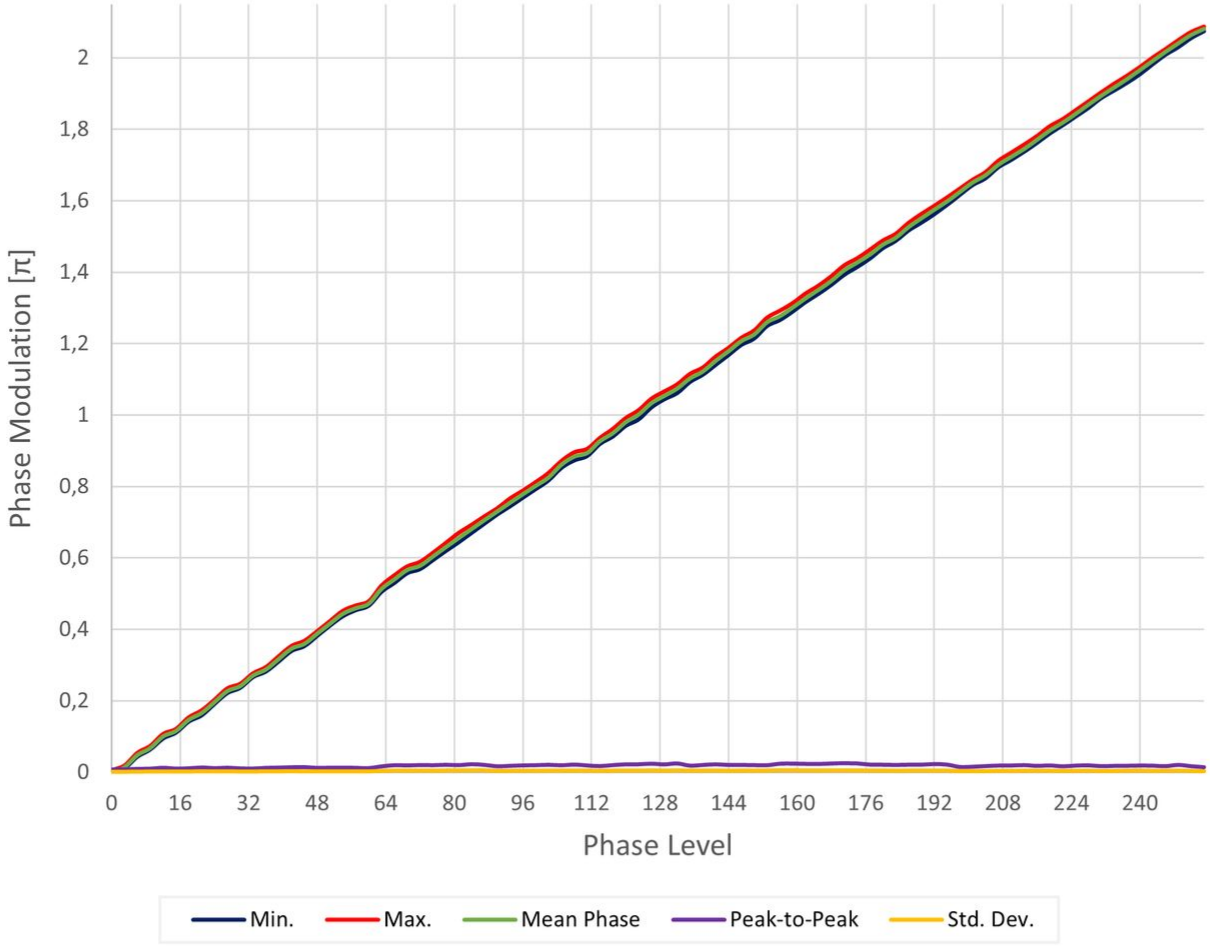


Figure 50: Phase flicker measured at 1550 nm with PLUTO-2.1-TELCO-142

Panel Version	PLUTO-2.1-TELCO-142
Max. phase shift @ 1550 nm	3.4 π
Flicker Std. Deviation: 2π @ 1550 nm	0.004 π
Flicker max. Peak-to-Peak: 2π @ 1550 nm	1.5 %
Response time: 2π @ 1550 nm (rise + fall)	35 ms + 160 ms

1.7.13 PLUTO-2.1-SWIR-157 (1700nm-2500nm)

Part no.:	HES 7020-1 6010-SWIR-157
Wavelength Range:	1700 – 2500 nm
Active Area:	15.36 mm x 8.64 mm
Pixel Pitch:	8 µm
Fill Factor:	93%
Reflectivity:	85%
Display Mode:	PAN (Parallel Aligned Nematic)

The PLUTO-2.1-SWIR-157 version can be used between 1700 nm and 2500 nm. This version features an AR coating which assures a front reflection of less than 0.5% between 1700 and 2500 nm. The display enables at least 2π phase retardation up to 2500 nm.

The display is equipped with a dielectric mirror to enhance reflectivity in the range of 1700 – 2500 nm. This also reduces absorption which enables the use of higher power sources compared to the standard PLUTO-2.1 versions.

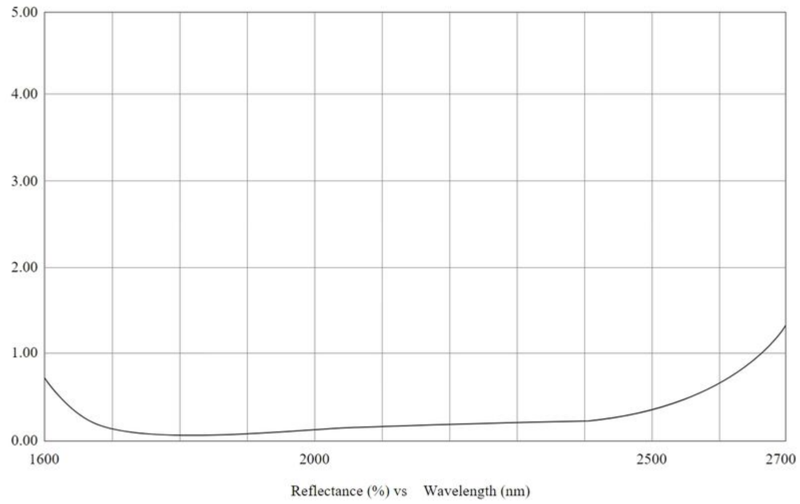


Figure 51: AR coating of the PLUTO-2.1-SWIR-157 panel

NOTE
For phase only modulation with this display version the incident polarization has to be along the long display axis!

Wavelength	Maximum Phase Shift	Reflectivity
1550nm	3.2 π	88 %
2000nm	2.5 π	85 %

Table 14: Maximum phase shift for PLUTO-2.1-TELCO-142

1.7.13.1 Phase Flicker & Response Time @ 1550 nm

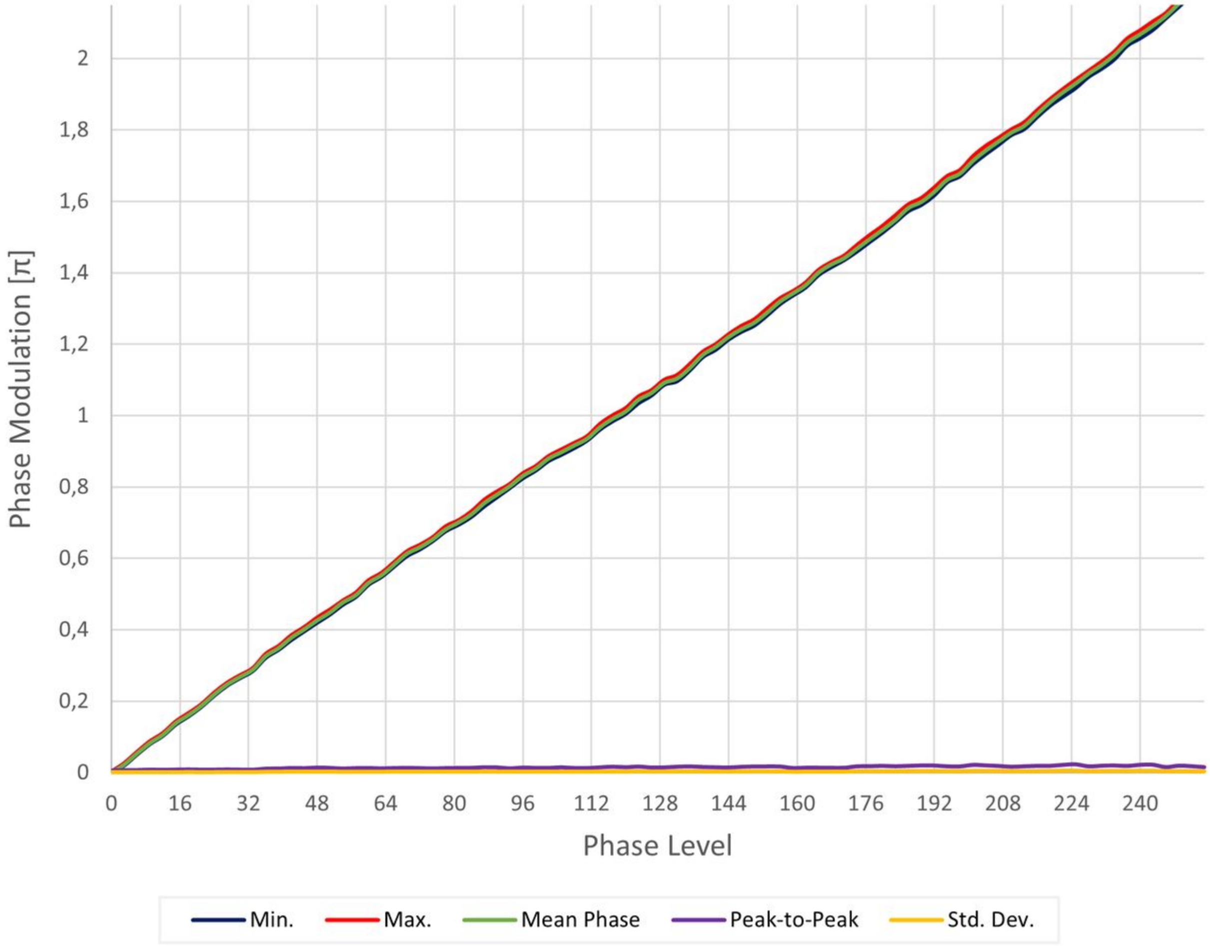


Figure 52: Phase flicker measured at 1550 nm with PLUTO-2.1-SWIR-157

Panel Version	PLUTO-2.1-SWIR-157
Max. phase shift @ 1550 nm	3.2 π
Flicker Std. Deviation: 2π @ 1550 nm	0.003 π
Flicker max. Peak-to-Peak: 2π @ 1550 nm	1.0 %
Response time: 2π @ 1550 nm (rise + fall)	82 ms + 165 ms

1.7.13.2 Phase Flicker & Response Time @ 2000 nm

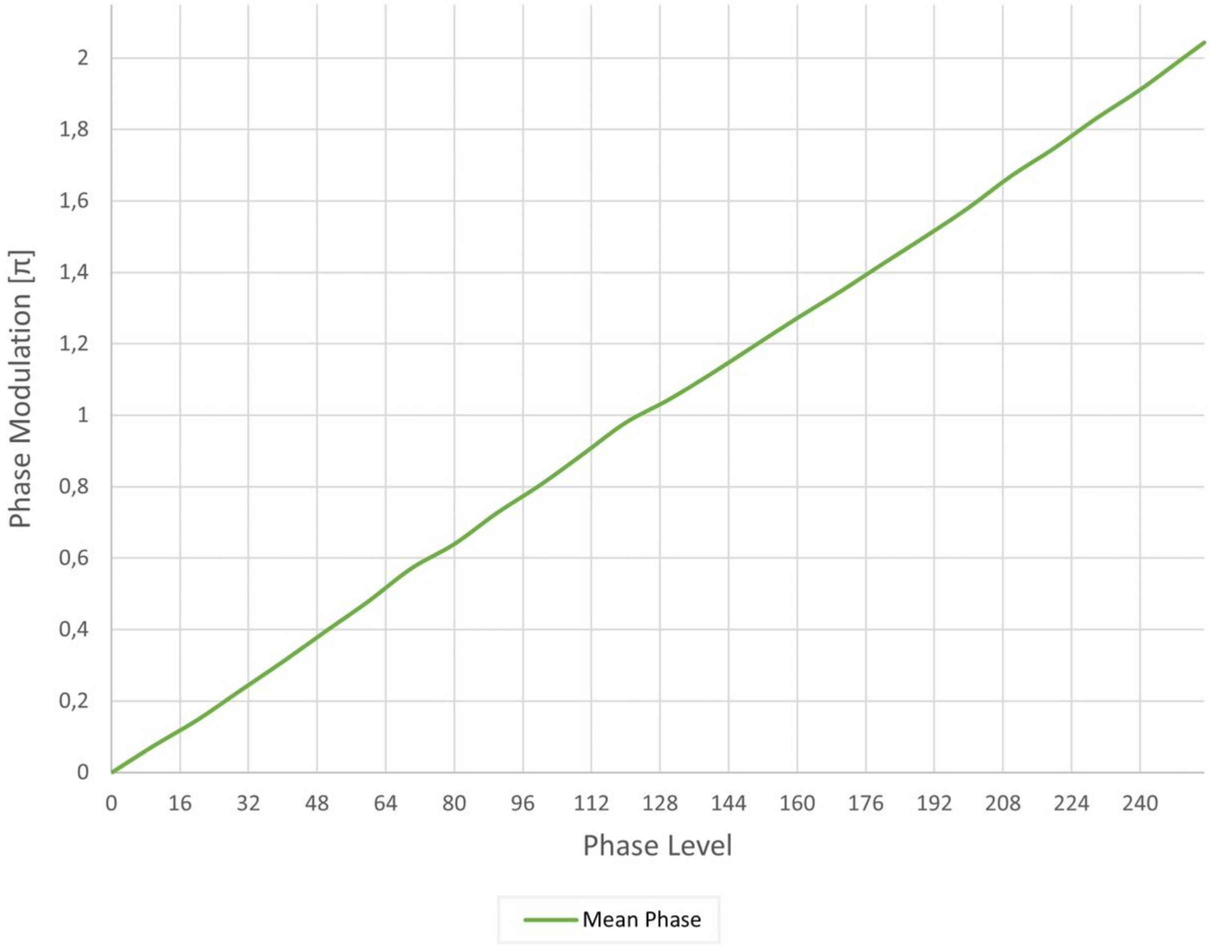


Figure 53: Phase flicker measured at 2000 nm with PLUTO-2.1-SWIR-157

Panel Version	PLUTO-2.1-SWIR-157
Max. phase shift @ 2000 nm	2.5 π
Flicker Std. Deviation: 2π @ 2000 nm	0.004 π
Flicker max. Peak-to-Peak: 2π @ 2000 nm	1.3 %
Response time: 2π @ 2000 nm (rise + fall)	43 ms + 162 ms

1.8 Diffraction Efficiency

The lattice structure of the LCoS display itself, caused by the pixelation, leads to diffraction into higher orders. The 0th order of the non-addressed display is in the area of 60%-95% dependent on the version.

The diffraction efficiency values see the 0th order intensities as a reference (100%). For the total light efficiency definition of the phase panel this needs to be considered.

Diffraction efficiency values in Table 38 have been determined for 8 level and 16 level blazed gratings at 405nm / 450nm / 520nm / 635nm / 800 nm / 1064nm / 1300nm / 1550nm (dependent on PLUTO-2.1 version) with a 9:5 sequence configuration and linearized phase response of ~2.1 π for the PLUTO versions.

The four main directions of a blazed grating encoded on the SLM are horizontal and vertical, both with positive and with negative slope. For a given configuration of the SLM the maximally achievable diffraction efficiency varies for these four directions of the grating. In table 15 the minimum and maximum value of the 1st order are given when measuring blazed gratings of all four directions. For the 0th order only the maximum value is given. The standard linearized configuration of each PLUTO-2.1-version was applied for these efficiency measurements.

Device	Grating	I_{+1st}	I_{0th}	I_{+1st}	I_{0th}	I_{+1st}	I_{0th}
Wavelength		**355 nm**		**405 nm**		**450 nm**	
-UV-099	8 level blaze	TBD	TBD	77%-81%	1%	78%-83%	1%
	16 level blaze	TBD	TBD	87%-90%	1%	88%-91%	1%
Wavelength		**450 nm**		**532 nm**		**635 nm**	
-VIS-016	8 level blaze	85%-89%	1%	81%-86%	1%	82%-86%	1.5%
	16 level blaze	91%-93%	1%	89%-92%	1%	90%-91%	1%
-VIS-014	8 level blaze	82%-90%	1%	84%-90%	1%	84%-89%	1%
	16 level blaze	90%-94%	1%	91%-94%	1%	91%-93%	1%
-VIS-130	8 level blaze	--	--	76%-81%	2%	76%-85%	1%
	16 level blaze	--	--	87%-91%	1%	87%-93%	1%
Wavelength		**635 nm**		**800 nm**		**1064 nm**	
-NIR-145	8 level blaze	76%-83%	2%	75%-84%	2%	76%-80%	3%
	16 level blaze	87%-91%	2%	86%-91%	2%	85%-90%	2.5%
-NIR-015	8 level blaze	78%-84%	2.5%	80%-85%	1.5%	76%-85%	1%

	16 level blaze	87%-91%	2%	89%-92%	1.5%	87%-92%	1%
-NIR-149	8 level blaze	--	--	--	--	71%-76%	2%
	16 level blaze	--	--	--	--	80%-86%	1%
Wavelength		**635 nm**		**800 nm**			
-NIR-113	8 level blaze	--	--	69%-77%	2.5%	--	--
	16 level blaze	--	--	80%-85%	2%	--	--
Wavelength		**1064 nm**		**1300 nm**			
-NIRO-024	8 level blaze	74%-84%	1%	71%-81%	1%	--	--
	16 level blaze	86%-92%	1%	82%-91%	1%	--	--
Wavelength		**1550 nm**		**2000 nm**			
-TELCO-013	8 level blaze	74%-77%	2.5%	--	--	--	--
	16 level blaze	85%-86%	1%	--	--	--	--
-TELCO-142	8 level blaze	71%-75%	2%	--	--	--	--
	16 level blaze	83%-85%	1%	--	--	--	--
-SWIR-157	8 level blaze	58%-70%	9%	56%-61%	6%	--	--
	16 level blaze	73%-80%	6%	76%-78%	5%	--	--

Table 15: Diffraction efficiency for certain grating structures

1.9 Optical Flatness

1.9.1 Wavefront Measurement

Due to the fabrication process, the backplane of the Liquid Crystal on Silicon display is not perfectly flat. This can introduce aberrations to a light beam and influence efficiency and wave front quality. Due to the nature of a 2D phase only SLMs, the device is able to compensate its own flatness imperfection by addressing a compensation function. We therefore characterize the wavefront error of each individual LCoS display with high accuracy and generate the corresponding compensation functions that are ready to use with the HOLOOEYE SLM software.

The characterization process at HOLOEYE utilizes a Shack Hartman Sensor (SHS) and a customized Twyman-Green Interferometer (TGI). While the SHS setup is mainly used for a quick incoming inspection, the TGI setup is used to generate the high quality compensation function, as it achives a higher accuracy, applying a high resolution CMOS camera and a piezo steered moveable mirror.

We determine the peak-valley-value in the whole active area of the display (PV_{active_area}) and the peak-valley-value in a circle (PV_{circle}) located in the middle of the active area. This region is used by the majority of the customers. The PV_{circle} values (even without compensation) are already much lower than in corners of the rectangular active area. The effect of compensation therefore is most effective for the whole active area.

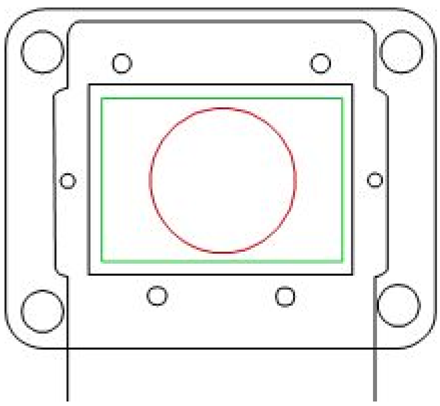


Figure 54: Display areas

Our TGI setup is used to generate wave front compensation functions to correct for the inherent LCoS backplane deformation.

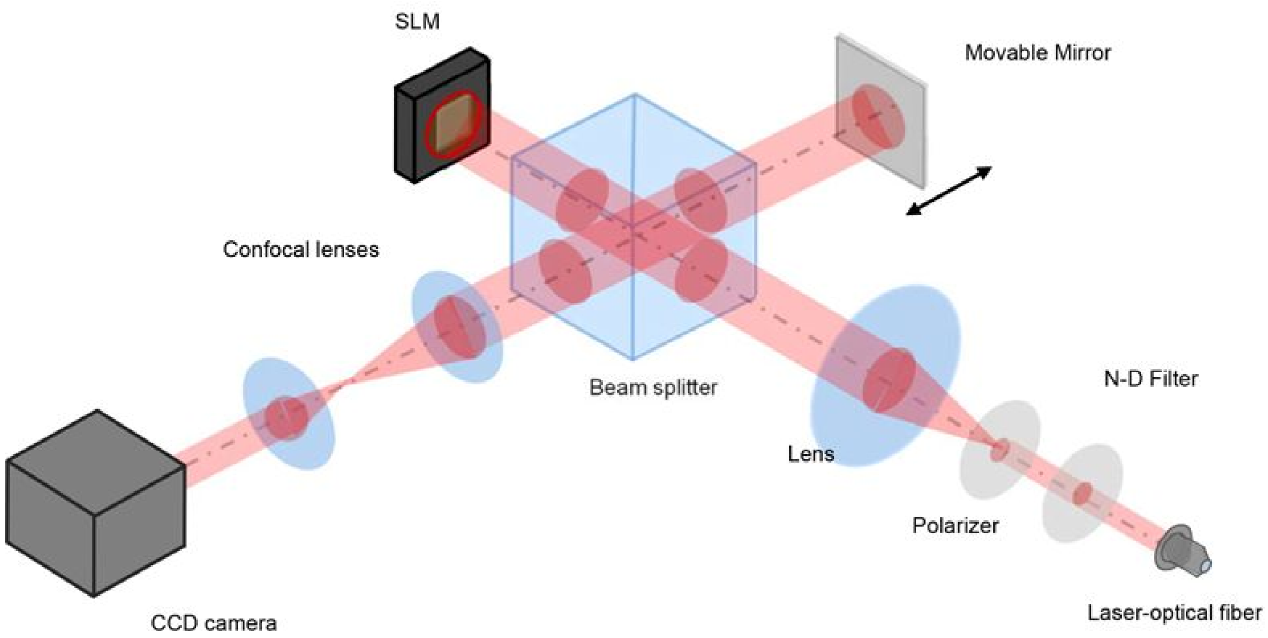


Figure 55: Optical setup for wavefront calibration based on Twyman Green interferometer

Figure 55 shows the TGI setup and figure 56 shows a 3D example of reflected wave fronts before and after compensation.

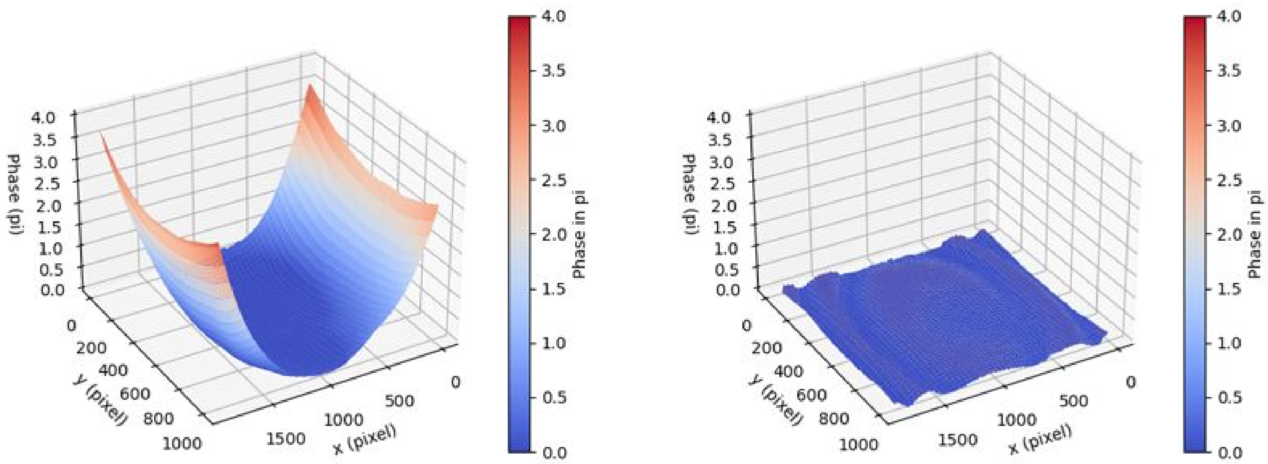


Figure 56: Measured wavefront before and after compensation

Figure 57 illustrates a 2D visualization (including some characterizing values) and resulting point spread functions (PSF) before and after correction.

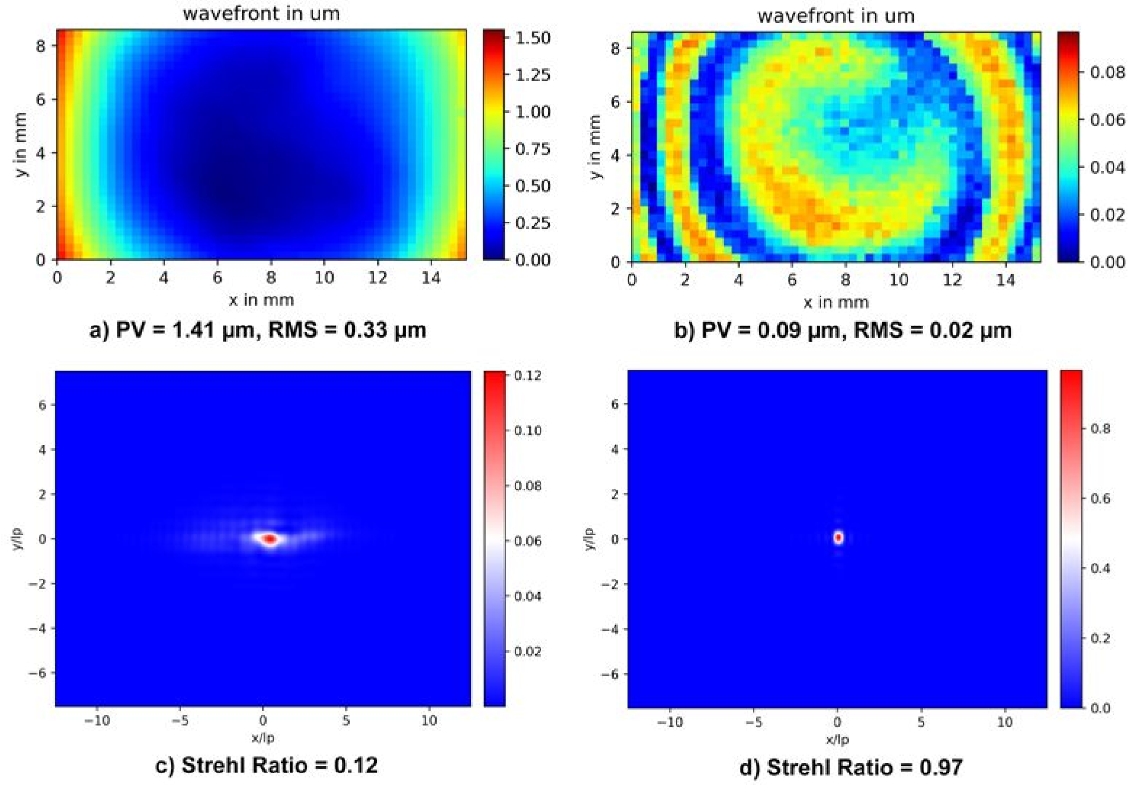


Figure 57: Wavefront and Point Spread Function measured with SHS before (a, c) and after (b, d) compensation.

An example for the impact of the compensation on the wavefront and Point Spread Function can be seen in figure 57. Since the display has a rectangular shape, we observe an elliptical shape of the corresponding PSF. The reduction of the RMS value (from λ/2 to λ/30) and the improvement of the Strehl ratio are considerable.

1.9.2 Wavefront Compensation for HOLOEYE SLMs

On the supplied USB drive you find a wavefront compensation file (*.h5 file). This wavefront compensation file can be loaded as background compensation using the Pattern Generator software or the SLM Display SDK to compensate wavefront distortions of the display.

When using the compensation function, make sure the geometry settings in the Configuration Manager do not flip the addressed phase content. This would result in a wrong orientation of the compensation function and corrupt the flattening of the wavefront. Also make sure to use the latest version of the PLUTO-2.1 Configuration Manager and the latest PLUTO-2.1 configuration for your display version and wavelength. Both can be downloaded from https://customers.holoeye.com/.

You can find more detailed information at the chapter "Wavefront Compensation Overlay".

2 Configuration Manager

The software "HOLOEYE PLUTO-2.1 Configuration Manager" is needed to configure the driver board of a HOLOEYE PLUTO-2 or PLUTO-2.1 Spatial Light Modulator. It enables the user to upload and download complete configurations, change the driving voltages of the SLM and modify the color look-up table (CLUT) inside the driver board. Furthermore, the image position can be adjusted and flipped, the signal source can be selected, and the connection of the display flex cable to the driver board can be checked.

On the left panel of the graphical user interface (GUI), status information like temperature, firmware version, and display information is shown.

When used with the optional HOLOEYE Thermal Management System (TMS), this Configuration Manager software also configures the temperature settings of the TMS.

This software is available for Microsoft Windows 7 SP1 (32-bit and 64-bit) and later.

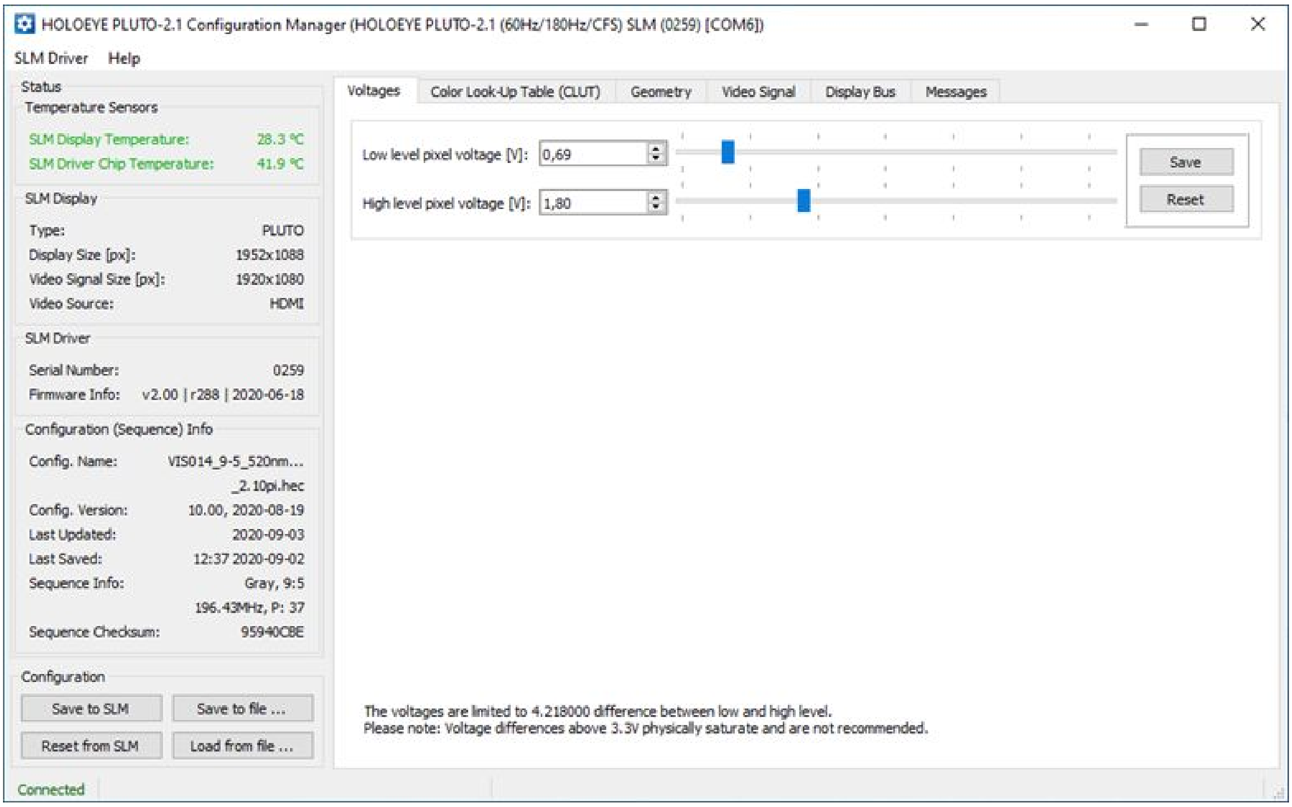


Figure 58: HOLOEYE PLUTO-2.1 Configuration Manager after connecting to the SLM.

2.1 Install PLUTO-2.1 Configuration Manager

Please run the installer with proper administrator rights and follow the instructions. You must accept the license agreement in order to use this software.

This software supports PLUTO-2 and PLUTO-2.1 SLMs. PLUTO-2.1 has an updated driver firmware and is not compatible with the older PLUTO-2 configuration managers any more. That means you need the PLUTO-2.1 Configuration Manager to connect to PLUTO-2.1 SLMs. This software is compatible with PLUTO-2 and PLUTO-2.1 SLMs. PLUTO-1 driver hardware is not fully functional in this software. For PLUTO-1, please continue to use the very old software shipped with the device.

2.2 USB to Serial Port Driver

The USB to serial port driver creates a virtual USB COM port, which is needed to communicate with the SLM.

To install the USB to serial port driver you have to connect the “USB RS232” (USB UART) port of the PLUTO-2[.1] SLM to a USB port of your computer.

If enabled in Windows, Windows 7 and later will automatically install the driver from Windows Update once the SLM is connected to the PC via USB.

If you have any issues with the automatic detection / installation, you can download and install the virtual COM port driver from https://www.ftdichip.com/Drivers/VCP.htm. A ZIP file is also included on the USB drive within the installation folder of this software.

To install the driver manually open the Windows Device Manager and right click “unknown device”. Select “Update Driver …” and select to install the driver from hard disk. Navigate to the folder containing the driver. The driver should be installed automatically.

After installing the virtual COM port driver manually, it might be necessary to repeat the procedure for upcoming serial ports.

The same applies when connecting to a HOLOEYE Thermal Management System.

2.3 Connection to Hardware

After starting the PLUTO-2.1 Configuration Manager, a connection dialog pops up and automatically searches for supported hardware (see figure 59). Please make sure the USB cable is connected and the virtual COM port drivers are installed properly (see chapter "USB to Serial Port Driver").

The hardware search takes a few seconds. In case no SLM was found, the selection box will be grayed out stating “No HOLOEYE SLM found”. If no SLM was found, please check the hardware (esp. USB connection) and either wait for the dialog to auto detect the device or redo the search by using the “Search” button.

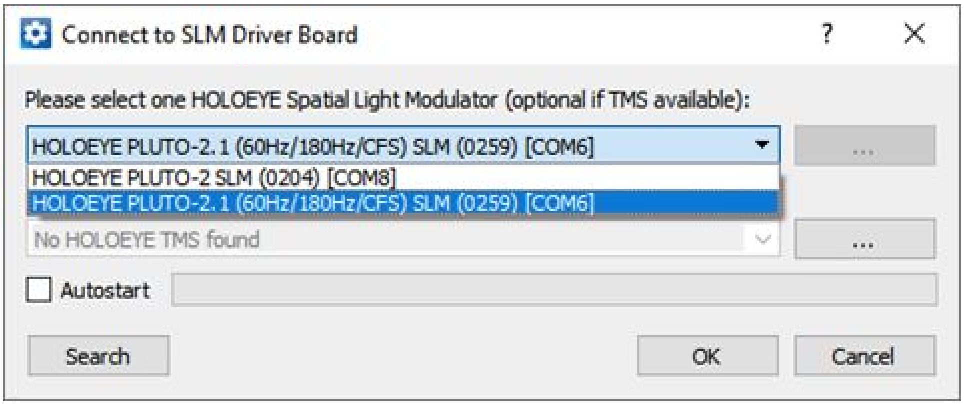


Figure 59: Connection dialog. A PLUTO-2 SLM is detected.

Proceed by clicking OK once the SLM is found. The software can be started with only one SLM, only one TMS, or both. If both are connected at the same time, temperature regulation of the display is possible.

The software will detect all supported HOLOEYE SLMs and HOLOEYE Thermal Management Systems, even if multiple hardware is connected. In figure 59, two Pluto-2 devices are found, one with the older firmware with support for only monochrome operation, and one with the newer firmware supporting multiple modes of operation. The name of each found SLM includes the type of the device, the serial number, which is the same number like printed onto the hardware, and the interface name, i.e. the COM port number.

Each instance of HOLOEYE Configuration Manager can only connect to one SLM and optionally to one TMS at the same time. In addition, only one instance can connect to a specific SLM. For example, if a first instance would connect to “HOLOEYE PLUTO-2.1 (60Hz/180Hz/CFS) SLM (0259) [COM6]”, the next instance started wouldn’t find the Pluto-2.1 device anymore and can only connect to the remaining Pluto-2 with serial number 0204 and COM port number 8 (see figure 59). If for some reason the second connection attempt would succeed, it is strongly discouraged to connect multiple software to a single device. The device could go into an undefined state, and recovery may be needed. Anyway, this shouldn’t be possible normally.

By checking the “Autostart” box of the connection dialog (see figure 59) the software will connect to the same devices at the next start. The auto start feature will always pick the last accepted hardware settings. If the last accepted hardware settings are not found, the auto start will not proceed until either the same hardware is found or OK button is pressed manually.

If the hardware is connected properly but no SLM and/or TMS is found automatically inside the connection dialog, you can select the COM port(s) manually by using the buttons "…" on the right side of the device list. In the upcoming dialog, please make sure to select the correct Pluto version (2 or 2.1) and the correct COM port number. Otherwise the manual connection cannot work. Please click OK in the manual connection settings dialog. If everything was correct, it takes a few seconds and the manually selected device will show up in the device list in the same way like when it is detected automatically.

After clicking OK in the connection dialog, Configuration Manager will start with the selected devices and adapt the user interface according to the hardware and its current configuration. A progress bar dialog will pop up indicating the transfer status of the configuration data from the device(s). This takes a few seconds.

If a HOLOEYE Thermal Management System is used, a separate tab shows up which allows configuration of the TMS. For more information on active thermal management, please refer to the TMS manual, which is accessible from the help menu of this software as soon as a TMS is connected.

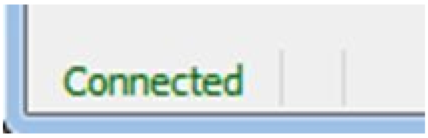


Figure 60: Indicator for a successful connection.

The connection status of the SLM is shown on the lower left corner of the status bar of the main window (see figure 60). If the SLM connection is working properly, it states "Connected".

If the connection is interrupted in any way the SLM will be disconnected and state "Disconnected". There will also be error messages in the "Messages" tab (see figure 77). There may be a longer timeout (about 15 seconds) on the COM port upon disconnection.

After such an interruption and the automatic disconnect, the software will search again for new devices. That means the connection dialog will pop up automatically and the "Search" button of the dialog will be pressed repeatedly until some hardware was found. If the auto start feature was enabled earlier, and the same hardware is detected again, Configuration Manager will reestablish the connection automatically. The latter will clear previous error messages, but the messages will remain in the log file, see chapter "Messages".

When the connection dialog is closed manually ("Cancel" button pressed), it does not pop up automatically. To reopen it manually, please use the menu "SLM Driver" → "Connect" or use the keyboard shortcut Ctrl+C.

2.4 The Status Panel

The left side of the main window contains the status panel (see figure 61), which shows current display and driver chip temperatures, information about the display and video signal, info about the SLM driver, and information about the currently loaded configuration.

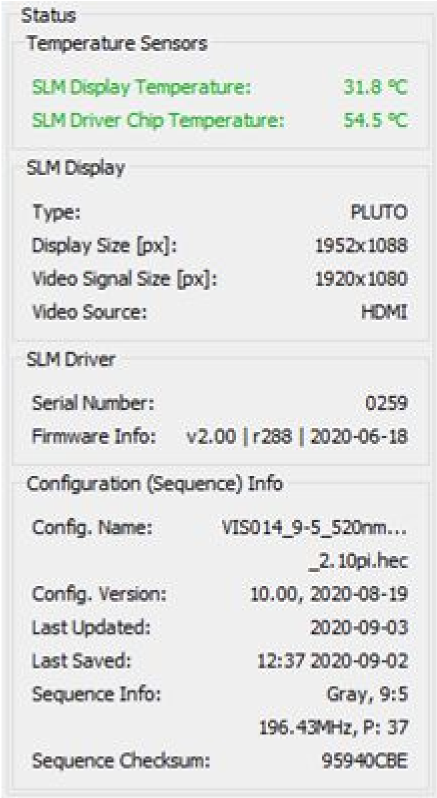


Figure 61: Status information panel on the left side of the main window.

2.4.1 Temperature

There are two temperature values shown: The display temperature and the driver chip temperature. The text color will change to indicate safe (green) and unsafe (red) temperature values.

The SLM display temperature is green for values between 15°C and 55°C, orange for values between 55°C and 65°C, and red above 65°C.

ATTENTION
Please note that the driver cannot report display temperatures above 65°C and below 10°C properly! The shown value will saturate, but the actual display temperature might be higher than 65°C or lower than 10°C. This means, even if the display would be at critical temperatures like 80°C or higher, it would still report about 65°C.
Therefore, please be very careful as soon as the temperature value turns to red color.

The heat dissipation of the display is very low and does not significantly heat up the display. That means without any external heat, it will be safe to operate the display under room temperature conditions.

If you have any external heat source, like a powerful laser, the SLM display temperature value may turn its color to orange or even red. In such a case, please watch the temperature carefully. Orange values indicate a temperature range where the diffraction efficiency of the SLM may be affected already, even when there is no harm to the SLM display. When the display temperature is red, there might be harm to the liquid crystal and/or display electronics depending on the actual temperature value, which is not correctly reported by the display above 65°C. However, depending on the display type, it may be fine to use the display at temperatures above 65°C, e.g. at 70°C, but the driver will not report the value correctly. In such a case, please watch the display temperature with additional equipment, or even better use a thermal management system like a HOLOEYE TMS.

The driver chip temperature is green in the range from 15°C to 65°C and orange between 65°C and 85°C. Above 85°C, the color turns to red.

NOTE
In case the chip temperature turns to **orange**, please try to mount the driver board housing on an optical post and let the ambient air cool the housing. The temperature should stay at a value of about 20-30K above ambient air temperature when mounted on a post.

ATTENTION
If the driver chip temperature color turns to **red** (above 85°C), please turn off the power of the SLM as soon as possible. The chip lifetime will decrease at such temperatures. There is no automatic switch off procedure!

A large, slowly running fan might solve temperature issues of the driver.

WARNING
Both temperature values turn to **blue** below 15 °C. Please make sure that you stay above the dew point, which is dependent on the relative humidity of the ambient air. The dew point in your environment may be at higher than 15 °C! Below the dew point, the display and/or driver electronics may get wet, which can damage the electronics.

2.4.2 Display Information

The SLM display information indicates that the SLM display is a PLUTO type, and shows the actual number of pixels of the display in horizontal and vertical direction (see figure 61, “Display Size [px]”). This value indicates if the display could have been recognized correctly by the driver board.

The value of “Video Signal Size” shows the number of pixels driven through the HDMI interface. All other pixels are set to the gray value 0. The position of the driven pixel area can be configured using the “Geometry” tab.

The label "Video Source" indicates which input signal source is selected. Basically there is “HDMI” input. Pluto-2.1 drivers also have the option to use an “Integrated Pattern Generator”, and under very special circumstances also an option “Embedded Linux System“.

2.4.3 Driver Board Information

The “SLM Driver” box contains the serial number of the connected SLM driver board and firmware version information of the FPGA controller. The serial number is the same as indicated on the hardware label on the SLM driver board housing. The same serial number is also shown in the EDID device detection of our display software. This information can be used to match hardware, configuration, and displayed content when multiple HOLOEYE devices are connected to the same computer.

The firmware information (version, revision, and date) is shown below the serial number. This software is developed to work with firmware version 2.00 r288 (2020-06-18), which is Pluto-2.1, and 1.05 r158 (2017-03-09), which is Pluto-2. Other firmware versions might be supported as well.

2.4.4 Configuration (Sequence) Info

This box shows multiple information about the current configuration of the SLM. Some information corresponds to the active and persistent configuration (e.g. the configuration name), and some only applies to the persistent configuration (e.g. time and date of last save action). Please refer to the chapter “Configuration Files” for more information about the device configuration.

The full device configuration contains data which is not editable using HOLOEYE Configuration Manager, but can be changed by uploading a different configuration file. An example of such data is the digital drive sequence for the display. Whenever a configuration file (*.hec for PLUTO-2.1, *.hex or *.anf for PLUTO-2) is loaded, the information in this box is updated. Changes to our basic configuration are typically indicated by a changed version number and date (“Config. Version” label).

The configuration name is set automatically to the last uploaded file name. The text may be cropped if it is too long and may be continued in the line below. This information can be used to know which file was last loaded, but does not change when other settings are applied.

The “Last Updated” label shows the date when the complete persistent configuration was last overwritten by a configuration file. This happens when you upload a file directly into the persistent memory (when asked, you must have selected “Persistent”), and when reverting the driver’s configuration to factory defaults using Configuration Manager.

The “Last Saved” label is always updated when any changes are saved into the persistent configuration of the SLM driver, except for uploading configuration files directly into the persistent configuration of the SLM.

When saving the configuration into a file, the last saved information is updated inside the file. That means you can make changes, save them into a file, upload the file into the persistent memory of the SLM, and you will see the time and date when the changes were last saved to the file.

Together with the “Last Updated” info, you can see when any changes were made to the persistent configuration of the SLM since the last configuration file upload into persistent memory.

2.4.5 Configuration Box

The box “Configuration“ (see figure 62) is a shortcut to the menu items to load and save complete configurations from and to files. In addition, the buttons “Save to SLM” and “Reset from SLM” provides access to the persistent memory of the SLM.

2.5 Configuration Files and Internal Memory

The SLM has internal memory storing the full configuration. There is memory holding the settings currently applied to the display (see chapter "Active Configuration"), and there is memory holding the full configuration for next power up. At boot time (power up of SLM), the SLM driver will always copy the persistent boot configuration into the active configuration.

Furthermore, the configuration memory of the SLM can be stored into files for later usage. HOLOEYE provides consistent configuration files for easily adapting the phase response settings to different display types and use cases. Each configuration file holds the complete boot configuration. Therefore, configuration files contain all settings of the SLM, like voltages, CLUT, geometry, sequencer code, and a lot more.

2.5.1 File Types

When connected to a Pluto-2.1 driver, the recommended and default file format is *.hec (HOLOEYE Configuration file).

Older Pluto-2 SLMs are still using the *.hex file format by default, and do not support the new *.hec format. All file formats save the complete persistent memory of the device.

Please do not edit the configuration files manually. The same applies to the file name extension. The extension is used to detect the file type, and if it doesn't match to the content, the file will be misinterpreted. Most probably such files will be rejected. However, in principle it can be accepted, and loading such a corrupted or incompatible configuration file may harm the SLM.

The CLUT can also be loaded and saved from and to files, resp., and the format is different. CLUT file types are typically saved as *.csv. For some cases HOLOEYE provides CLUT files and voltage settings together with a base configuration. The base configuration may be the factory defaults, but may also be any other configuration file (*.hec/*.hex). Please make sure you don't mix the file types and calibration data, i.e. a specific CLUT file only makes sense if used together with the correct base configuration and correct voltage settings.

The sequence inside a configuration file is typically indicated by the file name, e.g. "9-5_XXX.hec", which means the configuration includes a sequence of the type 9-5 (9 T-bits and 5 B-bits) which is the default sequence for PLUTO-2.1. These T/B-bit settings are shown in the CLUT tab and in the sequence info in the status panel on the left side of the main window. The default sequence type for Pluto-2 is 5-6 instead of 9-5. There are more sequence types available for PLUTO displays. Each sequence is optimized for a specific use case. The default sequences are optimized to be as general as possible.

2.5.2 Compatibility

Incompatible (and corrupted) files are most probably rejected when trying to load them into the driver. Anyway, configuration files of different HOLOEYE SLM types are not compatible. Therefore, please make sure to use the correct files. Even the files of Pluto-2.1 and Pluto-2 are not compatible. However, when a Pluto-2.1 driver is connected, a Pluto-2 configuration file can still be uploaded into the active configuration of the Pluto-2.1 driver (no question will be asked, see chapter "Load Configuration"). The software will adapt the old Pluto-2 configuration into the active configuration of the Pluto-2.1 driver. Afterwards, the active configuration of the Pluto-2.1 driver can be saved into the SLM as usual, see chapter "Persistent Configuration".

Please note that the new driver firmware of a Pluto-2.1 has higher performance, which will not be enabled in older configuration files made for Pluto-2. In case these files are used, the Pluto-2.1 SLM will behave like if it was a Pluto-2 SLM with the same configuration.

It is not possible to load configuration files saved with a Pluto-2.1 SLM into the driver of a Pluto-2 SLM.

2.5.3 Load Configuration File

To load a configuration from a configuration file (*.hec/*.hex), please use either the main menu entry “SLM Driver” → “Load configuration …“ (Ctrl+O, see figure 65), or use the appropriate button inside the “Configuration” box below the status panel on the left side of the main window (see figure 62).

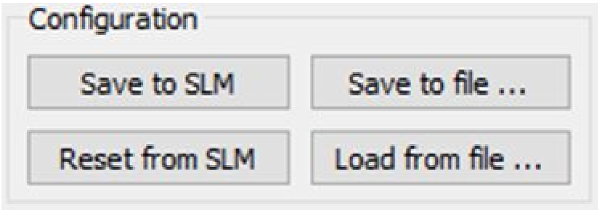


Figure 62: Access to complete configuration data.

A file selection dialog will open. Please select a valid configuration file (see chapters “File Types and “Compatibility“).

After accepting the configuration file selection, the software asks if the configuration shall be stored directly into the persistent (and active) configuration. Otherwise the file content will only be copied into the active configuration (see figure 63). Storing into persistent configuration is faster and overwrites the whole SLM configuration completely. Loading into active configuration leaves the persistent configuration of the SLM untouched. If you are not sure, please select yes.

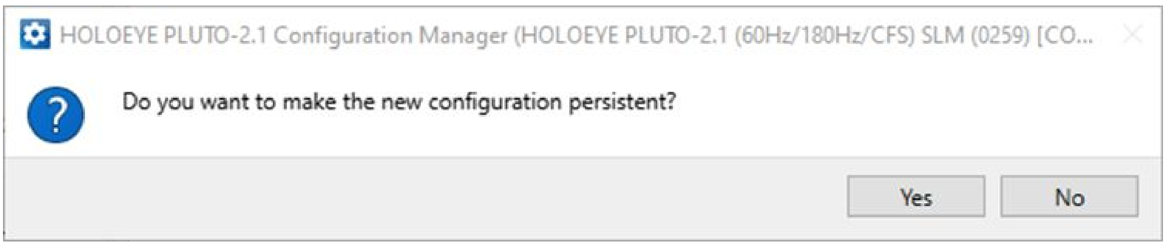


Figure 63: Question dialog after selecting a configuration file for loading into SLM driver.

In any case, loading and saving configuration files takes a few minutes. A progress bar will open during the operation, and after finishing there will be a message box dialog indicating successful operation.

2.5.4 Save Configuration File

To save the active configuration of the SLM into a configuration file, please use the main menu entry (Ctrl+S, see figure 65) or the button in the configuration box, similar to loading configuration files. Saving files always saves the active configuration.

2.5.5 Active Configuration

The active configuration holds all data in a volatile memory inside the SLM driver. By changing values in this volatile memory, the SLM directly responds to the changes. E.g. when moving a slider of the voltages tab, the data is directly transmitted into the active configuration of the SLM, and the phase response changes immediately. That means that all values accessible with Configuration Manager can be changed without affecting the SLMs persistent configuration. You can also load configuration files into the active configuration only and try out configurations without overwriting the SLMs boot configuration.

All changes made to the active configuration will be lost after unplugging the power supply of the SLM. To save it across power-cycles of the SLM please save it permanently into the SLM driver.

The active configuration can be changed without overwriting the boot configuration of the SLM. Just don’t use any “Save” buttons and select “No” after loading a configuration file to make sure the persistent configuration is not touched. This is helpful in case a well configured SLM is taken to play around with the settings. To switch back to the persistent boot configuration click the button “Reset from SLM” (see figure 62). Removing the power cord of the SLM will also reset to the persistent boot configuration.

2.5.6 Persistent Configuration (Boot Configuration)

The persistent boot configuration is used during boot up to initialize the active configuration.

Changes to the persistent configuration inside the SLM driver can be made in the following ways:

- Reset to factory default configuration.
- Upload of a configuration file directly into the persistent configuration.
- Saving the full active configuration into the SLM (see below).
- Saving single items like voltages, CLUT, geometry, etc. into the SLM (see below).

To make the active configuration permanent click “Save to SLM” in the configuration box below the status panel on the left side of the main window, see figure 62. The saving process takes about one minute. After the process is complete, the following message pops up:

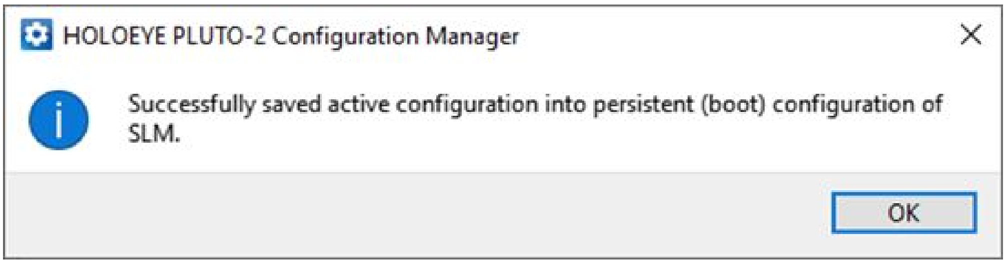


Figure 64: Message after saving configuration into device.

To restore the active configuration from the persistent storage, please use the button “Reset from SLM” in the configuration box, see figure 62. The process takes a little time, which is indicated by a progress bar dialog.

If applicable, each tab has its own “Save” and “Reset” button, which saves or loads the configuration to or from the boot configuration without affecting settings in other tabs.

2.5.7 Unsaved Changes

All changes made to the configuration will be lost when powering off the SLM. Unsaved changes made at the single tabs (Voltages, CLUT, Geometry, and Video Signal) are indicated by a star (*) at the end of the tab caption. You can use the save button of each of these tabs to save the changes permanently to the boot configuration.

There are some settings not related to any tab. These settings can also have unsaved changes. This can happen e.g. after loading a configuration file into the active configuration only. These changes are not indicated by a star (*), but when closing the application such changes will also make the program ask if you want to save.

2.5.8 Reset to Factory Defaults

A factory default file is included into Configuration Manager, and can easily be loaded to reset the SLMs persistent and active configuration to a very general default configuration without any calibration information applied and with the default sequence settings for the connected SLM type.

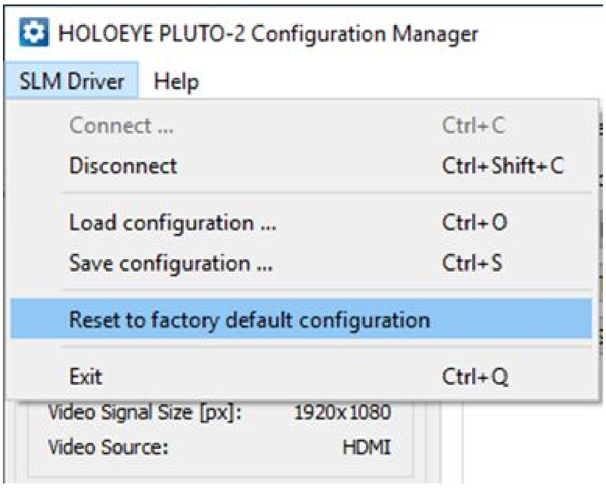


Figure 65: Configuration options from main menu: Load and save full SLM configuration, and reset device to factory defaults.

Loading factory defaults clears all customized data in the SLMs persistent configuration memory. Files which provide the correct calibration for a specific wavelength and a specific display type can be found on the HOLOEYE USB drive, which comes with the device.

To reset to factory defaults, please select the menu entry “SLM Driver” → “Reset to factory default configuration” (see figure 65).

A dialog pops up to confirm that all data will be overwritten. After confirmation, the factory defaults configuration file is directly applied and stored into the persistent (or boot) configuration of the SLM. The process of writing the configuration takes a couple of minutes. At the end of the process, a dialog pops up (see figure 66).

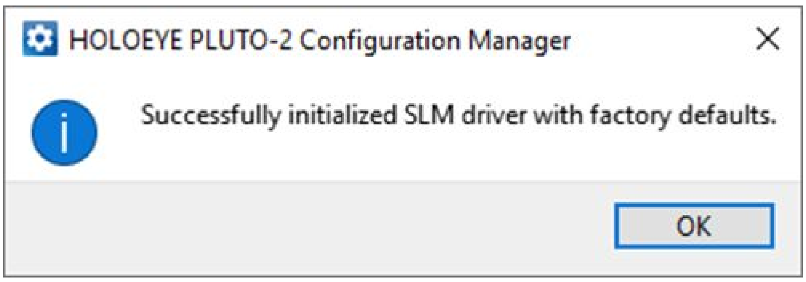


Figure 66: Reset to factory defaults finished with success.

2.6 Adjusting Voltages

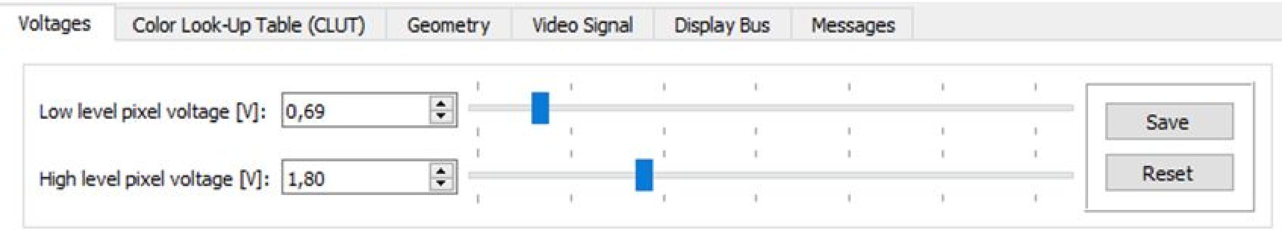


Figure 67: Voltage configuration.

Due to the digital driving of the HOLOEYE PLUTO-2 SLM, there are only two adjustable values: low level voltage and high level voltage. Both voltages are applied to the pixels depending on the sequence code, the CLUT and the addressed image. Typically, pixels addressed with black image data are driven at the low level voltage, and pixels addressed with white image data are set to the high level voltage.

The maximum allowed difference between low level and high level voltage is 4.22V, and the minimum difference is 0V. The maximum low level voltage is 4.22V, but only possible at a voltage difference of 0V. Incorrect values cannot be applied.

The voltages define the total phase shift and influence the electro-optical response curve of the liquid crystal. The voltage values should be set according to the used SLM type (display type), wavelength, angle of incidence, and maybe even displayed content.

Basically, the difference V_high - V_low defines the contrast, i.e. the total phase shift, and the voltage V_low defines the bias voltage. Due to the non-linear electro-optical response curve of the liquid crystal over voltage changes, this is not fully true, but can be used to understand the basic optical effect when changes to the sliders are made.

HOLOEYE provides default configurations, which also include voltage settings. Please use these configurations first before applying any other values. After applying such a HOLOEYE configuration you may be able improve diffraction efficiency a bit by slightly adjusting the high level and/or the low level voltage.

NOTE for PLUTO-2 Users

Since HOLOEYE Pluto Configuration Manager v1.13 (made for Pluto-1 and Pluto-2 SLMs) we increased the resolution of the voltages for Pluto-2 SLMs, so that smaller steps can be selected for the total phase shift. However, due to this, some values previously allowed are merged to slightly different values on Pluto-2 SLMs. For Pluto-2.1 SLMs, the resolution was further increased so that all values can now be set precisely.

On Pluto-2 SLMs, where the issue of slightly different voltages exists, you can upload a configuration file to the SLM, and Configuration Manager will take, apply and show the settings as stored in the configuration file. As soon as you move the sliders to select different voltages, the constraints of Pluto-2 due to the higher voltage resolution are applied. Normally a re-calibration should not be necessary after such small changes due to the new constraints. Pluto-2.1 SLMs are shipped with updated configurations anyway, and has improved voltage step sizes and are therefore not affected.

NOTE for PLUTO-2.1 CFS Users

Our monochrome configurations have only one voltage slider pair. However, when using a color configuration (CFS, and maybe 180Hz), there will be multiple voltage slider pairs. Each pair will be applied for the color channel name appearing in the box description of the slider pair. The name is for example “Red Color Channel”. The voltage settings of each color channel in a CFS configuration are independent of the other color channels.

2.7 Color Look-Up Table (Gamma Table)

The color look-up table (CLUT, also called “gamma table”) is used to apply a specific pulse code voltage modulation to the pixel of the SLM for each gray level addressed through the video input signal. It can be used to create a linear phase response over the gray levels from the video input signal (e.g. HDMI).

Instead of the phase shift, any observable changing over pulse codes or gray levels can be linearized, like brightness when using amplitude modulation. By creating your own CLUT file, any non-linear response can also be created. Anyway, in the following we assume linear phase modulation.

The box “CLUT Bit Interpretation” shows the settings of the sequencer, which also apply to the CLUT entries, because each CLUT entry contains a pulse code, and the [T:B]-bit setting determines how the pulse code indices are counted. Typically, a higher pulse code index means a higher average voltage applied to the pixel. This may differ, depending on the sequence, but is true for the default monochrome phase modulation sequences 5:6 (PLUTO-2) and 9:5 (Pluto-2.1). That means, when a configuration file with a different sequence is loaded, the pulse code indices are not compatible anymore. The new configuration file (*.hec/*.hex) will also provide a compatible CLUT, and you cannot use the old CLUT files anymore.

The pulse code interpretation is expressed in the number of thermometer bits (T) and binary bits (B). The label “N pulse code ind.” shows the number of existing pulse code indices, depending on T:B settings. Therefore, the highest pulse code index is the number of pulse code indices minus one. E.g. for the 5-6 sequence, we have 384 pulse code indices, going from 0 to 383. The 9:5 sequence has 320 indices, going from 0 to 319. Each of the 256 CLUT entries selects one of them.

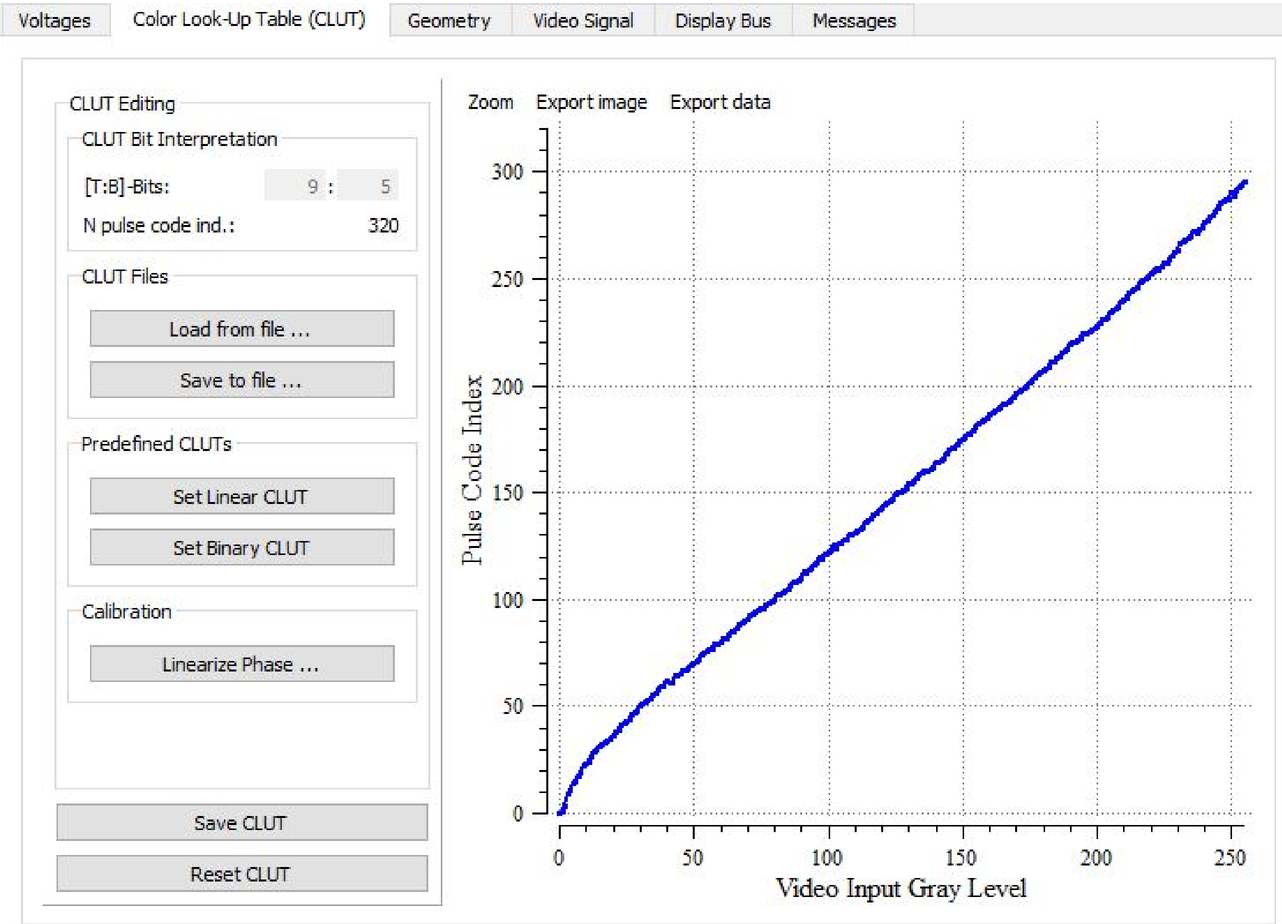


Figure 68: Color look-up table on a monochrome phase modulation configuration (9:5-sequence).

The buttons "Load from file ..." and "Save to file ..." (see figure 68) provide an interface to exchange the CLUT through look-up table files. We provide different look-up table files for specific pre-calibrations. CLUT file types are text based and therefore provide a way for manual CLUT editing. PLUTO-2[.1] supports look-up table files with the file name ending *.csv.

The *.csv file type stores the pulse code indices for easy spreadsheet editing. Each line of a *.csv look-up table file consists of just one value for the pulse code index, and the line number represents the corresponding video input gray level. The pulse code indices must be in the range from zero to the highest pulse code index, see above. Numbers in a *.csv file, which are out of range, will result in undefined behavior.

For compatibility reasons, older *.csv files with 1024 entries are still supported when loading CLUT files. When saving CLUT files, they are saved in 256 lines. To use these 256-line-csv-files with the old version 1.13 of PLUTO Configuration Manager, please repeat each line into 4 lines manually, e.g. by using a text editor or any spreadsheet software.

The buttons "Set Linear CLUT" and "Set Binary CLUT" in the box "Predefined CLUTs" allows writing either a linear looking or a binary CLUT directly into the active configuration, without the need for a file. This can be helpful when doing your own calibrations, see Creating A Phase Linear Configuration.

The button “Linearize Phase ...” opens a dialog to create a phase-linear CLUT out of phase measurement data, please see Creating A Phase Linear Configuration.

The “Reset CLUT” button restores the active CLUT from the persistent configuration. The “Save CLUT” button stores the CLUT currently applied to the active configuration into the persistent configuration of the SLM. A star (*) behind the tab caption will indicate unsaved changes.

INFO

Please note that there might be some confusion with linear look-up tables:
There is a linear-looking CLUT (“math-linear CLUT") which is a straight line interpolation between the available pulse code indices of the sequence and the available gray levels of the video image. On the other hand there is a phase-linear CLUT, which looks non-linear, but generates a linear phase response over the gray levels of the video input signal (see figure).

NOTE for PLUTO-2.1 CFS Users

When using a CFS configuration mode, each color channel has its own CLUT, which corresponds to the voltage slider pair of the same color channel. All the buttons inside the box “CLUT Editing” only access the CLUT for the selected color channel. The color channel can be selected in a box at the top of the “CLUT Editing” box.

2.8 Creating a Phase-Linear Configuration

Before creating a custom configuration as described in this chapter, please try the configuration files and CLUT files provided by HOLOEYE. Even if they do not exactly match the used wavelengths, slight adjustments can be done by changing voltage settings. The following can be useful if no configuration for your specific wavelength is provided or to try to improve diffraction efficiency.
To create a customized configuration, please set up an optical phase measurement setup (e.g. a two-beam-interferometer). In case you are calibrating to other observables, like brightness, please set up the needed optical setup yourself.

2.8.1 The phase measurement

On our web page an *SLM Application Note** can be downloaded containing an explanation of how to do a phase measurement (see chapter 2.1 of the Note). If you need further assistance doing the actual phase measurement, do not hesitate to contact HOLOEYE SLM support.
The measurement software can be e.g. a LabVIEW program addressing the SLM using our HOLOEYE SLM Display SDK (divided screen function) and reading out your camera. Please save your measurement data in a supported file format, see "Supported Phase Measurement Files".

* https://holoeye.com/wp-content/uploads/HOLOEYE_SLM_Application-Note_EN_view.pdf

2.8.2 Calibration steps

These steps require to do multiple phase measurements. Please make sure you are able to do such phase measurements before proceeding with the calibration procedure.
For an overview over the the calibration process, here are the main steps to execute during the calibration:

1. Setting up a linear looking CLUT into active configuration of the SLM. This optimized the number of measured pulse codes and makes sure the voltages are fully applied in the next steps.
2. Setting up default voltages for maximum phase shift (V_low = 0V / V_high = max. supported V_high, e.g. V_high = 3.6V).
3. Increase V_low until phase measurement curve starts right away (remove non-responsive part).
4. Increase or decrease V_high until desired phase shift has been reached (e.g. 2.2 π rad).
5. Do a high quality phase measurement with the voltages from steps 3 and 4 and using the linear looking CLUT.
6. Open Phase Linearization dialog in Configuration Manager and load the result of step 5 with the button "Open phase measurement ...".
7. Select the target phase shift (should already be correct if steps 3, 4, and 5 were done correctly) and press "OK" in the dialog to apply the new calibration.
8. Do a phase measurement with the new voltages and CLUT to check the linearity and phase shift of the result.
9. Save the result into the persistent configuration if step 8 produces the expected result.

2.8.3 Calibration process explained in more detail

Each gray value addressed through the video input interface (e.g. HDMI) is translated to a pulse code inside the SLM. The addressed pulse codes are determined by the color look-up table.

To measure as many pulse codes as possible, please set a math-linear CLUT (i.e. linear-looking CLUT) before doing the measurement (see chapter "Color Look-Up Table"). The math-linear CLUT can be set easily with the appropriate pre-defined button.

To create the best configuration possible, selection of proper voltages before doing the phase linearization is very important. The voltages need to be selected so that the total resulting phase shift (using the math-linear CLUT) is a little higher than the desired resulting phase shift, e.g. 2.1 or 2.2 π radian.

Before adjusting the voltages, it is recommended to do a phase measurement at default voltages (max voltage difference with lowest low level voltage) in order to get an impression of the displays dynamic range. Some display types may require higher low and high voltages to maximize phase shift. If the phase response is considerably larger than 2.2 π, please increase the low level voltage until the phase starts directly with an almost linear slope. The high level voltage can then be changed to reach the desired total phase shift.

After selecting the voltages, please perform a high-quality phase measurement using the selected voltages and the math-linear CLUT and save the resulting measurement into a file on disk. You can either save your measurement into a text file (see below for the supported format) or into an image file containing the interference pattern of each gray level in each line of the image. Please measure with a gray level step size of one (all gray levels). The saved phase measurement result should look similar to figure 71 if saved into an image file or similar to figure 72 if saved into a text file, see chapter "Supported Phase Measurement Files".

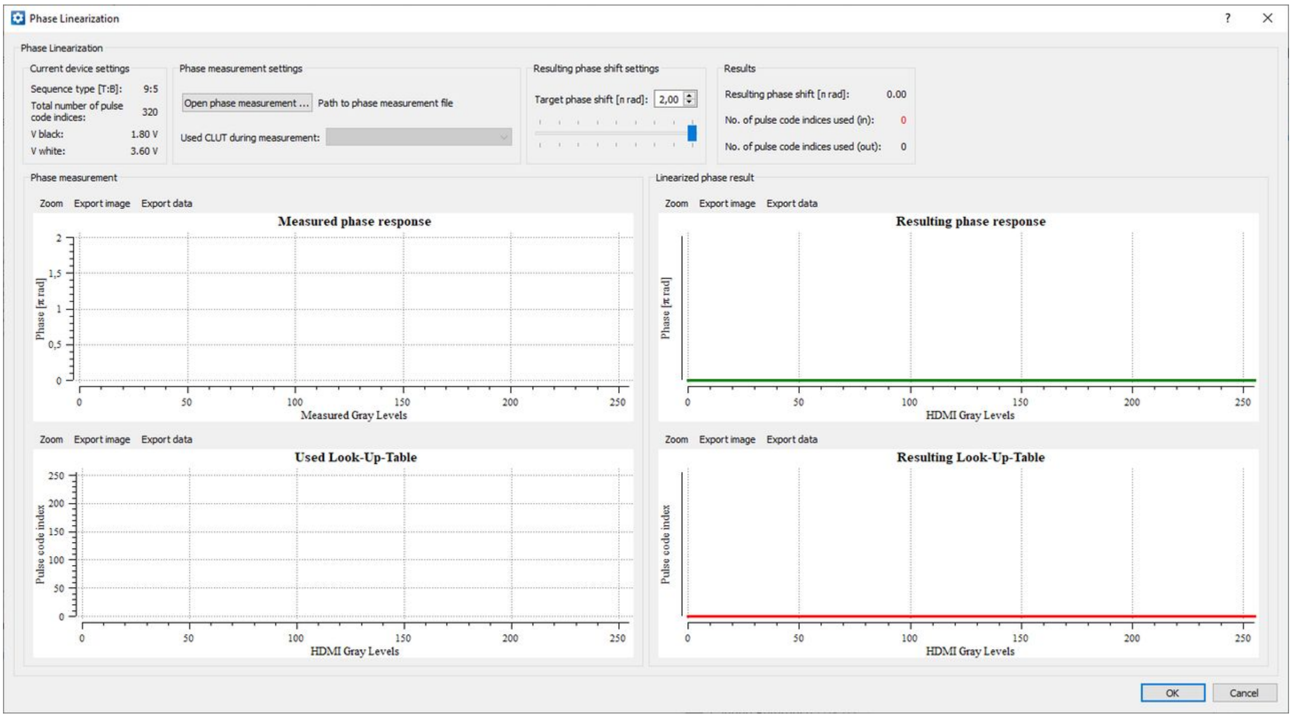


Figure 69: Initial appearance of the phase linearization dialog. Please open a phase measurement file to continue.

If the measurement was successful, please go to the tab “Gamma Table (CLUT)” in the SLM Configuration Manager software and open the phase linearization dialog by using the button “Linearize Phase …”. The initial look of the dialog is shown in figure 69.

In the top left box, some relevant SLM settings are shown which are read directly from the SLM and cannot be changed here.

To actually do the linearization, please open the phase measurement file (“Open …” in the box “Phase measurement settings”, see figure 69). Supported file formats are explained later in the chapter "Supported Phase Measurement Files". The measured phase response will show up in the upper left graph (see figure 70). The lower left graph shows the look-up table used during the measurement. By default, this look-up table is initialized to the current look-up table of the connected SLM. If the measurement was not done with the current look-up table of the active configuration, please select the correct look-up table used during measurement. This can be done in “Phase measurement settings”.

Please have a look onto the value “No. of pulse code indices used (in)”. It should be as high as possible. If it is the maximum value, its color turns to green. This is the most desired value. Otherwise, this number will be red indicating that there could be a better linearization result. However, some sequences with a total number of pulse code indices higher than 256 cannot be measured easily with all available pulse codes. In such cases the value should show 256.

In the phase linearization dialog, the next value you should pay attention to is the resulting phase shift. The value defaults to 2π radian because this is the theoretically desired value. However, there are some reasons like inter pixel cross-talk to select a slightly higher phase shift, e.g. 2.1 or even 2.2 π radian, depending on your display type and maybe also depending on the content used on the SLM. For some high retardation display types, the theoretically desired value might be 4 π or even 6 π radian instead. The value is limited to the maximum measured phase value.

If the phase measurement was done correctly, the most desired phase shift value is the phase shift of the measurement. Slightly reducing the phase shift with the gamma table might be necessary if the phase shift of the measurement is higher than the optimal phase shift, but please have in mind that the resulting gamma table will have less different pulse code indices used in most cases (see label “No. of pulse code indices used (out)” in the “Results” box). The number of used pulse code indices should also be as high as possible considering the correct phase shift, but cannot exceed 256.

The graphs on the right side of the dialog show both, the expected phase measurement result after applying the generated phase-linear gamma table and the resulting phase-linear gamma table which will be uploaded to the SLM as soon as you press “OK”. With the “Cancel” button, you can cancel the dialog and nothing will be changed on the SLM.

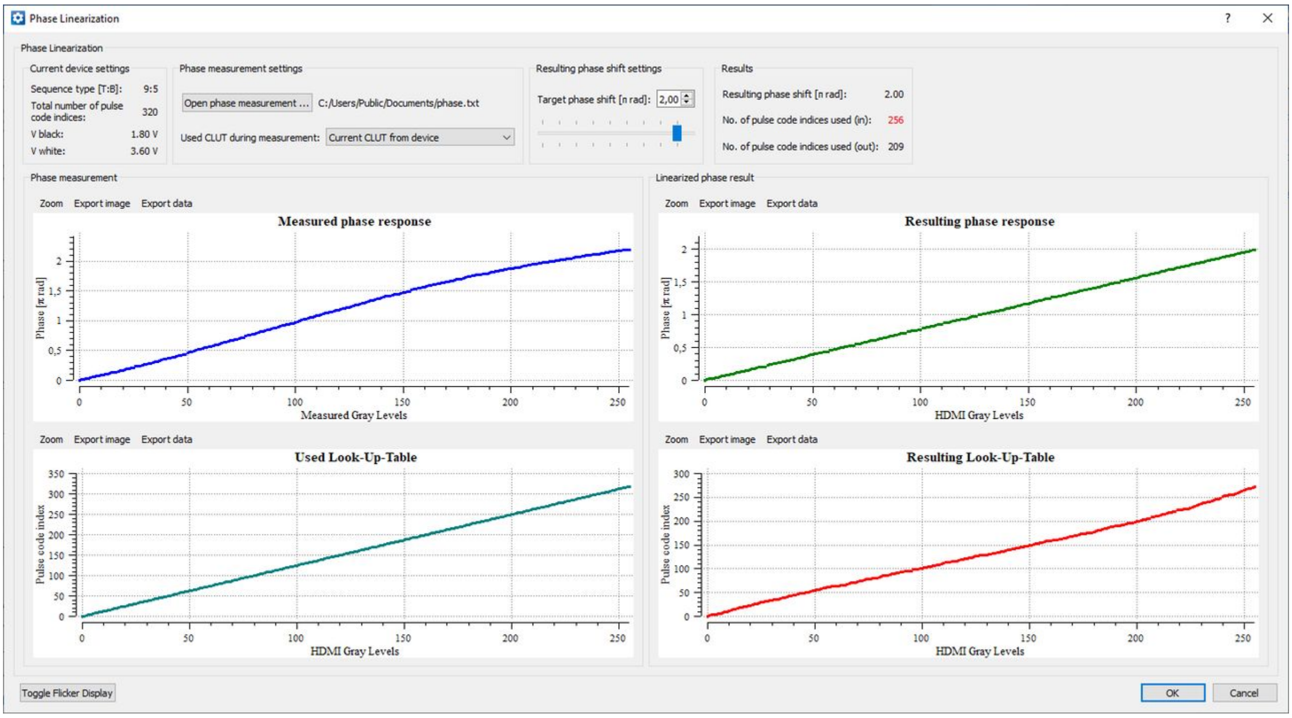


Figure 70: Phase linearization dialog after opening a phase measurement file. Just press "OK" to apply the new configuration.

After pressing "OK", the created CLUT is transferred to the active configuration of the SLM, and is not saved into the persistent configuration. To permanently store the new configuration into the driver board, please either use the Save button on the CLUT page or save the whole active configuration. The latter will make sure that also the used voltages are saved.

You can also save the new configuration directly into a *.hec/*.hex configuration file, with or without having it saved into the permanent boot configuration.

2.8.4 Supported Phase Measurement Files

Supported phase measurement files are both, image files and text files.

Image files (*.bmp and *.png) will be evaluated under the assumption that each line contains the intensity distribution of the interference pattern for one gray level. Typically, such an image consists of 256 lines with arbitrary width (e.g. width of the camera image). The line number corresponds to the gray level count.

The phase linearization dialog has a built-in phase evaluation algorithm which converts the interference pattern image data to phase shifts. The phase response is shown directly in the upper left graph of the dialog (see figure 70). This way, camera readout can easily be evaluated through this dialog without the need to extract the phase shift value from your camera images while doing the phase measurement. The phase shift data can then be exported using the "Export" tool buttons of the graph.

Figure 71: Example of a supported phase measurement image composition file with the interference pattern lines over the gray levels stored in the image lines. The top-most line is for gray level 0. The voltages should be adjusted to make the phase response as linear as possible before using the file.

Suitable text files consist of tabular data separated by tab and new line characters. Each line contains the gray level and the phase shift, separated by a tab. This allows easy editing and creation using Microsoft Excel or similar software (e.g. Libre Office Calc).

```
#Measured Gray Levels Phase [pi rad]:
    0	0.0087
    1	0.0128
    2	0.0111
    3	0.0193
    4	0.0101
    5	0.0000
    6	0.0121
    7	0.0238
    8	0.0131
    9	0.0134
   10	0.0156
   11	0.0193
   12	0.0243
   13	0.0273
   14	0.0339
```

Figure 72: Example phase measurement text file opened in Notepad++ showing all characters. The orange dots mark spaces, the arrows mark tabs, "CR/LF" mark new lines. Please note that all 256 gray levels should be provided.

Lines beginning with "#" are ignored. Spaces between numbers are also ignored.

Text files can be exported from the phase response graphs. Those files are supported by the phase linearization as measurement files.

2.9 Geometry

The “Geometry” tab enables you to move around the image in case the video resolution is smaller than the actual SLM resolution. This can be used for pixel wise adjustment of the addressed optical function with respect to the laser beam. It also allows flipping of the image in horizontal and vertical direction to fix orientation issues.

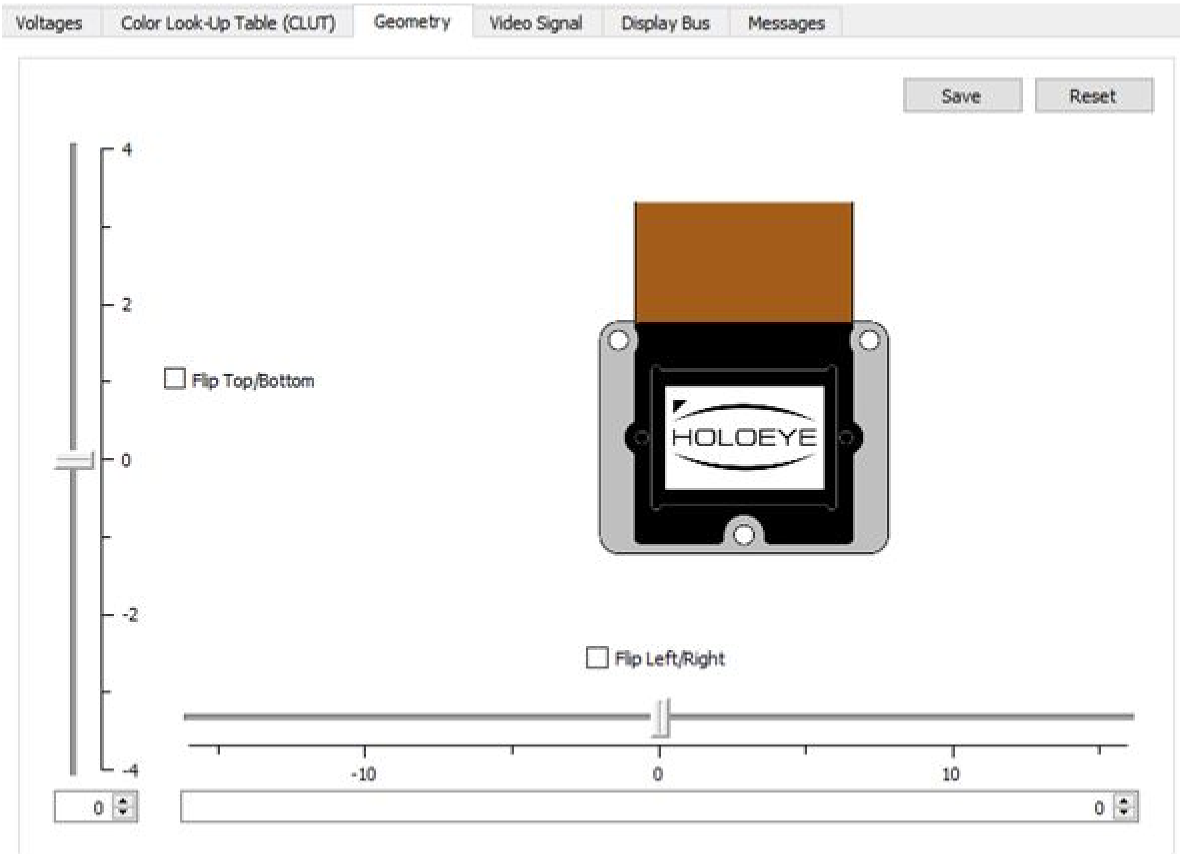


Figure 73: Geometry tab.

A shift of zero represents a centered image.

The “Reset” button restores the geometry configuration from the persistent configuration and the “Save” button writes the geometry configuration into the persistent configuration.

2.10 Video Signal and Internal Pattern Generator

On the “Video Signal” tab, the input video signal can be configured. The following input options are available when connected to a PLUTO-2.1 SLM:

- HDMI.
- Embedded Linux system.
- Integrated pattern generator.

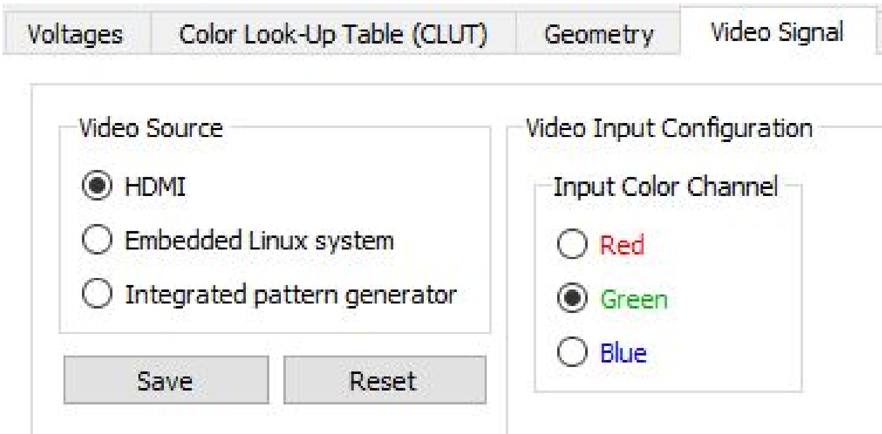


Figure 74: Video Signal tab.

In the “Video Source” box, the video input source to the display can be selected. Please click on one of the available options to change the input signal. Each video source entry can show its own settings in the box “Video Input Configuration”. The box will not be visible if no settings are available for one of the input options.

The HDMI option is the video signal from a computers graphics card received on the HDMI connector. HDMI video signal input always receives a colored (RGB) FullHD (1920x1080@60Hz) image, no matter how this data stream is used on the display. If the device is in monochrome mode, the SLM can address only one of the three color channels, and the video input configuration allows to select which one to use (Red, Green, or Blue). In color field sequential or 180Hz mode, all 3 color channels are shown sequentially on the display, and therefore in this case the color channel selection is not available, i.e. the “Input Color Channel” box is invisible.

In monochrome mode, the color channel selection can be used for example to connect two or three SLMs to the same HDMI signal using an HDMI splitter and selecting a different color channel for each SLM. Then, each SLM can be addressed separately through one of the three colors of the HDMI signal, synchronized to the same input signal.

The option ”Embedded Linux system” selects the data input interface through which an application running on the embedded system can show image data on the display. The embedded Linux system is off by default, and in this case there is no image data provided on this interface until the embedded Linux system is used. When selecting this interface without a running embedded system, the display typically shows a black image, but may also show some random leftover content from the previous signal. The input data format on the Linux system is an RGB image, like on HDMI, and therefore there is the same color channel selection available like in HDMI. This input option is only available in PLUTO-2.1 firmware.

The integrated pattern generator was added for the new PLUTO-2.1 SLM and currently uses a fixed configuration to show two alternating gray level ramps, one in horizontal and one in vertical orientation. The alternation frequency is about 1Hz. The gray level ramps can be used to see some modulation in phase and in amplitude mode.

INFO for PLUTO-2 Users
PLUTO-2 SLMs are fixed into monochrome mode by the firmware. They always show the color selection box in HDMI option. In addition, the other input options are not available for PLUTO-2. The integrated pattern generator is not available in the PLUTO-2 firmware, and the embedded Linux system video input can not be activated/switched through Configuration Manager on PLUTO-2. Embedded Linux users on a PLUTO-2 SLM need to make changes to the video input source from within the embedded Linux system itself.

The video signal is not changed automatically when HDMI signal is detected or lost, like in some other HOLOEYE SLMs. However, applications running on the embedded system can change the input signal.

The “Save” and “Reset” buttons allow restoring and saving the video signal setting from and to the persistent configuration, resp. It will also save and restore the individual input interface settings in the box “Video Input Configuration”.

2.11 Display Bus Check

On the tab “Display Bus Check” the data lines from the driver to the display can be checked. By clicking the large button on this tab, the driver performs a test procedure which will interrupt the content on the display during the check. The result of the display bus check is indicated at the 32 little boxes below the button.

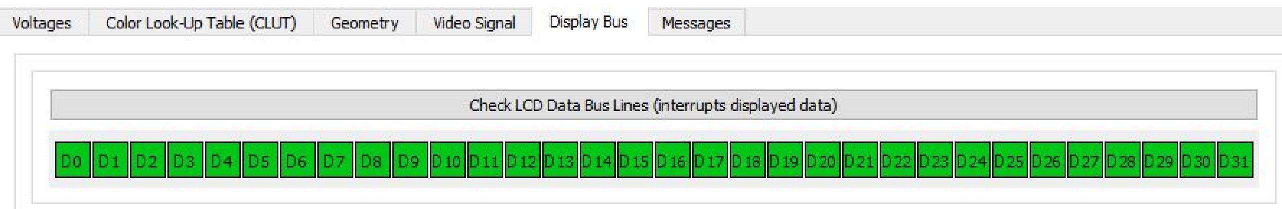


Figure 75: Display bus check.

If all boxes are green, the display is connected properly to the driver.

Red boxes indicate a connection issue between the driver and the display. Typically the flex cable is not connected properly to the driver.

2.12 Messages

While the software communicates with the SLM there are different types of messages shown in the messages tab. These messages log most events of the software, including device communication and user dialog boxes.

The message log might be helpful to evaluate the source of any errors. It can also be useful to see which actions were done. The messages log is cleared whenever a new connection is made.

The following type of messages are shown:

- Error messages (red).
- Warning messages (light blue)
- Start/Stop of progress bar dialog (dark blue)
- Question dialog messages, including selection options and actual selection (orange)
- Status messages (green)
- Information (black).

See figure 76 and figure 77 for example messages. In figure 76 the initial messages after a successful connection to a PLUTO-2.1 SLM is shown.

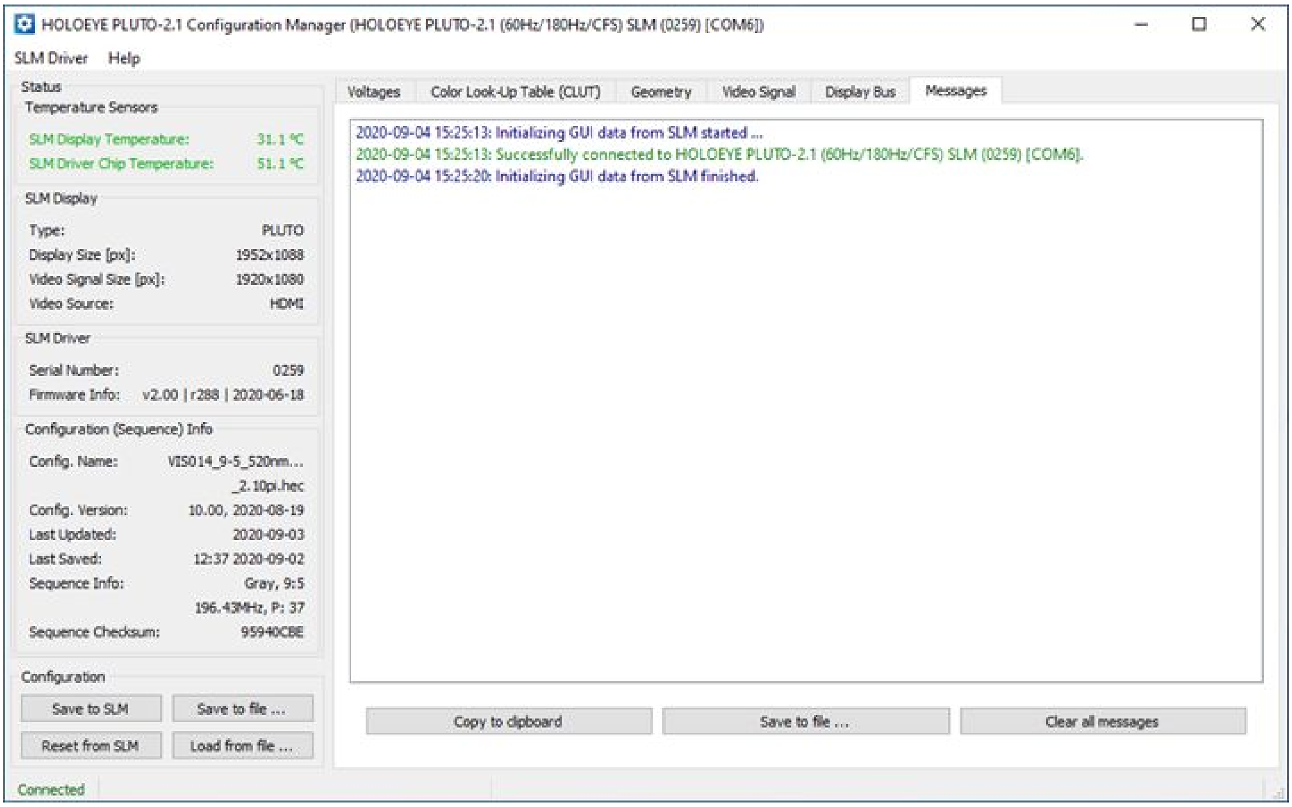


Figure 76: Messages tab after successful connection.

Error messages are displayed in red color. It is strongly recommended to read such messages and follow the suggestions (see figure 77). Error messages typically come from issues with the device and hardware interface, but may also indicate wrong user actions, like selecting an incompatible configuration file. Error messages could in principle also occur due to bugs in the software, but the software was checked carefully before the release.

Whenever an error message appears due to communication issues with the SLM, the requested action is stopped. In some cases this can lead to a corrupted device configuration. If you are not sure and your device does not behave like expected, please overwrite your device with the correct *.hec/*.hex configuration file to restore the correct configuration after communication errors. This does not necessarily apply to errors occurring from a disconnected device, when no action was performed (see figure 77). It applies especially when the device gets lost while uploading a configuration file into the persistent configuration.

Warning messages are displayed in blue color. You should also pay attention to such messages and follow the suggested actions.

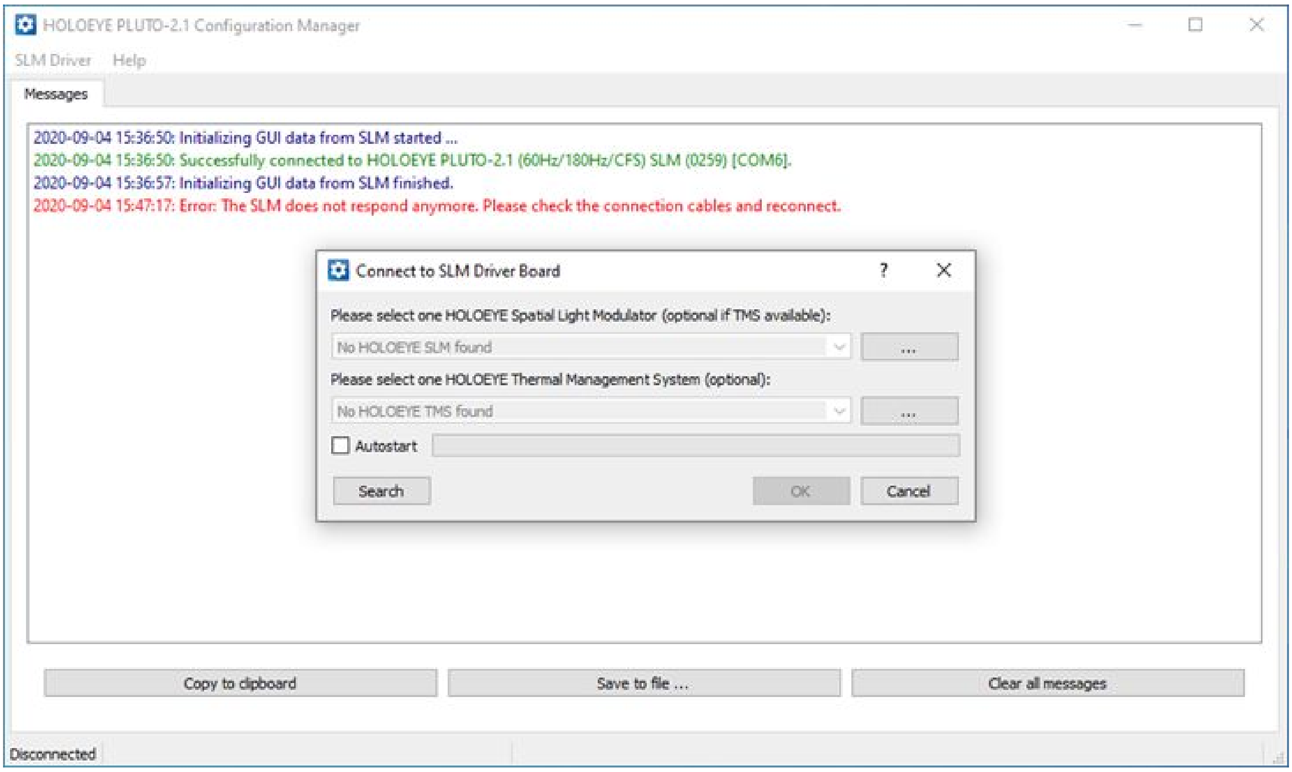


Figure 77: Messages tab after disconnecting the USB plug. At least one error message appears due to the lost connection.

All messages can be copied to the clipboard, saved to a text file or cleared by using the three buttons at the bottom of the tab.

The messages are logged automatically to a log file located at

C:\Users\<username>\AppData\Roaming\HOLOEYE Photonics\ PLUTO-2.1 Configuration Manager\message-log.txt

The log can be disabled through the configuration file located at

C:\Users\<username>\AppData\Roaming\HOLOEYE Photonics\ PLUTO-2.1 Configuration Manager.ini

Through the settings file, a few other things can be changed, like the log file path. It is recommended to leave the file as is, except for disabling the log feature.

To disable the log feature, please close all instances of Configuration Manager and change the entry “EnableLog=true” in the section [Messages] to “EnableLog=false”.

At next start, no messages will be written to this file anymore and the file size will not grow anymore. However, no error messages can be retrieved back in case Configuration Manager stops working. Therefore, by default the log is enabled.

Log file entries are not cleared on a new connection. That means, if not disabled, all messages from previous sessions can be retrieved back from the messages log, even if the software would crash. If the log file becomes too large, you can simply delete it while Configuration Manager is not running. Configuration Manager will create a new file on next start, if the log feature was not disabled in the application settings file, see above.

2.13 Software Updates

This software supports a search for new versions online. The search is not done automatically. To execute the search manually, please use the menu point “Help” → “Check for Updates …”.

A dialog will appear where you can click the button “Check for updates”. The software will connect to a HOLOEYE server and check the latest official release information. Both versions, the currently used and the latest available versions will be displayed. No other data is transferred to the HOLOEYE server.

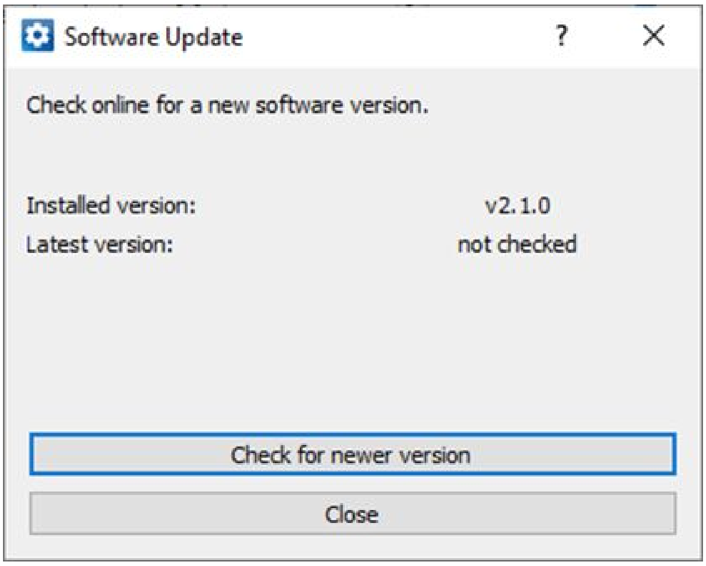


Figure 78: Check for updates dialog.

To actually update the software, please log in or register at our download website https://customers.holoeye.com/ and download the latest version.

2.14 Feedback and Bug Reports

If the software does not perform as expected, please open the “Help” → “About” menu and make a note of the version and revision number, which should be referenced when sending feedback about the software. Please also tell us the version information of your current firmware, which is shown on the left side panel of the main window.

In case of bugs in our software, the message log file may help, too. It is enabled by default, see chapter “Messages“.

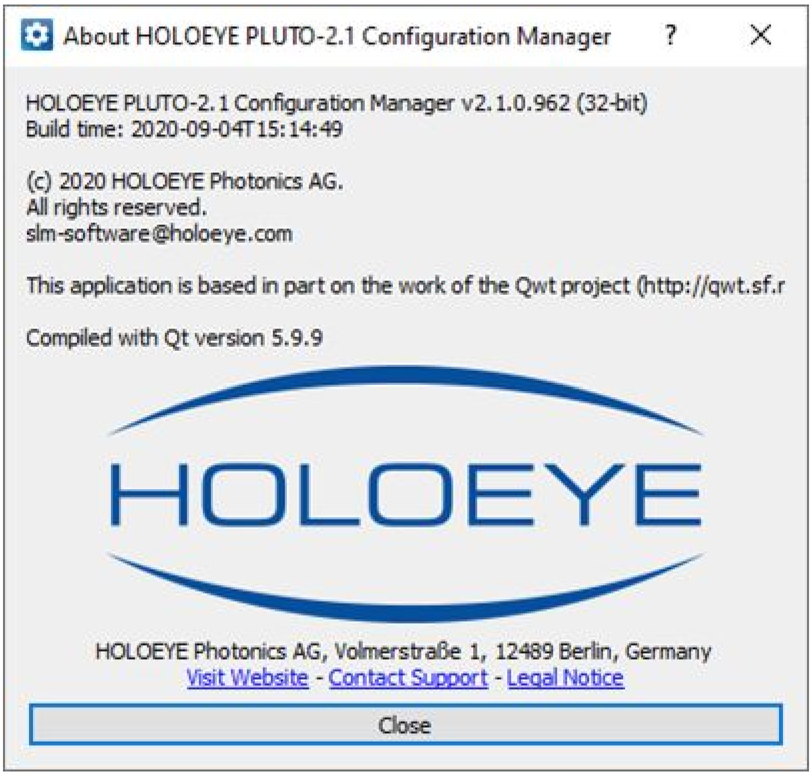


Figure 79: Please take version and revision information from about dialog and add to any communication about this software.

Please make use of the highlighted links to our website and to the contact email address.

3 Device Detection

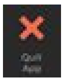
The HOLOEYE SLM Pattern Generator software, the Slideshow Player software and the SLM Display SDKs feature an EDID device detection. On start-up a device detection dialog pops up which checks if a proper HOLOEYE SLM device is connected and if all system settings are correct.

3.1 Autostart Dialog

The autostart dialog allows you to quickly operate a single HOLOEYE SLM device, if it is already configured correctly. This is the default behavior, if not disabled in the settings.

3.1.1 Available Actions

The following actions are available at any point:

	Leaves the autostart mode and opens the settings dialog.
	Leaves the autostart mode and shows the system information dialog.
	Leaves the autostart mode and opens the full device selection.
	Quits the device detection and the current application.

3.1.2 No Device Detected

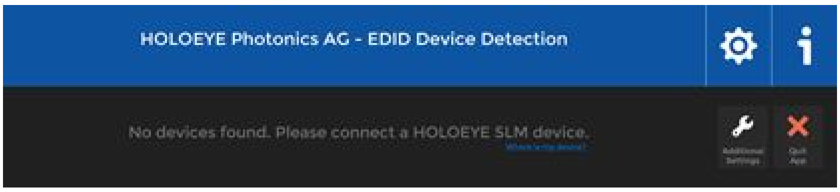


Figure 80: The autostart dialog if no device was detected.

If no device was found (figure 80), a text is shown to indicate it. If your device is already connected, you can click on “Where is my device?” to get instructions on how to fix the issue.

3.1.3 Correctly Configured Device Detected

Figure 81: A correctly configured device was detected and the autostart timer is running.

If a correctly configured device is detected, it is displayed and an autostart timer starts running. The duration of the timer can be changed in the settings. If another configuration is desired, the “Additional Settings” button can be clicked to leave the autostart mode and enter the normal device dialog (see "Device Selection Dialog"). Once the timer finishes, the autostart dialog will disappear and the actual application comes up. See "Device Settings" for more information on the current device settings.

3.1.4 Quit Autostart Mode

The autostart mode will not be shown if any of the following applies:

- The user clicks the „Additional Settings” button.
- A misconfigured device was detected.
- Multiple devices were detected.
- The autostart was disabled in the settings.

3.2 Device Selection Dialog

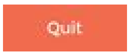
The device selection dialog allows you to select one device from all detected devices to run the application with. It also allows you to configure devices as desired.

3.2.1 Available Actions

The following actions are available at any point:

Leaves the autostart mode and opens the settings dialog.

Leaves the autostart mode and shows the system information dialog.



Quits the device detection and the current application.

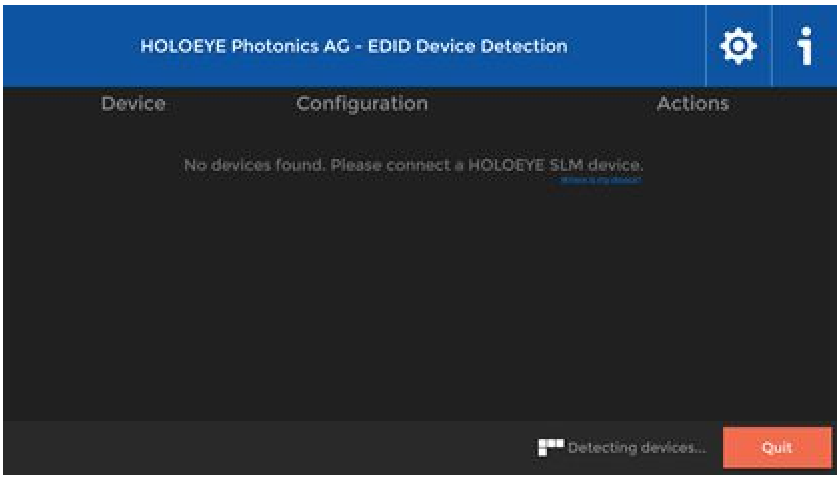


Figure 82: No device was detected.

When no device was found (figure 82), a text is shown to indicate this. If your device is already connected, you can click on “Where is my device?” to get instructions on how to fix this.

3.2.2 Detected Devices

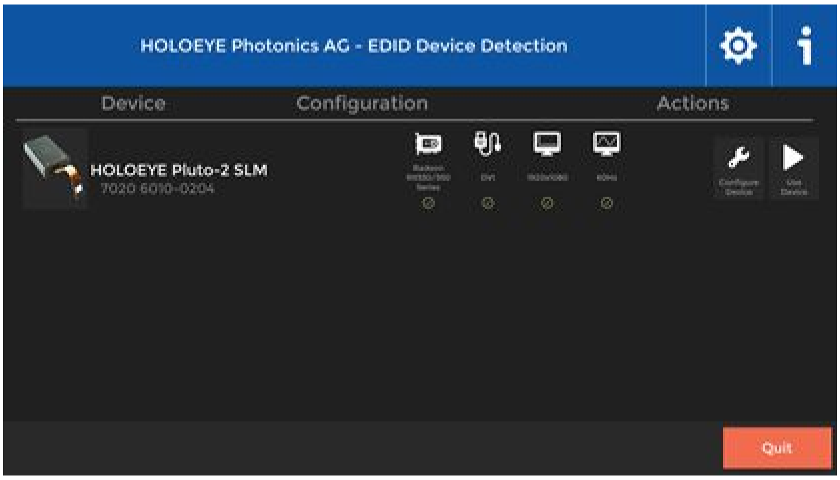


Figure 83: A single correctly configured device was detected and autostart is turned off.

If devices are detected, they are listed along with their basic properties.

3.2.3 Device Details

Figure 84: The details of the device.

The device details show the name of the device, an image representing the device as well as its serial number. For some older devices there may be no serial number displayed.

3.2.4 Device Settings

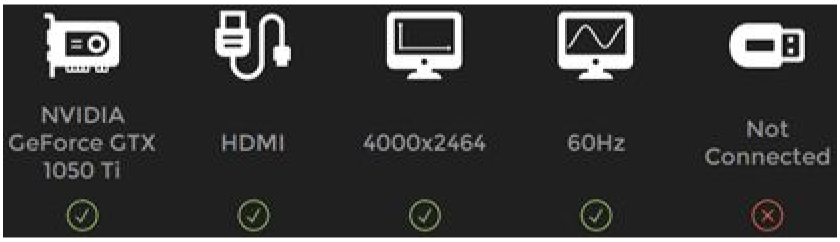


Figure 85: The current settings of the device.

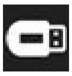
The current device settings are shown for the following categories:

 The graphics card the device is connected to.

 The cable and adapter used to connect the device.

 The current resolution the device is set to.

 The current refresh rate the device is set to.

 Some devices and features require a USB license dongle to be connected. In these cases, this shows the status of the USB license dongle and the required license.

3.2.5 Device Actions

The following actions can be performed for each device:

 Change the configuration of the device.

 Close the device detection and run the application using this device.

3.2.6 Multiple Devices

If multiple devices are detected, one single device can be selected to run the application.

3.3 Configure Device Dialog

This dialog allows you to change the configuration of a device.

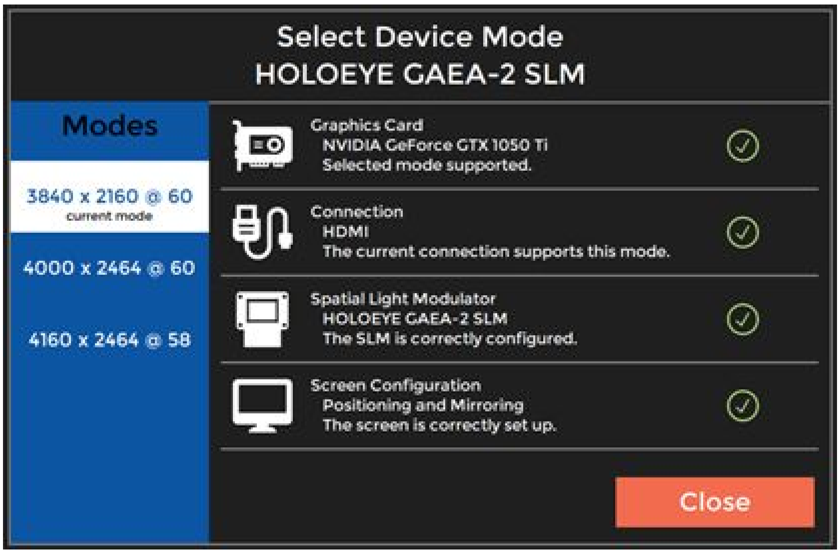
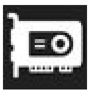
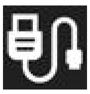


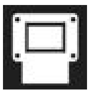
Figure 86: The current mode of the device.

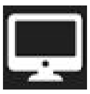
The modes supported by the device are listed on the left, where you can select the mode you want to change to. On the right you can see if the selected mode is supported by your hardware setup.

The following hardware is checked:


Checks if the graphics card the device is connected to supports the selected mode.


Checks if the used graphics card connector, cable and adapter support the selected mode.


Checks if the SLM device is correctly configured for the selected mode.


Checks if the screen setup is correct.

3.3.1 Switch Mode

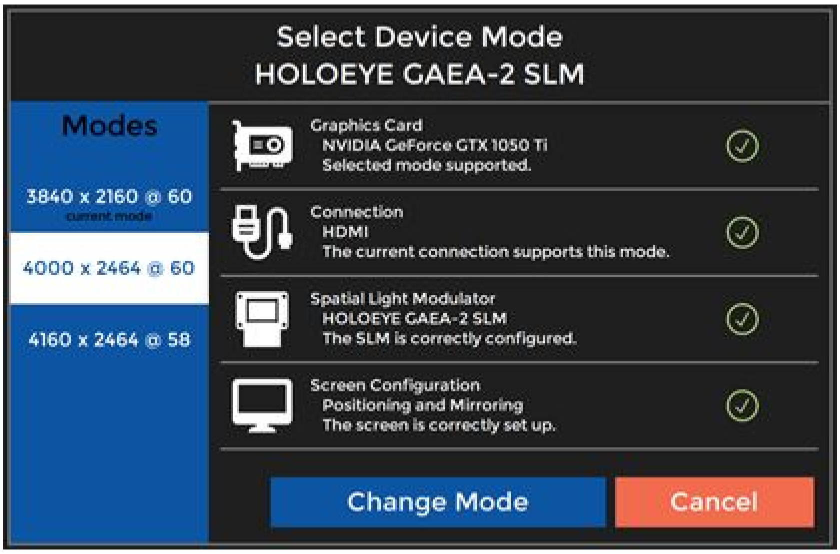


Figure 87: Dialog to change the current mode.

When selecting a different mode on the left, the information on the right updates to show if your hardware setup supports the selected mode. The “Change Mode” button becomes available, when there are no general problems with your setup. When clicking the button, the operating systems screen setup will adjust, so that the device is operated in the desired mode.

Not all modes can be checked immediately by the software. Some modes are only checked when you try to use them.

3.3.2 Unsupported Modes

If a mode is not supported, an info button will appear. Clicking this button will give you more details and instructions on how to solve the problem.

3.4 Settings Dialog

The settings can be opened via the icon in the top right corner of the device detection dialog.

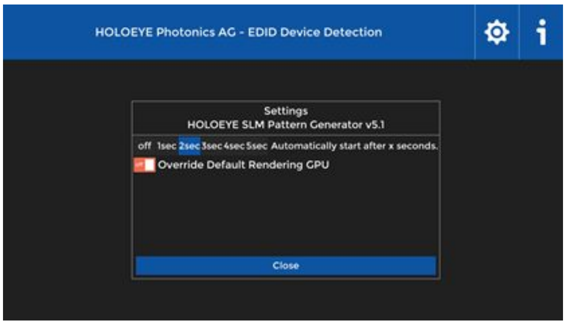


Figure 88: The device detection settings.

The settings dialog allows you to change some general settings of the device selection. The settings can be different for every application.

3.4.1 Autostart Timer

The duration of the autostart timer (see "Correctly Configured Device Detected") can be set here. You can also completely disable the autostart feature, if desired.

3.4.2 Override Default Rendering GPU

Using Windows, you can select which graphics card is used to calculate and render all the data. Usually, the device selection should automatically select the best GPU for this. After enabling this option and closing the settings, the GPU can then be selected from the device selection screen.

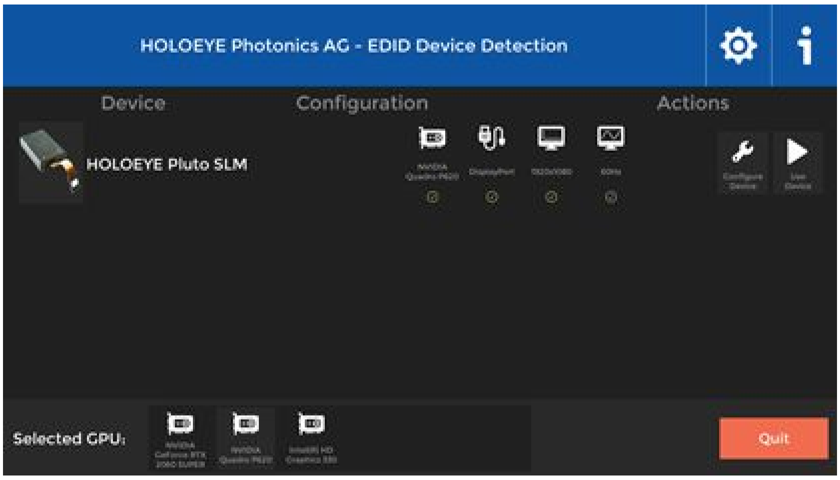


Figure 89: The GPU can be selected at the bottom left.

The application will use the GPU selected in the bottom left corner to handle the computation and rendering of data.

3.5 System Information

The system information dialogue shows you some general information about your system and your screen setup.

3.5.1 Operating-System Power Saving Features

As soon as there is data shown on the SLM, the software prevents the operating system from starting any power saving features, including screen locking. This means, all automatic functions, which would interrupt the SLM content display, are disabled.

Please note that if e.g. automatic screen locking is switched on for a good reason on the user's PC, it will be disabled as long as there is an open window on the SLM.

If you want to have a screen lock while displaying content on the SLM, please lock the screen manually. Of course, other energy saving features can be used manually too while there is content displayed on the SLM. However, when manually enabling such operating system power saving features, the actual addressed image output to the SLM hardware is interrupted.

3.6 Mirrored Displays (Monitor/SLM)

The SLM screen can be mirrored with a desktop monitor, using the same resolution. Mirrored displays are only accepted by the EDID device detection as long as the device detection window is not shown on the mirrored SLM screen.

4 Pattern Generator

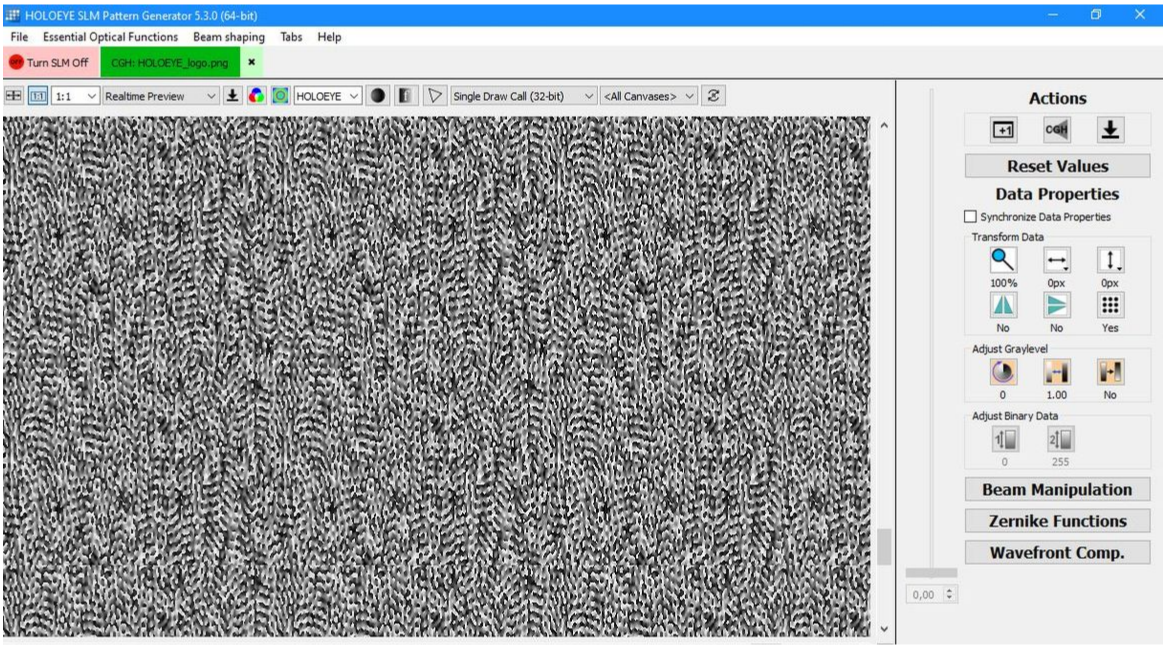


Figure 90: Screenshot of SLM Pattern Generator Software

The HOLOEYE SLM Pattern Generator software allows the computation of computer-generated holograms (CGH’s) from user defined image files as well as the generation of elementary optical functions such as different kind of gratings etc., as well as the superposition of different CGH’s. The generated CGH’s can be addressed to the SLM within the software and can be modified by a superposition of holographic functions on the fly. In addition, there is an option to load wavefront compensation data for the used SLM.
The current version of the software is available for Microsoft Windows 8 operating system or later. For Windows 7 or Linux Ubuntu 18.04 LTS 64 bit we may have older versions.

4.1 Installation

4.1.1 Microsoft® Windows®

In order to make a successful installation, you should make sure that you have sufficient privileges in the computer’s operating system (Microsoft Windows™ 10). You should be permitted to create a directory in the directory that contains programs and to copy files into that directory and to write into the ‘all users’ section of the start menu of your operating system. Of course, administrator privileges will be sufficient for all these operations.
Start the executable file ‘HOLOEYE SLM Pattern Generator 5.3 (64|32 bit).exe’ for 32- or 64-bit OS and follow the instructions of the installation menu.
Please accept the license agreement before selecting the program components to install. In order to install the complete version, mark all checkboxes. Choose the destination folder as well as the start menu folder. Select ‘Install’ to start the installation procedure and finally ‘Close’ to finish the installation.

4.2 Starting the Software

Before starting the software, it is recommended to connect the display interface (HDMI) as well as the power cable to the SLM and the computer. The correct display interface settings for the SLM can be done from within the EDID device detection, see next section.

Start the program using the icon of the software, which was created during the installation process. The EDID device detection will show up. If the SLM is connected properly, the software will automatically continue. If not, please connect the HOLOEYE SLM and select it. After the SLM was properly detected, the software will start and is ready to use.

4.2.1 SLM Device Detection

When you start the software a device detection dialog pops up which checks if a proper HOLOEYE SLM is connected and if the system is configured correctly. You can find detailed information on the device detection in the chapter "EDID Device Detection" of this manual.

4.3 User Interface Concept and Preview

The main window of this application integrates a tab system to work with multiple images in parallel. Only one tab can be active on the SLM screen at the same time. Always the currently active tab is active on the SLM. The active tab is marked in dark green, and the inactive tabs have light green buttons. The first tab button is always red. It is dark red when there is no content shown on the SLM screen, i.e. other applications, e.g. the Windows desktop background image, will be visible on the SLM. If it is light red, another tab is active and shown on the SLM screen.

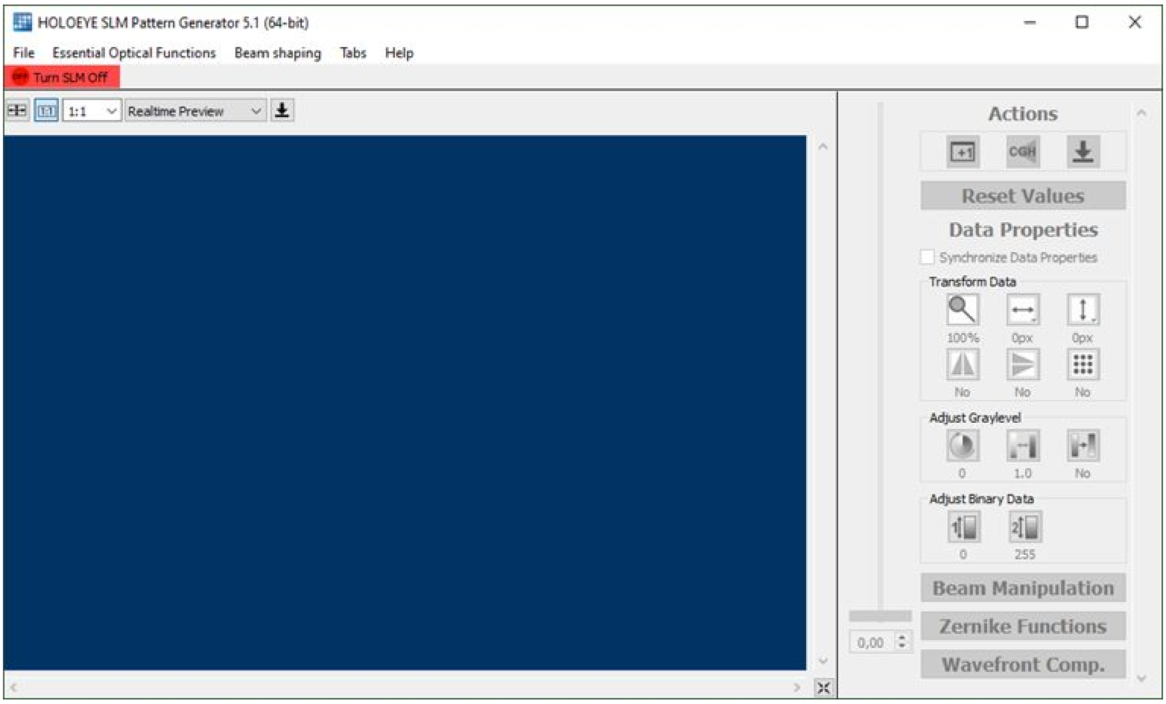


Figure 91: Main application window after start. There are no active tabs, and SLM screen is off (i.e. other applications can use SLM screen).

The image visible inside each tab is only a preview image of what is actually displayed on the SLM screen. The preview can be configured with the controls above the shown preview image. You have the option to scale the image in the preview for inspecting the content shown on the SLM. The default mode is “1:1” scaling, which means each pixel on the SLM is represented by a single pixel of your monitor. This is helpful to inspect most phase modulation pattern, like gratings etc.

The “Fit” option shows the full SLM screen and fits it into the preview area. This is helpful to get an overview of what is shown on the SLM screen. Anyway, you can put in any ratio, or select from predefined ratio numbers from the drop-down menu. In addition, the “Realtime Preview” mode can be changed to a “Capture SLM Screen” mode.

The “Realtime Preview” is faster but may not be 100% correct. The “Capture SLM Screen” mode is slower, but provides a better image quality and enables visualization of other applications visible on the SLM screen, like stay-on-top windows like Windows Task Manager or other applications using the SLM screen. The rightmost button of the preview controls saves the full SLM screen into an image file on disk. This image file can also be used to inspect the content on the SLM screen precisely.

Figure 92: Preview options of the current SLM screen content.

Beneath the preview is a sidebar, which allows manipulating the image data. Please refer to the chapter "Image Manipulation Sidebar" for more information on image and phase manipulation features.

4.4 Open Image Files

4.4.1 Open Amplitude or Pre-calculated Phase Data Image Files

Choose from the *File* menu the point 'Open amplitude/phase data from image file ...', and a file selection dialog will show up. Supported image formats are BMP, PNG, JPEG, GIF, XBM, XPM, MNG and the different PNM formats: PBM (P1 or P4), PGM (P2 or P5), and PPM (P3 or P6). Choose a supported image file and accept the file selection dialog. The image file(s) are loaded and are transformed to a picture with 256 gray-scale values. If the selected images contain an alpha channel, it will be ignored.

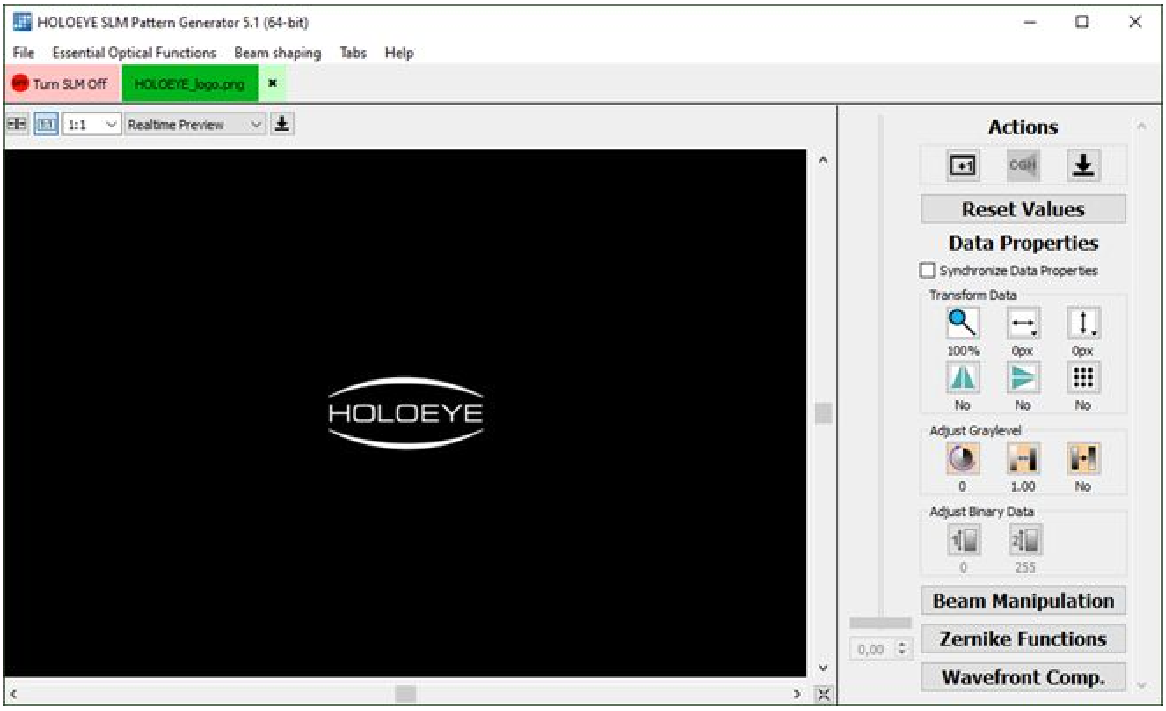


Figure 93: Image tab after opening the installed HOLOEYE logo from the signals folder.

The image file will appear in a new tab, and will be visible on the SLM screen directly. When selecting multiple files, all selected files will open in separate tabs, and the last of them will be active.

The image files are shown as is. In case of active manipulations synchronized from other tabs, these synchronized manipulations will be applied directly. When the check box 'Synchronize Data Properties' is off, images will open without any manipulations. The image file(s) cannot be computed into computer generated hologram (CGH) phase values if opened through this menu entry. This is indicated by the tab caption, which is the plain file name without any additions, and by the deactivated and grayed out action button "CGH".

Therefore, please use this menu entry only if you want to open either pre-calculated phase images or amplitude images. For creating phase images out of amplitude images using this software, please use one of the CGH computation options from the *File* menu. See below.

4.4.2 CGH Computation from Image Files

Please use the menu entry 'CGH computation from image files' from the *File* menu to select a single image file or a few image files for creating computer-generated holograms (CGH). The CGH computation needs information about the resulting holographic image in far field. A dialog will open once to select the resulting image size compared to the unit cell size, and to select the maximum unit cell size used in computation. When multiple files were selected, the dialog will open only once and will apply the same settings from the first image file to all. The CGH settings dialog is shown in figure 101 and is explained in the chapter "Calculating a Computer Generated Hologram (CGH)".
When you want to compute a lot of CGH files, e.g. for later slide show playback, please consider using the more advanced CGH batch computation dialog.

4.4.3 Open by Drag and Drop or via Clipboard

Images can be pasted directly into HOLOEYE SLM Pattern Generator from clipboard. To do so, please copy image data from image editing software to the clipboard and use the key combination CTRL-V to put the image into a new tab. The same can be done with image files. You can copy the file and paste it into the main window of HOLOEYE SLM Pattern Generator.

In addition, image files can be dragged from Windows Explorer and dropped into the main window of HOLOEYE SLM Pattern Generator. The files will be opened in the same way as if they would have been copied and pasted.

On each such paste or drop action, the software will ask in which mode the images shall be used, either as plain images with pre-calculated phase data or amplitude data, or as input image files for CGH computation. A dialog will open to select the mode, see figure 94. If multiple images are given at the same time, the dialog will apply the same mode for all images.

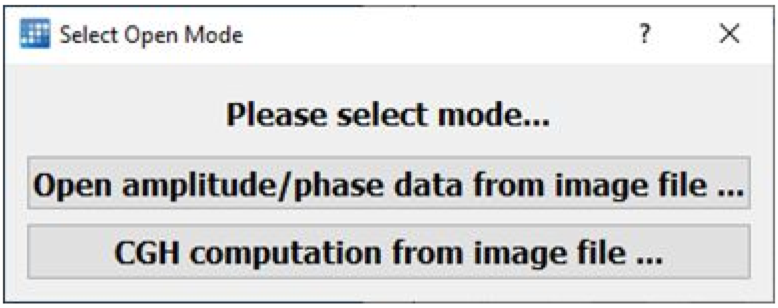


Figure 94: Selection dialog after dropping or pasting image files or data into the main window. Images files can either be shown directly or used as input for CGH computation.

Anyway, when multiple images are pasted or dropped, the software will open each image in a separate tab, using the selected mode.

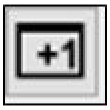
4.4.4 Copy Image Data

Please use the keyboard shortcut CTRL+C to copy the image data in full SLM size into clipboard. This data can then be pasted into other image editing software like Microsoft Paint in Microsoft Windows OS, Irfan View, GIMP, and many other similar applications.

4.5 Action Buttons in Sidebar

The top of the sidebar on the right side of the main window provides a few action buttons.

4.5.1 Clone Tab Action Button

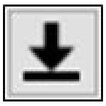


The first action button is to make a copy of the current tab with the loaded data and all current sidebar settings.

4.5.2 Compute CGH Action Button

This button is only enabled if the tab caption starts with ‘CGH: ’. This is the case when opening images in CGH computation mode, see "CGH Computation from Image Files" and "Open by Drag and Drop or via Clipboard". Pushing this button will re-open the CGH settings dialog (see figure 101). Please apply new CGH settings and accept the dialog to re-compute the hologram and update the content in the current tab. The CGH settings dialog has two settings: the slider for the resulting image size inside the diffraction unit cell of the far field and the maximum unit cell size. It is recommended to stay with the default maximum unit cell size. Please see chapter "Calculating a Computer Generated Hologram (CGH)" for more information on CGH computation.

4.5.3 Save Data Action Button



This button does the same like the same button in the preview settings. It stores the current SLM screen content into an image file. You can use this image file for detailed inspection of the SLMs content. The saved image file can also be used later in other software, like HOLOEYE SLM Slideshow Player.

4.6 Image Manipulation Sidebar

On the right side of the main window, beneath the preview, a sidebar is visible. It contains multiple image and optical phase manipulation features like zoom, shift, flip, tiling, gray level adjustments, beam manipulations (beam steering and (de-)focus), Zernike parameter overlay, and wavefront compensation. In addition, there are a few actions (Clone data into a new tab, re-compute CGH, save current SLM image). All these options have a hint text, which pops up when the mouse cursor stays over the button for a short period. The hint texts explain the function of the button and show additional helpful information.

To edit one of the available manipulation values, please use the left mouse button and click on the icon. The large vertical slider will take the selected function and enables changing the value, if applicable. Some functions like 'Tiling Data' will disable the slider, because there is no value except for Yes/No. The current value of each manipulation is written below the manipulation button icon.

4.6.1 Sidebar Synchronization over all Tabs

On the top of the sidebar there is a check box 'Synchronize Data Properties'. When it is checked, all tabs will be synced to the same sidebar settings, except a few manipulation options, which are related to the data type, like tiling option for CGHs, and binary values for binary functions. The synchronization is useful in case the adjustments are made due to the optical setup. Synchronization may help in case you have a lot of similar images opened. Using no synchronization is recommended when the adjustments are made for the used image data.

Zernike overlay and the wavefront compensation are always synchronized in all tabs, independent of the check box, because these settings are meant to be used to correct for optical setup and device imperfections, e.g. optimizing a beam focus or correcting for wave front imperfections due to optical elements, including the SLM. Therefore, Zernike and wavefront compensation will be applied to new tabs too, even when you open amplitude images, because they will be used like pre-computed phase functions by the software.

The wavefront compensation overlay may not be visible on the preview, depending on the settings, see figure 92. However, it has its own little preview in the sidebar, which may be hidden as well.

4.6.2 Reset Adjustments

There is one big 'Reset Values' button at the top of the sidebar. It resets all adjustments, which do not directly belong to the image data, except for a loaded wavefront compensation.

Additionally, each box can be reset separately by clicking the right mouse button onto the captions of the boxes. The same applies to each icon of the manipulations. You can right-click to reset its value to the default value.

4.6.3 Basic Image Manipulations

The first box is 'Transform Data' (see figure 95) with the following features:

- **Zoom/Resize**: Performs a zoom of the bitmap data, i.e. there will be interpolation effects at least for non-integer zoom factors.
- **Shift X / Y**: Move the image in x and y direction over the SLM screen. Please click and hold on the buttons to open a sub-menu to change the slider range, if needed. By default, the slider range is set to the size of the opened image file, or adapted to the essential optical function. For some optical functions, one or both buttons may be inactive.
- **Flip X (Left/Right)**: Mirrors the image along the vertical center line.
- **Flip Y (Top/Bottom)**: Mirrors the image along the horizontal center line.

- **Tile Data**: Makes smaller images appear periodically continued, i.e. tessellated, initialized with the base image 'tile' shown in the screen center. This feature is enabled by default for CGH computation results and a few essential optical functions.

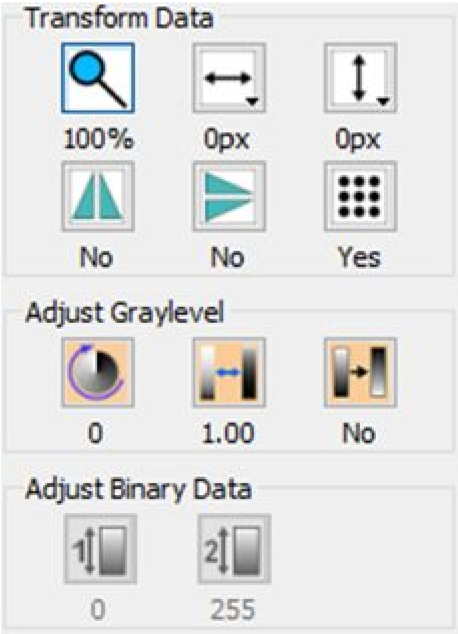


Figure 95: Basic image manipulations in sidebar.

The next box is 'Adjust Graylevel'. It allows overall adjustment of the gray levels of the currently used bitmap data. There are three adjustments:

- **Cyclic Shift**: Adds the selected gray value to the image, and if it exceeds the value 255, it jumps back to 0.
- **Gamma**: Applies an image gamma correction to the gray values.
  The actual formula is $v(x, y, \gamma) = v_{orig}(x, y)^{1/\gamma}$ with
  - $v_{orig}(x, y)$ is the value at pixel position (x, y) of the original data without gamma applied, and
  - $v(x, y, \gamma)$ is the gamma corrected value for the same pixel at (x, y) position. Values are in range [0, 1] instead of 8 bit gray values from 0 to 255.
  - γ is the gamma slider value. Gamma correction is applied to the whole image including all other manipulations.
- **Invert Values**: If enabled (Yes), this feature inverts the gray values in the image so that black gets white and vice versa.

The last group of basic image manipulations are the two sliders for the first and second gray level in the image. This feature is only available if the image contains binary data. This applies to all binary elementary optical functions created within HOLOEYE SLM Pattern Generator, like binary axicon, divided screens, etc., and all amplitude/phase data user images loaded from file or via drag-drop or copy-paste, which contain only two different gray values in the whole image.

4.6.4 Beam Manipulation Phase Overlay

The software allows superposition of a beam manipulation phase overlay to the image data of each tab. Three functions are available: Beam steering in both directions x and y (blazed gratings), and a Fresnel zone lens overlay. The values set through the sliders are unified to a range between -1.0 and +1.0. Outside this range, the pixel size of the SLM makes the functions inaccurate. For the lens we allow a larger range (-5.0 to +5.0), because inaccuracies are starting at the edges, and the lens is still fine in the center for larger absolute values. Anyway, values outside the [-1.0, 1.0] range will have artefacts in the edges.
The unified values are the same values, which can be applied into the data handle of our advanced Application Programming Interface of HOLOEYE SLM Display SDK.

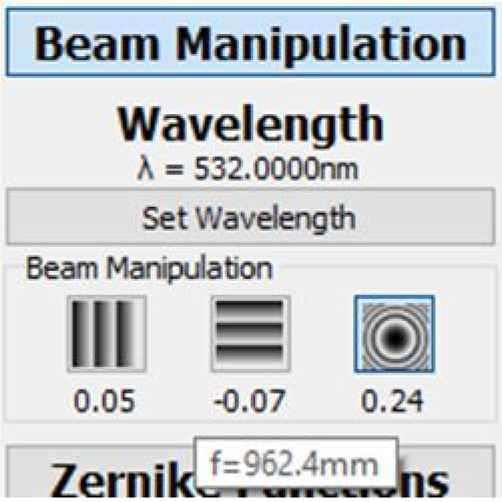


Figure 96: Beam manipulation feature.

To enable beam manipulation overlay, please click the large button ‘Beam Manipulation’ in the sidebar. If no incident laser light wavelength is set earlier, the software will ask for the wavelength when you apply any beam manipulation value. The incident laser light wavelength is needed to calculate the physical meaning of the unified values.

The labels below the icons show the unified value of the slider. The physical unit is shown in the hint texts of the labels.

The physical values are calculated as follows:

$$\alpha = \sin^{-1}\left[\frac{\lambda * beamSteerSliderValue}{2 * Pixelsize}\right] \quad \text{and} \quad f = \left[\frac{SLMWidthPixel * Pixelsize^2}{\lambda * beamLensSliderValue}\right]$$

- α is the corresponding beam deviation angle between 0th and first diffraction order.
- f is the focal length of the superimposed Fresnel zone lens.
- λ is the incident laser light wavelength.
- "Pixelsize" is the physical size of the SLMs pixel, e.g. 8µm for HOLOEYE PLUTO SLMs.
- "SLMWidthPixel" is the number of pixels in the large direction of the display.
- "beamSteerSliderValue" and "beamLensSliderValue" are the unified slider values.

4.6.5 Zernike Parameter Phase Overlay

To enable the Zernike overlay, please click the large button 'Zernike Functions' in the sidebar. Additional slider values will pop up. Please use the sliders to set Zernike parameters. There is an enable check box, which allows toggling between the selected slider values (i.e. Zernike parameters) and no Zernike overlay. When the button 'Zernike Functions' is pressed again, the Zernike sliders are hidden, but the values are still enabled until the enable check box is unchecked or the sliders are reset to 0. Figure 98 shows the Zernike sliders with the enable check box.

Zernike parameters will create a smooth optical wave front added to the displayed phase data. The phase values are generated out of the Zernike polynomials with their corresponding Zernike parameters (slider values). The Zernike polynomials are only defined inside the Zernike radius. Therefore, it makes sense to use the half SLM diagonal as the Zernike radius, but this software allows using your own Zernike radius, if needed. Anyway, the half diagonal is the default Zernike radius. To make the Zernike radius visible in the preview, the preview options are extended with a button. By pressing the button, the region outside the Zernike radius will be dyed red in the preview only to indicate the area where the Zernike polynomials are undefined.

Figure 97: Preview options when Zernike values are enabled. Please use the red button to visualize the undefined area outside the Zernike radius in the preview.

Please make sure to set the Zernike radius before applying the Zernike parameters. Using a smaller Zernike radius may be interesting for example when not using the whole SLM area.

Zernike polynomials and parameters are available up to the 4th order. Zernike parameters will be applied to all tabs synchronously. The feature was added to correct for optical setup imperfections, like correcting the flatness of an optical element or optimizing the beam profile.

The general formula for calculating the phase shift over the area of the SLM is

$$\phi(\rho,\theta) = 2\pi\mathrm{rad} \sum_{(n=0)}^{4} \sum_{(m=0)}^{n} A_{nm} U_{nm}(\rho,\theta)$$

with

$$\rho = \frac{r}{r_z} = \frac{\sqrt{(x^2+y^2)}}{r_z},$$

$$0 \le r \le r_z\,,$$

$$0 \le \rho \le 1\,,$$

$$\theta = \mathrm{atan2}(y, x)\,,$$

$$-\pi < \theta \le \pi\,.$$

Figure 98: Zernike coefficients and Zernike radius sliders.

Below you find a list of the used Zernike polynomials:

Name	Polynomial	n	m	Icon
Piston	1	0	0	
Tilt x	$\rho \sin(\theta)$	1	0	
Tilt y	$\rho \cos(\theta)$	1	1	
(De)focus	ρ^2	2	0	
Astigmatism 45°	$\rho^2 \sin(2\theta)$	2	1	
Astigmatism 0°	$\rho^2 \cos(2\theta)$	2	2	

Name	Polynomial	n	m	Icon
Trifoil X	$\rho^3 \sin(3\theta)$	3	0	
Trifoil Y	$\rho^3 \cos(3\theta)$	3	1	
Coma (3rd order) X	$(3\rho^2\text{-}2\rho) \sin(\theta)$	3	2	
Coma (3rd order) Y	$(3\rho^2\text{-}2\rho) \cos(\theta)$	3	3	
Spherical abberation	$6\rho^4\text{-}6\rho^2\text{+}1$	4	0	
Astigmatism 2nd 45°	$(4\rho^4\text{-}3\rho^2) \sin(2\theta)$	4	1	
Astigmatism 2nd 0°	$(4\rho^4\text{-}3\rho^2) \cos(2\theta)$	4	2	
Quadrafoil X	$\rho^4 \sin(4\theta)$	4	3	
Quadrafoil Y	$\rho^4 \cos(4\theta)$	4	4	

Table 16: Zernike polynomials

Each Zernike parameter (i.e. slider value) can be changed in the range from -5.0 to +5.0. Parameters with a value of ±1.0 create a phase function, which modulates in the range [inside the Zernike radius.

The piston is not available as a Zernike parameter slider. If you need the piston, please use the 'Cyclic Shift' feature of the 'Adjust Graylevel' sliders instead.

The Zernike parameter values applied here can be applied with the function `heds_slm_zernike()` of our HOLOEYE SLM Display SDK, too. Both software will produce the same phase function for the same set of values.

4.6.5.1 Save and Load Zernike Parameters

The complete set of Zernike parameters available through the sliders can be saved into a text file format for later usage. The 'File' menu provides the options 'Load Zernike parameter file ...' and 'Save Zernike parameter file ...'.

Both menu entries open a file selection dialog, where you need to either select an existing file when loading values, or select a new file for saving Zernike parameter values. The menu entries are only available when there is at least one tab open with any optical function.

The save menu entry stores the currently applied set of Zernike parameter values into the selected text file. The text file is saved with a file name ending '.zernike.txt' by default, so that the ending indicates the type but is also easily editable with any text editor. The text format of the file content contains one parameter per line. Each parameter is indicated by its name, followed by the value, separated by a tab. In addition to the parameters, the Zernike radius is saved, too.

Loading such a zernike.txt file can for example be used to restore Zernike parameter values from a previous session. When loading the file, it is allowed that some Zernike parameters are not available in the file. Missing parameters will be assumed to be zero. The Zernike radius must be part of the file content, because the Zernike parameter values produce different phase functions for different Zernike radius values. After successful loading of such a file, the currently applied values in the sliders are overwritten instantly with the new values loaded from file.

4.6.6 Wavefront Compensation Phase Overlay

With version 5.1, there is an additional overlay button in the sidebar called “Wavefront Comp.”. If no wavefront compensation is loaded, pressing the button will open the “Wavefront Compensation Setup” dialog, see "Wavefront Compensation Overlay". Otherwise, the button will hide or show the sidebar box of the loaded wavefront compensation field, see figure 99.

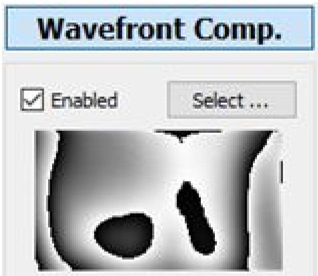


Figure 99: Wavefront compensation option in sidebar.

The “enable” check box will toggle the wavefront overlay on the SLM screen. The “Select …” button allows re-opening of the “Wavefront Compensation Setup” dialog.

Figure 100: Preview options when a wavefront compensation is loaded and the wavefront compensation is visible in the preview (i.e. button with hint text “Show Wavefront Compensation” is pressed).

As soon as a wavefront compensation overlay is loaded, the visibility in the preview windows “Realtime Preview” mode can be activated, see figure 100.

4.7 Calculating a Computer Generated Hologram (CGH)

To compute a CGH from an image, please open an image in the CGH computation mode, see chapter "CGH Computation from Image Files" and "Open by Drag and Drop or via Clipboard". Alternatively, there is a CGH batch computation dialog, which simplifies computation of multiple similar images.
After opening images for CGH calculation, the CGH settings dialog will appear, see figure 101. The same dialog is integrated into the CGH batch computation dialog shown in figure 103.

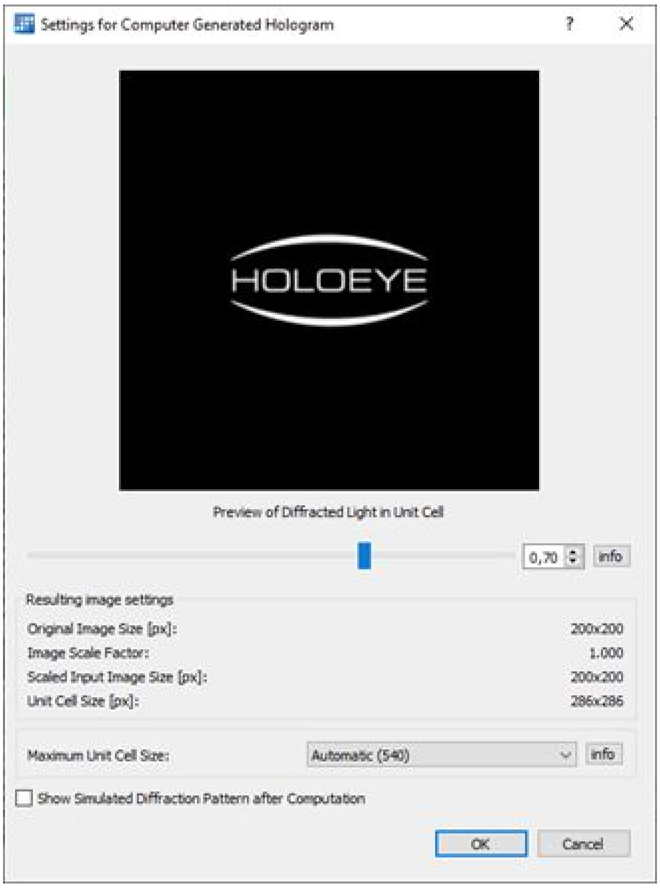


Figure 101: CGH settings dialog

After accepting the CGH settings dialog, the CGH computation will start.

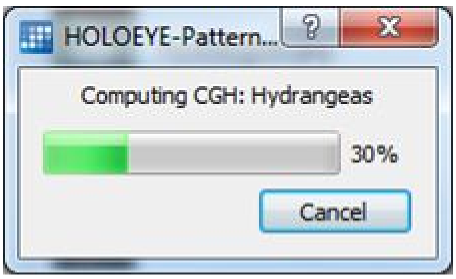


Figure 102: Progress of the CGH computation.

The computation of the hologram phase function will take a while, depending on the used unit cell size and the computer performance. The computation progress is indicated with a progress dialog like shown in figure 102.
The result of the CGH computation is opened in a new tab, if new image files was opened. If a CGH is re-computed using the action button, the updated hologram will override the image data in the current tab.
If the check box “Show Simulated Diffraction Pattern after Computation” is checked in the CGH computation dialog, a numerical simulation of the resulting optical image in the far field will open in a separate, modal window. That means you must close the dialog first before using the main window again. The check box is not available if multiple image files are opened. The check box is unchecked by default because the information gain from the simulation is typically very small compared to the faster calculated preview inside the CGH settings dialog. However, in case of uncertainty, you can check the theoretical holographic projection result of the CGH computation for your input data.

For all tabs opened by the CGH computation, the tab caption starts with ‘CGH: ‘ and the re-compute action button is available.

4.7.1 CGH Settings Explained

For the computation of a hologram, we need to define the size of the unit cell. We measure the size in pixels of the SLM. There are two issues to be considered while selecting the unit cell size. The first issue is the resolution of the optical far field result. The larger the unit cell size, the better the quality of the optical result. However, if the unit cell on the SLM is not illuminated completely, then the quality will decrease. This means the second issue is to take into account the used beam diameter on the SLM.

The unit cell size is calculated automatically. It uses the input image size and the selected image size in the unit cell to use an optimal unit cell size. To account for the complete illumination of the unit cell, the algorithm uses a setting for the maximum unit cell size. This setting is automatically selected to be the SLM height divided by two. By selecting a smaller value, the algorithm is forced to reduce the quality and increase computation speed. By selecting a larger value, the algorithm gets more freedom to select a proper unit cell size. The maximum unit cell size can be increased up to the SLM height. However, selecting a higher maximum unit cell size should only be done if the beam diameter on the SLM is as large as the selected value or larger.
Please adjust the settings by using the dialog shown in figure 101 or the settings embedded into the CGH batch computation dialog, shown in figure 103.

The computation uses the Iterative Fourier Transformation Algorithm (IFTA). Note that the process of computing may take a short while, depending strongly on the unit cell size. Both progress dialogs (figure 102 and figure 104) permits interruption of the ongoing computation. The unit cell size is selected in multiples of 2, 3, 5, 7, 11, and 13 to optimize FFT performance, so that slowly computing FFTs are avoided (mostly prime numbers are avoided).
The result of the IFTA algorithm is a phase function, which can be addressed on the SLM directly. The algorithm converts the phase into gray levels from 0 to 255 assuming the SLM is properly calibrated to 2.0 π rad phase shift. The phase data result is a grayscale image. Either it will open in a new tab after accepting the CGH settings dialog, or when using the batch dialog, the resulting images are directly saved to disk.

4.8 CGH Batch Computation

With version 4.0 and later of the HOLOEYE SLM Pattern Generator Software, we introduce a new feature called CGH batch computation. The CGH batch computation should be used when many image files shall be used to generate hologram phase functions (see "CGH Computation from Image Files" and "Calculating a Computer Generated Hologram (CGH)". It is especially designed to compute image sequences for later slide show playback, e.g. using HOLOEYE SLM Slideshow Player software. Therefore, it can save the resulting phase fields directly into image files. Additionally, it provides easy testing by directly addressing the result onto the SLM screen.

Please use the menu 'File' → 'Open CGH Batch Computation …' to open the batch window. It will open a new window.

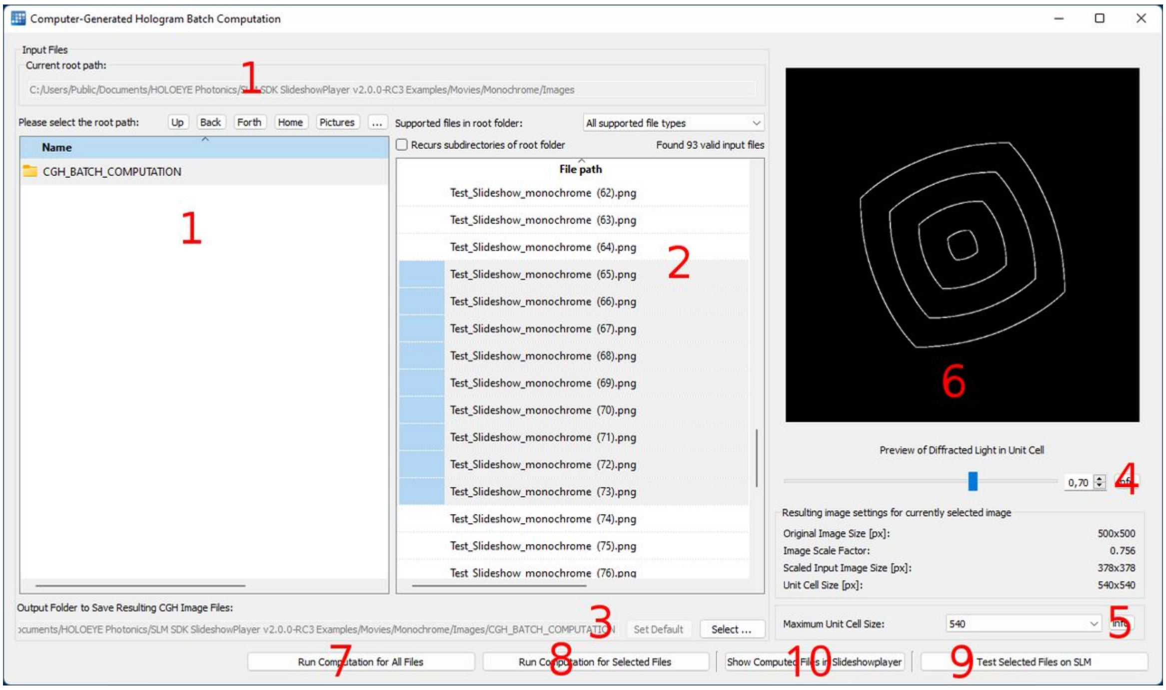


Figure 103: CGH Batch Window

The dialog consists of a folder selection box for the root path (1), a list of found files in the selected root folder (2), the CGH settings including a preview (4, 5, and 6), and the output folder selection (3). The buttons 7, 8, and 9 are used to start the computation process. The button 10 is a link to open the result of buttons 7 and 8 in our HOLOEYE SLM SDK Slideshow Player 2.0 software for direct playback of the image sequence on the SLM. Button 10 can only work if HOLOEYE SLM SDK Slideshow Player is installed separately on the PC.

First, please navigate with the browser (1) to the base folder where all your input image files are stored. The currently selected root path is shown on the top. Please use the buttons 'Up', 'Back', and 'Forth' for navigation through the folders. The buttons 'Home' and 'Pictures' can be used as a shortcut to your current user directory and to the pictures folder of your current user directory. With the button '…' a system folder selection dialog will open which can also be used to navigate to the desired root folder.

As soon as the root folder changes, the files inside the root folder are being searched and listed in the file selector (2). The files are searched recursively if the check box 'Recurse subdirectories of root folder' is checked. Only valid input files are listed. The files can be filtered by the file extension. By default, all supported file extensions are shown. Other file extensions can be filtered with the drop-down-selector. During the file search, the text below the drop down selector will show 'Searching valid input files: N'. When all files are searched through, the text changes to 'Found N valid input files'. During the file search, the button (7) is disabled.

The image files in the file selection box (2) can be multi-selected. The latest selected file will be loaded into the preview (6). The buttons 8 and 9 are disabled until at least one file is selected.

Please use the slider or the related edit field (4) to set up the image size in the unit cell. See explanation in section CGH Settings Explained. If needed, the maximum unit cell size can also be changed (5).

Please note that both settings (4 and 5) apply to all images which are computed in one batch run. However, this means that the unit cell size is still selected for each image individually.

The preview (6) is a grayscale animation of the theoretically resulting optical far field of the unit cell, respecting the made settings. The animation has some image quality improvement algorithm enabled to look better when downscaling the preview due to the window size. The actual far field image may look different.

The text fields in the box 'Resulting image settings for currently selected image' show the resulting scale and unit cell size settings for the currently selected image in (2), which is also shown in preview (6) for the far field result.

The output folder path (3) is selected automatically to be the subfolder 'CGH_BATCH_COMPUTATION' of the currently selected root path. The output path can also be selected manually. If a custom output path is selected, the output path is not adjusted automatically anymore after the root folder was changed manually. If the output folder does not exist, it will be created automatically during the batch computation process.

Image files ending on "_cgh.png" are not shown in the files list (2), because it does not make sense to use the phase shift data stored in image files as computation input files.

With the two buttons 7 and 8 the output holograms will be computed and saved as *.png (*_cgh.png) image files into the selected output folder. The files only consist of the unit cell image data, which needs to be shown on the SLM in tiled mode, i.e. the image needs to be repeated in x and y direction until the SLM screen is filled. This Pattern Generator does this automatically, and our latest Slideshow Player software does it automatically, too. If using HOLOEYE SLM Display SDK, you need to enable PresentTiledCentered mode through show flags.

With the button 9 the selected files in (2) will be computed and opened in SLM data tabs directly and no files will be saved (no output folder needed). Each selected input file, which finishes computation, will be directly addressed to the SLM when button 9 was used.

During the file based computation (7 and 8), a progress dialog will open, which shows both, the progress of each image file and also the overall progress of the batch computation (see figure 104). The progress dialog also shows the preview and the used settings of the currently processed image file. It allows cancelling the whole batch computation process.

Figure 104: CGH Batch Progress Dialog

4.9 Wavefront Compensation

Since version 5.1, the software allows to load a full screen phase overlay field, which electro optically compensates for physical deformation of the displays backplane. The deformation of the backplane typically leads to a deformation of the wavefront of the reflected light. This can be compensated by addressing the inverse deformation as a phase pattern on the SLM. It requires a measurement of the wavefront deformation introduced by the display.

Wavefront compensation files are available for SLM devices shipped after March 2021, containing an optical path difference field of the deformation. Please note that such a compensation is limited to the static deformation. If you introduce additional deformation, e.g. due to your display mounting solution, this cannot be compensated with data provided by us.

The wavefront compensation file is located on the USB stick shipped with the device. It is in format HDF5 and ends with .h5. The name of the file is typically <displaynumber><SLM serial number>.h5.

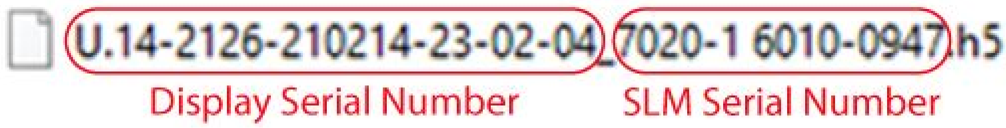


Figure 105: .h5 file description

The display number can be found at the label on the back side of the flex cable of the display. The SLM serial number can be found on the type label on the bottom of the driver housing.

Figure 106: Display serial number on back side of flex cable

If you are unable to locate the .h5 file, please contact HOLOEYE.

To use the compensation file click the menu item “File” → “Load Wavefront Compensation Phasemap from file …”, see figure 107.

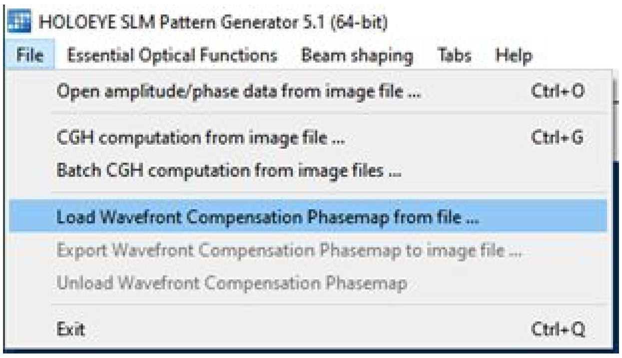


Figure 107: Menu entries for wavefront compensation

If no incident laser light wavelength of your setup was set in Pattern Generator yet, the wavelength will be requested in an additional dialog before the main dialog opens.

Now the Wavefront Compensation Setup dialog will open (see figure 108).

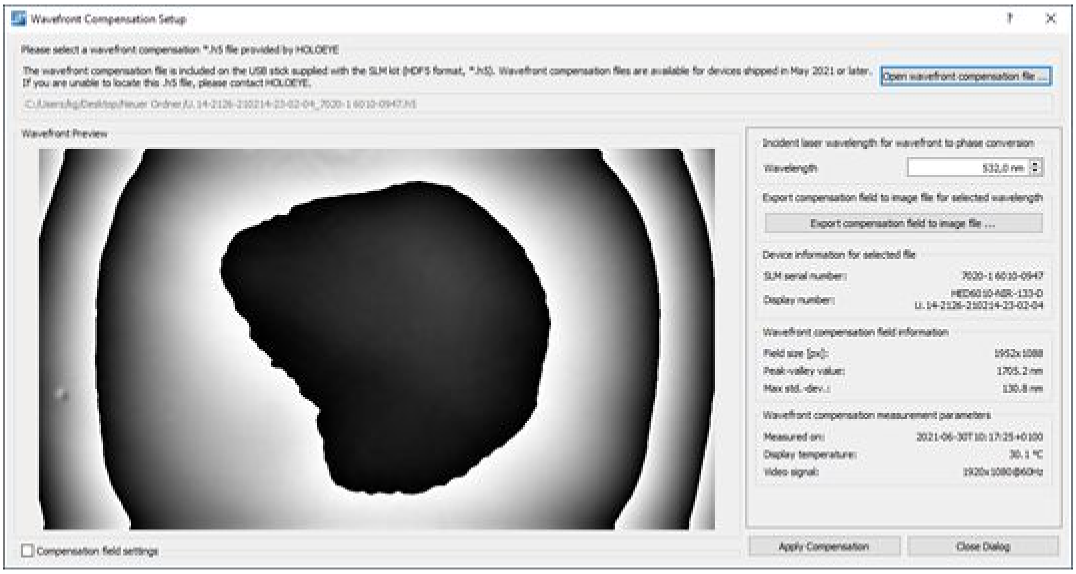


Figure 108: Wavefront compensation setup dialog

In the dialog, a previously applied file will be automatically selected and loaded. The path of the currently selected file is shown in the box at the top of the dialog. To select a new file or to change the selected file, please click the button “Open wavefront compensation file …”. A file selection dialog will open. Please select the .h5 file shipped with the device or was provided by us.

After a file was successfully loaded, the right bar is filled up with information provided by the file, and the measured wavefront field is loaded, adapted, and shown in the preview of this dialog.

The preview shows the adapted compensation phase function like it will be visible on the SLM screen and like it will be exported into an image file by default. There are a few adaptions made to the field:

- The given wavelength is used to convert the field from optical path difference in nm into phase values represented in video signal gray levels.
- The field is inverted to be a compensation field instead of the deformation.
- The field is cropped from the display size to the video signal size, and optional flipping and shifting is applied depending on the settings.

The wavelength can be adapted in the dialog again, and the field will be adapted on the fly.

Please make sure that the SLM serial number shown at the “device information for selected file” field fits the actual serial number of the connected device. If the serial number does not fit, the displayed SLM serial number will red and the “Apply Compensation” button is disabled.

For some HOLOEYE SLMs (e.g. PLUTO-2.1) it is possible to use different display versions with one driver. If you are using a display with another driver than the one it was delivered with you will get an error as described above. In this case please contact HOLOEYE to send an adapted wavefront compensation file.

In the box “Export compensation field to image file for selected wavelength” there is a button to export the currently loaded field into a *.png or *.bmp image file. The exported image file can be used to address the compensation independently of Pattern Generator, e.g. using your own display software.

If the exported image is used directly without any additional computations, the wavefront will be compensated like displaying a blank screen of gray level 128 in Pattern Generator while the wavefront compensation is applied.

The exported compensation image file can also be used in older versions of Pattern Generator (version 3 and lower). Please make sure to export the image for the correct wavelength setting used with the importing software.

Note
If you have set flipping and/or shifting options in the SLM Configuration Manager, you need to enable the “Compensation field settings” box and adapt the options accordingly. The “Compensation field settings” box allows flipping and shifting of the compensation field in order to adapt these to the settings in the SLM configuration. Shifting is only available depending on the display and video signal resolutions. We recommend using up-to-date SLM configurations with flipping turned off by default, because the wavefront compensation won’t work as intended if these settings are not consistent between Pattern Generator and Configuration Manager software.

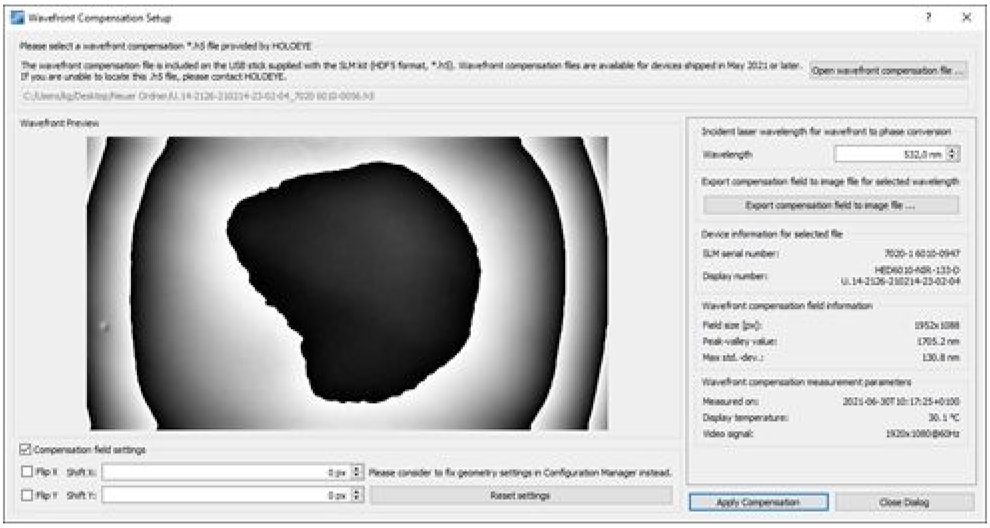


Figure 109: Compensation field settings

After you have set up the wavefront compensation, press the button “Apply Compensation”. This will close the dialog and the wavefront compensation is now active on the display, as soon as you open any function or image.

Please note: By default, the “Realtime Preview” does not include the wavefront compensation overlay. There is a button to enable it, see Figure 11. The “Capture SLM Screen” preview mode will always show the addressed image on the SLM screen, so the wavefront compensation overlay is always visible in this mode.

The sidebar displays a small preview of the wavefront compensation. You can use the sidebar to enable/disable the wavefront compensation, without the need to reload the data, see figure 99.

The “Close Dialog” button in the wavefront compensation dialog will close the dialog and will not change the currently active wavefront compensation. It will also reject all changes made in the dialog, i.e. if you have selected a new file, the last opened file will not change.

Depending on the used working wavelength it may happen that the compensation image contains phase wraps in the center of the LCoS panel which can lead to weak scattering effects. Adding a constant phase offset using “Cyclic Shift” values (at the “Data Properties” panel -> Adjust GrayLevel) can help to reduce such phase wraps in the center of the image (which typically is the area actually used/hit by the circular incident beam) and shift them to the edges (see figure 110).

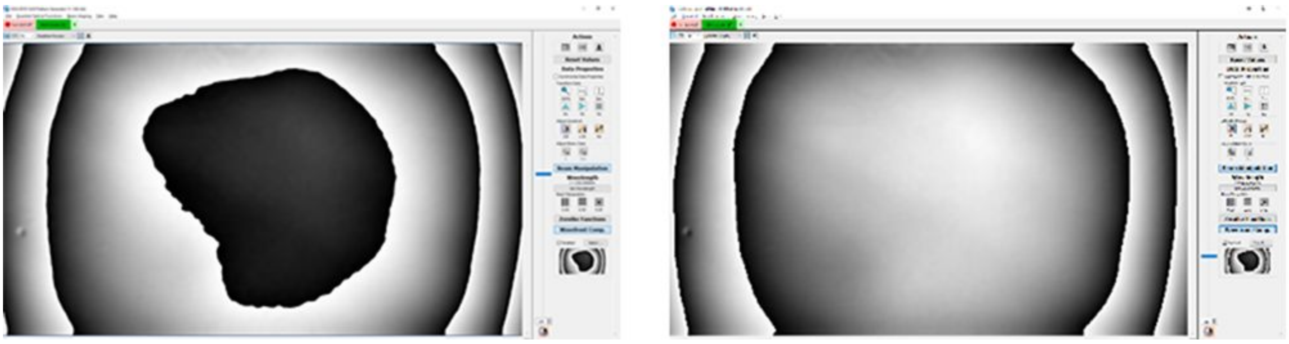


Figure 110: Left – original phase overlay image. Right – reduced phase wraps using Cyclic Shift.

4.10 Creating Essential Optical Functions

All optical functions from the menu point "*Essential Optical Functions"* appear in a new tab after the required parameters are given. Depending on the optical function, binary or multilevel, some sidebar sliders may be disabled.

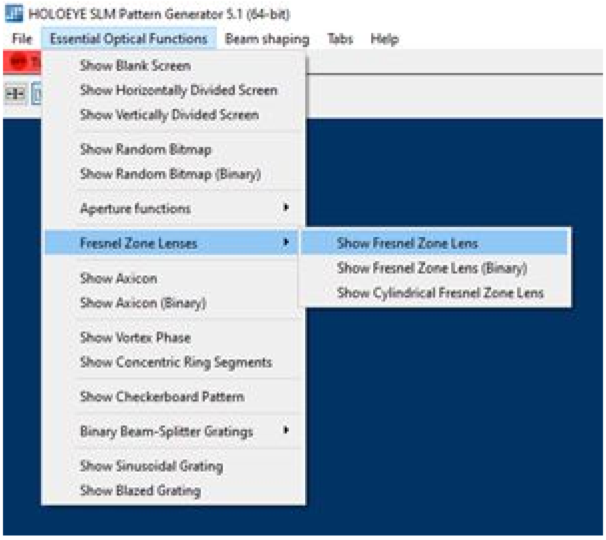


Figure 111: Menu entries for optical functions

4.10.1 Blank Screen

With this function, you can create a homogeneous graylevel screen. You will be asked to enter the desired graylevel. The given graylevel will set the 'Cyclic Shift' slider.

4.10.2 Horizontally Divided Screen

With this function you will create a horizontally divided screen, consisting of two homogeneous graylevel partial screens. Please use the gray level adjustment sliders to change the two values.

4.10.3 Vertically Divided Screen

With this function you will create a vertically divided screen, consisting of two homogeneous graylevel partial screens. Please use the gray level adjustment sliders to change the two values.

4.10.4 Random Bitmap

With this function you will create a random pixel distribution using 256 graylevels. This function can be used to realize the optical function of a random phase plate.

4.10.5 Random Binary Bitmap

With this function you will create a random pixel distribution using only two grayscale values. This function can be used to realize the optical function of a random binary phase plate.

4.10.6 Aperture Functions

4.10.6.1 Rectangular Aperture

Use this function to create a rectangular aperture. The size of the aperture can be defined by specifying the aperture width and aperture height. With the sliders on the taskbar one can change the gray levels of the background and of the aperture.

4.10.6.2 Circular Aperture

Use this function to create a circular aperture. The radius of the aperture can be defined by specifying a numbers of pixels. With the sliders on the taskbar one can change the graylevels of the background and of the aperture.

4.10.6.3 Single Slit and Double Slit

To create a single slit choose the point 'Show Single Slit' from the menu point *Aperture Functions.* The slit width can be defined by the number of pixels in the dialog window.

To create a double slit choose the point 'Show Double Slit' from the menu point *Aperture Functions.* Moreover the slit distance can also be defined. This refers to the distance between both slits.

4.10.7 Fresnel Zone Lenses

4.10.7.1 Fresnel Zone Lens

Use this function to create a 256-level Fresnel Zone Lens grayscale image representation. In the dialog field the lens function can be characterized by the radius of the smallest ring, which is defined by a number of pixels. The focal length of the lens is given by

$$\mathrm{f} = \frac{(\mathrm{n_{r,min}p})^2}{2\lambda}$$

where λ is the wavelength of the laser which was entered when starting the software. It can be specified whether the image representing the lens should be positive or negative.

4.10.7.2 Fresnel Zone Lens (Binary)

Use this function to create a Binary Fresnel Zone Lens graylevel image representation. In the dialog field the lens function can be characterized by the radius of the smallest ring, which is defined by a number of pixels $n_{r,min}$. The focal length of the lens is given by

$$\mathrm{f} = \frac{(\mathrm{n_{r,min}p})^2}{\lambda}$$

where λ is the wavelength of the laser which was entered when starting the software.

4.10.7.3 Cylindrical Fresnel Zone Lens

Use this function to create a 256-graylevel image representation of a Cylindrical Fresnel Zone Lens. In the dialog field the lens function can be characterized by the width of the central zone, which is defined by a number of pixels $n_{w,min}$. The focal length of the cylindrical lens is given by

$$f = \frac{(n_{w,min} p)^2}{8\lambda}$$

where λ is the wavelength of the laser which was entered when starting the software. The angular orientation of the cylindrical lens can be entered in degrees (integer values only).

4.10.8 Axicon (Binary)

Use this function to create a Binary Axicon graylevel image representation. In the dialog field the lens function can be characterized by the radius of the smallest ring, which is defined by a number of pixels.

4.10.9 Axicon

Use this function to create a 256-level Axicon grayscale image representation. In the dialog field the axicon function can be characterized by the radius of the smallest ring, which is defined by a number of pixels. It can be specified whether the image representing the lens should be positive or negative.

4.10.10 Vortex Phase

Use this function to create a 256-graylevel image representation of a vortex phase (often also referred to as ‘helical phase’ or ‘spiral phase’). In the dialog field the radius a central zone with constant phase can be specified as a number of pixels. The order of the vortex can be entered also as an integer value, for production of higher-order Laguerre-Gaussian beams.

Note that the angular orientation of the line where the phase changes from 0 to 2 π can be modified by superposition of the displayed phase with a constant phase value (see chapter "Basic Image Manipulations": ‘Cyclic Shift’ of ‘Adjust graylevel’ box).

4.10.11 Concentric Ring Segments

Use this function to create binary images consisting of concentric ring segments. In the dialog field the image function can be characterized by the radius of the smallest ring, which is defined by a number of pixels, and the desired number of segments, which can be varied from two to 20 (even numbers only).

4.10.12 Airy Beam 1D

Use this function to create a 256-level grayscale image representation of a one-dimensional cubic phase function for the generation of a one-dimensional Gaussian-Airy beam. In the dialog field the Airy beam function needs to be characterized by the smallest inner zone, which is defined by the number of pixels at which the generated phase function reaches a phase shift of 2 π for the first time starting at the center of the phase field. In addition, a rotation angle of the Airy beam can be set in degree, which rotates the phase function in the (x,y)-plane.

Note that in the center of the generated phase function, the phase value changes from positive to negative values by default, which produces a wrap from black to white in the center. This wrap line cannot be avoided in general, but it can be moved outside the center by applying a cyclic shift on the gray levels, please see chapter "Basic Image Manipulations": ‘Cyclic Shift’ of ‘Adjust graylevel’ box.

4.10.13 Airy Beam 2D

Use this function to create a 256-level grayscale image representation of a two-dimensional cubic phase function for the generation of a two-dimensional Gaussian-Airy beam. In the dialog field the Airy beam function needs to be characterized by the smallest inner zone, which is defined by the number of pixels at which the generated phase function reaches a phase shift of 2π for the first time starting at the center of the phase field. In addition, a rotation angle of the Airy beam can be set in degree, which rotates the phase function in the (x,y)-plane.

Note that in the center of the generated phase function, the phase value changes from positive to negative values by default, which produces a wrap from black to white in the center. This wrap line cannot be avoided in general, but it can be moved outside the center by applying a cyclic shift on the gray levels, please see chapter "Basic Image Manipulations": ‘Cyclic Shift’ of ‘Adjust graylevel’ box.

4.10.14 Laguerre-Gauss Modes

This function creates phase masks that generate Laguerre-Gaussian modes. Please indicate the following parameters:

- *p* order - Radial Index [0- 50]
- *l* order - Azimuthal Index [-50 ... 50]
- Beam Waist Radius w0 in mm (please mind the dimensions of the active area of your SLM)

The development of the numerical function to generate the Laguerre-Gaussian modes was based on this publication: William N. Plick and Mario Krenn, Phys. Rev. A 92, 063841 (2015) https://doi.org/10.1103/PhysRevA.92.063841

4.10.15 Variable Beamsplitter

Use this function to generate an array of *M* x *N* beams from the incident beam.

Parameters:

- Beam numbers *M* and *N* in *x*- and *y*-directions [3- 25]
- Padding Factor [0.1 - 5.0]

The 'padding factor' refers to the zero-padding around the desired array of beams in the far-field diffraction plane. The larger the selected padding factor, the smaller will be the inter-beam angle of the array, and accordingly the total diffraction angle. The total angular modulation range of the SLM, determined by the laser wavelength λ and the SLM's pixel size *p*, will be shared between the M x N desired beams and the surrounding suppressed beam in the zero-padding region.

4.10.16 Binary Beam-Splitter Gratings

4.10.16.1 Linear Gratings and Crossed Linear Gratings

Choose from the menu *Binary beam-splitter gratings* the item ‘*Show Binary Linear Grating*’ to create a grating. The grating period can be defined by the number of pixel. By selecting the boxes the grating direction can be chosen to horizontal or vertical. Check both boxes to overlap a horizontal with a vertical grating and obtain a crossed grating.

4.10.16.2 Built-in Binary Beam-Splitter Designs

Choose from the menu *Built-in binary beam-splitter designs* one of the menu items

- *Show Binary Linear 1-to-5 Linear Beamsplitter Grating* (Grating period 26 pixel)
- *Show Binary 1-to-(2x2) Separable Array Beamsplitter Grating* (Grating period 18x18 pixel)
- *Show Binary Array 1-to-(5x5) Separable Array Beamsplitter Grating* (Grating period 26x26 pixel)
- *Show Binary Array 1-to-(5x5) Non-separable Array Beamsplitter Grating* (Grating period 26x26 pixel)

to obtain a tab with one of the mentioned diffractive elements.

The basic tiles of these gratings are fixed and usable as examples for separable and non-separable binary diffractive optical elements (DOEs).

4.10.17 Sinusoidal Grating

Choose from the menu point *Essential Optical Functions* ‘*Show Sinusoidal Grating*’ to create a sinusoidal grating. The size of the grating period can be specified by the number of pixels.

4.10.18 Blazed Grating

Choose from the menu point *Essential Optical Functions* ‘*Show Blazed Grating*’ in order to create a blazed grating. The size of the grating period can be specified by the number of pixels.

4.11 Calculating a Beam-Shaping Phase Function for Gaussian Input Beams

For incident laser beams with Gaussian beam profile, the SLM can modify that beam shape into other intensity profiles by utilization of an appropriate phase function. The HOLOEYE SLM Pattern Generator software provides phase functions for two special cases of such transformation: conversion of a Gaussian beam into spherical and rectangular flat-top profiles.

The computation of the beam shaping phase field needs the incident laser light wavelength. If it is not set before creating such a phase function, a dialog will pop up to select the wavelength (see figure 112).

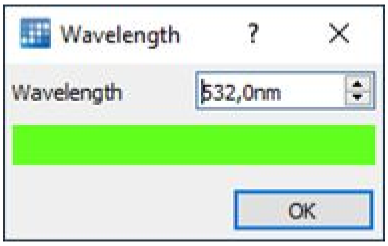


Figure 112: Please provide the wavelength of the incident laser light.

4.11.1 Transformation of a Gaussian Beam to a Circular 'Flat-Top' Beam

Select '*Transformation of Gaussian to circular Top-Hat beam*' from the '*Beam Shaping*' menu. The required parameters are the beam diameters ($1/e^2$) in the plane of the SLM, and the parameters of the desired output beam. The parameter 'Order of Super-Gaussian' will influence the slope steepness of the obtained profile. Higher Super-Gaussian Modes have a higher slope steepness.

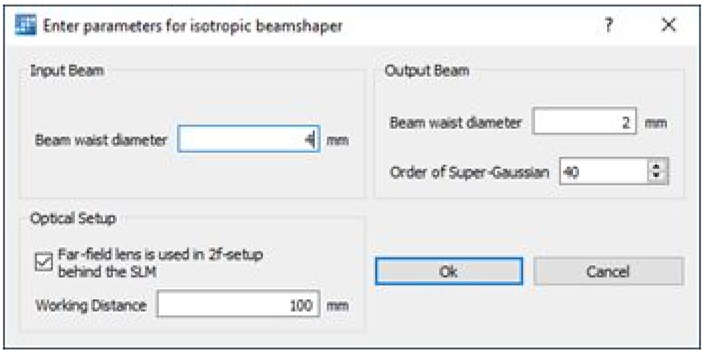


Figure 113: Parameters for computation of a beam-shaping phase

A laser beam can only be focused to a certain diameter depending on beam diameter, lens focal length and wavelength, and beam shaping phases cannot enable focusing below such limit. Therefore, if the target beam diameter is too small, the software will issue a message and suggest a more realistic target value. (The software currently does not check if the desired target beam size may be too large.)

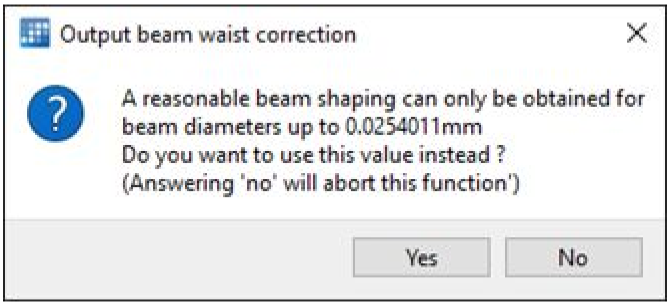


Figure 114: Warning message shown if target beam diameter is too small

The beam-shaping setup may incorporate a Fourier-lens and in this case the working distance is equal to its focal length, as the target plane is identical to the back focal plane. If no lens is used (and the corresponding checkbox is unchecked in the dialog shown above), the lens phase will just be superimposed to the beam-shaping phase.

4.11.2 Transformation of a Gaussian Beam to a Rectangular 'Flat-Top' Beam

Select '*Transformation of Gaussian to rectangular Top-Hat beam*' from the '*Beam Shaping*' menu. The required parameters are the beam diameters ($1/e^2$) in x and y direction in the plane of the SLM, and the size in x and y direction of the desired output beam. The parameter 'Order of Super-Gaussian' will influence the slope steepness of the obtained profile. Higher Super-Gaussian Modes have a higher slope steepness.

If the target beam dimension is too small to be feasible in either direction, the software will suggest a suitable beam size, maintaining the aspect ratio of the originally desired target beam.

4.12 The 'Tabs' Menu

The 'Tabs' menu item lists all currently open tabs and allows switching between them, even if a lot of tabs are open. The item 'Close all tabs' closes all currently opened tabs with a single click.

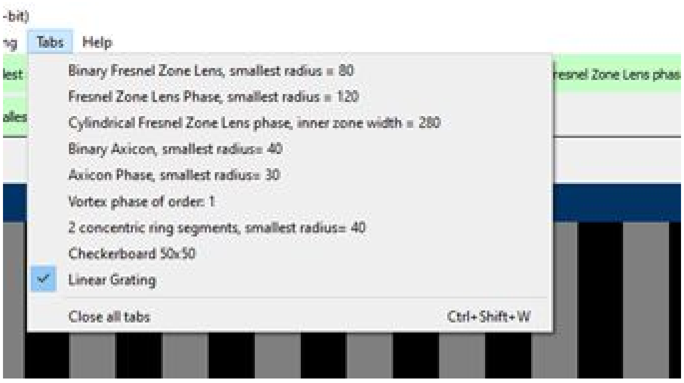


Figure 115: The menu 'Tabs' lists all tabs and allows switching and closing all.

4.13 The ‘Help’ Menu

This menu item provides information about this software, including the connected SLM. You can access this manual, and check if there is a newer software version available online.

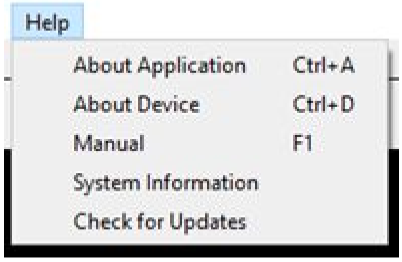


Figure 116: The menu ‘Help’ provides information about this software.

4.13.1 About Application

The about dialog of our software shows version information and provides web links to our web page, contact form, and trademark information.

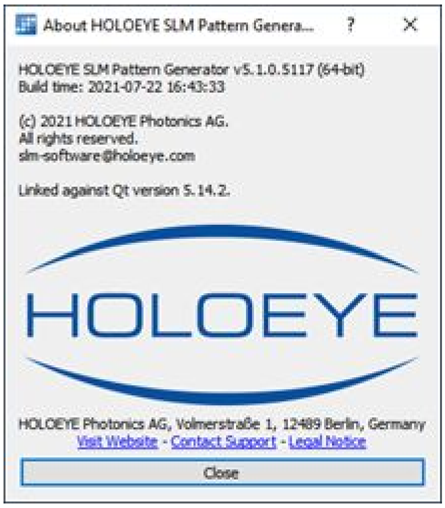


Figure 117: The about dialog shows basic version information and provides web-links to our web page. For detailed version information, please refer to system information.

Feel free to use the ‘Contact Support‘ link if you have questions related to this software. If you do so, please provide the system information text, which is available in the help menu ‘System Information’ and in the device detection’s info button. The latter is useful in case your SLM is not recognized correctly and this help menu is not accessible.

4.13.2 About Device

This menu entry opens a dialog, which shows information on the used SLM.

Figure 118: Device Information dialog.

4.13.3 Open Manual

This menu entry opens this manual in the configured PDF file viewer of your operating system.

4.13.4 System Information

This menu entry opens a dialog, which shows information on your system including connected monitors, graphic card driver version etc.

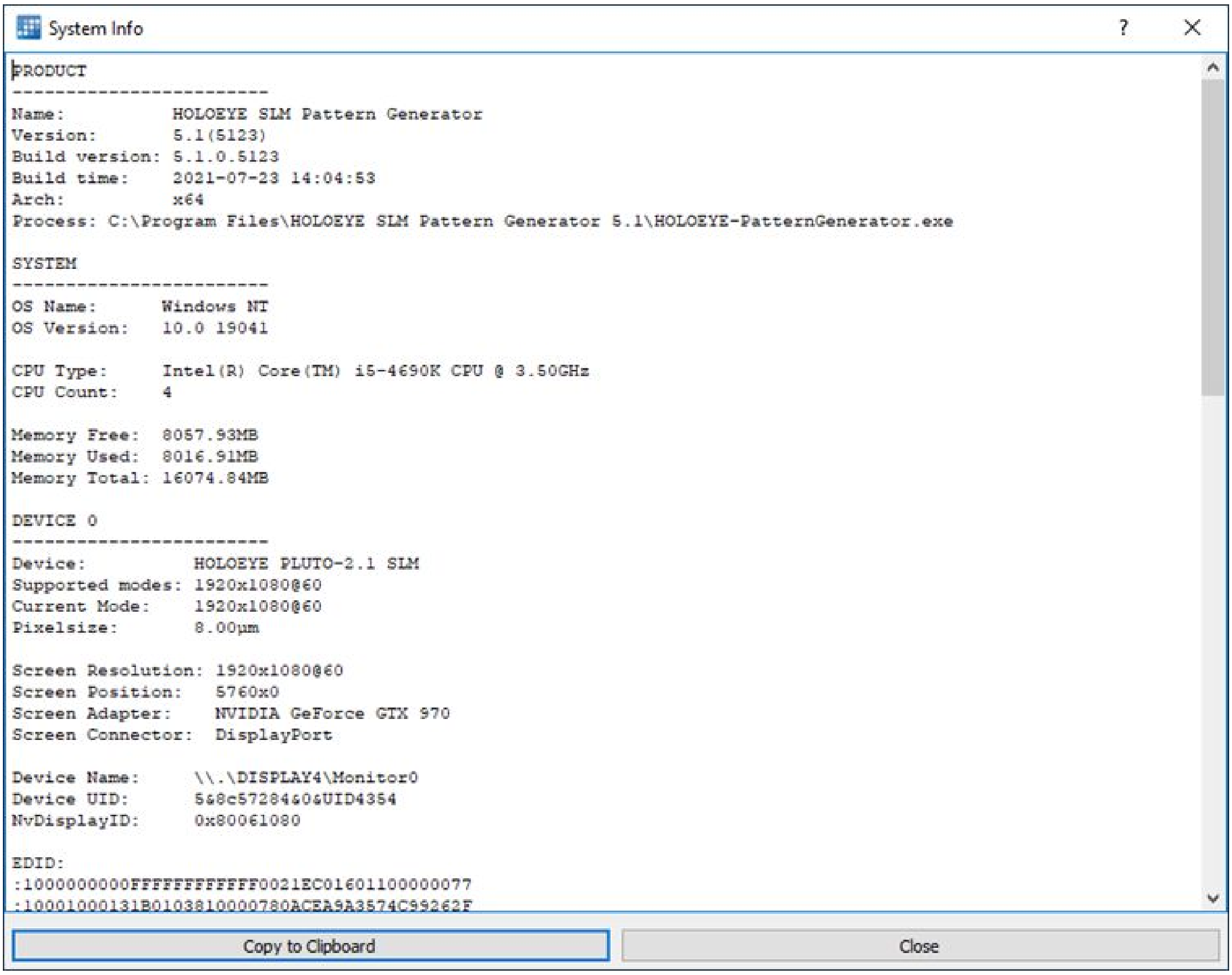


Figure 119: System Information dialog.

Please use the button ‘Copy to Clipboard’ to copy the full text into the clipboard of your operating system. Please provide this text to us when you contact our support team.

4.13.5 Check for Updates

This menu entry opens a dialog, which provides an easy way to check if there is a new software version available online. The software will not send out any information to us until you press the button 'Check for newer version' (see figure 120).

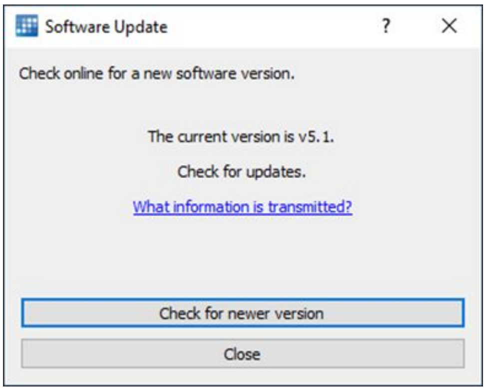


Figure 120: Software update dialog before the update check.

Please click on the blue text 'What information is transmitted?' to open a message dialog showing all information sent to our server at the update check if you have concerns about your privacy (see figure 121).

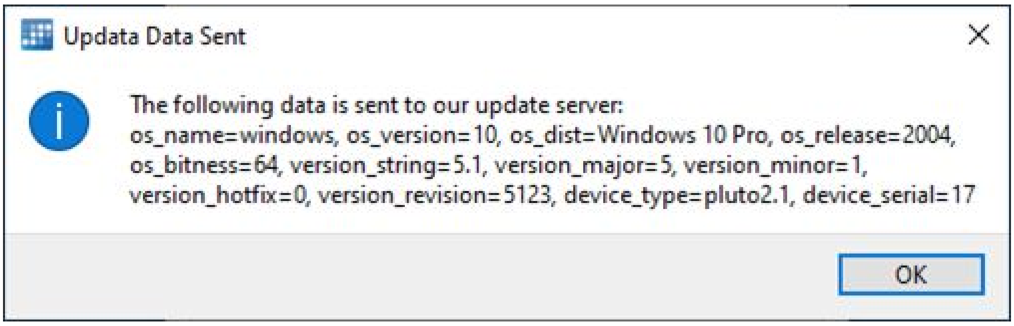


Figure 121: What information is transmitted?' opens a dialog, which shows data sent when checking for new version.

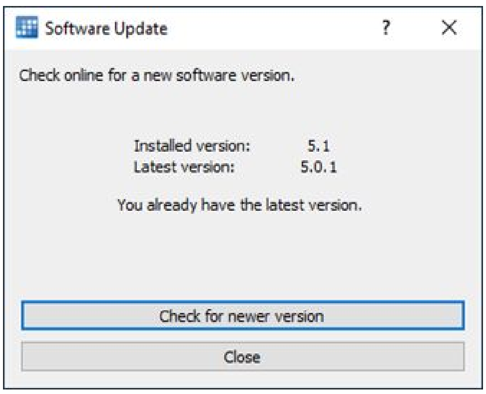


Figure 122: Software update dialog after the update check.

5 Slideshow Player

The “SLM Slideshow Player” software is intended to ease the display of images and image sequences on HOLOEYE Spatial Light Modulator (SLM) devices. These image files may represent phase maps (if the SLM is set up as a phase modulating device) or amplitude distributions (if the SLM is set up as an amplitude modulating device utilizing crossed polariser configuration). For details of these *operation modes*, please refer to “Device Operation Instructions” in the manual of the connected SLM device.

During start-up, the software will detect the connected SLM device to make sure that images will be displayed on the SLM device properly. In order to do so, it will check if the SLM is set up properly as a screen in your operating system and use this screen for displaying images.

The software permits a selection of image files inside a folder to be displayed on the SLM. A file for the slideshow playlist configuration can be placed into this folder or is created by the software. Some slideshow settings can be changed during operation of the software. The concept of such folder, where all files are in one place, is to avoid missing files and make simple setups possible.

The software is intended to display selected images as a sequence on the SLM with a user selected frame rate. This sequence of images is treated internally as a so-called 'playlist'. Playlists can be saved and loaded using this software. When saving a playlist, the play modes, speed and other settings are also saved as part of the playlist. The purpose is: For doing repeated experiments or demonstrations with an SLM device, it should be convenient to recover all related settings fast and to be able to start directly with displaying the prepared image sequence contained in such a playlist.

5.1 Requirements

5.1.1 Operating System Requirements

The following operating systems are supported by HOLOEYE SLM Slideshow Player:

- **Microsoft Windows™** 8 or higher

5.1.2 Hardware Requirements

Before starting the SLM Slideshow Player please connect one of the following HOLOEYE SLM to the device on which the software is running:

- PLUTO / PLUTO-2 / PLUTO-2.1
- GAEA-2
- GAEA-2.1
- LETO / LETO-3
- LUNA
- ERIS
- LC 2012
- LC-R 1080
- LC-R 720
- HES 7020-1 6001 (amplitude SLM)

Please make sure that the SLM is detected by the operating system as a separate screen and is configured with the correct resolution.

5.2 Installation

Please make sure that you have sufficient rights to install the software. You may need administrator privileges to install the software.

Start the executable installer file “HOLOEYE SLM Slideshow Player”.

After starting the installer, you are asked to accept the licence agreement. Please read it carefully. If you do not accept this agreement, you are not allowed to install or use this software.

Follow the instructions of the installer. It is recommended to select all components to be installed. Otherwise, parts of the software may not work as intended.

After pressing the button “Install”, the installation will start. When installation is finished, select “Close” to exit the installer.

The installer will create a directory in the start menu folder for all users. To start the software, please use the start menu entry (e. g. “HOLOEYE SLM Slideshow Player”).

If the same version is already installed, the installer will ask to uninstall the previous version before installing the new one. Please do so if you do not need this previous version anymore. The settings are saved in a user specific directory and will not be changed by the uninstaller.

The "HOLOEYE SLM Slideshow Player" is installed into the folder:

%PROGRAMFILES%\HOLOEYE SLM SDK SlideshowPlayer 2.0 …

The examples are copied into the folder:

%HOMEDRIVE%\Users\Public\Documents\HOLOEYE Photonics\SLM SDK SlideshowPlayer v2.0.0 …

The user settings will be saved here:

%USERPROFILE%\AppData\Roaming\HOLOEYE PHOTONICS AG\HOLOEYE SLM SDK SlideshowPlayer.ini

The log file data output is in the following folder:

%USERPROFILE%\HOLOEYE Photonics\Slideshow Player

5.3 Operation of the Software

Before opening the software it is recommended to connect the SLM device and set it up correctly. The SLM needs to be set up as a separate screen via the graphics card settings of the operating system (OS). When using Microsoft Windows, this mode is called “Extended Desktop”. This software is not intended to be used in cloning mode of the SLM with the primary screen. However, if two or more displays and the SLM are connected to the same computer, the secondary display can be cloned with the SLM.

To open the application “HOLOEYE SLM Slideshow Player” please use the menu entry installed to your OS.

The first time you launch the application, you may also need to accept the HOLOEYE SLM Display SDK licence as this slideshow player software is based on HOLOEYE SLM Display SDK.

5.3.1 SLM Device Detection

When you start the software a device detection dialog pops up which checks if a HOLOEYE SLM device is connected and if the system is configured correctly. You can find detailed information on the device detection in the chapter **"**Device Detection**"** of this manual.

5.3.2 First Start

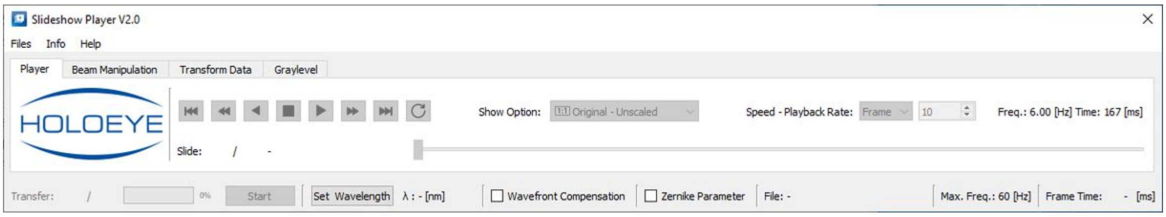


Figure 123: The "HOLOEYE SLM Slideshowplayer" main window after starting the software.

The software consists of four main tabs: “Player”, “Beam Manipulation”, "Transform Data" and "Graylevel".

5.3.2.1 Generating a new slideshow

There are three different ways to set up a new slide show

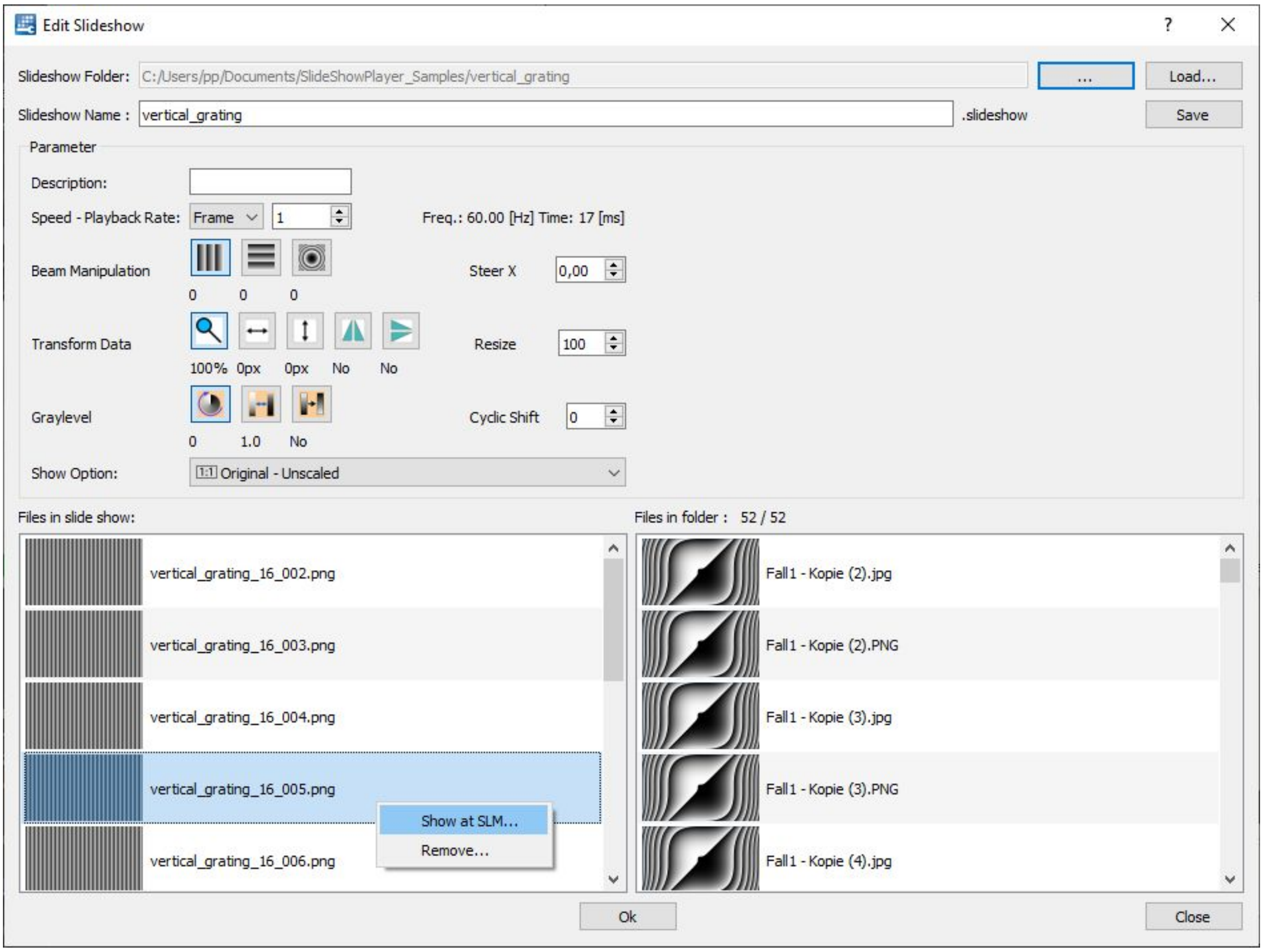
1. Drag and drop a folder filled with image files to the application.
2. Drag and drop images to the application.
3. Selecting in 'Files' Menu 'New Slideshow...'. An image selection dialog opens to create a new slideshow.

To finalize and configure the new slideshow, the 'Edit Slideshow' dialog opens.

Please note: **All images of a slideshow have to be in one folder, including the slideshow configuration file.**

5.3.3 Edit Slide Show

The Slideshow editor is an intuitive tool to configure and edit a new or current slideshow.



In the '**Parameters**'-section, the name and a description of the slideshow can be set, the playback speed and parameter for beam manipulation can be edited. The '**Description**'-text-field is intended for notes or a short description of the slideshow.

The '**Speed-Playback Rate**' of the slideshow can be set in:

- **Frame** - duration in frames
- **Time** - in milliseconds
- **Frequency** - in Hertz

The speed is limited to the frame rate of the SLM.

The editable '**Beam Manipulation**' values for Steer X, Steer Y and Lens are abstract and no physical values.

'**Files in Folder**' contains all images in the selected folder. Only the permitted file formats (*.png, *.bmp, *.gif, *.jpg) are displayed. By selecting images from this list, they can be added to the 'Files in slide show' list via drag and drop. The list is multi selectable. The selected order of the images is adopted when adding. The image can be displayed immediately on the SLM using the dropdown menu item 'Show at SLM...'.

All images of the slide show are contained in '**Files in slide show**'. The order of the slides is defined there. The order can be changed by dragging and dropping within the list. Slides can be removed using the dropdown menu item 'Remove' in the list. You can also use the Delete button on the keyboard. The list is multi selectable. The image can be displayed immediately on the SLM using the dropdown menu item 'Show at SLM...'.

With the '**Ok**' button, the slideshow configuration is accepted, and the data transferred to the memory of the graphics card unit (GPU). Please note that the configuration is not yet saved in the configuration file (*.slideshow) at this point. For saving the configuration to a file, please use the dedicated '**Save**' button. The filename of the slideshow can be edited in '**Slideshow Name**'.

The changed slideshow configuration is discarded with the '**Close**' button!

5.3.4 Player

The "Player" tab facilitates control of playback of a selected playlist.

Skip to first slide

Step one slide backward

Play backward

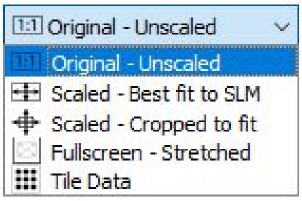
Stop play

Play forward

Step on slide forward

Skip to last slide

Select **Play mode** - Loop, Ping Pong, Single



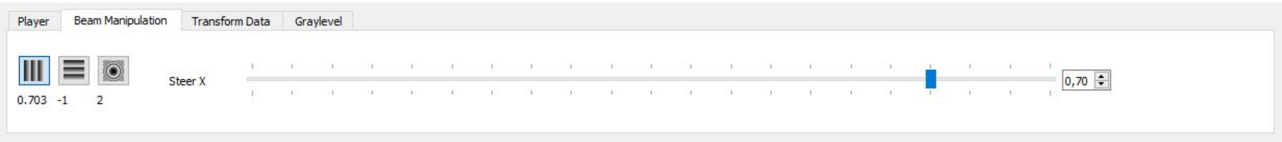
Scaling options

Show Option

The current slide file name and counter is displayed to the left of the navigation slider. The navigation slider is used to move quickly within the slide show. The slide will appear immediately. The **Speed - Playback Rate** of the slide show can optionally be set via '**Frame**', '**Time**' and '**Frequency**'. The conversion of the speed information is automatically calculated and displayed.

5.3.5 Beam Manipulation

To enable beam manipulation overlay, please to click the ‘Beam Manipulation’ in the tabulator.



Steer X **Steer Y** **Lens**

With right mouse click on the buttons the parameter will be set to default.

The software allows superposition of a beam manipulation phase overlay to the image data of a slide. Three functions are available: Beam steering in both directions x and y (blazed gratings) and a Fresnel zone lens overlay. The values, set through the sliders, are unified to a range between -1.0 and +1.0. The range is chosen to avoid sampling error. For the lens we allow a larger range (-5.0 to +5.0), because inaccuracies are starting at the edges, and the lens is still fine in the center for larger absolute values. Anyway, values outside the [-1.0, 1.0] range will have artefacts at the edges.

The unified values are the same values, which can be applied into the data handle of our advanced Application Programming Interface of HOLOEYE SLM Display SDK.

If incident laser light wavelength is set earlier, the software calculates the real physical values from the standardized values.

The physical values are calculated as follows:

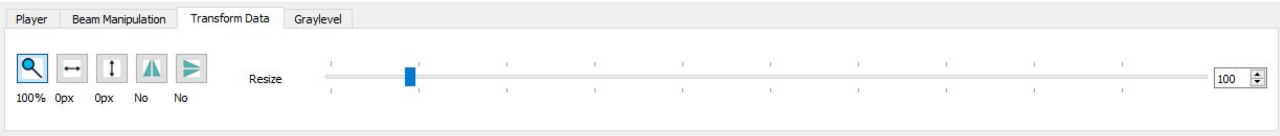
$$\alpha = \sin^{-1}\left[\frac{\lambda * beamSteerSliderValue}{2 * Pixelsize}\right] \quad \text{and}$$

$$f = \left[\frac{SLMWidthPixel * Pixelsize^2}{\lambda * beamLensSliderValue}\right]$$

- α is the corresponding beam deviation angle between the 0th and the 1st diffraction order.
- f is the focal length of the superimposed Fresnel zone lens.
- λ is the incident wavelength.
- "Pixelsize" is the physical size of the SLMs pixel, e.g. 8µm for HOLOEYE PLUTO SLMs.
- "SLMWidthPixel" is the number of pixels in the large direction of the display.
- "beamSteerSliderValue" and "beamLensSliderValue" are the unified slider values.

5.3.6 Transform Data

To enable data transformation manipulation overlay, please to click the ‘Transform Data’ in the tabulator.



Zoom/Resize: Performs a zoom of the bitmap data, i.e. there will be interpolation effects at least for non-integer zoom factors.

Shift X: Move the image in x direction over the SLM screen.

Shift Y: Move the image in y direction over the SLM screen.

Flip X (Left/Right): Mirrors the image along the vertical center line.

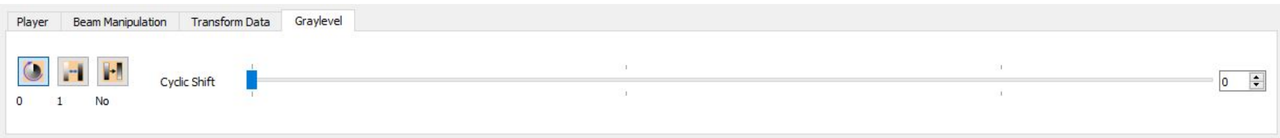
Flip Y (Top/Bottom): Mirrors the image along the horizontal center line.

Upon a mouse right-click on any of the buttons, the associated parameter will be set to the default value.

The 'Zoom/Resize' and 'Shift X/Y' buttons do not work while the "Fit" show option is selected.

5.3.7 Gray Level

To enable gray level manipulation overlay, please to click the ‘Graylevel’ in the tabulator. It allows overall adjustment of the gray levels of the currently used bitmap data.



Cyclic Shift: Adds the selected gray value to the image.

Gamma: Applies an image gamma correction to the gray values.

Invert Values: If enabled (Yes), this feature inverts the gray values in the image, so that black gets white and vice versa.

Upon a mouse right-click on any of the buttons, the associated parameter will be set to the default value.

5.3.8 Status Bar

The **Transfer** section shows the current status of the slide download to the GPU (Graphic Processing Unit). The transfer can be cancelled at any time and restarted later.

The **Wavelength** of the laser will be set and displayed here. The wavelength has an impact on the beam manipulation and must match the 'Wavefront Compensation'. Please see the 'Wavelength' chapter.

The **Wavefront Compensation** can be switched on and off using the checkbox. The wavefront compensation file (*.h5) must have been loaded beforehand. A wavefront compensation file can be loaded via the menu item 'File' + 'Load Wavefront Compensation file...'. However, the file can also be loaded by dragging and dropping the file into the application.

The **Zernike parameters** can be switched on and off using the checkbox. A Zernike parameter file (*.zernike.txt) must have been loaded beforehand. A Zernike parameter file can be loaded via the menu item 'File' + 'Load Zernike Parameter file...'. However, the file can also be loaded by dragging and dropping the file into the application.

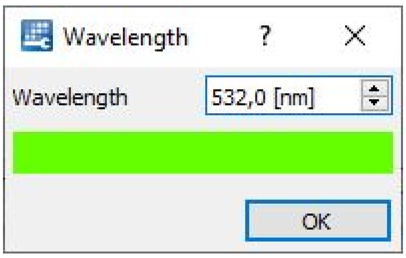
File displays the loaded slideshow file. Double-clicking on the element opens the folder of the current slide show file with Windows Explorer.

Max Freq. shows the maximum allowed playback frequency of the SLM (FPS - Frames per Seconds).

The **Frame Time** is the measured display time of the current slide/frame. It is the frame time of the last shown slide.

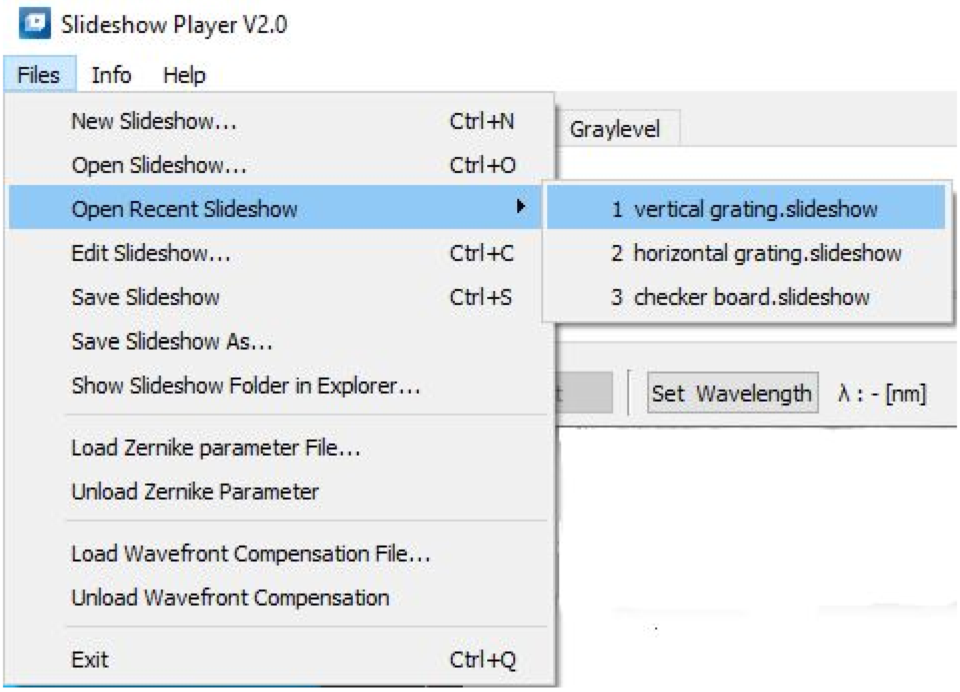
5.3.8.1 Wavelength

The calculation for physical values of beam manipulation requires the wavelength of the incident laser light.



5.3.9 The 'File' Menu

The menu item 'Files' provides all file loading and saving functions. From this menu the slideshows, Zernike and Wavefront-Compensation files can be accessed.

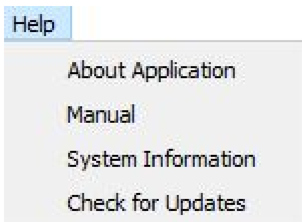


5.3.10 The 'Info' Menu

The menu item 'Info' contains 'SLM Preview'. From there the SLM Preview window can be opened.

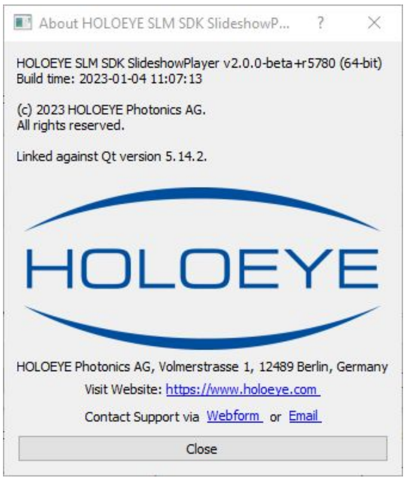
5.3.11 The 'Help' Menu

This menu item provides information about this software. You can access this manual, and check if there is a more recent software version available online.



5.3.11.1 About Application

The 'About' dialog shows version information and provides web links to the HOLOEYE web page, contact form and trademark information.



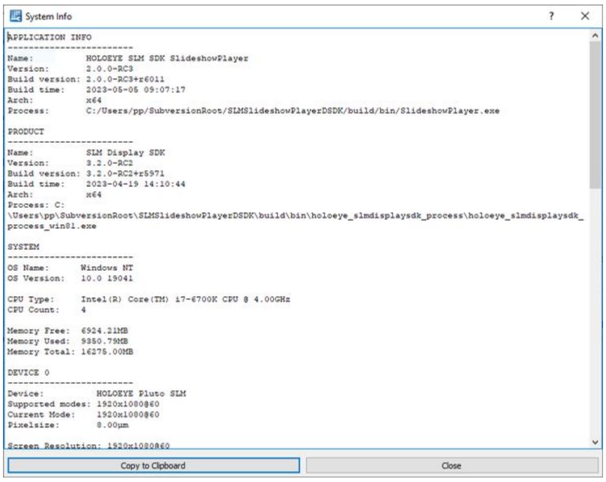
Feel free to use the ‘Contact Support‘ link if you have questions related to this software. If you do so, please provide the system information text, which is available in the help menu ‘System Information’ and in the device detection’s info button. The latter is useful in case your SLM is not recognized correctly and this help menu is not accessible.

5.3.11.2 Open Manual

This menu entry opens this manual in the configured PDF file viewer of your operating system.

5.3.11.3 System Information

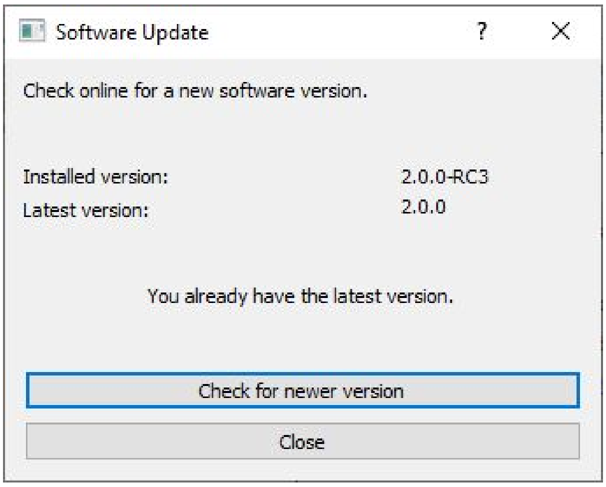
This menu entry opens a dialog, which shows information on your system including connected monitors, graphic card driver version etc.



Please use the button ‘Copy to Clipboard’ to copy the full text into the clipboard of your operating system. Please provide this text to us when you contact our support team.

5.3.12 Check for Updates

This menu entry opens a dialog, which provides an easy way to check if there is a new software version available online. The software will not send out any information to HOLOEYE until you press the button 'Check for newer version'. The software will connect to a HOLOEYE server and check the latest official release information. Both versions, the currently used and the latest available versions, will be displayed. No other data is transferred to the HOLOEYE server.



To actually update the software, please log in or register at our download website https://customers.holoeye.com/ and download the latest version.

6 Display SDK

The HOLOEYE SLM Display Software Development Kit (SDK) is an interface to show images and data/phase arrays directly on the SLM from within many programming languages. It also supports some data manipulation functions like phase overlay calculated from Zernike coefficients, optical beam manipulations, data transformations, and a wavefront compensation field provided by HOLOEYE together with devices shipped since August 2021.

In order to make any use of this SDK, you need to have a supported development environment installed. Currently supported development environments are

- C or C++ compiler (e. g. Microsoft Visual C++ Compiler)
- National Instruments LabVIEW 2017 and later
- MathWorks MATLAB R2009b and later
- Octave 8.4 (Octave 9.1 and 9.2 are not working)
- Python 3.x.

In general, any development environment, which can import shared library files (.dll or .so) with C header files, can be used, but we will not provide any bindings and/or support for other languages than listed above.

The current version is only available for Microsoft Windows 10 and 11 operating system. The Windows version includes binaries for 64-bit and 32-bit development environments.

With SDK version 4, we have reworked the API completely to allow multi SLM use cases. In addition, we separated the functional API provided by the library from the language dependent convenience API part. So that there are now the following APIs available:

- ANSI C Library API
- C++ Convenience API providing the namespace HEDS, and classes like SDK, SLM, SLMWindow, SLMPreview, etc.
- Python Library API, available through HEDS.SDK.libapi namespace.
- Python Convenience API. Similar to C++ Convenience API.
- MATLAB/Octave Library API. Provided through *.mex* files.
- MATLAB Convenience API.
- LabVIEW API wrapper VIs, using the ANSI C Library API and providing additional convenience API VIs.

The provided example scripts all use the Convenvience API, if possible. All Convenience APIs are implemented on top of the Library APIs, so that it is fully transparent how the Library API is used at the end. The Library APIs are all implemented as similar as possible, especially the Library API function names are exactly the same in all implementations, and provide exactly the same parameters. In addition, the Library API types are all the same, except for MATLAB, there the prefix “heds_types.” is needed to access the types.

In addition to this manual file, there is a folder installed into each SDK providing an HTML web page documenting the APIs, examples, and features, including screenshots of each examples resulting image, so that you can check if the examples run for you like expected.

> The SDK installs examples demonstrating almost all functionality of the SDK. See below for detailed information. Please first try to use the examples before developing your own applications. The examples should run out-of-the-box without issues. Please derive your own applications from our example files. On each new version, please check if the new examples have changes compared to your own code, which was hopefully derived from the old examples. There is also a migration guide in the HTML documentation, which describes how to adapt your old code to a new version.

6.1 Installation

6.1.1 Microsoft® Windows®

Before starting any installer of this SDK, it is highly recommended to install the desired development platform, i.e. LabVIEW, MATLAB, Octave, Python, and/or C++ compiler. The SDK may not be fully installed otherwise. (see figure 124)

The SDK can only be installed with administrative privileges. Please make sure you have administrative rights on the target Windows operating system.

The SDK comes in different installation packages (installers). Each installer is meant to be used with the specified development environment only. Every installer will install the files needed to use the 32-bit and the 64-bit version.

Please start the appropriate installer file and click through the installation steps. Please accept the license agreement to continue with the installation.

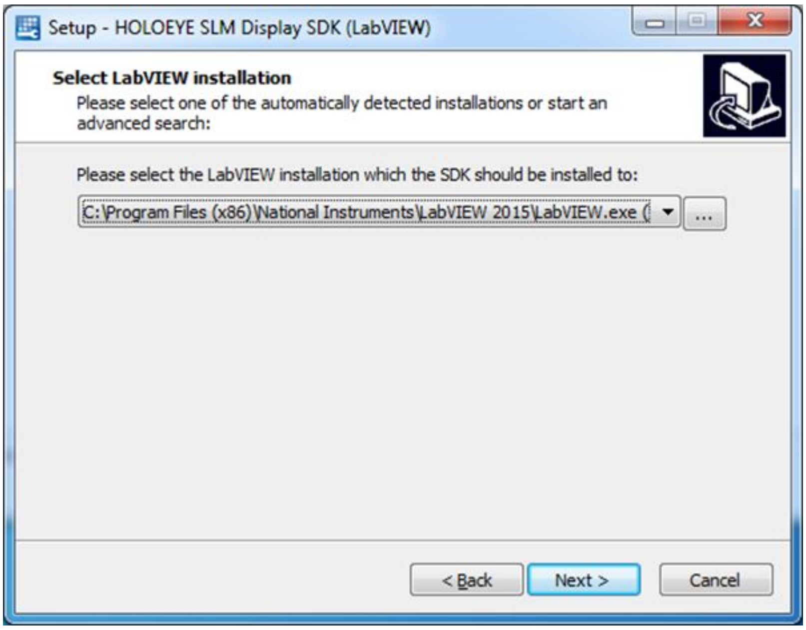


Figure 124: Select LabVIEW installation. The button "…" allows you to do a custom search on your system for valid LabVIEW installations. For an Octave SDK installation, also please make sure to select the proper octave.exe file on this page.

For the LabVIEW and the Octave installers, a selection dialog will appear (see figure 124). The installer will search automatically for the required development environment. This typically works, and you just need to click next in the installer after something was found. If it fails for some reason, i.e. nothing was found, or if you have multiple environments installed (e.g. LabVIEW 2017 and LabVIEW 2019), please select the one you want to use with the SDK manually. If nothing was found automatically although the environment is installed properly, please press the "…" button and search for the files manually (see figure 124). It needs to find the "LabVIEW.exe" or "octave_cli.exe" or similar file to run Octave. If this step is not done properly, the installation is incomplete. For LabVIEW, the installer copies the wrapper VI files into the user.lib folder inside your LabVIEW installation, and for Octave the installer needs to compile the mex files properly. The Octave version would not be able to access the API functions out-of-the-box, and you would need to do the (complicated) compilation manually afterwards.

For the LabVIEW SDK installation, please note that the VI files needed to access the SDKs .dll (.so) file are just copied into the LabVIEW user.vi library folder for the selected LabVIEW version. If you have multiple LabVIEW versions installed, and you want the VIs available in multiple versions, then please copy the appropriate HOLOEYE SLM Display SDK subfolder inside the “user.vi” folder manually into the other versions after finishing the installer, but before saving them for the first time in LabVIEW. (LabVIEW would store them in the newer format on saving).

For more details, please see chapter "LabVIEW" and "Octave".

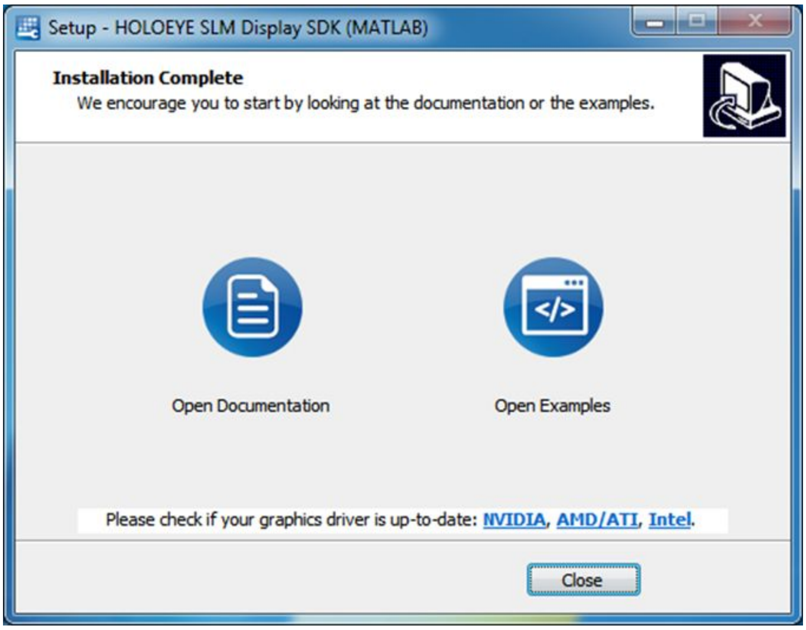


Figure 125: Installation finished. You can access examples and documentation from here, or from the start menu folders later.

Select ‘Install’ to start the installation procedure. After the installation is complete, a page opens which gives shortcuts to the examples and the documentation. You can use the examples also to validate the installation. See figure 125.

The SDK is installed into the folder

```
%PROGRAMFILES%\HOLOEYE Photonics\SLM Display SDK …
```

and the examples are copied into the folder

```
%HOMEDRIVE%\Users\Public\Documents\HOLOEYE Photonics\SLM Display SDK …
```

The HTML documentation is installed inside the program files installation folder into

```
doc/__index__.html
```

inside the main installation folder.

Additionally, this manual and the license file as well as the uninstaller are installed inside the main installation folder.

We recommend not using any outdated graphics card drivers. This SDK makes use of DirectX11 / OpenGL functionality to speed up painting on the SLM screen. The graphics card plays an essential part when using this SDK. You can use the links on the last page of the installer to get to the main graphics card manufactures and to download their current drivers.

After you looked into the documentation and/or example files, you can press ‘Close’ to finish the installation. The example files might not work until you re-login your user account after the SDK installation is complete.

6.2 Getting Started with Software Development

All installations should be usable out-of-the-box after installation, as long as you have installed the required development environment (LabVIEW, MATLAB, etc.). Therefore, you can start right away by running the example files provided for each HOLOEYE SLM Display SDK version. The example files show most of the functionality of the Display SDK, and it is highly recommended to use the examples as a start for your own projects. The example files are checked for working properly on each release.

For a full list of supported API functions of each SDK version, the documentation is installed as an HTML webpage into the main installation folder in the subfolder “doc”. There are links to this folder installed into Windows Start Menu and on the last page of the installation procedure.

For each SDK version the installer installs the binary files which are responsible for the main functionality of the SDK. These binary files are platform specific files and are installed into the subfolders “win32” and “win64” when using a Microsoft Windows operating system. Both folders are installed on a 32-bit and 64-bit Windows, in case the SDK needs to be used on a different architecture later. The architecture is automatically detected normally.

The binary files consists of a shared object file (.dll, .so), which provides the "Library API" interface to our SDK in a general way and a background process, which is executed by the shared object file automatically.

The binary files on Microsoft Windows operating system depend on the Microsoft Visual C++ redistributables. The proper redistributable installers for both 32-bit and 64-bit binaries are installed automatically during the installation process and are also added into the subfolder “redist” for manual installation purposes, e.g. when there was an issue during Display SDK installation procedure.

For each development environment, there are additional files installed to make the use of the shared object file possible through the same "Library API", and in addition to add a more convenient API optimized for the programming language. These files are explained in the following sub-chapters.

6.2.1 General Usage

Before SLM Display SDK can be used, it needs to be initialized, by providing the major and minor version of the SDK your script or program was developed with, to later be able to check compatibility of your program against the called SDK version:

C++:

```
auto err = HEDS::SDK::Init(4,0);
HEDS_CHECK_ERROR_CPP(HEDS::SDK::logError, err, return 1)
```

Python:

```
err = HEDS.SDK.Init(4,0)
assert err == HEDSERR_NoError, HEDS.SDK.ErrorString(err)
```

MATLAB / Octave:

```
heds_sdk_init(4,0);
```

C:

```
heds_errorcode err = heds_sdk_init(4,0);
HEDS_CHECK_ERROR(stderr, err, return 1)
```

Now, after the SLM Display SDK is completely set up, you can open a new SLM comfortably, and at the end close the underlying SLM window like this:

C++:

```
auto slm = HEDS::SLM::Init();
HEDS_CHECK_ERROR_CPP(HEDS::SDK::logError, slm.errorCode(), return 1)

...

auto err = slm.window().close();
HEDS_CHECK_ERROR_CPP(HEDS::SDK::logError, slm.errorCode(), return 1)
```

Python:

```
slm = HEDS.SLM.Init()
assert slm.errorCode() == HEDSERR_NoError, HEDS.SDK.ErrorString(slm.errorCode())

...

err = slm.window().close()
assert err == HEDSERR_NoError, HEDS.SDK.ErrorString(err)
```

MATLAB / Octave:

```
slm = heds_slm_init();

...

heds_slmwindow_close(slm.slmwindow_id);
```

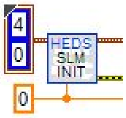
C:

```
heds_slm_id slm;
heds_errorcode err = heds_slm_init(&slm, "");
HEDS_CHECK_ERROR(stderr, err, return 1)
```

```
...

err = heds_slmwindow_close(slm.slmwindow_id);
HEDS_CHECK_ERROR(stderr, err, return 1)
```

In LabVIEW, the Convenience API implementation combines the SDK and SLM initialization within the VI heds_slm_init.vi:



Of course, the LabVIEW SDK init can be called independently from the SLM init, too, but it is more convenient in LabVIEW to just pass the SDK version directly into SLM init.

The SLM init call will open the EDID Device Detection and return the newly opened SLM on the selected screen. There is also the option to provide a preselect string into the heds_slm_init("...") call, to bypass the EDID Device Detection GUI, see examples and documentation.

For further usage and functionality, please have a look into the example scripts and into the HTML documentation. Most functionality can be found within the SLM class or heds_slm_… namespace after the initialization of the SLM is done. For more options on initializing multiple SLMs, please refer to the SLMWindow class or heds_slmwindow_… namespace.

6.2.2 Import of SDK in C and C++

The installer for the HOLOEYE SLM Display SDK (C and C++) will install two additional subfolders called “api/ansi_c“ and “api/cpp” to allow binding the holoeye_slmdisplaysdk.* shared library file into C and/or C++, and provide a more convenient API in C++. The pure ANSI C compatible code also provides an incompletely but sometimes useful convenience API include file.

The subfolder “api/ansi_c/libinc” contains all header files of the shared library file, which is completely ANSI C compatible. The library file can either be linked statically using the *.lib file (some compilers can directly link the DLL instead), or the library can also be linked dynamically using the headers and source files located in “api/ansi_c/libdynlink“.

To make use of the ANSI C Library API, your source code files shoud just include the header file

```
#include <holoeye_slmdisplaysdk_ansi_c.h>
```

to get maximum convenience API in pure C.

When using C++, please include

```
#include <holoeye_slmdisplaysdk_cpp.h>
```

instead to get the Library API included automatically together with the full C++ Convenience API.

In order to make all this work in your development environment, you will need some project configuration file, for example a Visual Studio solution file, a QMake project file, a CMake project file, etc. . We provide QMake *.pro and *.pri files to easily import the library when using Qt Framework to compile the example files. If you want to use a different build system, just translate the qmake code into your build system. The qmake language is very simple and clear on what is done, and allows splitting the project using *.pri include files. Therefore, the folders “api/ansi_c/build” and “api/cpp/build“ contain QMake *.pri files for including either the C++ and/or the C API files. The examples provide a *.pro file, which includes the *.pri files already, using dynamic DLL linking. The *.pri files include the API headers and sources from the installation directory using the enviroment variable set by the installer. They also add the library search paths so there is no need to copy any files around.

The C++ API expects that the ANSI C API files are also included already, because it is based on the ANSI C Library API.

The ANSI C build files provide two different include modes: static DLL linking and dynamic DLL linking. The C++ API always includes the dynamic DLL linking file, but that can be changed of course.

In the future we may provide more build system files, but the QMake files already work well as soon as you have Qt installed. If you need help using the SDK with Visual Studio, we can provide some more information to help you. Unfortunately, there is no way to provide a generally working solution file.

6.2.3 Import of SDK in Python

The installer for the HOLOEYE SLM Display SDK (Python) will install one additional subfolder called “api/python” to allow binding the holoeye_slmdisplaysdk.* shared library file into Python. That means, these files make the Library API of this SDK available in Python.

For more convenience, there is a subfolder "HEDS" within the examples folder, which implements the Convenience API for Python. This subfolder needs to be copied into the same path like the Python scripts you write for SLM Display SDK, then the Python Convenience API can be imported like this:

```python
import HEDS
from hedslib.heds_types import *
```

The HEDS subfolder contains a script “detect_heds_module_path.py“, which is used to import the Library API as well. It uses the environment variable set by the installer to detect the import path.

By importing the heds_types module like this, all types like enum values etc. are available without any namespace writing.

6.2.4 Import of SDK in MATLAB and Octave

Before using any function of this SDK, you need to add the path of the *.m and *.mex files of the Convience API and Library API (resp.) to the MATLAB search path by running the command

```
add_heds_path;
```

The script file "add_heds_path.m" is installed into the folder where all MATLAB example scripts are installed to. All examples call this script at the beginning to make sure the path to the SDK installation API folders is known by MATLAB. Please copy this file into your projects, and call it at the beginning of all your scripts like the examples do. Alternatively you can run the script once and save your MATLAB path permanently (command savepath). We recommend calling add_heds_path in all your scripts and optionally save the path into MATLAB. There is no harm calling this script multiple times.

All API functions have *.m-files installed which provide the API documentation accessible inside MATLAB by calling

```
help heds_{function_name}
```

which puts the documentation of this function into the MATLAB command line window.

To get a list of supported function names, you can enter "heds_" and press the "tab"-key in the command-line window. A list of functions from this SDK appears.

To make full use of the SDK, you need to make some type definitions available globally:

```
load_heds_types;
global heds_types;
```

The types are now available through heds_types.____, e.g. heds_types.HEDSERR_NoError. These type names are exactly the same in all languages, but in MATLAB they are only available through the heds_types.* namespace (struct).

6.2.4.1 Octave

The Octave installer is very similar to the MATLAB installer, so please read the section for MATLAB users. However, the compilation of the mex files needs to be done again for each Octave version. Because of this, the installer is doing this compilation procedure during the installation automatically with the built-in compiler of the selected Octave installation.

The file structure of the installation is the same like for the MATLAB installer. All examples are compatible with MATLAB and Octave. You can use the integrated help, too. Anyway, the installer for Octave will install into a different base path, so that Octave and MATLAB versions can be installed and used in parallel. Some Octave mex-compilers may not work with our SDK files. In that case, please use Octave versions which we have tested, see supported development environments on the beginning of this document.

6.2.4.2 Compiling MEX Import Files Manually (MATLAB/Octave)

The installer installs precompiled *.mexw64 files for MATLAB 64 bit versions. So typically this procedure is not necessary for MATLAB users. In case you want to recompile mex files manually, please read the following:

The installer of the MATLAB (and Octave) version of this SDK creates a subfolder “api/matlab” inside the installation folder containing all files needed to bind to the holoeye_slmdisplaysdk.* library file. The subfolder “hedslibapi_mex” consist of a list of C++ files, one for each Library-API function. Each *.cpp file is meant to be compiled into a *.mex[w64] file for MATLAB/Octave, which allows access to that API function in a MATLAB compatible way. The compilation process also needs to access the ANSI C API, which is installed in "api/ansi_c", and needs to be able to link to the binary shared object file, located in "bin/...".

The generated binary *.mex[w64] files are created inside the “api/matlab/hedslibapi_mex” folder. If you recompile the files for another installation (e.g. in Octave) or another architecture, the preinstalled files would be overwritten.

To recompile the mex files within MATLAB, you must have installed a proper MATLAB compatible C++ compiler. Octave ships with a compiler already.

There is a MATLAB/Octave script installed, which automates the compilation procedure for all API functions. The script is located in

```
<SDK-Install-Path>/api/matlab/build/build_sdk_mex_files.m
```

If you need to compile the mex files manually, please run the script from a MATLAB/Octave command line and make sure the current MATLAB/Octave path is the path to that script:

```
build_sdk_mex_files
```

After the mex files are compiled successfully, all the functions can be used inside MATLAB like normal m-file-based functions as long as this SDK is added to the MATLAB path using the script "add_heds_path.m".

6.2.5 Accessing SDK in LabVIEW

The installer of the HOLOEYE SLM Display SDK for LabVIEW will install the complete C SDK and the "Virtual Instrument" ("VI") files needed to call the C API functions from within LabVIEW (API wrapper VIs). Like all other installers, it will also install each example of the C SDK implemented in a LabVIEW VI.

The API wrapper VI files are installed to a subfolder called "LabVIEW API VIs" in the main installation path of SLM Display SDK for LabVIEW. The same files are also installed to the "user.lib" folder inside your LabVIEW installation path, e.g. "C:\Program Files\National Instruments\LabVIEW\2019\user.lib\HOLOEYE SLM Display SDK 4.0". Please note that these files can only be installed when running the SLM Display SDK installer after installing LabVIEW, and only for the LabVIEW version selected during installation. If you need them for multiple LabVIEW versions, you can either place copy them after installation of SLM Display SDK into the oder LabVIEW installation folders, or copy all the needed VIs into your project directory.

Figure 126 shows how the VIs installed into the users.lib folder will be accessible inside LabVIEW after the SDK is installed for all users and a LabVIEW installation was found and selected during installation.

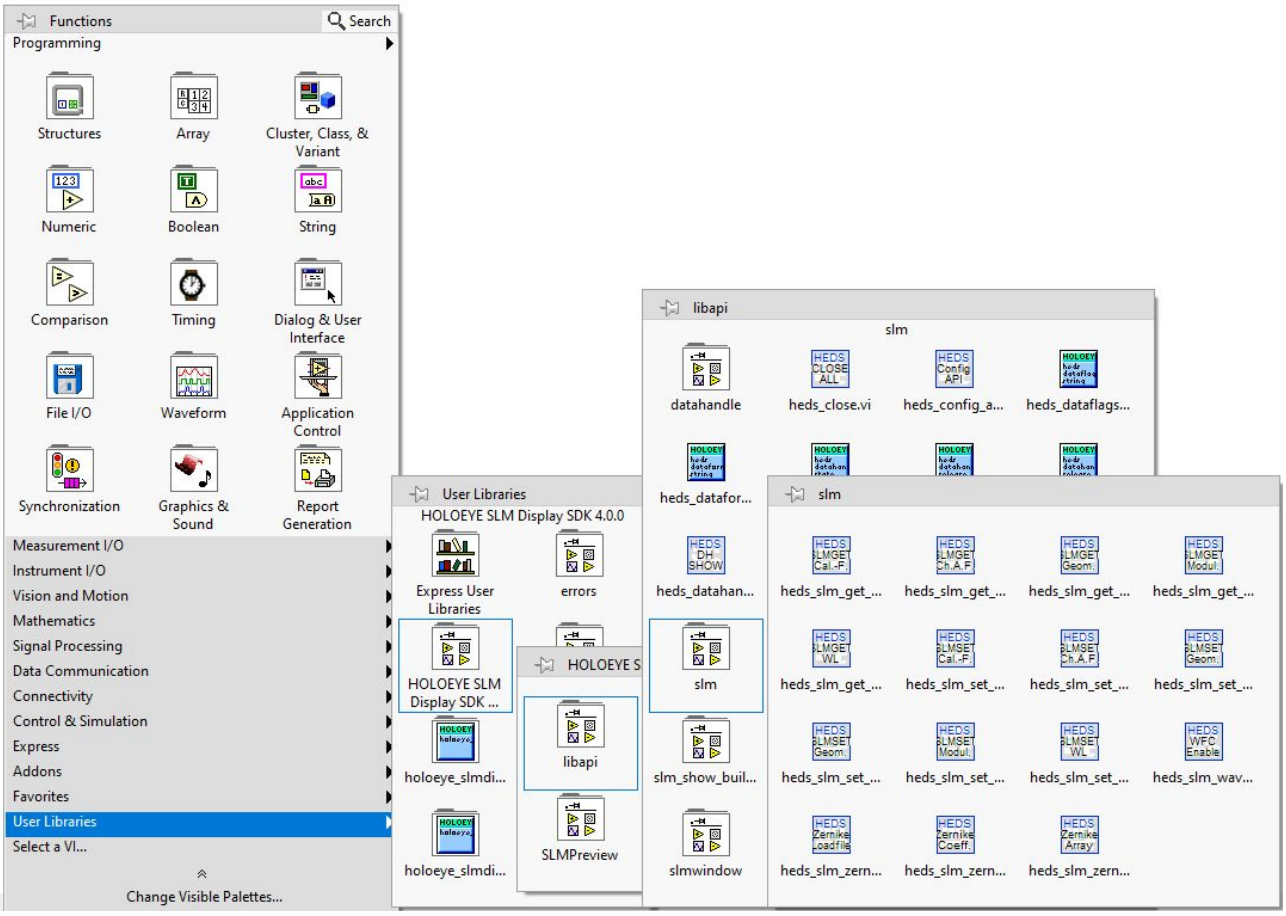


Figure 126: HOLOEYE SLM Display SDK access from LabVIEW.

The wrapper files (VIs) exist for all relevant ANSI C API functions and include the C-API help text. Some ANSI C API functions are combined into a single wrapper. For further documentation of HOLOEYE SLM Display SDK, the ANSI C (and C++) HTML documentation is installed together with the LabVIEW version, too. It can be accessed through the Windows-Start-Menu and is installed into the main installation folder ("C:\Program Files\HOLOEYE Photonics\SLM Display SDK (LabVIEW) v4.0...\doc\ __index__.html"). This documentation is especially useful when adding library nodes inside LabVIEW directly into your code without using the wrapper VIs. This way the C API functions can be called directly.

Anyway, please have a look into the example VIs. Please start your own SLM Display SDK projects by just copying and then modifying one of the provided example files. This will make sure all the necessary initialization steps are done properly in your code. In addition, you may not need to read the ANSI C documentation at all.

If you already used an older version of HOLOEYE SLM Display SDK for LabVIEW, then please note that the folder structure and the names of the wrapper VIs changed completely, together with all the changes made to the ANSI C API. If you consider migrating your existing code, it is not sufficient to just replace a few VI-calls. It may be worth it rewriting your code part accessing SLM Display SDK.

For a complete list of all LabVIEW wrapper VIs accessible through the LabVIEW User Libraries, please have a look into the user.lib subfolder of your LabVIEW installation.

The *.ctl files are controls which are used as strict type definitions representing the C API enums and structs.

6.3 SLM Initialization

Almost all API functions of this SDK require a properly connected and configured HOLOEYE SLM, which is supported by the SDK. The SLM needs to be set up as an extended desktop monitor.

When calling an API function, which requires a properly initialized SLM, the function will return an error code or invalid data (like a pixel number of 0) if no valid SLM was set up.

6.3.1 SLM Device Detection

When you start the software, typically by running a program or script calling the SDK Library API function

```
heds_slmwindow_open()
```

a device detection dialog pops up, which checks if a proper HOLOEYE SLM device is connected and if the system is configured correctly. You can find detailed information on the device detection in the chapter "EDID Device Detection" of this manual. There is the option to provide a pre-select string into heds_slmwindow_open("...") function, to bypass the EDID Device Detection GUI and pre-select one of the detected devices automatically without any further user interaction. If the pre-select string can not identify an SLM for sure, EDID Device Detection will open for manual selection, anyway. For more information about the pre-select string options, please have a look into the multi-SLM initialization examples, and into the documentation of heds_slmwindow_open().

The HOLOEYE SLM Display SDK shows a tray icon as soon as the device detection opens:

Figure 127: Windows tray icon of HOLOEYE SLM Display SDK.

The icon is gray-colored until an SLM is successfully connected, or the previously connected SLM is lost. While an SLM is successfully connected, the icon is blue-colored, like shown in figure 127.

By clicking the mouse on this icon (left, right or mid mouse button), a menu will pop up with all available options. The menu allows you to access the following:

- Open/Close SLM Preview window.
- Help:
  - Version and system information.
  - License.
  - SDK documentation (this PDF manual).
  - API documentation (HTML page).
- Check for updates.

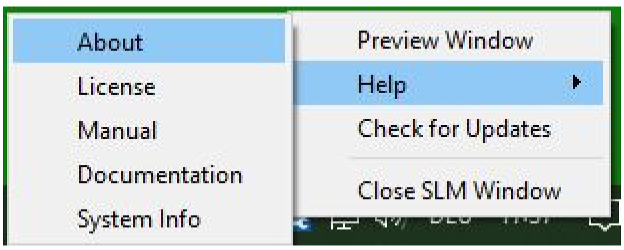


Figure 128: HOLOEYE SLM Display SDK menu. Please click on the tray icon to open.

6.3.2 SLM Full-Screen Support Within Extended Desktop

Since version 1.1 of the HOLOEYE SLM Display SDK, a built-in SLM Preview Window was introduced to inspect the shown content on the SLM easily. However, this SLM preview window might have an impact on the performance of video-like data playback on the SLM. To get an SLM preview, which has almost no performance issues, there is still the possibility to connect an additional monitor with the same pixel count (resolution) like the SLMs pixel count and mirror it with the SLM. For example on a Pluto SLM, a FullHD (1920x1080 pixel) monitor can be used (see figure 129).

The result will be one primary display, one display mirrored with the SLM and maybe more displays. This way, development gets much easier because you can inspect the content of the SLM very easily on the mirrored monitor. Please note that in the case of mirroring a monitor with the SLM, screen tearing on either the SLM and/or monitor might occur. This is a graphics adapter limitation.

Since version 2.0 of the SDK, the preview window will not have a big performance impact any more if the mode "Realtime Preview" and not "Capture SLM Screen" is selected.

Here are some more ways to inspect the content on the SLM:

1. Use the SLM preview window included in the SDK.
2. Use the "Save Data" button of the SLM preview window included in the SDK. You can save the frame generated by the SDK as well as the entire screen (dependent on the selected capture mode).
3. Use the screen magnifier of Microsoft Windows in "docked" mode and move the mouse to the SLM each time you need to look.
4. Press the "Print" key and paste the content to any image editing software, e. g. Microsoft Paint.
5. Use the SLM in amplitude modulation with a suitable polarizer configuration. A simple linear polarizer and sufficient light is typically sufficient to roughly inspect the content.

Please note that for holographic applications, a scaled preview, like the taskbar preview, is not sufficient. You will also not be able to see single line errors when using a polarizer, but such errors will impact the quality of the holographic images.

In such holographic applications, it is recommended to test the content of the SLM with an appropriate polarized laser and look onto the diffracted light.

Figure 129: SLM display configuration to be used as an extended screen with a mirrored additional monitor. "1" is the primary monitor, "2" and "3" are the SLM and the additional monitor. A decent graphics card might be required for this setup.

6.3.3 Built-in SLM Preview Window

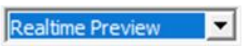
The SLM preview can be opened for each open SLM window either by using the popup menu of the tray icon from an already open SLM window (i.e. running SDK process) or by using the library API command inside the calling program

```
heds_slmpreview_open(slmwindow_id);
```

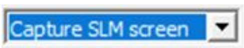
with slmwindow is the SLM window ID of the SLM window to open the SLM preview window for.

The library API commands allow multiple manipulations of the SLM preview window, like open/close, changing the scale, moving the window position and size, etc. There may be convenience API classes and or functions available to do the same, depending on the used language.

Please note that as long as the SLM preview window is opened, the performance of the program using the SLM through the SLM Display SDK can be influenced. The performance impact is much lower when operating the SLM preview in the default mode “Realtime Preview”, which uses the data directly from the GPU and just does another rendering into the SLM preview window. This is only true in case the monitor the SLM preview is opened on has the same frequency like the SLM screen, otherwise, even the "Realtime Preview" mode may limit the playback performance on the SLM considerably.



Due to the direct rendering of the "Realtime Preview", it can only capture the content shown through the SDK, and not any other windows, e.g. when another software tries to display data on the SLM and the SDK is not able to get on top of that window.



The capture mode “Capture SLM screen” can show the actual content exactly like shown by the graphics card on the SLM except the mouse cursor. In this mode, you will see all windows shown on the SLM screen, even if the SDK cannot get its content to the top level. However, this mode has much higher performance impact when running a video-like playback.

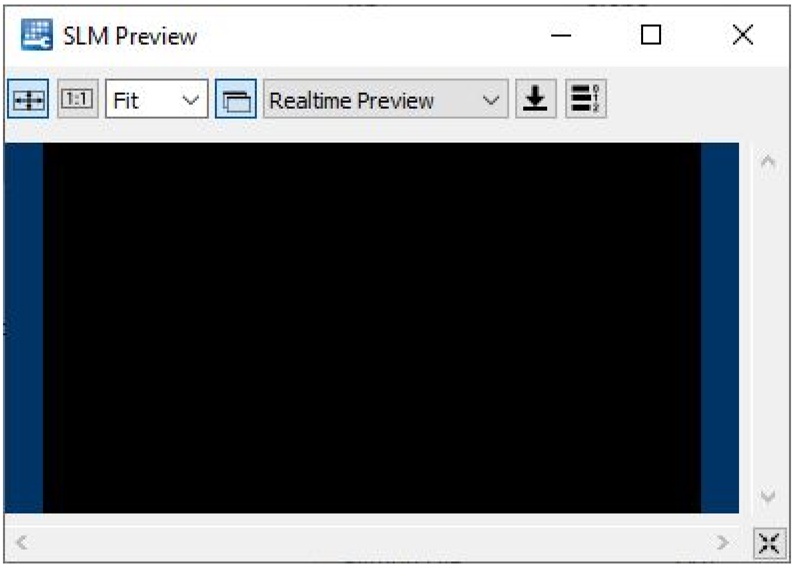


Figure 130: Default look of the SLM preview window. The blue part just fills empty space due to the window geometry and does not represent the SLM screen.

In the SLM preview the display scale can be selected. Valid options are “Fit” and any number in the format “1:1”, “x1”, and “/1”. The numbers can also include a point (comma). By default, it starts with the scale “Fit”, which means that the full SLM screen is scaled down so that nothing is cropped. Mode “1:1” has a separate button to easily switch. “1:1” means each pixel shown on the SLM is represented by one pixel in the SLM preview window.

The left most button on top of the window is a shortcut to the “Fit” scale, the next button is the shortcut to the “1:1” scale option and the drop-down-selector can be used to select any scale. Since SDK version 2.0, the scale along with other options can be set through the API function

```
heds_slmpreview_set_settings(slmwindow, flags, zoom).
```

A zoom of 0 will set the “Fit” option. With

```
heds_slmpreview_move(slmwindow, x, y, w, h)
```

the preview window geometry can be changed through the API.

Please be very careful with the scale modes because strange results can happen when using misleading scale values. Please see figure 131 for an example. All images in figure 131 show the same content on the SLM, which is a vertical binary grating with a pixel width of 1 for the gray value 0 and also 1 for the gray value 255. Here is the API call used to show the grating (MATLAB API):

```
heds_slm_show_grating_binary_vertical(slm, 1,1, 0,255);
```

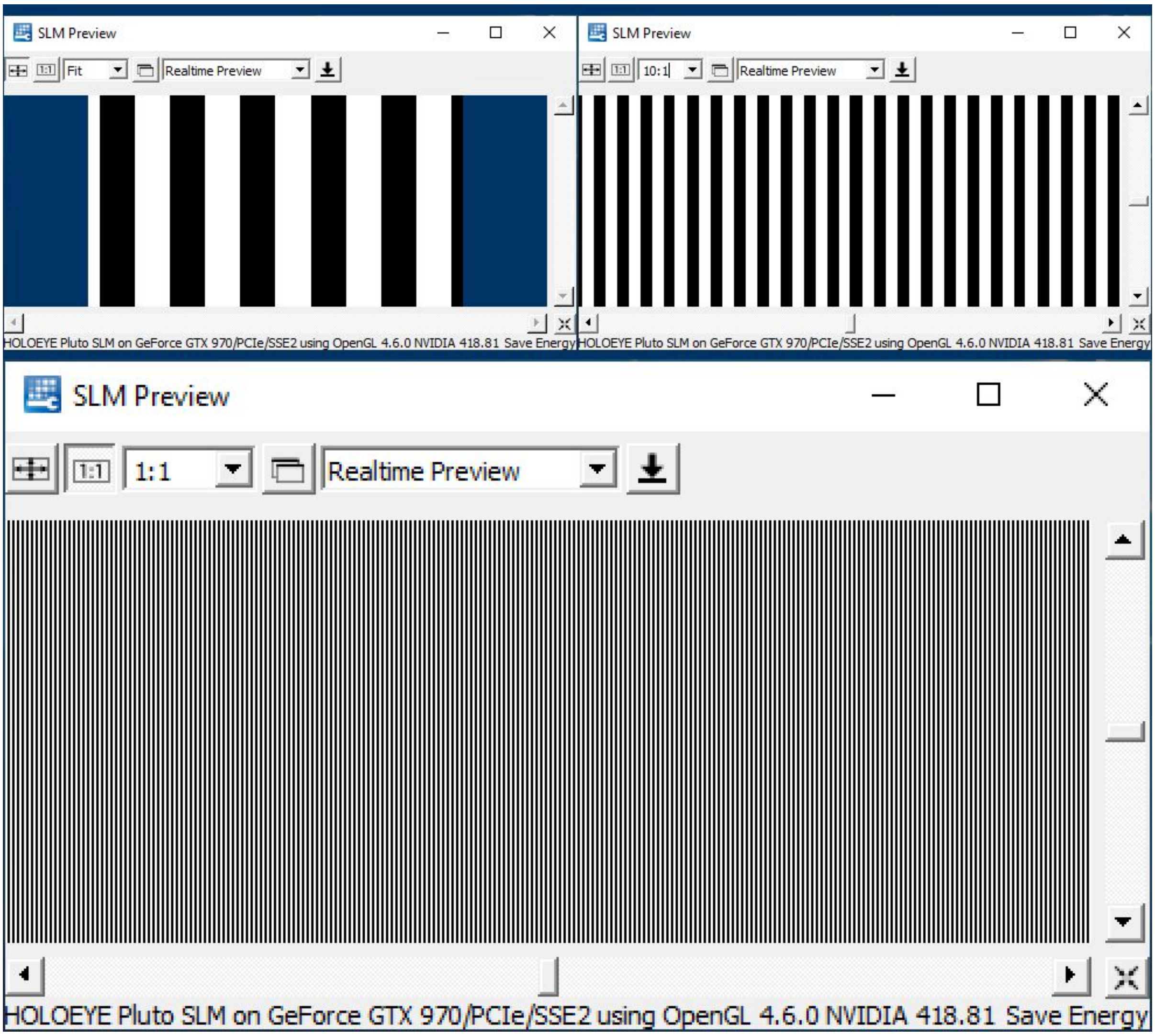


Figure 131: SLM preview window with scale "Fit" (top left), "1:1" (bottom), and "10:1" (top right). All three SLM previews show the same binary grating (1-1) on the SLM. The "Fit" scales down the pixels so much that a completely different looking image occurs. Please be careful with the scale modes which scale down (<1). The magnifying scale "10:1" means 10x10 pixel of the preview window show one pixel of the SLM screen.

The top left picture in figure 131 shows the grating in the scale mode "Fit", the larger bottom picture shows the SLM preview in mode "1:1", and the top right picture shows the SLM preview in scale mode "10:1", which is equal to "x10". The down sampling of the content on the SLM screen to the SLM preview results for this special content in a very different SLM preview image. The magnified scale mode is used ("x10") in the top right picture, which clearly shows that a 1-1 vertical binary grating is actually addressed on the SLM, and not the 180-180 grating appearing in "Fit" scale mode.

However, the "Fit" scale mode is very useful to get an overview of the content addressed on the SLM screen, and is therefore active by default.

In "Fit" or some smaller scale modes, areas in the SLM preview not filled with data from the SLM screen are shown in dark blue.

When the zoomed SLM screen is larger than the SLM preview area, e.g. when using magnifying zoom values, a horizontal and a vertical slider is shown to move the position of the shown part of the SLMs content. The button in the bottom right corner can be used to reset both sliders back to the center position.

The “Stay on Top” button makes the SLM preview window stay on top of all other windows as long as this button is pressed down: 

Since SDK version 2.0 this feature can also be set through the API function

```
heds_slmpreview_set_settings(slmwindow_id, flags, zoom)
```

by using the flag “OnTop”.

By default, the position and size of the SLM preview window is set to the center of the main screen and can be modified either manually or since SDK version 2.0 by using the API function

```
heds_slmpreview_move(slmwindow_id, x, y, w, h).
```

The examples makes use of this either within the SLM init functions, or doing it directly. Within the convenience APIs of the different languages, there may be a convenience function to place the SLM preview on a secondary monitor into a layout of multiple SLM preview windows in case of multi-SLM window scenarios. It uses the Library API heds_info_monitor_…() functions to retrieve information about connected displays within the operating system.

6.3.4 Additional Features in SLM Preview

6.3.4.1 SLM Data Handle Properties

The button “SLM Data Handle Properties”  in the SLM preview window toolbar opens another window with all available properties of the currently visible data handle. If the same data handle was shown before, there is no new window opened, and for different data handles, new windows will appear.

The data handle properties editable through the API can be changed in this window, and the result will be visible on the SLM screen directly. This is helpful for example during development, and to try out some features of the data handle, like beam manipulations, data transformations and show flags. It can also be useful to easier access the timing statistics of the currently visible data field.

This button  is not visible until any data or phasevalues are shown through an API function.

The window will always show the data handle visible on SLM screen when the button is pressed. Due to performance optimization, the SLM Data Handle Properties window will not update its values when new data is shown on the SLM screen or when the handle is changed. To update the window for a specific data handle, the data of this specific handle must be visible on screen again and then you need to press the button again.

The “SLM Data Handle Properties” button will open a new data handle properties window for not opened handles. That means you can edit multiple handles in parallel, but the windows will only update after pressing the button while the specific handle is addressed on the SLM screen. If the load functions were used to upload the data, the handle ID will be shown in the window caption.

Some selectable options might not make sense to combine, but this is also true when using the API functions to set these values.

Please refer to the API documentation of the data handle for more information about each option.

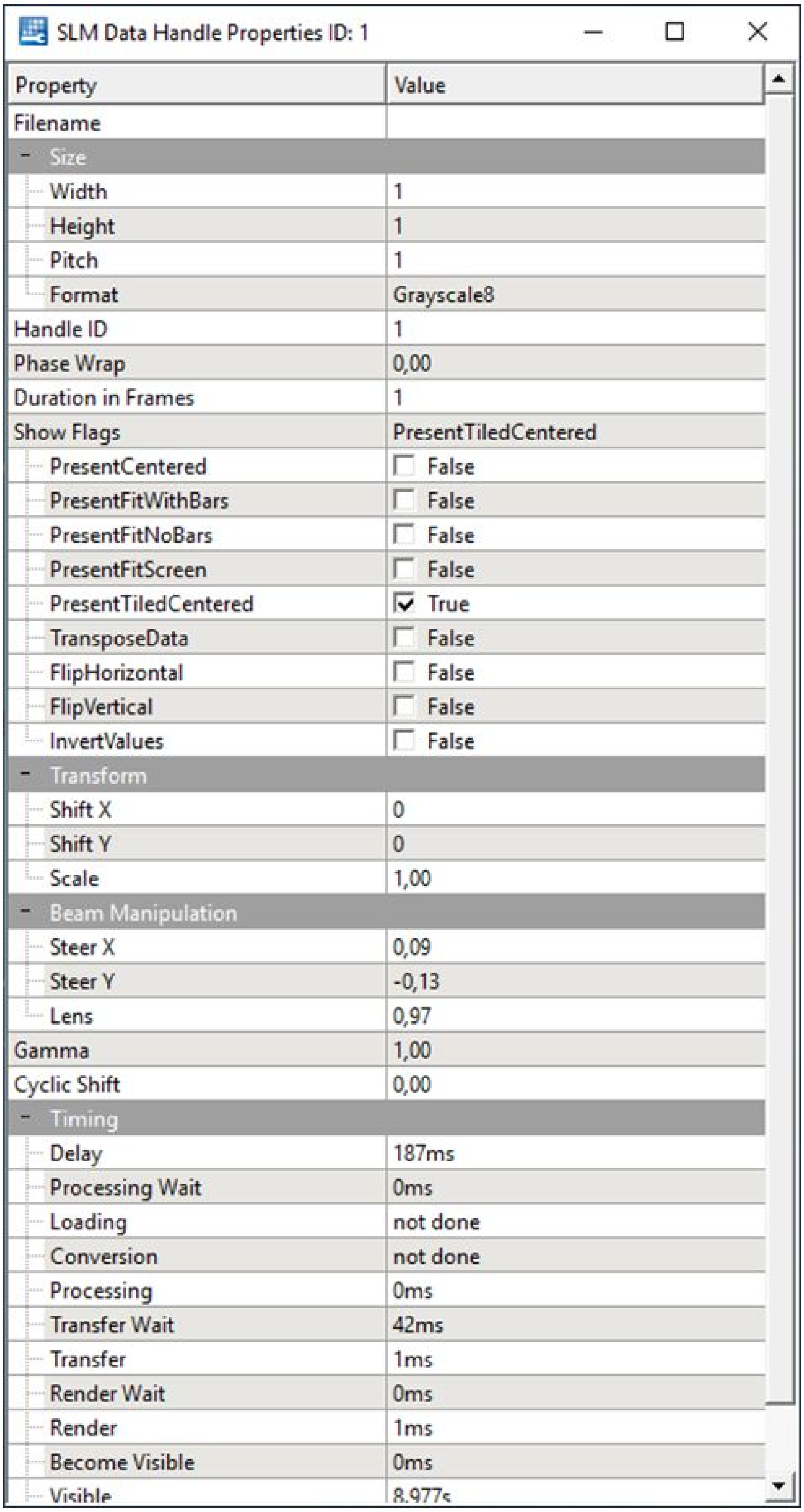


Figure 132: Data handle properties of the handle with the ID 1. The window allows inspecting and for some values also editing the available fields of the data handle.

6.3.4.2 Zernike Radius Indicator

The “Show Zernike Radius” button in the toolbar of the SLM preview can be pressed down to enable indication of the valid area for the currently set Zernike radius. In figure 133 the button is pressed, and the Zernike radius is set to the half SLM height plus half a pixel.

This button only makes sense and is only shown when there are Zernike coefficients set to the SDK through the Library API function (C)

```
heds_slm_zernike_set_parameters(const heds_slm_id *slm_id, const float
 *zernike_params, int param_count, heds_color_channel color_channel
HOLOEYE_DEFARG(HEDSCC_Mono)).
```

When the button is pressed down, only the SLM preview in mode “Realtime Preview” gets a red-colored overlay rendered into the shown data. That means the content on the SLM screen does not change when using this button, but the SLM preview indicates where the Zernike coordinates are out of the well-defined range. The Zernike radius is the first element of the Zernike values array passed to the API function.

The button is not pressed down by default, but can be enabled by using the flag “HEDSSLMPF_ShowZernikeRadius” in the API function

```
heds_slmpreview_set_settings(slmwindow_id, flags | HEDSSLMPF_ShowZernikeRadius,
zoom).
```

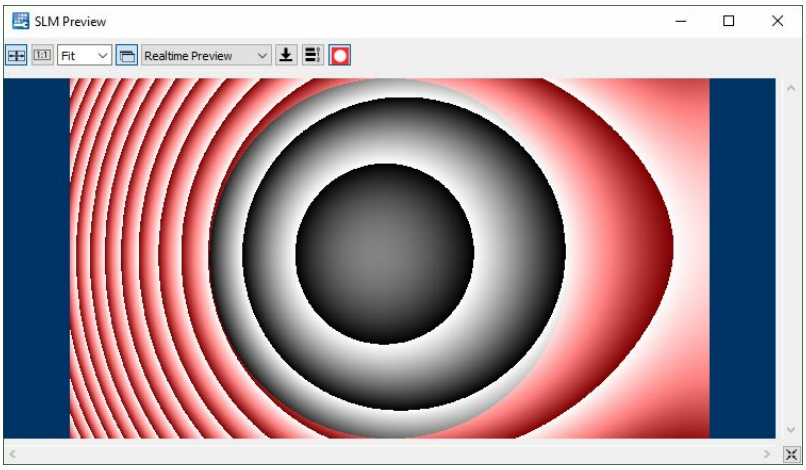
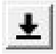


Figure 133: Data handle properties of the handle with the ID 0. The window allows inspecting and for some values also editing the available fields of the data handle.

The screenshot was created using the “phase_overlay_zernike” example shipped with the SDK.

6.3.4.3 Saving SLM Screen Data

Please use the "Save Data" button  in the toolbar of the SLM preview to save the entire SLM screens currently shown data to an image file. After pressing the button, a file selection dialog will open where you must select a file name and path to save the image file.

If time critical data is played on the SLM while using this feature, there will be some jitter added for a short period to the playback when the file dialog is opened.

The saved image file will not contain any indications added by the SLM preview. It will just contain the data like addressed to the SLM screen. Therefore, this feature is useful to inspect the SLM screen.

The saved image data differs depending on the selected preview mode. The "Realtime Preview" mode will save the data before applying wavefront compensation, gamma factor value, and output color and image size manipulations like in ERIS 120 Hz case. The "Capture SLM Screen" mode will take a screenshot of the SLM window screen and save this into the file, i.e. the image file will exactly contain the image send to the SLM device through the video signal.

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