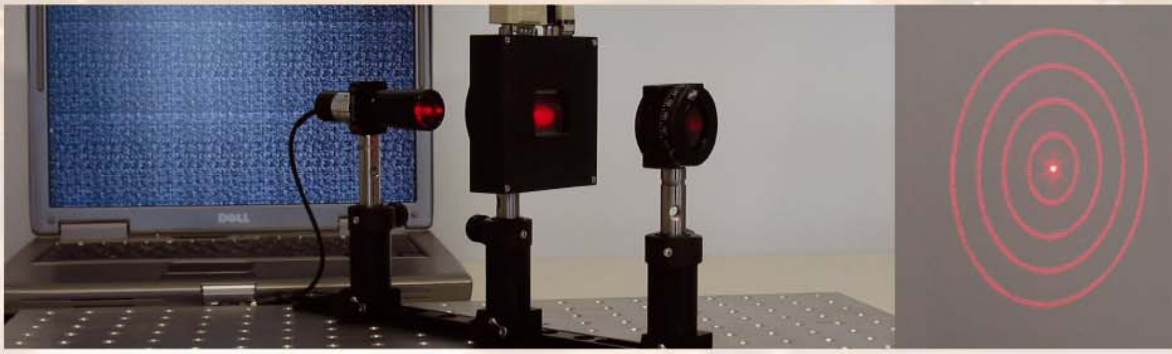
Newport
DOEK Education Kit

- SLM Operating Instructions
- Tutorial DOEK Application Software
- Laboratory Tutorial



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First printing 2006

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Newport Corporation
1791 Deere Avenue, Irvine, CA 92606 USA

Model Number: DOEK-KIT-TEXT

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Service Information

This section contains information regarding factory service for the source. The user should not attempt any maintenance or service of the system or optional equipment beyond the procedures outlined in this manual. Any problem that cannot be resolved should be referred to Newport Corporation.

Technical Support

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E-mail: rma.service@newport.com

When calling Newport Corporation, please provide the customer care representative with the following information:

- Your Contact Information
- Serial number or original order number
- Description of problem (i.e., hardware or software)

To help our Technical Support Representatives diagnose your problem, please note the following conditions:

- Is the system used for manufacturing or research and development?
- What was the state of the system right before the problem?
- Have you seen this problem before? If so, how often?
- Can the system continue to operate with this problem? Or is the system non-operational?
- Can you identify anything that was different before this problem occurred?

Table of Contents

List of Figures

1 Safety Precautions

1.1 Definitions and Symbols

The following terms and symbols are used in this documentation where safety-related issues occur.

1.1.1 General Warning or Caution

Figure 1 General Warning or Caution Symbol

The Exclamation Symbol in the figure above appears in Warning and Caution tables throughout this document. This symbol designates an area where personal injury or damage to the equipment is possible.

1.1.2 Electric Shock

Figure 2 Electrical Shock Symbol

The Electrical Shock Symbol in the figure above appears throughout this manual. This symbol indicates a hazard arising from dangerous voltage. Any mishandling could result in irreparable damage to the equipment, and personal injury or death.

1.1.3 CSA Mark with “C” and “US” Indicators

Figure 3 CSA mark with “C” and “US” Indicators

The presence of the CSA mark with “C” and “US” indicates that it has been designed, tested and certified as complying with all applicable U.S. and Canadian safety standards.

1.1.4 European Union CE Mark

Figure 4 CE Mark

The presence of the CE Mark on Newport Corporation equipment means that it has been designed, tested and certified as complying with all applicable European Union (CE) regulations and recommendations.

1.2 Warnings and Cautions

The following are definitions of the Warnings, Cautions and Notes that are used throughout this manual to call your attention to important information regarding your safety, the safety and preservation of your equipment or an important tip.

WARNING

Situation has the potential to cause bodily harm or death.

CAUTION

Situation has the potential to cause damage to property or equipment.

NOTE

Additional information the user or operator should consider.

1.2.1 General Warnings

Observe these general warnings when operating or servicing this equipment:

- Heed all warnings on the unit and in the operating instructions.
- Do not use this equipment in or near water.

- Route power cords and other cables so they are not likely to be damaged.
- Disconnect power before cleaning the equipment. Please refer to chapter 4.1.5.
- To avoid explosion, do not operate this equipment in an explosive atmosphere.
- Qualified service personnel should perform safety checks after any service.

1.2.2 General Cautions

Observe these cautions when operating or servicing this equipment:

- If this equipment is used in a manner not specified in this manual, the protection provided by this equipment may be impaired.
- Follow precautions for static sensitive devices when handling this equipment.
- This product should only be powered as described in the manual.
- There are no user-serviceable parts inside the Product.
- To prevent damage to the equipment, read the instructions in the equipment manual for proper input voltage.
- Adhere to good laser safety practices when using this equipment.

1.3 Location of Warnings

1.3.1 Laser

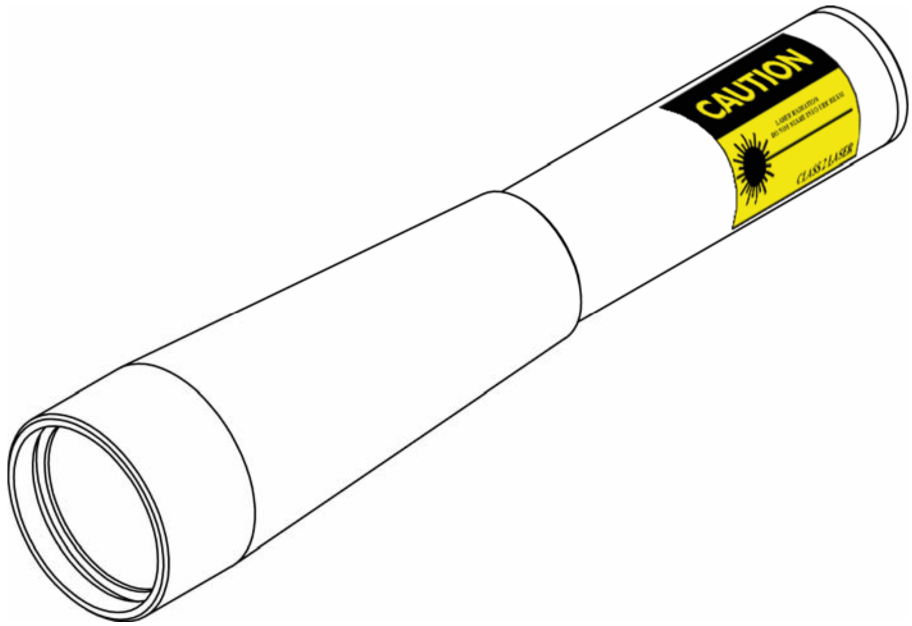


Figure 5 Locations of warnings on the Laser

2 General Information

2.1 Introduction

Main component of the “Projects in Diffractive Optics” Educational Kit is the spatial light modulator (SLM) DK-LCMH-800A. The device is a general purpose and easy-to-use device for displaying images by use of a monochrome, transparent liquid crystal display (LCD). It simplifies the application of LCD’s in experimental set-ups, e.g., for prototype development or in research labs. The small size of the device and its comfortable control interface are major characteristics for enabling an easy usage.

Key Features

The SLM can be used e.g. for purposes in technical optics, image projection, machine vision, diffractive optics, pattern recognition, optical information processing, sensing, etc.

The device is designed to be plugged to the graphics board of a personal computer with a resolution up to SVGA format, i.e. 800 x 600 pixels. The device converts colour signals into corresponding grey-level signals.

2.2 Functionality

The SLM can be plugged to a personal computer using the serial RS-232 port. After installing the SLM driver software the image parameters of the LCD can be easily controlled by the computer. The driver software always saves the current setting of the image parameters. Hence, whenever the system is started, this latest setting will be automatically loaded.

2.3 Offering Description/Comparison

Five experiments with several possible questions show the wide area of physical phenomena, which can be investigated experimentally with the "Projects in Diffractive Optics" Educational Kit. These are e.g. optical set-up of a projector, properties of polarized light, optical properties of liquid crystals, phase- and amplitude modulation of light fields, diffraction of light at dynamically changing structures, diffractive optical elements (DOE's) and the combination, Spatial frequency filtering and interferometry (phase shifter).

Thus the device is suitable for introductory and advanced laboratory classes in physics and engineering study courses.

3 Getting Started

3.1 Unpacking and Handling

- do not touch the LCD

3.2 Inspection for Damage

⚠	**WARNING** **Do not attempt to operate this equipment if there is evidence of shipping damage or you suspect the unit is damaged. Damaged equipment may present additional hazards to you. Contact Newport technical support for advice before attempting to plug in and operate damaged equipment.**

3.3 Parts List

- (1) DK-LCMH-800A: LCD image display device (SLM)
- (1) PS-LCMH-1: Power supply 15V= / 0,8A
- (1) 232-CBL-M/M : RS-232 adapter cable
- (1) VGA-CBL-LCMH : VGA monitor cable
- (1) DOEK-HLD: Mounting ring for laser module

- (1) LD-635-20MM: Beam expander laser module / focus adjustable
- (1) PS-LD-DOEK: Power supply 5V / 1A

- (1) DK-LCMH-800A User's Manual
- (1) DOEK-KIT-CD: CD-ROM with
  - Driver-Software
  - Application Software
  - DOE sample structures

- (1) MRL-12M: 12" Micro Optical Rail
- (5) MCF: Flat Carrier
- (4) VPH-2: 2" Post Holder
- (4) SP-2: 2" Post
- (2) LH1-1R: 1" Lens Holder
- (2) LM1-R: Lens Mount
- (1) 12454: Polarizer Disk

If you are missing any hardware or have questions about the hardware you have received, please contact Newport Corporation.

3.4 Electrical Requirements

Before attempting to power up the unit for the first time, the following precautions must be followed:

	WARNING **To avoid electric shock, connect the instrument to properly earth-grounded, 3-prong receptacles only. Failure to observe this precaution can result in severe injury.**

4 User’s Manual DK-LCMH-800A

4.1 Cautions

The DK-LCMH-800A (SLM) is an electro-optical device of high quality and value. In order to operate and maintain the SLM in a proper manner, be sure to read this manual carefully.

4.1.1 Avoid humidity and dust

Do not use the SLM outside buildings and in humid or dusty places.

4.1.2 Keep heat away

Keep the SLM away from extreme heat as it may cause damage. When using the SLM its display case and power pack become warm. Take care for sufficient ventilation, and keep the devices away from heat such as heating radiators, strong sun light, etc.

If you plan to apply the SLM with powerful light sources, heat-protection filters must be introduced between light source and LCD matrix. We strongly recommend you to consult Newport in this case.

4.1.3 Keep water away

If water or some other liquid is spilled into the SLM device serious damage can occur. Please, consult Newport services in such a case.

4.1.4 Avoid touching the LCD

Avoid touching the LCD because this might cause damage to it or reduce its optical quality.

4.1.5 Cleaning the LCD

Wipe the LCD very carefully with a soft, dry and clean cloth or with compressed air. If you are not sure if and how to clean the LCD, consult Newport services.

4.1.6 Electrical Connections

Connect the SLM only to other components if the power supplies of all components are switched off. For power supply of the SLM use only the power pack plug which is delivered with the SLM.

4.1.7 Housing

Do not open and touch the SLM device as this is dangerous and may seriously damage it. Do not attempt to disassemble the SLM. There are no user serviceable or adjustable parts inside.

NOTE

If the stated cautions are disregarded, the warranty claim expires.

4.2 Technical Data

Display:

Type:	SONY LCX016AL
Colours:	Grey-level image playback
Active Area:	26,6 mm x 20,0 mm (1,3")
Number of image pixels:	832 x 624
Pixel Pitch:	32 µm
Image frame rate:	max. 60 Hz
Contrast ratio:	typically 200:1

Device:

Dimensions (L x W x D):	82 mm x 82 mm x 23 mm
Weight:	0,15 kg
Operating voltage of power pack plug:	100-240 V DC, 50-60 Hz
Power input of power pack plug:	max. 150 mA
Operating voltage of LC2002:	15 V AC + 5%
Positive terminal at inner pin	
Power input of LC2002:	ca. 250 mA

4.3 Connectors

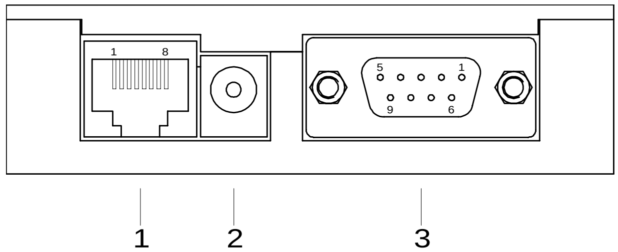


Figure 6 Connectors of the DK-LCMH-800A.

The device provides three female connectors. As depicted in Figure 6, these connectors are:

1. the serial port connector for configuration of the device
2. the power supply connector
3. the VGA video input connector

4.3.1.1 Serial Port

Configuration of serial port connector (1):

Pin 1	+5V AC	Pin 5	RXD
Pin 2	+5V AC	Pin 6	CTS
Pin 3	TXD	Pin 7	GND
Pin 4	RTR	Pin 8	GND

Connection parameters:

Transfer rate	4800 - 19200 Bit/s
Data bits	8
Parity	No
Stop bits	1
Data flow control	Hardware handshake RTR / CTS

4.3.1.2 Power Supply

The direct current (DC) connector (2) is used for power supply of the device. The power pack cable (15 V) has to be plugged to this connector. The positive terminal is the inner connector pin.

4.3.1.3 Video Input

The video input (3) must be connected to the graphics board of a personal computer using the VGA adapter cable delivered with the SLM. The computer is used as the source of image and video data. The connector configuration is specified as follows:

Pin	Function
1	Red colour signal
2	Green colour signal
3	Blue colour signal
4	HSYNC (line synchronisation signal)
5	VSYNC (image synchronisation signal)
6	GND red colour signal
7	GND green colour signal
8	GND blue colour signal
9	GND

4.4 Connecting the DK-LCMH-800A for Usage

For using the SLM at least one computer with an VGA graphics board is required. The computer is required for controlling the SLM and providing images or videos to be displayed on the LCD. Instead of the PC, a VGA camera can be used as image-signal source.

First, the SLM driver software must be correctly installed on the computer. Then, the computer can be connected to the SLM as shown in Figure 7.

Attention: Plug the serial port and VGA connector first and the power supply connector always at last.

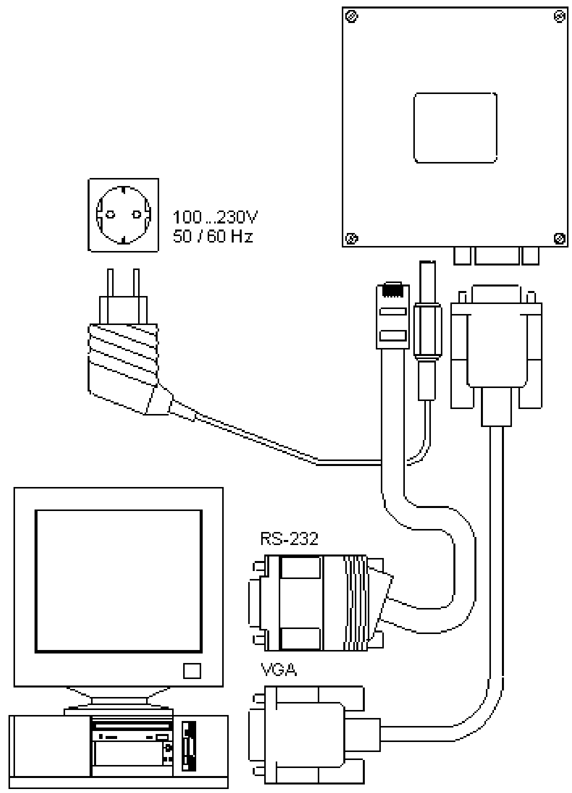


Figure 7 Connecting the DK-LCMH-800A for usage.

4.5 DK-LCMH-800A Control Software

4.5.1 System Requirements

- IBM- or compatible PC
- Processor: 80486 or Pentium
- 32 MB main memory or more
- VGA graphics board

- Free RS-232 port (COM1 or COM2)
- CD-ROM drive
- Operating systems: Windows 95, 98, 2000 and XP

4.5.2 Installation

For installing the control software execute the program SETUP.EXE on CD-ROM. This program requests for all information required for the installation process.

After the installation has been completed successfully, the SLM control software can be started from the Microsoft *Windows* ‘Start menu’ as shown in the next section.

4.5.3 Start of DK-LCMH-800A Control Program

You can start the SLM control program by selecting **‘Programs→LC2002 Control Program’** in the Microsoft *Windows* ‘Start menu’ as shown in Figure 8.

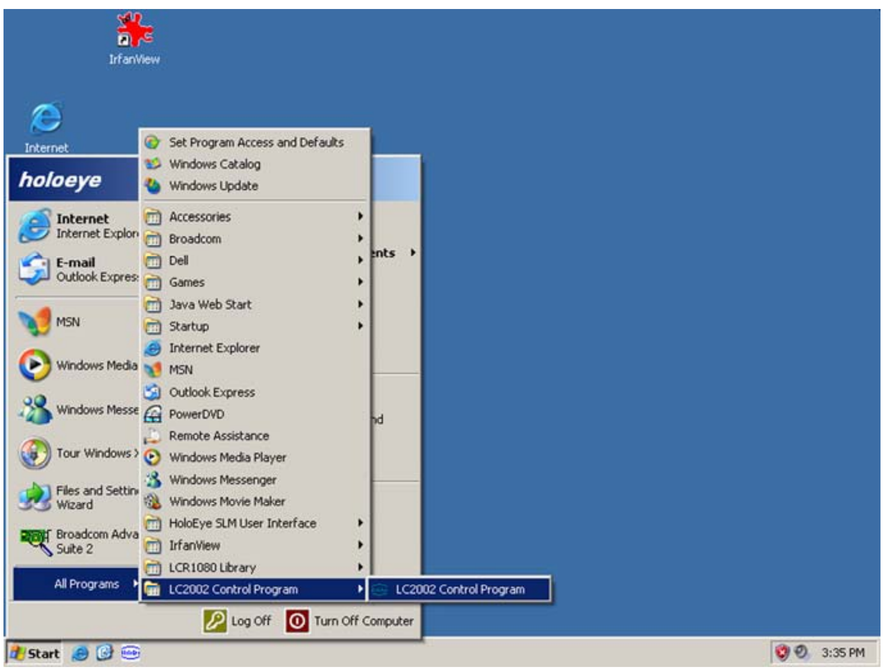


Figure 8 Starting the LC2002 control program.

After starting the program the user dialog ‘LC2002’ as shown in Figure 9 appears. At the same time the program tries to identify automatically the

SLM display that should be connected to the RS-232 port (COM1 or COM2). If the identification succeeds, the coloured ‘Connected’ sign appears in the lower right corner of the dialog window.

In the title of the dialog window the version of the LC2002´s firmware and its individual series number are displayed.

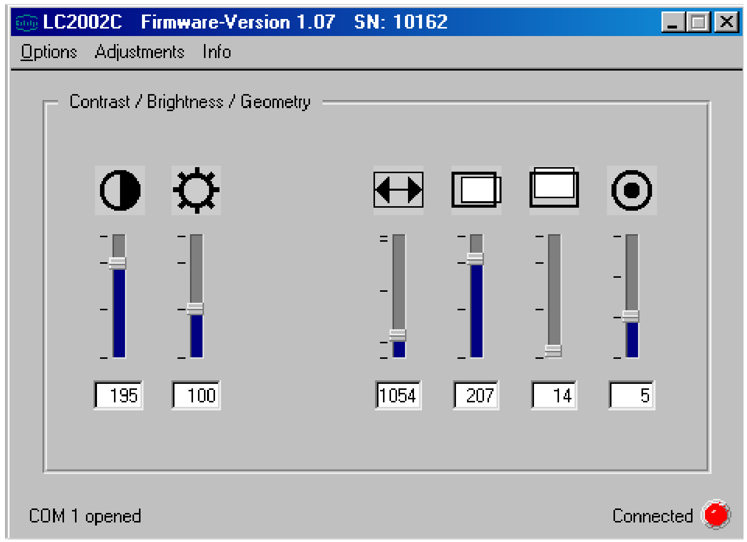


Figure 9 User dialog of the control program after start-up.

If no SLM device is found to be connected to the RS-232 interface, the error message in Figure 10 will be displayed.

Figure 10 Error message if no DK-LCMH-800A device has been recognised

In this case, confirm the message to make the program change into the demonstration mode. In this mode no commands are directed to RS-232 port. Then, check if all cables are properly connected to their corresponding ports.

It is also possible to select the COM port from the user dialog. This is shown in Figure 11 where the COM2 port is selected from the menu **'Options'→ 'Select Port'→'COM2'**. The currently used COM port is marked by a tick.

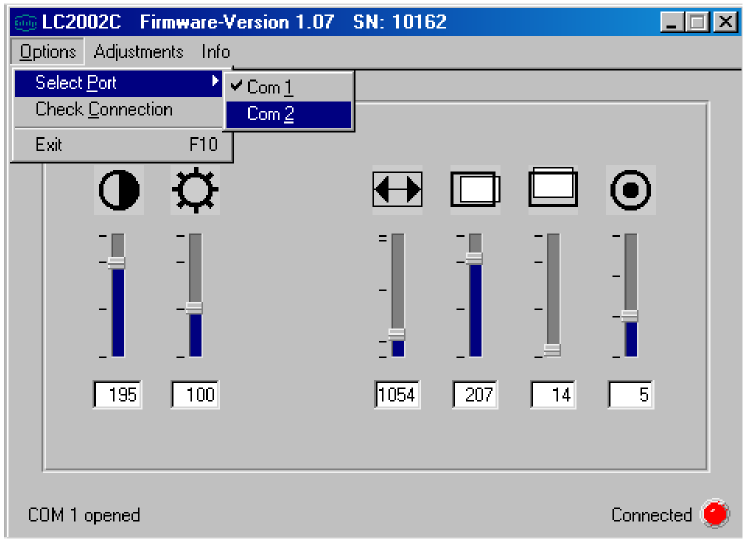


Figure 11 Selection of COM port.

If the selected port is still free, then the status message

'COM 2 opened'

is displayed in the status bar in the bottom left of the dialog. In case the selected COM port does not exist or is not free, the message in the status bar states

'COM 2 already in use or not available' .

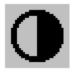
Now, if the selected COM port is free, select from the menu **'Options→Check Connection'** to establish the connection to the SLM. If the SLM is correctly connected as described in section 4.4, it is automatically identified and its configuration data are transmitted to the control program.

The user dialog displays the mostly used parameter controls in the field 'Contrast / Brightness / Geometry'.

4.5.4 Controls: Contrast, Brightness, Geometry

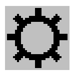
The field ‘Contrast / Brightness / Geometry’ is obtained by selection of ‘**Adjustments→Video’** from the menu and pushing the **F2** button.

The controls are



Contrast Control

This control can be used to modify the image contrast.



Brightness Control

This control can be used to modify the image brightness.

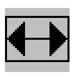
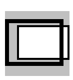


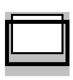
Image Width Control

This control can be used to modify the image width. Many technical applications require a very exact control of the image width. For this purpose a test image with a fine stripe pattern is used. If the image width is not adjusted exactly, a Moiré pattern results from the stripe pattern and the pixel structure of the LCD matrix. This Moiré pattern can be seen in the projected test image and vanishes when the image width is correctly adjusted.



Horizontal Image Position Control

This control can be used to modify the horizontal image position.



Vertical Image Position Control

This control can be used to modify the vertical image position.

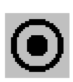


Image Sharpness Control

This control can be used to modify the image sharpness. Many technical applications require a very exact control of the image width. For this purpose a test image with a fine vertical stripe pattern and a bright-dark transition is recommended to be used. If the image sharpness is not exactly adjusted, shadow effects (‘ghosts’) can appear. However, if the adjustment is corrected the stripe pattern is rich in contrast and sharpness, and no ghost patterns appear.

4.5.5 Controls in the Field "Gamma Correction"

The ‘Gamma Correction’ function of the SLM is supposed to be used in advanced experiments, as it requires experiences to be used in an effective manner. The ‘Gamma Correction’ controls, shown in Figure 12, can be accessed by the menu option ‘**Adjustments→Gamma Control’** or by pushing the **F3** key. These controls influence the linearity of the transmission of image brightness signals. Within certain limits, the ‘Gamma Correction’ can be used to equalise non-linearities in the LCD´s transformation of electrical signals into optical transparency signals.

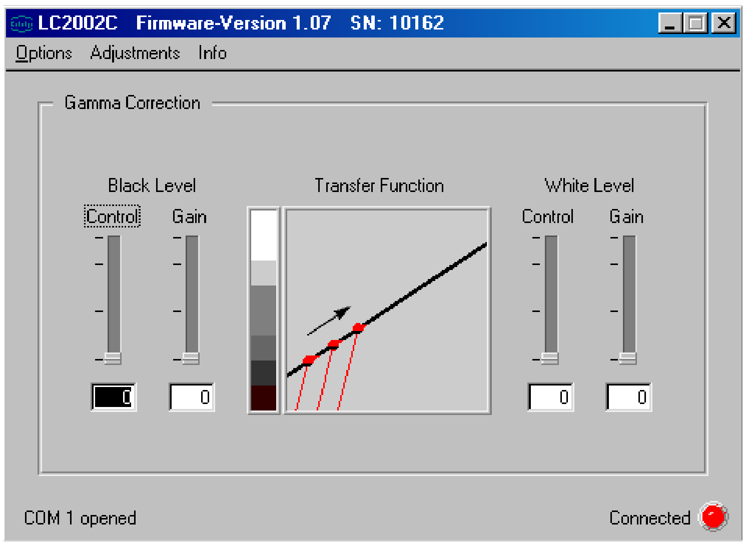


Figure 12 ‘Gamma Correction’ controls.

There are four different controls the resulting effect of which is depicted by the image of the transfer function in the centre. Depending on which control is selected the image of the transfer function changes respectively. The grey-scale is used to visualise which video signals, corresponding to grey levels and image location, are influenced by a control.

Black-Level Control

This control operates on the gamma correction of ‘darker’ image pixels. The control shifts the given correction entry-point onto a certain grey level. With respect to this point all ‘darker’ image pixels, and corresponding image locations, are gamma-corrected.

Black-Level Gain

This control specifies the intense of the correction effect on dark image pixels, i.e. the increase of the intense beyond the correction entry-point.

White-Level Control

This control operates on the gamma correction of ‘brighter’ image pixels. The control shifts the given correction entry-point onto a certain grey level. With respect to this point all ‘brighter’ image pixels, and corresponding image locations, are gamma-corrected.

White-Level Gain

This control specifies the intense of the correction effect on bright image pixels, i.e. the increase of the intense beyond the correction entry-point.

After first start-up of the control program all ‘gamma correction’ controls are set to zero, i.e., they have not effect. In order to use the gamma correction in a sensible manner suitable test images and optical instruments for measuring the LCD´s transmission properties are required.

4.5.6 Controls in Field "Screen Format"

The screen format controls, shown in Figure 13, can be used to modify the image resolution an orientation. They can accessed by the menu option ‘**Adjustments → Screen Format’**.

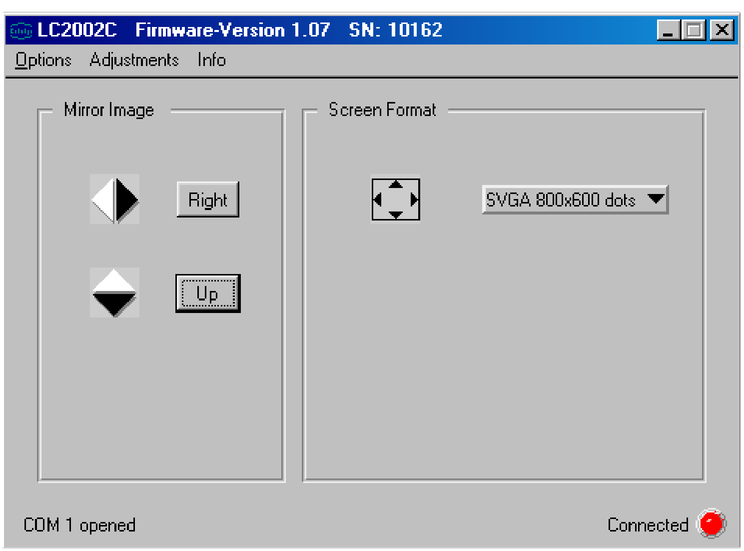
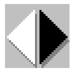
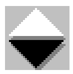


Figure 13 Image orientation and image format.

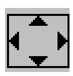
You can use the buttons on the left hand side to mirror the image on the LCD in both directions. This is helpful to make optical experiments more comfortable.



Right Button
Pushing this button mirrors the image horizontally.



Up Button
Pushing this button mirrors the image vertically.



Format Button
Pushing this button you can select the image format to be applied. Three standard image formats, **SVGA**, **VGA** and **PC-98** are offered for selection. The image is always displayed in a pixel-synchronised manner. That means, images of formats with less than 800 x 600 pixels are centric positioned and have a surrounding black frame.

4.5.7 Factory Defaults

At every time the driver's configuration memory can be reset to the delivery state. To do this, select '**Upload Factory Defaults'** from the '**Adjustments'** menu, shown in Figure 14.

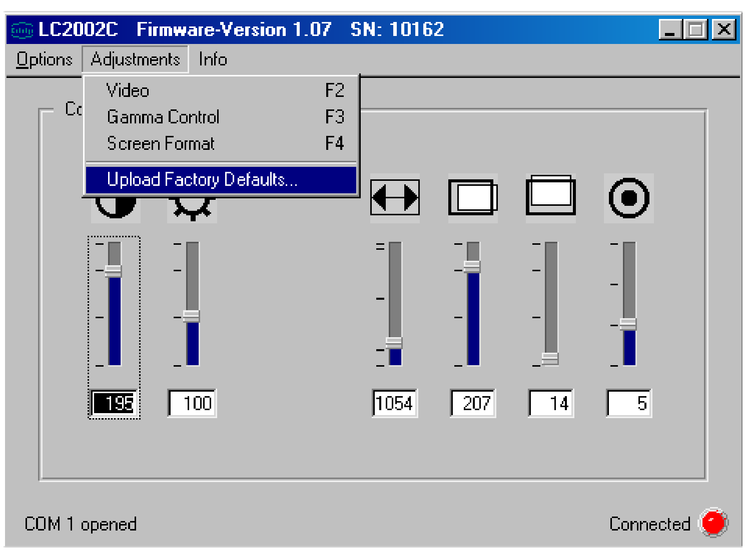


Figure 14 Upload Factory Default

As shown in Figure 15 a new user dialog appears. Just load the pre-selected *factory.ini*. This will reload the Factory Defaults.

The *lc2002.ini* is used for manufacturer's settings only and should not utilised by customers.

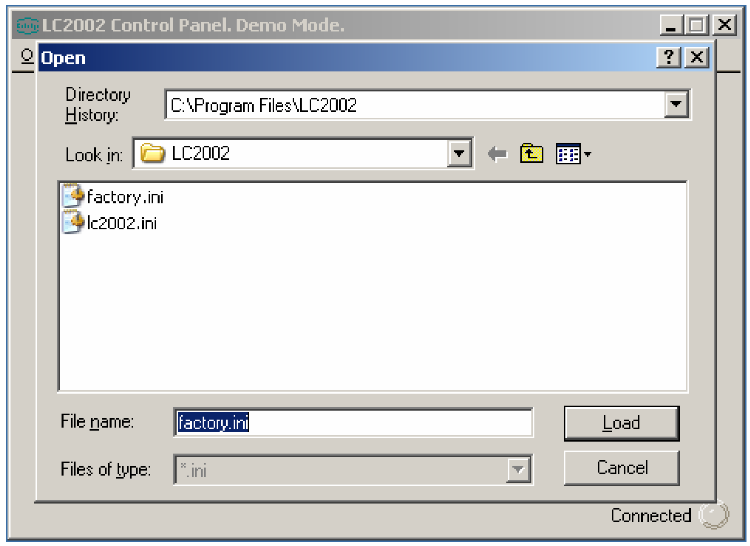


Figure 15 Factory Defaults Setting

Remarks: All adjustments effect the display immediately but need at least 10 seconds to be permanent.

4.6 RS-232 Commands

4.6.1 Command structure

The SLM control program uses RS-232 commands to perform its tasks on the LCD. In principle, these commands can be also send by another control device. This makes it possible to integrate the SLM in prototype systems where the control unit may be a different device than a PC. In the following we describe the RS-232 commands that are used to control the SLM.

The RS-232 commands are strings of ASCII symbols that have to end with an end symbol. An end symbol is used to separate a command from its subsequent one and trigger the LC2002 to decode and execute the command.

Specified end symbols are **Carriage Return** (0Dh), **Line Feed** (0Ah) and **semicolon** (3Bh).

For the commands there is no distinction between capital and small letters. Generally, blanks are not allowed in a command unless they are directly in front of an end symbol.

The SLM device has an „echo“ function that confirms each correctly decoded command. After successful decoding the string „**OK**“is sent by the SLM to its RS-232 interface. In case of a false command or an unsuccessful execution the SLM send an error code, e.g., „**ERR 3**“. The list and meaning of all error codes is given in section 4.7.

The echo function can be switched on and off. When the device is switched on, the echo function is automatically switched on as well.

In the following all available commands and their meaning are described. The commands are ended with <CR>, respectively. The response of the SLM to each command is written indent.

Remark: The symbol <CR> is obtained by pressing the enter button (↵) on the keyboard. So, do not use the symbols „C“ and „R“.

4.6.2 Request Commands (Requests)

Request commands always result in a response of the SLM. They are characterised by a question mark at the end of the command, followed by an end symbol.

4.6.2.1 Request the device ID number

IDN?<CR>

  LC2002A

4.6.2.2 Request the firmware version

VER?<CR>

  1.07

4.6.2.3 Request the configuration

```
CONF?<CR>
   4 1E BE 13  0  0  0  1  0  0  5 1C
  CC 77 FF A7  0  0  A  0  0 89  D 15
   F  A 3C  6
```

The response values shown here are examples and can vary with respect to the configuration of the device. The meaning of the bytes can be obtained from the following table. The bytes specify user-specific as well as device-internal configurations.

4.6.3 Configuration Commands (Configs)

Configuration commands consist of a command name and a parameter value that is separated from the name by a colon. The parameter value must be given as an integer.

Byte No.	Meaning	Internal symbol
0	Most significant byte PLL factor	
1	Least significant byte PLL factor	
2	HPOS, image position horizontal	
3	VPOS, image position vertical	
4	Internal configuration	HDN
5	SHP, pixel synchronicity of image playback	
6	Internal configuration	HCKP
7	Internal configuration	HSTP
8	Internal configuration	CLPP
9	Internal configuration	SHD
10	Internal configuration	SH
11	Internal configuration	MBK
12	MODE, image format switching	
13	DIR, e.g. scanning direction	
14	GCW, entry point gamma corrector white	
15	GCB, entry point gamma corrector black	
16	GGW, enhancement gamma corrector white	
17	GGB, enhancement gamma corrector black	

18	BRT, brightness (medium transparency	
19	CON, contrast	
20	Internal configuration	BLIM
21	Internal configuration	WLIM
22	Internal configuration	SBRT
23	Internal configuration	SID
24	Internal configuration	VCOM
25	Internal configuration	CENT
26	ID number, Most significant byte	
27	ID number, Least significant byte	

4.6.3.1 Image width

Command name	Parameter	
	min.	max.
PLLP	**848**	**2045**

Example:

PLLP:1054<CR>

OK

The parameter influences the pixel synchronicity of the image playback. For the image format SVGA (800 x 600 image pixels) usually 1054 is the correct value.

4.6.3.2 Horizontal image position

Command name	Parameter	
	min.	max.
HPOS	**0**	**255**

Example:

HPOS:207<CR>

OK

4.6.3.3 Vertical image position

Command name	Parameter	
	min.	max.
VPOS	**0**	**255**

Example:

VPOS:19<CR>

OK

4.6.3.4 Pixel phase (pixel synchronicity)

Command name	Parameter	
	min.	max.
SHP	**0**	**15**

Example:

SHP:1<CR>

OK

4.6.3.5 Image format

Command name	Parameter	Meaning
MODE	**204**	SVGA 800x600 (CCh)
	201	PC-98 640x400 (C9h)
	206	VGA 640x480 (CEh)

Example:

MODE:204<CR>

OK

Remark: When setting the image format using the MODE command, the pixel-synchronised playback is preserved. Image formats that that do not fill up the display are automatically centred and surrounded by a black frame.

4.6.3.6 Entry point of gamma correction white

Command name	Parameter	
	min.	max.
GCW	**0**	**255**

Example:

GCW:1<CR>

OK

4.6.3.7 Intense of gamma correction white

Command name	Parameter	
	min.	max.
GGW	**0**	**255**

Example:

GGW:1<CR>

OK

4.6.3.8 Entry point of gamma correction white

Command name	Parameter	
	min.	max.
GCB	**0**	**255**

Example:

GCB:1<CR>

OK

4.6.3.9 Intense of gamma correction black

Command name	Parameter	
	min.	max.
GGB	**0**	**255**

Example:

GGW:254<CR>

OK

4.6.3.10 Contrast

Command name	Parameter	
	min.	max.
CON	**0**	**255**

Example:

CON:196<CR>

OK

4.6.3.11 Brightness

Command name	Parameter	
	min.	max.
BRT	**0**	**255**

Example:

BRT:183<CR>

OK

4.6.4 Other Commands

4.6.4.1 Echo switching on/off

The command **ECHO:OFF**<CR> suppresses the mandatory response with **OK** on each correctly decoded command or error code messages. The command **ECHO:ON**<CR> can be used to switch the echo on again.

4.7 Error Messages

The meaning of error messages is given in the following list:

ERR 1	Overflow of the symbol-receiving buffer	RS-232 handshake does not work, internal or external error
ERR 2	Unexpected symbol in command (neither letter, digit, nor underscore)	Command incorrect
ERR 3	Unknown command	Command incorrect
ERR 4	Parameter of preceding command not allowed	Parameter incorrect
ERR 5	Unknown parameter	Parameter incorrect
ERR 6	Unexpected symbol in parameter (neither letter, digit, nor underscore)	Parameter incorrect
ERR 7	Digit was expected but a different symbol received	
ERR 8	Command did not end correctly; instead of end symbol another symbol was received	
ERR 9	Command parameter missing	
ERR 10	Internal error (EEPWR)	LC2002 defective
ERR 11	Internal error (EEPRD)	LC2002 defective
ERR 12	Internal error (DACWR)	LC2002 defective
ERR 13	Internal error (EPTWR)	LC2002 defective
ERR 14	Internal error (RESTORE)	LC2002 defective

4.8 Assembly Drawing

In order to assemble the SLM device on one side four drill-holes M2 are provided.

Caution: The assembly screws must not go deeper than 8mm into the box.

Figure 16 presents the SLM assembly drawing. The dimension values are given in mm.

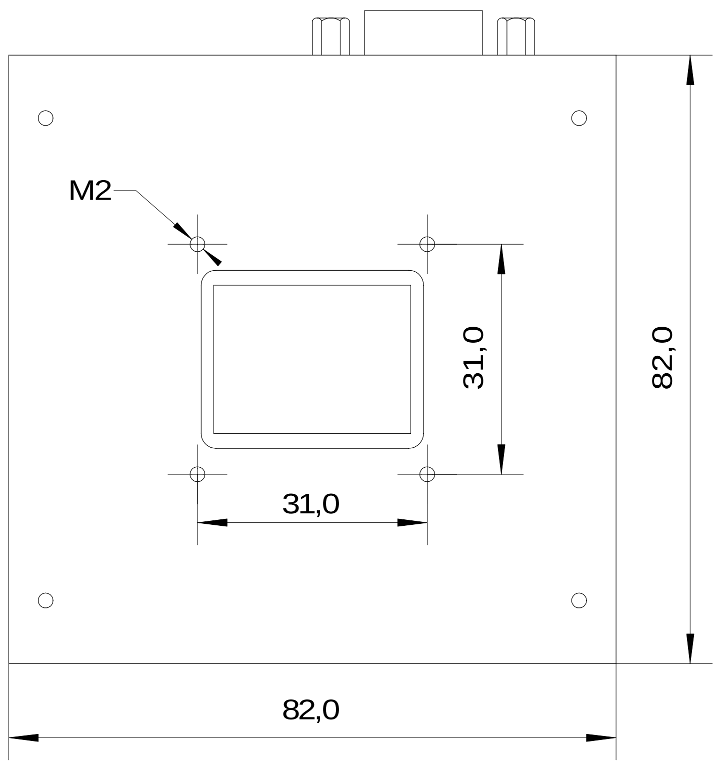


Figure 16 DK-LCMH-800A assembly drawing.

5 Laser Module

5.1 Technical data

Wavelength:	532 nm
Operating voltage:	5 V (DC)
Power input:	< 250 mA
Aperture:	15-20 mm
Output power:	1 mW
Beam diameter:	focus adjustable
Operating temperature:	15°C ~ 30°C
Laser class:	Class 2 laser with FDA registration

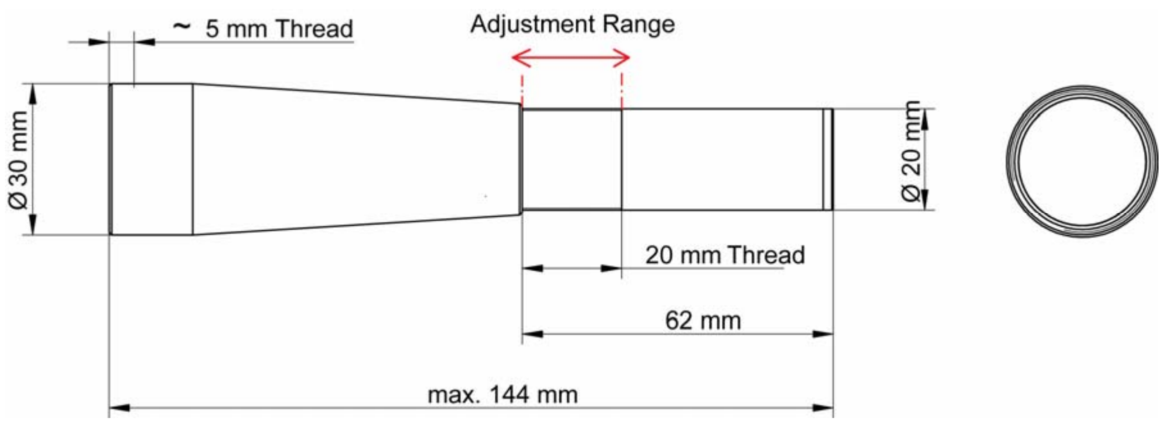


Figure 17 Geometrical size of the provided laser module.

The provided laser is a class 2 laser module.

Class 2 laser products can emit 1 mW of accessible laser emission. A class 2 laser can cause eye damage if a person deliberately forces himself to stare into the beam despite the strong natural reflex to avert his gaze.

Do not look into the laser beam or on any reflections!

Some basic guidelines for Laser Safety:

1. Never look into the beam of any laser.
2. Be aware of the hazards posed by your laser.
3. Aim the laser well away from others.
4. Use an appropriate target.
5. Do not allow the beam to inadvertently reflect from metal or glass surfaces.
6. Use protective eyewear.

Certain preventive measurements have to be done before the usage of the provided laser. Inform yourself about applicable regulations with laser products of the class 2 and consider these by application of the laser.

NEWPORT assumes no liability for any damage caused by the laser.

6 Application Software Manual

6.1 Installation

Start “installer.exe” and follow the instructions of the installation menu. Please accept the license agreement before choosing the required program components. Mark all checkboxes to install the complete version. Choose the destination folder as well as the start menu folder. Click “Install” to start the installation procedure and click finally “Close” to finish the installation.

6.2 Starting the software

Start the program using the start menu entry “Application Software” .

6.3 Opening an Image

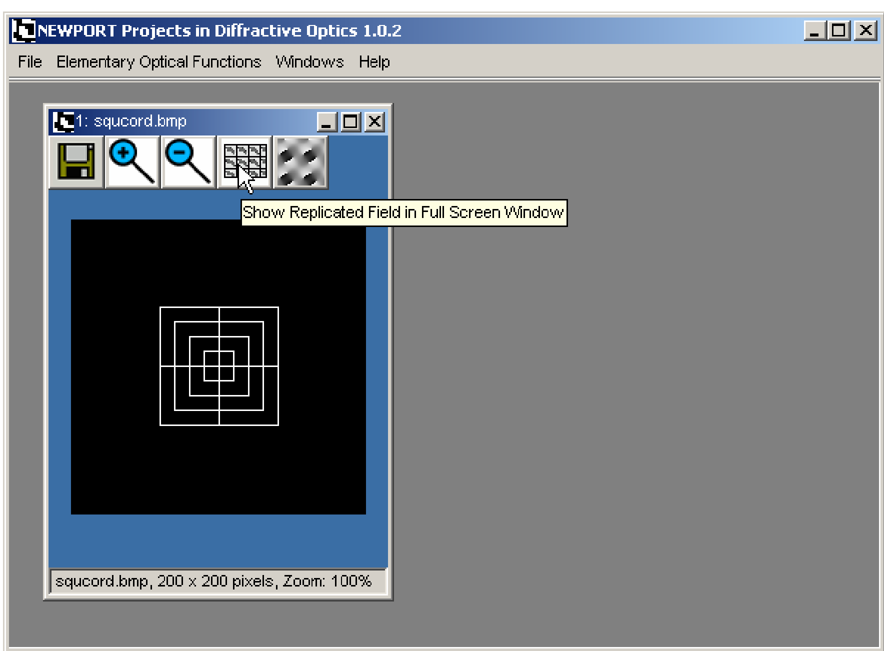


Figure 18 Image window of the application software

Choose from the *File* menu the point „Open Image File“. Possible image formats that can be opened are JPG, BMP, PNG, PGM. The loaded picture will be transformed to a 256 grey scale picture. In order to display all 256 gray scales a monitor setting of minimum 16 Mio. colours (24bit) is required.

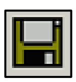
The image window will have the following buttons:

‘Zoom In’ Button

Pushing this button will perform a fast ‘zoom in’ operation on the image.

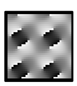
‘Zoom Out’ Button

Pushing this button will perform a fast ‘zoom out’ operation on the image.



‘Save’ Button

Pushing this button will open a dialog in which a file name can be specified for saving the image in one of the supported formats (PNG or BMP Image, ASCII textfile matrix of integer values representing the grayscale values).

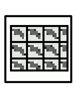


‘Compute DOE’ Button

This button will only appear if the displayed image (taking zoom operations into account) is no larger than 200x200 pixels.

Pushing this button will start a computation of a Computer-generated hologram (CGH) phase function for the signal displayed in the image window. Please see section 6.5 for more information.

The result of the computation will be displayed in a full-screen window where it can be manipulated as explained in section 6.4.



‘Replicate to full screen size’ Button

Pushing this button will open a full-screen window in which the shown image is used as a single tile which is replicated until the whole screen is covered.

6.4 Full-Screen window functions

This full-screen image will display a task-bar immediately after its appearance. This taskbar will disappear but emerge again when the position of the mouse pointer of the PC is moved towards the right edge of the window.

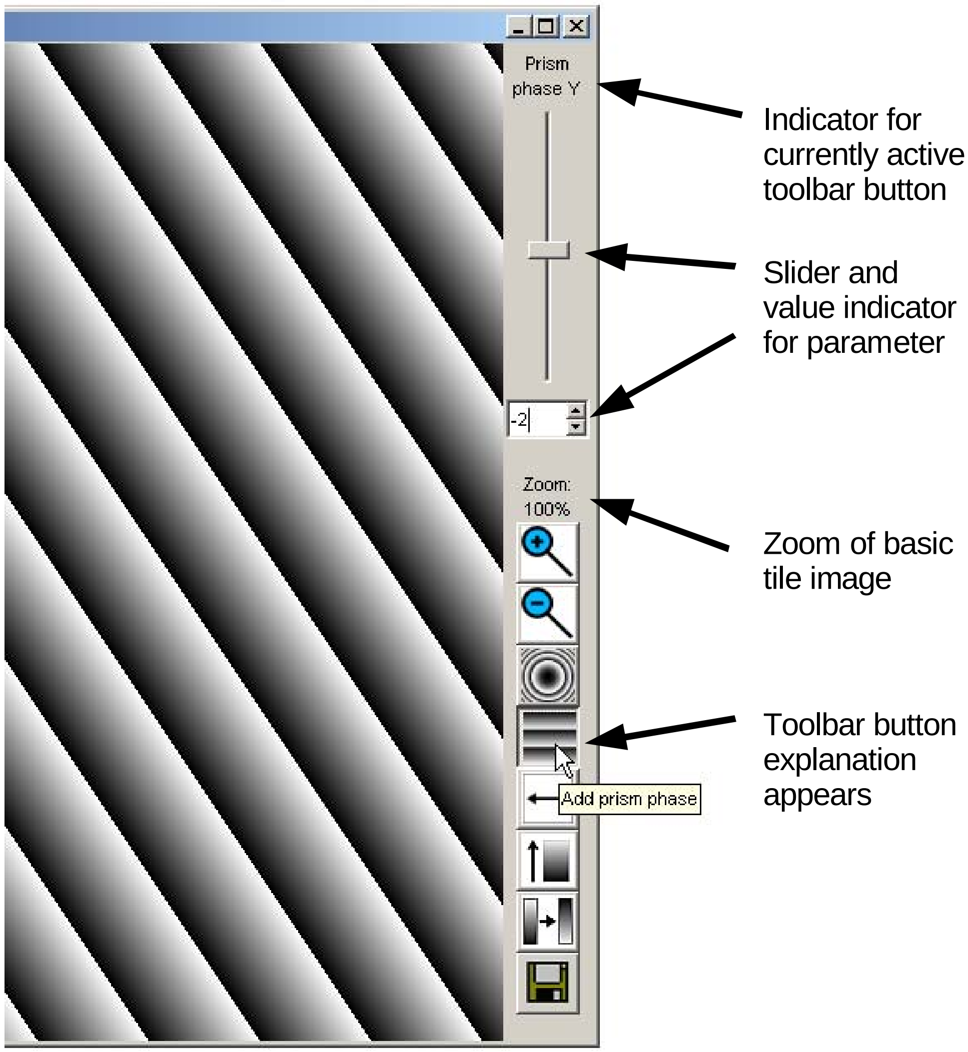


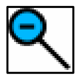
Figure 19 Toolbar of the full-screen window

The functions accessibly by the taskbar buttons offer the possibility to manipulate the ‘basic tile’ image by superposition of signals that represent optical elements (lens, prisms), by zooming and translating the image and by changing its grayscale values.

The taskbar will have the following buttons:

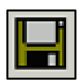
'Zoom In' Button

Pushing this button will perform a fast 'zoom in' operation on the image that is the basic tile of the displayed image composition. Note that the zoom does **not** change superimposed optical functions, it will only be applied to the 'basic tile'.



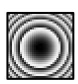
'Zoom Out' Button

Pushing this button will perform a fast 'zoom out' operation on the image that is the basic tile of the displayed image composition. Note that the zoom does **not** change superimposed optical functions, it will only be applied to the 'basic tile'.



'Save' Button

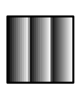
Pushing this button will open a dialog in which a file name can be specified for saving the full-screen image image in one of the supported formats (PNG or BMP Image, ASCII textfile matrix of integer values representing the grayscale values). The image will be saved as displayed, i.e. including effects by superposition of optical functions etc.



'Superimpose lens' Button

This button will superimpose the displayed image with a XY grayscale signal that resembles the optical phase function of a lens. This means that the focal plane of the light source incident on the LC Display is changed when such function is superimposed.

The focussing/defocussing strength of the optical lens function can be changed by adjusting the value given on the task bar by moving the slider or by directly entering a value.

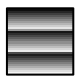


'Superimpose prism in *X* direction' Button

Pushing this button will superimpose the displayed image with a grayscale signal that resembles the optical phase function of a prism in X direction. This means that all diffraction angles created by the signal on the LC Display are changed when such function is superimposed.

The strength of the optical prism function can be changed by adjusting the value given on the task bar by moving the slider or by directly entering a value.

In order to switch to a prism superposition in Y direction, click on the button again.

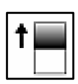


'Superimpose prism in *Y* direction' Button

Pushing this button will superimpose the displayed image with a grayscale signal that resembles the optical phase function of a prism in Y direction. This means that all diffraction angles created by the signal on the LC Display are changed when such function is superimposed.

The strength of the optical prism function can be changed by adjusting the value given on the task bar by moving the slider or by directly entering a value.

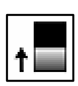
In order to switch back to a prism superposition in X direction, click on the button again.



'Adjust Graylevel 1' Button

This button will only be accessible if the 'basic tile' image is binary, i.e. consists of only two different graylevel values.

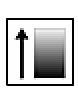
Pushing this button will than permit a change of one of the two grayscale values by moving the slider or by directly entering a value.



'Adjust Graylevel 2' Button

This button will only be accessible if the 'basic tile' image is binary, i.e. consists of only two different graylevel values.

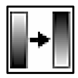
Pushing this button will than permit a change of the second of the two grayscale values by moving the slider or by directly entering a value.



'Adjust Gamma curve' Button

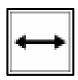
This button will be accessible if either the 'basic tile' image is binary and a lens and/or prism functions are superimposed, or if the 'basic tile' image is not binary.

Pushing this button will than permit a simultaneous change of all grayscale values by moving the slider or by directly entering a value. The gamma curve is linear if the entered value is 0, and can be changed to concave and convex nonlinear curves by entering positive and negative values, respectively.



'Invert displayed bitmap' Button

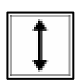
This toggle button will invert the grayscale value of the displayed full-screen image. This includes any superimposed lens and or prism functions. This inversion can be reversed simply by clicking the button again, which will cause the button to be no longer toggled.



'Translate in *X* direction' Button

Pushing this button will move the shown image with respect to the X direction. This function can be used to align the displayed functions with respect to the incident beam. Note that the translation does change the 'basic tile' **and** any superimposed optical functions (if present) simultaneously.

In order to switch to a translation in Y direction, click on the button again.



'Translate in *Y* direction' Button

Pushing this button will move the shown image with respect to the X direction. This function can be used to align the displayed functions with respect to the incident beam. Note that the translation does change the 'basic tile' **and** any superimposed optical functions (if present) simultaneously.

In order to switch back to a translation in X direction, click on the button again.

6.5 Calculating a diffractive optical element (DOE)

To compute a DOE, the signal image size needs to be smaller than 200x200 pixel. DOE computation for larger pictures is not supported by this software.

Load the image as described in section 6.3. If the image is not larger than 200x200 pixel the **'Compute DOE' Button** will appear with the option to calculate a diffractive optical element (DOE) for this image. Press this button to start the iterative Fourier Transformation Algorithm (IFTA). Note that the process of computing may take a while, depending strongly on the signal picture size.

When the process is finished, two windows will appear. They show the DOE phase function (in a full-screen window) and the calculated intensity of the diffraction pattern. This calculated intensity should look quite similar to the image in the original window, if the DOE calculation algorithm has properly converged.

6.6 Creating elementary optical functions

All optical functions from the menu point *Elementary Optical Functions* appear in a new windows after input of the required parameters. Depending on the optical function, binary or multilevel, the task bar of the full-screen window will be slightly different (compare section 6.4).

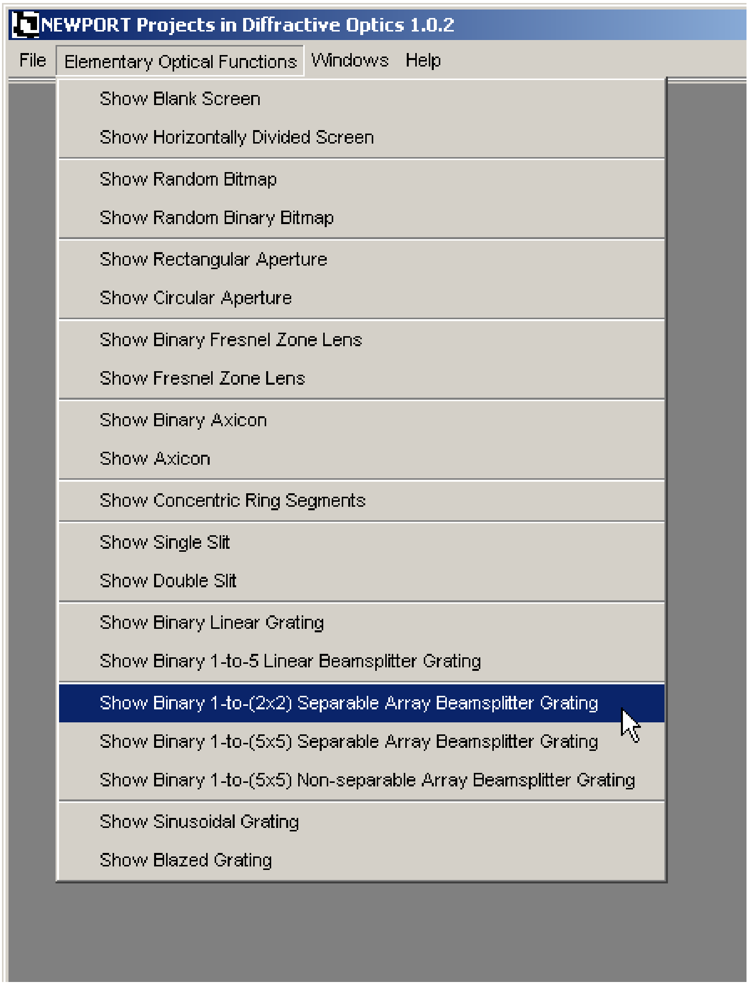


Figure 20 Menu entries for optical functions

6.6.1 Blank Screen

(binary)

With this function you can create a homogeneous gray level screen. If the mouse pointer is moved to the right edge of the window a taskbar for changing the addressed gray level occurs.

6.6.2 Horizontally Divided Screen

(**binary**)

With this function you will create a horizontally divided screen, constitng of two homogeneous graylevel partial screens. If the mouse pointer is moved to the right right edge of the window a taskbar for changing the addressed gray levels occurs.

6.6.3 Random Bitmap

(**multilevel**)

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

6.6.4 Random Binary Bitmap

(**binary**)

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.

6.6.5 Rectangular Aperture

(**binary**)

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.

6.6.6 Circular Aperture
(**binary**)

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.

6.6.7 Binary Fresnel Zone Lens
(**binary**)

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

6.6.8 Fresnel Zone Lens
(**multilevel**)

Use this function to create a 256-level Fresnel Zone Lens graylevel image representation. In the dialogue field the lens 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.

6.6.9 Binary Axicon
(**binary**)

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

6.6.10 Axicon
(**multilevel**)

Use this function to create a 256-level Axicon graylevel image representation. In the dialogue 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.

6.6.11 Concentric ring segments
(**binary**)

Use this function to create binary images consisting of concentric ring segments. In the dialogue 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).

6.6.12 Single Slit and Double Slit
(binary)

To create a single slit choose the point „Show Single Slit“ from the menu point *Elementary Optical 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 *Elementary Optical Functions.* Moreover the slit distance can also be defined. This refers to the gap between both slits.

6.6.13 Linear Gratings and Crossed Linear gratings
(binary)

Choose from the menu *Elementary Optical Functions* 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 horizontal and/or vertical. Check both boxes to overlap a horizontal with a vertical grating.

6.6.14 Linear and Array Beamsplitter Gratings
(binary)

Choose from the menu Elementary Optical Functions one of the menu items

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

- Show Binary Array 1-to-(5x5) Non-separable Array Beamsplitter Grating (Grating period 26x26 Pixels)

to obtain a full-screen window 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 DOEs.

6.6.15 Sinusoidal Grating (multilevel)

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

6.6.16 Blazed Grating (multilevel)

Choose from the menu point *Elementary Optical Functions* „Show Blazed Grating“ to create a blazed grating. The size of the grating period can be specified by the number of pixels.

6.7 The ‘Window’ Menu

The Menu ‘Windows’ contains the usual options for tiling, cascading and closing windows that are opened inside the main window.

When fullscreen windows are open outside the main window, they can be closed via a separate menu point ‘Close all windows outside the main window’. Of course the menu item ‘Close all windows inside the main window’ does not affect full-screen windows outside and vice versa.

7 Tutorial – Theoretical Part

Five experiments have been chosen which demonstrate the wide range of physical phenomena, which can be investigated experimentally with this educational kit.

These are e.g. the optical set-up of a projector, properties of polarized light, optical properties of liquid crystals, the modulation of phase, amplitude and polarization of light fields, the diffraction of light at dynamically changing structures, Diffractive Optical Elements (DOE's), Spatial frequency filtering and interferometry (phase shifter).

Thus the device is suitable for introductory and advanced laboratory classes in physics and engineering study courses.

7.1 Preliminary remarks

The diffraction of light at dynamically adjustable optical elements as represented by the LC cells of a spatial light modulator can be described by the transmission through the LC material, which is characterized by its electrooptical properties, and the following pattern formation due to propagation for the diffracted wave. Diffractive optical elements (DOE's) are applied more and more in modern optical instruments. The optical function is caused by the diffraction and interference of light in contrast to refractive optical components.

The usage of diffraction and interference requires structures in the dimension of the optical wavelength. These structures became available in the context of modern methods of Nano-technology. Lithographical production technologies and replication processes have made it possible that DOE's can be produced in mass production. Thus diffractive optical elements, which act as lenses, prisms, or beam-splitters to create images or writings as diffraction patterns, are easier to produce and more compact than corresponding conventional elements, if they exist at all. A well known example are DOE's, which can be mounted on laser pointers to create arrows, crosses and other patterns. Also, diffractive optical beam splitters can create beams with the same intensity in a geometrical grid, for example to measure objectives and telescope mirrors faster and more precisely compared to the possibility with one beam or with mechanical scan devices.

In the tutorial a liquid crystal modulator will be used as a spatial light modulator to create diffractive optical structures, for exploration of dynamical diffraction structures as well as the investigation of the functionality and the physical properties of the device itself. Liquid crystal displays (LCD's) with pixel sizes significantly smaller than 100 µm are used nowadays in digital clocks, digital thermometers, pocket calculators and video- and data projectors. Due to the low cost, robustness, compactness and the advantage of electrical addressing with low power consumption LCD's are superior to other technologies. They feature an even wider spectrum of applications than the mentioned and open further fascinating possibilities in the frame of photonics, as a key technology of the 21st century.

Main component of the kit is a spatial light modulator based on a translucent LCD. Five experiments (see section 8) with questions show the diversity of topics, that can be experimentally investigated. Hence the experiments are qualified for introductory courses and advanced laboratory in scientific classes depending on the chosen questions.

7.2 Introduction to liquid crystal physics

Liquid crystals (LCs) are a phase of matter where the molecule order is between the crystalline solid state and the liquid state. The LCs differ from ordinary liquids due to long range orders of their basic particles (i.e. molecules) which are typical for crystals. As a result they usually show anisotropy of certain properties, including dielectric and optical anisotropies. At the same time they show typical flow behavior of liquids and do not have stable positioning of single molecules.

There are different types of liquid crystals, among which are *nematic* and *smectic* liquid crystals. Nematic liquid crystals show a characteristic linear alignment of the molecules, they have an orientational order but a random distribution of the molecule centers. Smectic liquid crystals additionally form layers, and these layers have a different linear orientation directions. Therefore smectic liquid crystals have an orientational *and* a translational order.

For usage in LCD's, liquid crystals are arranged in spatially separated cells with carefully chosen dimensions. The optical properties of such cell can be manipulated by application of an external electric field which changes the orientation of the molecules in a reversible way. Due to the long range order of the molecules and the overall regular orientation, a single LCD element features voltage-dependent birefringent properties.

The LC cells have boundaries which are needed to firstly separate the cell and secondly to accommodate the wires needed for adressing each cell with an independent voltage value. Because the cells are arranged in a regular two-dimensional array, the cell boundaries act as a two-dimensional grating and produce a corresponding diffraction effect.

7.2.1 Twisted nematic LC cell

The following discussion will focus on LCD based on *twisted nematic* liquid crystals. In the cells of such LCDs, the bottom and the top cover have alignment structures for the molecules which are typically perpendicular to each other. As a result of the long range order of the LC, the molecules form a helix structure, which means that the angle of the molecular axis changes along the optical path of light propagating through the LC cell.

The helix structure of twisted nematic crystals can be used to change the polarization status of incident light. When the polarization of the light is parallel to the molecules of the cell at the entrance facet, the polarization follows the twist of the molecule axis. Therefore the light leaves the LC cell with a polarization that is *perpendicular* to the incident polarization.

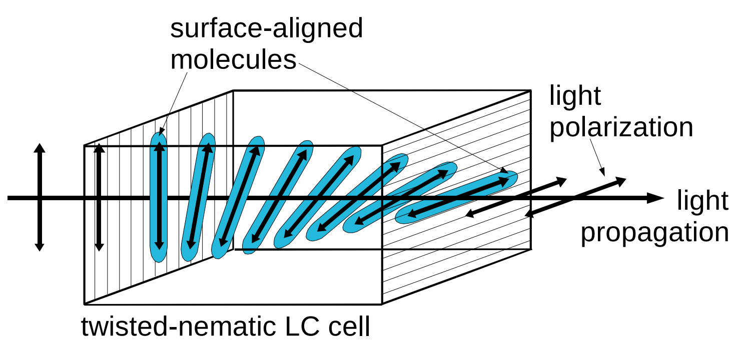


Figure 21 Polarization-guided light transmission

In order to realize a dynamic optical element, a voltage is applied to the LC cell. This voltage causes changes of the molecular orientation, as is illustrated in Figure 22 for three voltages V_A, V_B, V_C . Additionally to the twist caused by the alignment layers (present already at V_A=0), the molecules experience a voltage-dependent tilt if the voltage is higher than a certain threshold (V_B>V_{thr}). With increasing voltage ($V_C \gg V_{thr}$), only some molecules close to the cell surface are still influenced by the alignment layers, but the majority of molecules in the center of the cell will get aligned parallel to the electic field direction.

If the helix arrangement of the LC cell is disturbed by the external voltage, the guidance of the light gets less effective and eventually ceases to happen at all, so that the light leaves the cell with unchanged linear polarization.

It is straightforward to combine such switchable element with a polarizer (referred to as analyzer) to obtain a ‘light valve’ for incident polarized light. For unpolarized light sources, it is only necessary to place a second polarizer in front of the LC cell to obtain the same functionality. To gain a more detailed insight, it is necessary to review the polarization of light fields.

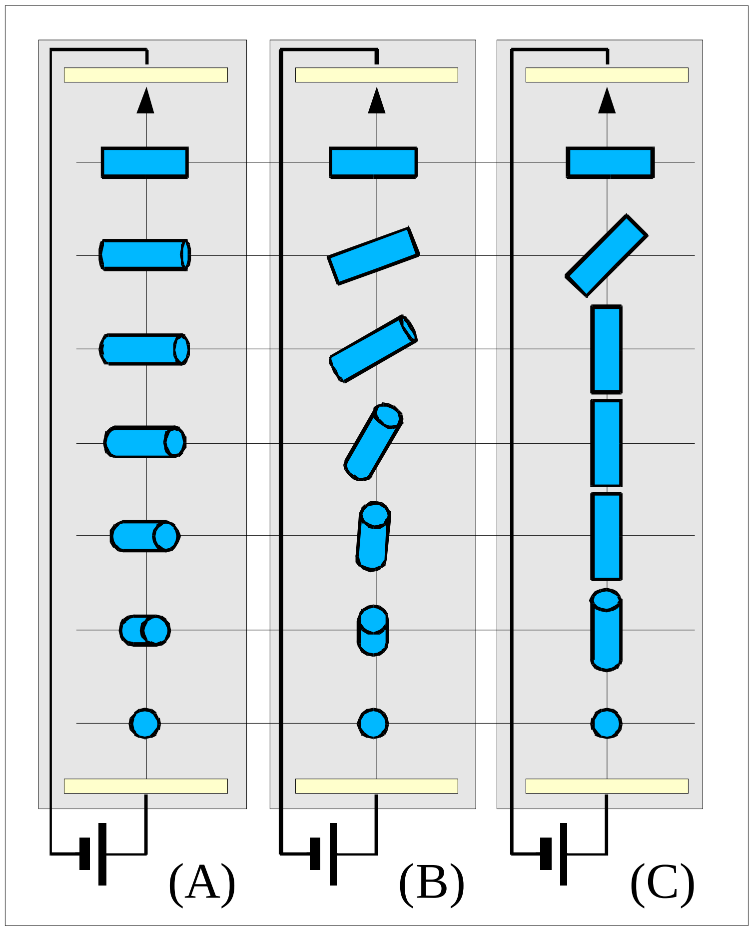


Figure 22 LC cells with different applied voltages

$V_A=0$ with untilted molecules, $V_B>V_{thr}$ with tilted, partially aligned molecules, $V_C \gg V_{thr}$ with aligned molecules in the central region of the cell.

7.2.2 Polarization of light

The polarization of light is defined by orientation of its field amplitude vector. While *unpolarized* light consists of contributions of all the different possible directions of the field amplitude vectors, polarized light can be characterized by either a single field component (*linear polarization*) or by a superposition of field components in two directions.

The state of polarization of a light field propagating into the z direction can be expressed by a Jones vector representation

$$\mathbf{V} = \begin{pmatrix} V_x \\ V_y \end{pmatrix}$$

where V_x and V_y are complex numbers which tell about the relative amplitudes and phases of the two basic linear polarizations. It is convenient to normalize this vector **V** so that $|\mathbf{V}|=1$ and the field strength (i.a. amplitude) is expressed in a separate variable.

A linear polarization is given by vectors of the form

$$\mathbf{V} = \begin{pmatrix} \cos\alpha \\ \sin\alpha \end{pmatrix}$$

which tells that the polarization components in x and y direction do not have a mutual phase delay. Arbitrary states of polarization are referred to as *elliptic polarization* and are given by vectors

$$\mathbf{V} = \begin{pmatrix} \cos\alpha \ \ \exp(\mathrm{i}\Gamma/2) \\ \sin\alpha \ \ \exp(-\mathrm{i}\Gamma/2) \end{pmatrix}$$

where Γ denotes the phase delay between the polarization components.

The expression of polarization states can be used to analyse the propagation of light in anisotropic media like solid state matter crystals or liquid crystals.

7.2.3 Propagation in anisotroptic media

Materials which on the atomic level can be decribed as a regular arrangement of particles in a well-defined lattice are referred to as *crystals*. If the material is not isotropic, this highly ordered state of matter nevertheless leads to the existance of *optical axes* in the material. Liquid crystals can be described by the same model due to the translational order of the molecules.

Light propagation parallel to an optical axis is characterized by two indices of refraction n_1 and n_2, which are usually different, and are valid for two different states of polarization. This effect is referred to as *birefringence*. Here the discussion shall be limited to *uniaxial* crystals, in which the polarization states are referred to as *ordinary (o)* and *extraordinary (eo)* polarization with refractive indices n_e and n_o.

The impact on a transmitting light wave can be expressed by matrices which convert the Jones vector of the incident light (see previous section) to a new Jones vector. The different refractive indices introduce a mutual phase delay between the two partials fields corresponding to the two linear polarizations which are propagating with the velocities c/n_o and c/n_{eo} .

The transmitted light after a distance d (given by the thickness of the material) is therefore given by

$$\mathbf{V'} = \begin{pmatrix} V'_o \\ V'_{eo} \end{pmatrix} = W_d \begin{pmatrix} V_o \\ V_{eo} \end{pmatrix}$$

where

$$W_d = \begin{pmatrix} \exp(-\mathrm{i}\frac{n_o \omega}{c} d) & 0 \\ 0 & \exp(-\mathrm{i}\frac{n_{eo} \omega}{c} d) \end{pmatrix}$$

An optical component with parallel entrance and exit facets made from an uniaxial birefringent material with its optical axis perpendicular to the direction of light propagation is referred to as a *waveplate*.

7.2.4 Waveplates

The matrix W_d of a waveplate can be expressed in the form

$$W_d = \exp(i\phi)\begin{pmatrix} \exp\left(-\mathrm{i}\frac{\Gamma}{2}\right) & 0 \\ 0 & \exp\left(\mathrm{i}\frac{\Gamma}{2}\right) \end{pmatrix}$$

where the quantities Γ and ϕ are given by

$$\Gamma = (n_o - n_{eo})\frac{2\pi}{\lambda}d$$

and

$$\phi = \tfrac{1}{2}(n_o + n_{eo})\frac{2\pi}{\lambda}d$$

A *half-wave plate* is a particular example of a waveplate with a thickness

$$d = \frac{\lambda}{2(n_o - n_{eo})}$$

so that the mutual phase delay is given by Γ=π. This means that the one polarization direction is delayed by an optical path of half the wavelength with respect to the other polarization. The Jones matrix of a half-wave plate is obtained as

$$W_{\mathrm{HWP}} = \begin{pmatrix} -\mathrm{i} & 0 \\ 0 & \mathrm{i} \end{pmatrix}$$

If the incident light is linearly polarized with an angle α of the polarization vector to the ordinary polarization direction, its Jones vector can be expressed by means of a rotation matrix $R(\alpha)$ as

$$\mathbf{V} = \begin{pmatrix} V_x \\ V_y \end{pmatrix} = R(\alpha)\begin{pmatrix} V_o \\ V_{eo} \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix}\begin{pmatrix} V_o \\ V_{eo} \end{pmatrix}$$

The matrix of a waveplate in the *xy* coordinate system is then given by

$$W_{\mathrm{WP}} = R(-\alpha)W_d R(\alpha)$$

For linearly polarized incident light with an angle of α=45° of the polarization with respect to the ordinary polarization, the half-wave plate (with the thickness d as given above) will modify the incident light as given by the matrix

$$W_{\mathrm{HWP}}^{(45°)} = \begin{pmatrix} 0 & -\mathrm{i} \\ -\mathrm{i} & 0 \end{pmatrix}$$

This means that light polarized parallel to the x direction, which is assumed to have an angle of 45° with respect to the direction of ordinary polarization, will have its Jones vector changed from

$$\mathbf{V} = \begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

to

$$\mathbf{V}' = \begin{pmatrix} 0 & -\mathrm{i} \\ -\mathrm{i} & 0 \end{pmatrix}\begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ -\mathrm{i} \end{pmatrix} = \exp(-\mathrm{i}\pi)\begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

which corresponds to a rotation of the polarization direction by an angle of 90°.

7.2.5 Amplitude and phase modulation by a TN LC cell

A twisted nematic LC cell can be described as a succession of a high number of very thin waveplates which change the orientation of their optical axis according to the change of the direction of the molecular axis. The total Jones matrix of the cell is then obtained by matrix multiplication of all the matrices of the assumed thin waveplates as

$$W_{\text{TN-LC}} = R(\beta)\begin{pmatrix} \cos\chi - \mathrm{i}\left(\frac{\Gamma}{2\chi}\right)\sin\chi & \left(\frac{\beta}{\chi}\right)\sin\chi \\ -\left(\frac{\beta}{\chi}\right)\sin\chi & \cos\chi + \mathrm{i}\left(\frac{\Gamma}{2\chi}\right)\sin\chi \end{pmatrix}$$

where is β is the total twist angle of the molecules throughout the cell and the quantity χ is given by

$$\chi = \sqrt{\beta^2 + (\Gamma / 2)^2}$$

Even though the assumptions which are necessary for the derivation of the Jones matrix given above require some approximations, the resulting theory is sufficient for understanding the main optical properties of the cells.

If a LC cell satisfies $\beta \ll (\Gamma/2)$, which is the case for thick cells, the Jones matrix can be significantly simplified and permits an intuitive interpretation:

$$W_{\text{TN-LC}} \approx R(\beta) \begin{pmatrix} \exp\left(-\mathrm{i}\frac{\Gamma}{2}\right) & 0 \\ 0 & \exp\left(\mathrm{i}\frac{\Gamma}{2}\right) \end{pmatrix}$$

If the incident light is polarized parallel to the *x*- or *y* axis the polarization axis will be rotated by the twist angle β between the direction of the alignment layers, as implied by the intuitive explanation illustrated in Figure 21.

If a voltage is applied to the cell, the molecules tend to align parallel to the electric field. Thereby the anisotropy of the liquid crystal is reduced because the angle between the direction of light propagation and the molecular axes gets smaller until eventually both direction are parallel and the liquid crystal appears to be isotropic (see Figure 22).

In terms of the analysis done here, the difference $\Delta n = n_o - n_{eo}$ gets smaller and therefore for sufficiently high voltages one gets $\Gamma \rightarrow 0$. For this situation the Jones matrix can be approximated as

$$W_{\text{TN-LC}} \approx R(\beta) \begin{pmatrix} \cos\beta & \sin\beta \\ -\sin\beta & \cos\beta \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

which means that for a strong voltage applied to the LC cell the light polarization is not changed.

The analysis of the intermediate cases in which the molecules are no more aligned in the helix structure but not yet parallel to the field can be done with the matrix $W_{\text{TN-LC}}$ without one of the two approximations given above. With such analysis, the voltage-dependent optical properties can be obtained. As a result, incident light with linear polarization leaves the cell with an elliptic state of polarization.

However, the voltages applied to the LC cell are not directly accessible in the SLM device contained in this kit. The voltages applied to the cells can be controlled via a costumized electronic drive board. This drive board receives information on what voltage should be applied to the cell as graylevel values of the signal created by the VGA output of a graphics adapter of a common PC.

The voltages that are applied to the cells of the LC display are in a range that permits an almost continuous transition between the 'helix state' which rotates the incident polarization to the 'isotropic state' in which the polarization remains unchanged. It is obvious that by inserting an analyser behind the display the LC display one can achieve an ***amplitude modulation*** of a transmitting polarized light wave.

By examination of the Jones matrices $W_{\text{TN-LC}}$ one can also deduce that the phase of the light passing the analyser is changed dependent on the voltage-dependent parameter Γ. If the SLM is illuminated by a a coherent light sources (e.g. a laser) various diffraction effects that are based on this ***phase modulation*** can be observed. For the experiments it is important to note that the incident polarization for obtaining a comparatively strong phase modulation with only weak amplitude modulation is *not* parallel or perpendicular to the alignment layers.

For the experiments dealing with diffraction effects that can be done with the SLM, it is sufficient to understand that *mutual voltage-dependent phase shifts* between the waves passing through individual LC cells can be obtained. This means that diffractive optical elements can be realized with the help of LCD's. In the same way, optical elements like Fresnel lenses, gratings and beam splitters are switchable by means of electronics.

7.3 Introduction to scalar diffraction theory

In the following some keywords will be discussed, which are important especially for the experiments described in sections 8.2 and 8.3.

7.3.1 Diffractive optical element (DOE)

For a designated diffraction pattern a diffraction structure can be calculated as a solution of the inverse diffraction problem and manufactured with a suitable method. The result is a DOE, which reconstructs by illumination the desired picture in the far field. Within certain limits lenses can be replaced by DOE's. DOE's can also act as beam splitters and beam shapers or more advanced optical elements like multi-focus lenses. A problem not yet satisfactorily solved is the elimination of the 0^{th} order as well as the diffused light from other diffraction orders. However, DOE's exhibit severe chromatic aberrations and due to the fabrication issues, they usually will diffract light into the 0^{th} order, may this be desired or not. Moreover the light efficiency is usually limited.

(Keywords: Solution of the diffraction integral, Dammann-Gitter)

7.3.2 Computer generated hologram (CGH)

Diffractive optical elements are sometimes referred to as *Computer Generated Holograms*. This term was introduced because it is possible to compute the interference pattern created by an object with a reference wave and to fabricate an optical element from the obtained data *without* an interferometric recording technique which is used for conventional holograms.

In such recording technique, the diffuse light wave reflected by an object interferes with a reference wave and the appearing interference wave field is recorded in a photosensitive material or detector, in the majority of cases a photo film. If the object wave is created by a three-dimensional object with an irregular shape, the interference pattern leads to a structure of a complex diffraction grating in the recording material.

A requirement for recording such a hologram is the ability for interference (referred to as *coherence*) of object and reference wave field. If the hologram is illuminated with a reference wave, it behaves like a diffraction grating and a wave field proportional to the object wave appears in one particular diffraction order. Thus optical waves are created that permit the three-dimensional observation of the recorded object.

It is possible to compute the diffraction patterns created by object and reference waves leading to the name Computer generated Hologram for objects that create the same spatial wave modulation by means of a microstructure of a swichable light modulator. For such computation, the intensity and phase must be calculated and accordingly added for every object and hologram point. Such computation is very demanding and therefore CGHs which reproduce three-dimensional objects will not be the subject of the experiments in this kit.

(keywords: off-axis, on-axis set-up, thin and thick holograms, coherence, CGH)

7.3.3 Kirchhoff diffraction integral

A plane wave

$$E^i = E_0 e^{\mathrm{i}(kz-\omega t)}$$

propagates in z- direction and is incident onto an object at z=0. Here ω denotes the frequency of the light and

$$k = \frac{2\pi}{\lambda}$$

is the wavenumber, which is inversely proportional to the wavelength of the light λ.

This object is assumed to be thin so that it can be described by a complex transmission function $\tau(x,y)$. The transmitted field is

$$E^t(x,y,z=0) = \tau(x,y)E^i(x,y,z=0)$$

The resulting light propagation can be described by applications of *Huygens' principle*. According to this principle, a spherical wave is created by each point (x,y) at z=0 of the diffraction structure. All spherical waves must be added (i.e. integrated), to obtain the field amplitude from a point (x',y',z) behind the diffracting object.

This description contains also waves in negative z-direction, which are not observed. In the Fresnel-Kirchhoff diffraction theory a direction factor is therefore introduced, which excludes the waves in negative z – direction. The resultant field is obtained as

$$E(x',y',z) = \frac{e^{\mathrm{i}kz}}{\mathrm{i}\lambda z}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E^t(x,y,0)e^{\mathrm{i}k((x'-x)^2+(y'-y)^2)}(1+\cos(\vec{e}_z\vec{r}))dxdy \quad .$$

In general this equation is too complicated to solve diffraction problems, but for many relevant situations suitable approximations can be used.

7.3.4 Fresnel approximation

The spatial dimension of the diffracting object should be small, compared to the distance between object and diffraction pattern (paraxial approximation). In this case

$$\cos(\vec{e}_z\vec{r}) \approx 1$$

and the distance can be written as

As the amplitude is less sensitive than the phase, within the denominator the

$$r \approx z + \frac{(x'-x)^2}{2z} + \frac{(y'-y)^2}{2z}$$

approximation with $r \approx z$ can be used.

From this we have

$$E(x', y', z) = A(x', y', z)\mathcal{F}[E^t(x, y, 0)e^{\frac{i\pi}{\lambda z}(x^2+y^2)}](\nu_x, \nu_y)$$

This equation describes the convolution of the transmitted field with a impulse response of the structure. Multiplying the quadratic expression in the exponent results in

$$E(x', y', z) = \frac{e^{ikz}}{i\lambda z}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E^t(x, y, 0)e^{\frac{ik}{2z}\left((x'-x)^2+(y'-y)^2\right)}dxdy$$

with

$$A(x', y', z) = \frac{e^{ikz}}{i\lambda z}e^{\frac{ik}{2z}\left(x'^2+y'^2\right)}$$

and

$$\nu_x = \frac{x'}{\lambda z}, \quad \nu_y = \frac{y'}{\lambda z}$$

which are referred to as spatial *frequencies* analog to the frequencies of the Fourier transformation (above written as $\mathcal{F}$) of temporal signals.

The Fresnel diffraction covers the common situation in which the observation plane is at an finite distance behind the object.

7.3.5 Fraunhofer approximation

The Fraunhofer diffraction is a special case (and analytically a simplification) of the Fresnel diffraction, which is valid for large distances. The Fraunhofer approximation applies if

$$\left(x^2 + y^2\right)\frac{\pi}{\lambda} << \mathrm{z}$$

is satisfied for (x,y) and (x',y') . In this case

$$E(x',y',z) = A(x',y',z)\mathcal{F}[E(x,y,0)](\nu_x,\nu_y)$$

with

$$A(x',y',z) = \frac{\exp(\mathrm{i}kz)}{\mathrm{i}\lambda z}$$

The far field in the Fraunhofer approximation is given by the Fourier transformation of the field directly behind the diffracting object. The spatial frequencies of the diffracting structure create waves, which propagate with the angles

$$\alpha \approx \tan\alpha = \frac{x'}{z} = \lambda\nu_x$$

and

$$\beta \approx \tan\beta = \frac{y'}{z} = \lambda\nu_y$$

to the optical axis, respectively.

Thus, the far-field diffraction pattern of a spatial distribution of phase or amplitude transmission values (given by a graylevel bitmap signal) of the LCD can be calculated with a Fourier transformation. With the help of a lens the far field of the light propagation can be obtained in the focal plane of the lens (see section 7.3.7).

This means that in optics propagation of the light field realizes a Fourier transformation in a natural way simply by propagation. The Fourier transformation of a two-dimensional object can be observed directly in terms of the spatial frequencies, which can be associated with diffraction orders. These spatial frequencies can be manipulated and filtered. The *Fourier filtering* is a passive parallel image processing performed at the speed of light (see section 7.3.8).

A rather well-known application of the Fourier Transformation (FT, written in formulas as $\mathcal{F}$) is its use to compute the frequency spectrum of a time-dependent signal. In *Fourier optics*, the signal is dependent on a spatial coordinate rather than on a time coordinate.

Moreover, the spatial optical field is two-dimensional rather than one-dimensional. In other words, in optics the corresponding variables are the positions (x,y) and the so called spatial frequencies (ν_x, ν_y), which are linked by the two-dimensional FT (and its inverse transformation).

$$F(\nu_x, \nu_y) = \mathcal{F}[f(x,y)](\nu_x, \nu_y)$$
$$= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)\exp(-2\pi i(\nu_x x + \nu_y y))\, dxdy$$

7.3.6 Diffraction at spatially periodic objects

Spatially periodic objects, which are often referred to as *gratings*, have a far field diffraction pattern that is discrete in contrast to the contiguous diffraction pattern produced by nonperiodic objects. The discreteness of the spectrum of spatial frequencies contained in a periodic object leads to maxima in the far field diffraction, which are observed at well-defined diffraction angles and referred to as *diffraction orders*.

For simplicity of the discussion, only objects with a periodicity in one spatial dimension will be treated here. If the *grating period* (i.e. the distance after which the diffraction object repeats its structure) is denoted by the symbol g, the diffraction angles φ_m can be obtained from the grating equation

$$g(\sin(\theta + \varphi_m) - \sin\theta) = m\lambda$$

where the incidence angle is denoted as θ, and from the simpler form

$$g \sin\varphi_m = m\lambda$$

which is valid for waves incident perpendicular to the grating.

As a result, the Fourier transformation integral is simplified to a Fourier series with coefficients A_m, describing the field amplitudes of the diffracted waves, given by

$$A_m = \int_0^g \tau(x)\exp(-2\pi i \frac{mx}{g})\, dx$$

In this formula, the diffracting object is described by a spatially resolved complex-valued transmission function $\tau(x)$ which summarizes changes of amplitude and phase of the transmitted wave as a function of the position. The given integral does not take the second spatial coordinate into account, so that it is only valid for objects with a constant transmission function with respect to the y direction (*linear gratings*).

Such transmission function can be sinusoidal, as in the case of a grating obtained by holographic recording of a two-wave-interference. The transmission function may in this example take any value within a certain range.

In contrast, the values of the transmission function obtained when addressing a LCD are limited to 256 values due to the transmission of the signal as a VGA grayscale value. The most simple example is of course a signal that consists of only two different transmission values (*binary elements*).

For a binary linear phase-only grating, the structure can be described by the *transition points* x_k, at which the grating changes its transmission value from $\tau_1=\exp(\mathrm{i}\Phi_1)$ to $\tau_2=\exp(\mathrm{i}\Phi_2)$ or vice versa. The diffraction orders obtained from such gratings are given by

$$A_m = \frac{\sin(\Delta\phi/2)}{\pi m} \sum_{k=1}^{N} (-1)^k \exp(-2\pi \mathrm{i} \frac{m x_k}{g})$$

for all diffraction orders with $m\neq 0$, where $\Delta\Phi=\Phi_1-\Phi_2$ denotes the phase difference between the two transmission values. For simple examples, the diffraction pattern can be easily analysed with this formula.

7.3.7 Fourier transformation with a lens

The diffraction image has to be changed with a lens from an infinite to a finite-dimensional distance. The transmission of the field through the lens results in a position depending phase shift and can be described by multiplication with the following lens transmission function

$$\tau_{lens} = e^{-\mathrm{i}\frac{k}{2f}\left(x^2+y^2\right)}$$

The description of the diffraction occurs because of the finite distance in the Fresnel approximation. Here Δz is the distance behind the lens, were the Fourier transform of the light is observed.

$$E(x,y,\Delta z) = \frac{e^{\mathrm{i}kz}}{\mathrm{i}\lambda\Delta z} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E(x',y',0)\, e^{-\mathrm{i}\frac{k}{2f}\left(x'^2+y'^2\right)} e^{\frac{\mathrm{i}k}{2\Delta z}\left((x'-x)^2+(y'-y)^2\right)} dx'\,dy'$$

The exponents of the exponential function are quite similar. By using $\Delta z=f$ (Shift of the observation point to the focal plane of the lens) both can be simplified.

$$E(x,y,f)=\frac{e^{\mathrm{i}kf}}{\mathrm{i}\lambda f}e^{\mathrm{i}\frac{k}{2f}\left(x^2+y^2\right)}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}E(x',y',0)e^{\frac{\mathrm{i}k}{f}\left((x'x)+(y'y)\right)}dx'dy'$$
$$=\frac{e^{\mathrm{i}kf}}{\mathrm{i}\lambda f}e^{\mathrm{i}\frac{k}{2f}\left(x^2+y^2\right)}\mathcal{F}\left[E\right]\left(\frac{x}{\lambda f},\frac{y}{\lambda f}\right).$$

In the focus plane of a lens a field distribution is obtained, which is similar to the Fourier transformation of the lens multiplied with a phase factor. The corresponding intensity distribution is proportional to the intensity distribution obtained from Fourier transformation of the incident field, which describes its far field diffraction pattern.

7.3.8 Spatial frequency filtering

For an object placed in front of a lens having a distance d to it, the light propagation in front of the lens can be simulated using the Fresnel approximation of the Kirchhoff diffraction integral. The result shows that the light in the focal plane is only changed by a phase factor dependent on d, and for the special case $d = f$ the field in the focus plane is equivalent to the Fourier transformation of the field in the object plane (apart from a factor, which does not depend on x and y).

The calculation yields

$$E(x,y,f)=\frac{e^{\mathrm{i}k2f}}{\mathrm{i}\lambda f}e^{\mathrm{i}\frac{k}{2f}\left(x^2+y^2\right)}\mathcal{F}\left[E\right]\left(\frac{x}{\lambda f},\frac{y}{\lambda f}\right)\quad .$$

The spatial frequency spectrum can be manipulated in the focus plane (Transformation and inverse e.g. with 4f set-up.)

8 Tutorial - Experimental Part

The first part deals with a white-light set-up, in order to demonstrate phenomena like light polarization and basic properties of LC-Displays along with the necessary basic geometrical optics. In the second part basic experiments relating to diffraction and interference of light will be performed. Part number three deals with diffractive optical elements (DOE's) and computer generated holograms. Basic examples of Spatial frequency filtering in the Fourier plane are described in the fourth part. Finally a Mach-Zehnder-Interferometer set-up is used in the fifth part. With this interferometer the phase shift generated by the liquid crystals can be measured. This set-up requires additional high quality optical components, which are not included in the basic set.

8.1 Projection and display characterisation

8.1.1 Objective

Implementation of the modulator as a projection device: identification of the mode of operation; creation of amplitude modulation by rotation of the polarization axis of the light as a function of the applied voltage; identification of parameters like: pixel size, length of molecule axis, maximum phase shift; illuminating and imaging optical path.

8.1.2 Required elements

Modulator; halogen lamp with condenser (e.g. 2 bi-convex field lens f~130 to 150 mm); 2 rotary polarisers; objective lens (e.g. simple lens / iris diaphragm and/or an achromatic lens f~80 to 130 mm) with high aperture; projection screen; colour filter (red, blue); LDR photo resistor and Ohmmeter; optional: iris diaphragm

8.1.3 Set-up

Optical path for illumination: adjust the halogen lamp in such a way, that it emits parallel (or slightly convergent) light. The parallel light beam should illuminate the display completely. Make sure, that no scattered light bypasses the display (preferably use a rectangular aperture, e.g. e made of black cardboard, in front of the display).

Place and adjust polarisers (1^{st}: polariser, 2^{nd}: analyser) in front of and behind the display in a way that the polarisation axes are 90° rotated to each other. Address a test image onto the display.

Optical path for imaging: Place an objective lens (e.g. simple lens / iris diaphragm and/or achromatic lens) behind the display and adjust it in such a way, that a focused and enlarged image appears on the screen.

For measuring the parameters, the photo resistor has to be placed in the focal plane of the lens. The total intensity will be measured this way. A neutral density filter may be necessary to reduce the intensity. In fact a photo resistor measures indirectly proportional but compared to a photo diode, the linear characteristic is more than 3 orders of magnitude higher.

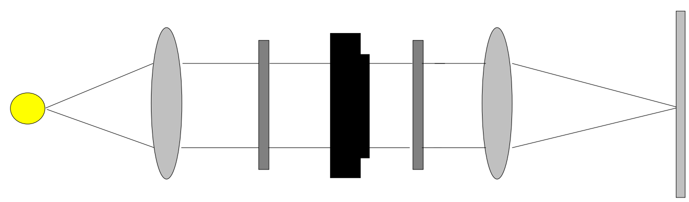


Figure 23 Set-up for Projection and display characterisation

8.1.4 Suggested tasks:

1. Measure the polarisation characteristics of the light source. (Lamp with condenser, rotary analyser, objective lens, photo resistor)
2. Create linearly polarised light (lamp with condenser, polariser) and measure the angle distribution of the intensity with the 2^{nd} polariser (analyser). Present the results in polar coordinates. Which mathematical function describes the results? Make sure to verify the linearity of the detector.
3. Arrange the projection set-up with illuminating and imaging beam path. A classical photo slide is helpful and will be replaced later on by the "polariser / LC-Display / analyser" . As objective lens try a normal lens with different iris diaphragm apertures and the

achromatic lens. Discuss the influence of the aperture regarding to the depth of focus, brightness, influence of lens aberrations as well as the way to avoid aberrations.

4. Set up the projection arrangement with the LC- display and optimise the contrast. Therefore a picture has to be addressed to the monitor and the LC – display. The picture should be imaged onto the projection screen. Rotate the polarisers, which are perpendicular to each other, in adequate angle steps (ca. 10°) and measure the changing contrast quantitatively.
5. What do you observe, if one or both polarisers are removed? What do you observe with both polarisers at best contrast, if the polarisation position of the analyser is rotated by 45°/90°/180°? Discuss the results. Use a grating with grating period 400 to create an image half white half black. This image should be used to measure the contrast with the LDR – photo resistor.
6. Determine the orientation of the molecule axis of the addressed liquid crystal pixel from the results.
7. Determine the pixel size from the geometrical reproduction scale unit and a e.g. rectangular image, what is defined by a specific number of pixels on the monitor / display (use geometrical optics for calculation). The magnification of the lens system should be known.
8. Investigate the dependency of pixel voltage and twist on the polarization direction. Change the voltage by using different homogeneous full screen gray level images (use the supplied software) and measure the intensity with the LDR–photo resistor in the focus of the objective lens. Use a projection set-up with the optimal contrast. The results should be presented graphically. In order to compare the results, a linear dependency should be theoretically assumed (if necessary consider an offset). In this connection the calculated progression of the translucent intensity as a function of the addressed voltage should be presented in the same diagram (a detailed calculation has to be given). Discuss the differences. Figure out a function in which the polarisation angle on a scale from 0° to 90° can be varied. This is possible by an appropriate choice of a polynomial (an appropriate order/level must be chosen).
9. Repeat the experiment from point 7 using colour filters for red and blue light.
10. For the case of maximum polarisation change the ellipticity of the transmitted light (originally linear) should be estimated by measuring the Stokes parameter (Set-up as used in point 7; measure the intensities at analyser positions 0°, 45°, 90°, -45°).

11. Discuss and summarize the function of an LC-display as a polarisation modifier. Does it have influence on the amplitude or phase of light? How can you get an amplitude modulation of light?
12. If experiment 4 "Mach-Zehnder interferometer" has already been accomplished, please try to figure out how a separate phase and amplitude modulation with two modulators can be realised.

8.1.5 Keywords for preparation

Polarization of light; possibility to create polarized light; optical elements for changing the polarization state; contrast, stokes parameter; birefringence; connection between polarisation state and angular momentum of photons; mathematical description of a plane wave; liquid crystal; functionality of an LC display; pixel size; fill factor; functionality of a photo resistor and characteristic line; geometrical optic; Köhler illumination; field lens; lens aberration; aperture

8.2 Generation and analysis of dynamic diffractive structures

8.2.1 Objective

Implementation of the modulator to create different primary diffractive structures, which base on phase modulation of light. Descriptive comparison of direct changes of the diffractive pattern by changing the projected diffractive structure. Comparison of the diffraction behaviour of complement structures. (Babinet's theorem). Measurement of the progression of diffraction intensity and definition of diffraction efficiency of selected structures. Superposition of simple diffraction pattern as a base for diffractive optical elements.

8.2.2 Required elements

Modulator; laser with beam expander (can be used as a collimator and also to replace the fourier lens by creating a slightly convergent beam to get a focal plane); fourier lens (optional); one or two lenses for example (+100 or +50, +80 or +100, -50 mm) to magnify the diffractive structure; iris diaphragm (to eliminate the higher diffraction orders which appear due to the pixel structure of the display); two polarisers; projection screen; digital camera or LDR-photo resistor with aperture plate 1mm or Si- photo diode on a relocatable carriage for documentation and measurement of the diffraction structures

8.2.3 Set-up

The expanded and collimated laser beam (if no Fourier lens for focusing is used, the laser module should be set slightly convergent to get a focus) illuminates the display in a homogenous manner. Determine the focal plane with the help of an adjustment paper. The image, which is created in this plane (far field diffraction pattern), should be projected precisely. It may be enlarged with the help of further lenses.

Higher diffraction orders can be eliminated with the iris diaphragm. Turn the linearly polarized laser until an optimal diffraction pattern can be seen. A digital camera can be mounted on a tripod to take pictures from the screen. A LDR-photo resistor on a carrier can measure the diffraction pattern as well. The whole set-up can reach a length of 2 to 2,5 m. Hence, a folded set-up with the help of mirrors is recommended.

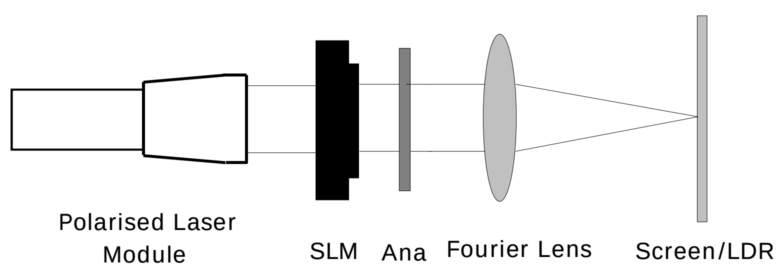


Figure 24 Set-up for investigation of dynamic diffractive structures

8.2.4 Suggested tasks

1. Preparative tasks on the computer: Create bitmap structures of a diffraction structure in a desktop resolution of 800x600 pixel with the software.
   - 3 gratings with different grating period (lines + grooves) in black and white (geometrical identical - Ronchi grating) stripes (use the “grating functions” of the software)
   - an inverted grating
   - a 90° rotated grating
   - three different basic slits (choose low slit width)
   - three double slit arrangements
   - 3 circular apertures and the corresponding inverse structures

- 1 cross grating and the inverse structure
- 1 grating in 5 versions, in which the primary black areas are filled with different grey levels
- rectangular aperture

2. Record the projected diffraction patterns e.g. with a digital camera and interpret them.
3. Determine the intensity distribution of the obtained diffraction pattern and the diffraction efficiency for the gratings and the slits (I_0 is the total intensity of the central order which passes the iris diaphragm for a non addressed modulator). The intensity distribution measurement can be done with a LDR photo resistor or from digital camera pictures. Compare the results with the theoretical expectations.
4. Determine the ratio of the grating period (relative to the grating with the highest grating period) of the diffraction pattern and the bitmap structures.
5. Determine the diffraction efficiency of the diffraction structures for all graylevel gratings. Diffraction efficiency is defined as the ratio between the intensities of the desired orders (e.g. the +1st and –1st orders) and the intensities of the incident light.
6. Discuss the results of the inverted structures.
7. Discuss the diffraction structures of the circles with respect to possible constructions of a diffractive lens (Fresnel zone lens).
8. Vary the grating period of a grating with the application software. Explain your observations.
9. Place a horizontal grating on the left side and a vertical grating on the right side of the monitor. Explain the observed diffraction pattern.
10. If the beam expander of the laser module is used as a collimator, discuss the function of the Fourier lens directly behind the modulator. If the beam expander of the laser module is used instead of the Fourier lens, discuss why the lens function may be added to the beam *before* transmitting the display.
11. Analyse the diffraction efficiency of phase- and amplitude gratings: Place crossed polarisers in front and behind the modulator (at maximum contrast – compare with experiment 8.1). Choose as diffraction structure a symmetric black-white Ronchi-grating. Measure the diffraction pattern with a camera or with the LDR-photo resistor (aperture plate) or a Si- photo diode. Remove both polarisers, measure once more and compare the results. Discuss the differences in terms of the various ways of the diffraction pattern development.
12. Measure the sinc-function of the diffraction structure without iris diaphragm and with non-addressed display.

8.2.5 Keywords for preparation

Liquid crystal, functionality of a LC-display, plane wave, coherence, diffraction, interferometry, diffraction on slit / double slit / grating / circle aperture, mathematic description in the far field, slit function, grating function, Fraunhofer- and Fresnel-diffraction, Babinet's theorem, Fourier transformation, resolution

8.2.6 Addition

If there are more laser with different wavelengths available, diffraction pattern of different wavelengths can be analysed. The possible contrast is depending on the wavelength.

8.3 Diffractive optical elements (DOE)

8.3.1 Objective

Creation of diffractive optical elements with the spatial light modulator, observation of diffraction patterns in the far field, symmetry considerations for diffraction patterns, superposition of different diffractive optical elements.

8.3.2 Required elements

Modulator; laser with beam expander (can be used as a collimator and also to replace the Fourier lens by creating a slightly convergent beam to get a focal plane); (Fourier-) lens f=300-400 mm (optional); two lenses (for example +100 and –50 mm) for the enlargement of the diffractive structure in a telescope arrangement (optional); projection screen; digital camera; optional: one polarizer.

8.3.3 Set-up

The expanded parallel laser beam illuminates the display homogenously. A lens with large focal length should be placed closely behind the display. Define the focal plane of the lens with the help of an adjustment paper. The light pattern, which is observed in this plane, corresponds to the far field of light propagation.

Higher diffraction orders can be eliminated with the iris diaphragm. A digital camera can be mounted on a tripod to take pictures from the screen.

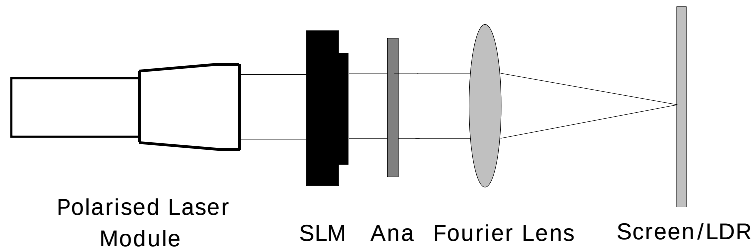


Figure 25 Set-up for "Diffractive optical elements" experiment

8.3.4 Suggested tasks

1. Address one of the provided DOE-images (preferably "grid" or "coord") onto the screen / display and observe the far field diffraction pattern. Record this pattern with a camera or make a hand drawing showing the essential features of your observations. Determine the minimum distance for a far field observation and give an explanation of this value. What do you observe in the near field?

   Advice 1: For the analysis of the phase-DOE, no polarisers are required. Consider the linear polarisation of the laser. The display effects and turns the polarisation plane even in a non-addressed state. Therefore the polarisation axis of the laser should be adjusted by rotating the laser in order to obtain a bright and clear diffraction pattern.

   Advice 2: Display all images in full screen, because the edges of "windows", "buttons" and "task-bars" have an influence on the light field which may distort the desired far field pattern.

2. Open binary images representing linear beamsplitters and array generators. Optimize the observable diffraction pattern by adjusting the contrast. This can be done by changing the grayscale values using the corresponding sliders. Note down at which grayscale values the best diffraction pattern is observed.

3. Observe the diffraction patterns in the far field

   a. of the provided 5x5 binary *separable* array beam-splitter DOE image

b. of the provided 5x5 binary *non-separable* array beam-splitter DOE image

Note down and explain your observations, especially concerning the symmetry properties of the diffracted light pattern.

4. Observe the diffraction patterns in the far field

   a. of the provided 2x2 binary array beam-splitter DOE image

   b. of a checkerboard bitmap with a grating period of 18 pixels (i.e. 9 pixels line and 9 pixels groove)

   c. of checkerboard bitmaps with the same grating period, but uneven duty cycles (e.g. 12 pixels line and 6 pixels groove, 13 pixels line and 5 pixels groove)

   Why are certain diffraction orders missing for some of the DOEs ?

   Hint: the images are separable, i.e. the transmission function $\tau(x,y)$ of the LCD can be written as a product $\tau(x,y)=\tau_1(x)\tau_2(y)$. The diffraction pattern in each direction x and y can be understood from the Fourier series expansion of the diffraction pattern as a function to the transition function (see section 7.3.6)

5. Change the scale of an image representing a DOE. To do this, magnify or shrink the image using the zoom buttons of the application software. Discuss the results.

6. Cover the image representing the DOE on the screen or just on the display to half or ¾ size with a blacked out area. Observe each time the light pattern in the far field. Compare them regarding the contrast and speckles and discuss the results.

7. Place two different images representing DOEs on the screen next to each other, so that both of them are illuminated by the laser beam transmitting the LCD. Discuss the light pattern observed in the far field.

8. Compute a image representing a DOE using an asymmetric image as desired far field light pattern (use e.g. the file “newportlogo”). In a full-screen window created from the computed DOE image, invert the DOE using the provided toolbar button. Explain your observations. What happens to the phase function created by the LCD when the grayscale image is inverted ?

9. Superimpose a DOE with a lens with the application software. Create different superpositions using different lens strengths and determine the plane of the best observation of the diffraction pattern as a function of the lens strength. Explain the result.

10. Create a bitmap consisting of several black and white circles. This should be addressed with the following shapes onto the display:

a. concentric full circles
b. positive and negative concentric half circles
c. positive and negative concentric quarter circles

Evaluate the diffraction patterns in the far field. Note down your observations.

11. Use the function of the software to create a binary Fresnel zone plate. The radius of the smallest ring can be defined to change the focal length.

    a. Try and check the “lens effect” with different radii of the smallest ring.

    b. Determine the focal length of different binary Fresnel zone lenses – experimentally as well as theoretically. Compare the results.

    c. Calculate the pixel size of the display from the focal lengths measured for different smallest radii of the zone lenses. If experiment 8.1 “Projection and display characterisation” has already been accomplished, compare the obtained pixel sizes.

12. Use binary DOEs contained in the ‘elementary optical functions’ of the application software to evaluate which symmetry the diffraction patterns have. Calculate a DOE image for a high-contrast, asymmetric picture of your choice with the application software.

    Does the diffraction pattern you have obtained follow the symmetry of the diffraction patterns of binary elements ? If not, why can multilevel DOEs produce diffraction patterns with different properties ?

13. Acquire information of how computer generated holograms of a complex structure are created.

14. If you have done the projection experiment figure out how to get separated phase and amplitude modulation with two SLMs.

8.4 Spatial frequency filtering

8.4.1 Objective

Projection set-up, spatial filtering in Fourier plane, high- low- pass filter, filtering of structures

8.4.2 Required elements

Modulator, laser with beam expander, (Fourier-) lens f=300-400 mm, Spatial filter diaphragms: Iris-diaphragm, rectangle diaphragm (two razor blades), negative hole diaphragm (middle size pinhead), projection screen, digital camera, polarizer

8.4.3 Set-up

The expanded and collimated laser beam illuminates the display homogenously. The linear polarisation of the laser has to be adjusted in that way that the addressed image will be displayed with optimal contrast and brightness. Use a (Fourier) lens with a long focal length for projection. A focused and enlarged projection without other lenses can be created. Define the focal plane of the lens with the help of an adjustment paper. The Fourier image in that plane can be filtered spatially. The filtering has to be progressed only in the central diffraction order (blind out other orders). A digital camera can be mounted on a tripod to take pictures from the screen.

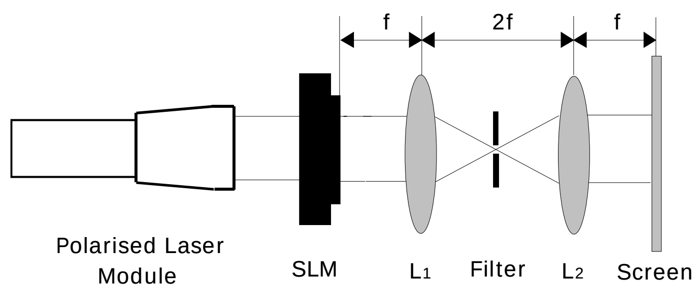


Figure 26 Set-up for Spatial frequency filtering

8.4.4 Suggested tasks

1. Why don’t you need polarisers before and behind the display? Test the influence of an analyser behind the display.
2. Use a grating with a well known diffraction image in the Fourier plane. Exercise the following spatial filtering:
   a. block the zero diffraction order
   b. keep the zero diffraction order
   c. keep only higher diffraction orders (e.g. higher than 3rd order)

3. Use two crossed gratings as image (chess board pattern). Carry out a spatial filtering and see if the horizontal lines disappear on the projection screen.
4. Design a simple image with a drawing program (black/white, lines and filled plain). Address this image onto the display and make sure that a clear projection is on the screen.
5. Carry out a high- and low-pass filtering in the focal plane of the Fourier lens. Record the filtered images with a digital camera.

8.4.5 Keywords for preparation

Liquid crystal, functionality of a LC-display, phase- and amplitude modulation, two dimensional Fourier transformation, spatial filtering, 4f set-up, high- low- pass filtering, resolution

8.5 Mach – Zehnder – Interferometer with controllable phase shift

8.5.1 Objective

The modulator should be used as a phase shifting element in an interferometer set-up. Define the phase shift as a function of the addressed voltage (important parameter of a modulator).

8.5.2 Required elements

Modulator, laser with beam expander, LDR- photo resistor or Si- photo diode with pin diaphragm, two beam splitter (mirror or cube), two in two axis adjustable surface mirrors

8.5.3 Set-up

The expanded (slightly collimated) laser beam illuminates a large part of the display homogeneously. A homogenous full screen pattern is addressed onto the display. The semiconductor laser with beam expander optics included in the kit should rotated until the light is horizontally polarised (along the axis of the elliptical beam profile).

Place a beam splitter in front of and behind the modulator. Assemble a Mach – Zehnder – interferometer using the adjustable surface-mirrors , in what the display is situated in one arm. Cut a small area (as big or a bit smaller than one fringe) from the beam in front of the detector in that way, that changes can be realised in the interference pattern. The set-up has to be stabilized for outside vibrations and requires high demands regarding the experimental know-how. It is advisable to use high-quality optomechanical elements.

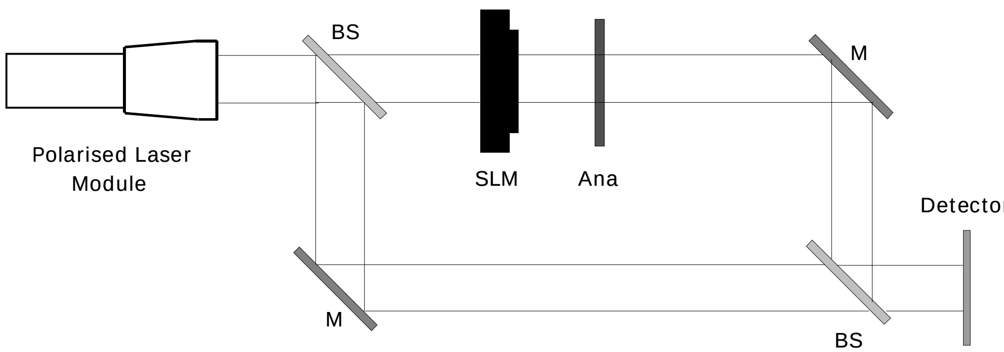


Figure 27 Set-up for Mach – Zehnder – Interferometer experiment

8.5.4 Suggested tasks

1. Adjust the set-up in such a way, that an interference pattern can be seen. Adjust the pin diaphragm to the centre of the interference stripes.
2. Increase the applied voltage step by step and measure the intensity with the detector.
3. Repeat the procedure for different wavelength.
4. Present the results in a diagram. Define the phase shift for all wavelengths as a function of the addressed voltage.

8.5.5 Keywords for preparation

Liquid crystal, functionality of a LC-display, coherence, interference, mathematical description of light propagation (plane wave), phase-speed, group- speed, optical path, (Michelson-, Mach-Zehnder interferometer) interferometry, interferometric methods in the spectroscopy.

9 Maintenance and Service

	CAUTION
⚠	**There are no user serviceable parts inside any components of the "Projects in Diffractive Optics" Education Kit. Work performed by persons not authorized by Newport Corporation will void the warranty.**

1.

9.1 Obtaining Service

The components of the "Projects in Diffractive Optics" Education Kit contain no user serviceable parts. To obtain information regarding factory service, contact Newport Corporation or your Newport representative. Please have the following information available:

2. Instrument model number (on the device)
3. Instrument serial number ()
4. Description of the problem.

If the instrument is to be returned to Newport Corporation, you will be given a Return Number, which you should reference in your shipping documents. Please fill out a copy of the service form, located on the following page, and have the information ready when contacting Newport Corporation. Return the completed service form with the instrument.

9.2 Service Form

Newport Corporation
U.S.A. Office: 800-222-6440
FAX: 949/253-1479

Name ________________________________ **Return Authorization #**__________________
(Please obtain RA# prior to return of item)

Company ____
(Please obtain RA # prior to return of item)

Address _________________________________ ____________________Date _________________

Country ________________________ Phone Number ____

P.O. Number ____________________ FAX Number ____

Item(s) Being Returned:

Model # ________________________ Serial # ___________________________

Description ____

Reason for return of goods (please list any specific problems):

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