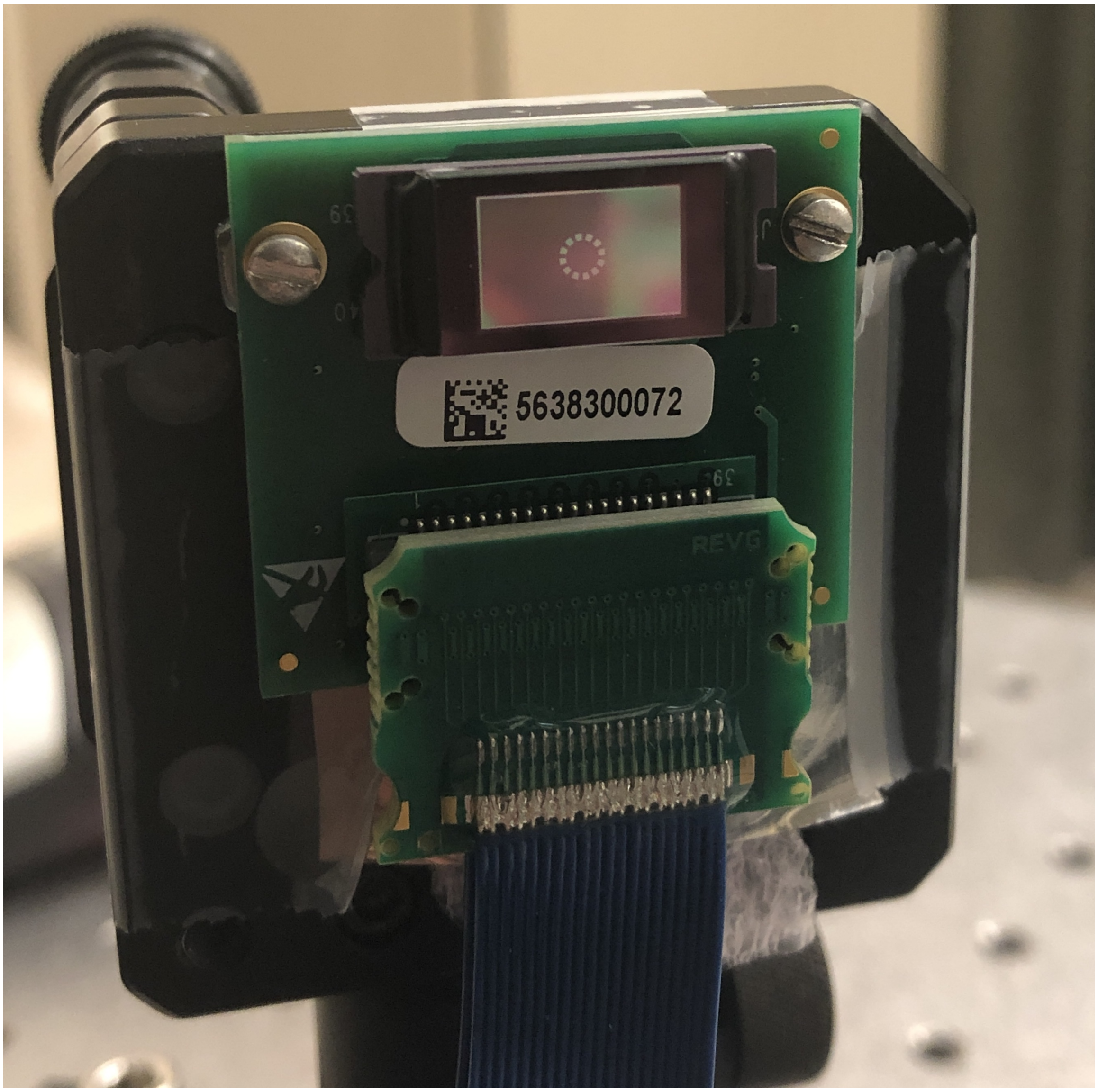
Guide to the LC4500 Digital Micromirror Device



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Abstract

In the field of atomic physics, light is an extremely useful tool, used to make measurements of atomic and molecular energy levels, trap and manipulate atoms, laser cool atoms, and to gain information about spatial position and velocity through imaging. Often, in order to perform an experiment, one must precisely control certain characteristics of the light being used to take measurements, such as wavelength, phase, and spatial and temporal intensity distribution. A Digital Micromirror Device (DMD) is one of the many devices (known as spatial light modulators) used to control the spatial intensity distribution of light. In this guide, we characterize the LC4500 DMD by Keynote Photonics, with the goal of using it in an experiment in Professor Dominik Schneble's Bose-Einstein condensate apparatus.

Contents

1 Useful files

These resources can be found in the folder titled "Useful Files"

1. **LC4500_GUI_v3.4_Windows-Installer.exe**
   This is the GUI through which one can load images onto the device's memory. It is important to use this version of the GUI instead of v3.5, as I ran into some issues with v3.5. After contacting Keynote Photonics, they told me to switch to v3.4.

2. **LC4500 User's Guide.pdf** [4]
   This is Keynote Photonics's guide to the GUI above. I used this document for troubleshooting the device, learning how to add images to the flash memory (Section 3.3.2.1), and understanding how images are displayed on the device (Appendix C).

3. **DiagEdge.m, forked.m, forkedAltered.m**
   Examples of Matlab code for creating images that can be displayed on the DMD. DiagEdge.m is for creating a diagonal edge, forked.m is for creating a forked grating, and forkedAltered.m is for superimposing two forked gratings with opposite charge.

4. **DLP4500Manual.pdf** [1]
   This is Texas Instrument's manual for the DLP4500 DMD. It contains inforamtion about the DMD array dimensions and geometry, window transmittance, and general specs for the device.

5. **DigitalControllerManual.pdf** [2]
   This is the Texas Instruments manual for the DLPC350 digital controller, a chip on the LC4500 that is used to control the DMD. I only used Sec 8.1 from this manual in order to understand the importance of bit-depth in displaying images.

2 Guide to creating and displaying a static image

All of this info can also be found in Keynote Photonic's LC4500 User's Guide [4].

First, you must create an image to load onto the DMD. It needs to be a black and white bmp file with dimensions $912 \times 1140px$. Note that this image is oriented as a portrait, but the DMD will stretch it into landscape. For example, we will be using the forked.m MATLAB code to generate a forked grating. Open the MATLAB code and hit "Run" to generate the bmp.

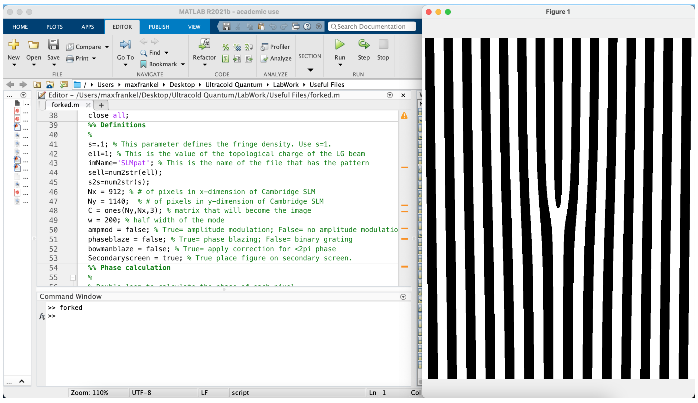

Figure 1: Use of forked.m MATLAB code to create forked grating

The program should create a file titled "SLMpats0.1l1.bmp."

Now we must upload this image to the DMD. Run LC4500_GUI_v3.4_Windows-Installer.exe to install the GUI that can be used to upload images. When you open the GUI, it should look like this:

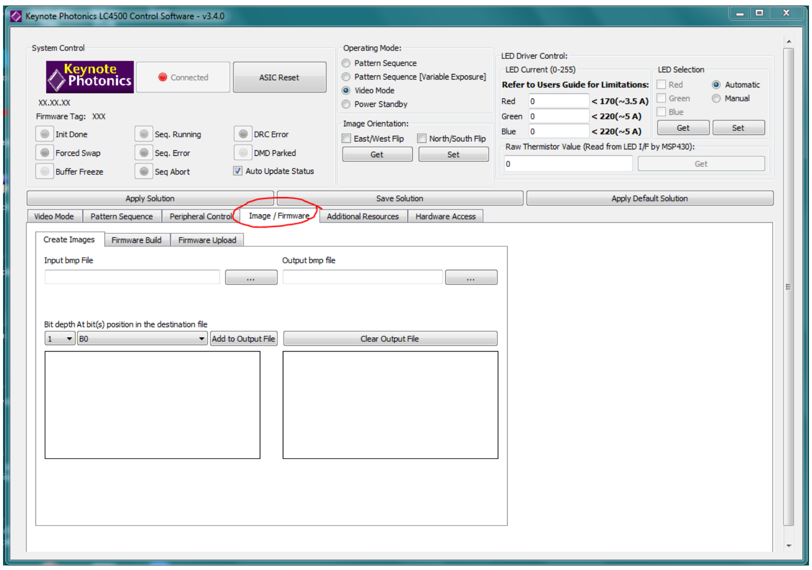

Figure 2: Screenshot of the LC4500 GUI. Circled in red is the Image/Firmware tab. Click on it in order to create an image to load onto the DMD.

In order to ensure that the bmp file is compatible with the device, we need to run it through the "Create Images" function of the GUI. Under "Input bmp File," input the file directory of the image you want to upload to the DMD. Under "Output bmp File," input the file directory where you want to save the processed file.

Select a bit depth of 8 and click "Add to Output File." Click on the "At bit(s)..." tab and add all three selections to the output file. The end result is shown in the figure below:

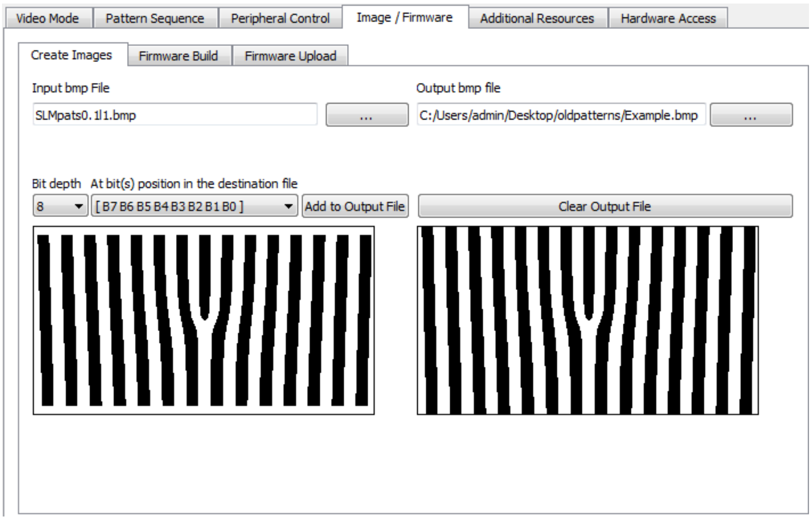

Figure 3: Creation of an output file that can be uploaded to the DMD

Now, navigate to the "Firmware Build" tab under the "Image/Firmware" tab. Click the button to browse for a firmware file.

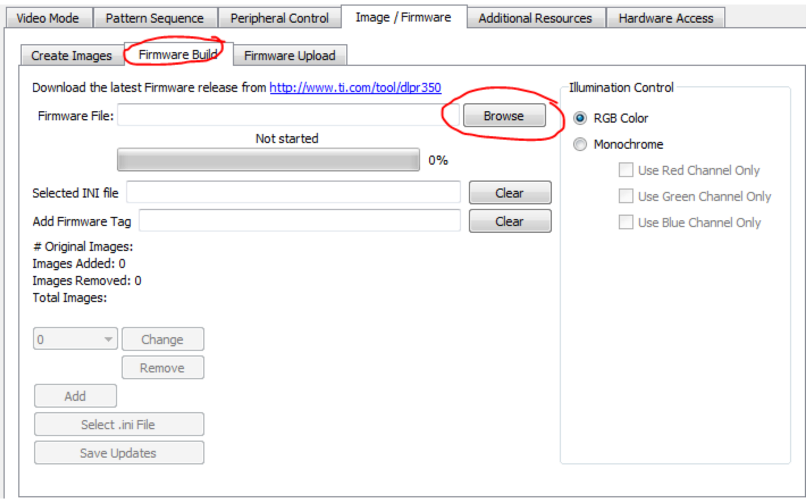

Figure 4: Firmware build tab

You must select the file titled "DLPR350PROM_v4.0_KP_RGB.bin." This is the default firmware for the LC4500, and we want to upload an edited version. The GUI crashes on me while trying to use other files.

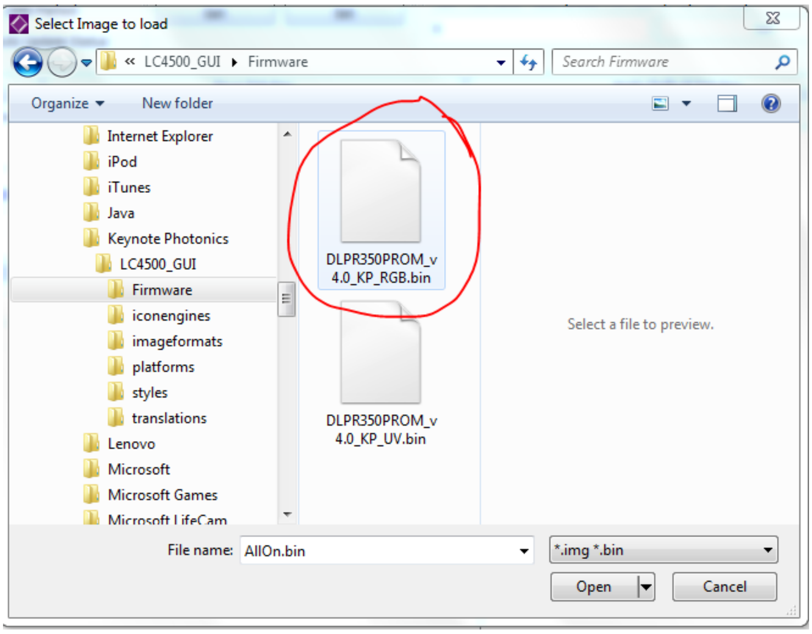

Figure 5: Selecting a firmware file for creating a build

The default firmware comes with some images. Click "Remove" to get rid of them.

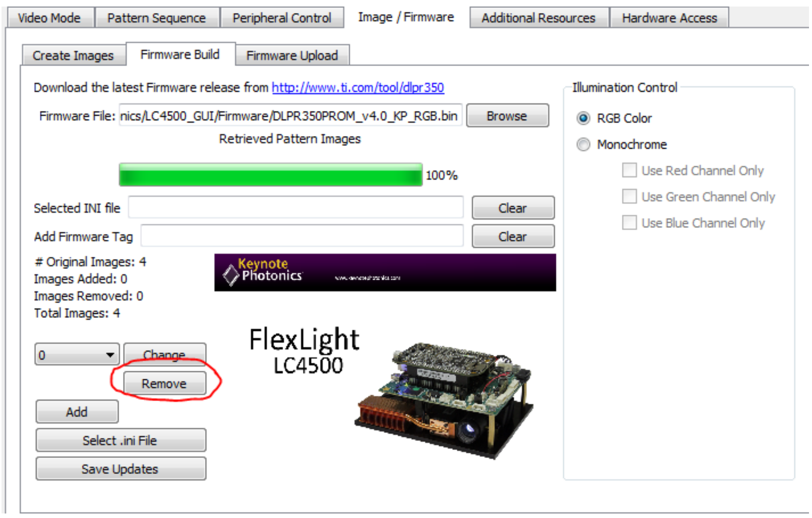

Figure 6: Removing default images

Now click "Add" to add any of your own images. You need to create a tag that will be displayed in the top left of the GUI when the DMD is on.

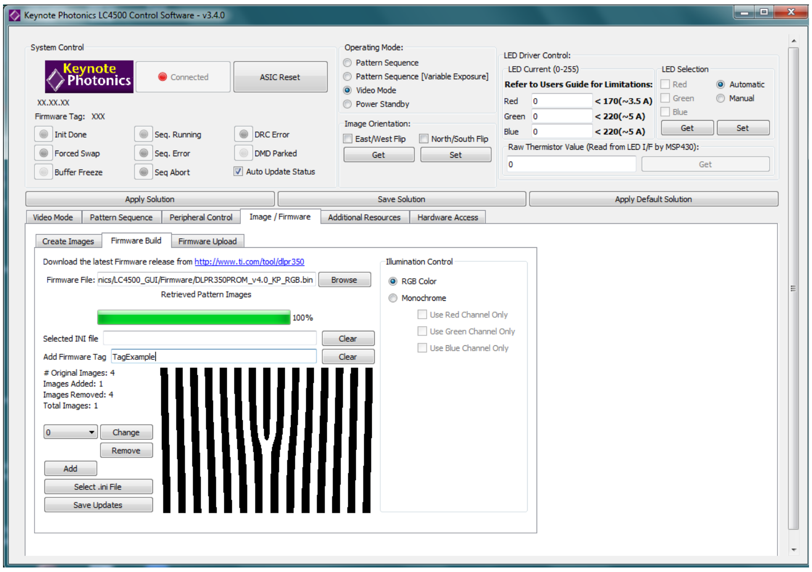

Figure 7: Caption

Click save updates and save your file with the .bin extension. Then navigate to the "Firmware Upload" tab, right next to "Firmware Build." Select your build to upload.

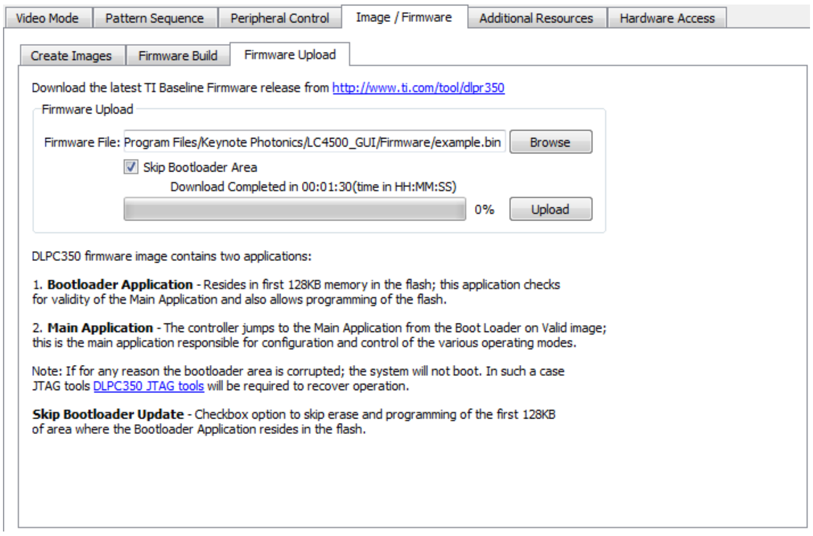

Figure 8: Uploading firmware to the DMD

Now we need to power up the LC4500 and connected it to the computer. Simply plug the device into a wall outlet and connect it to the computer by USB, as shown in the figure below:

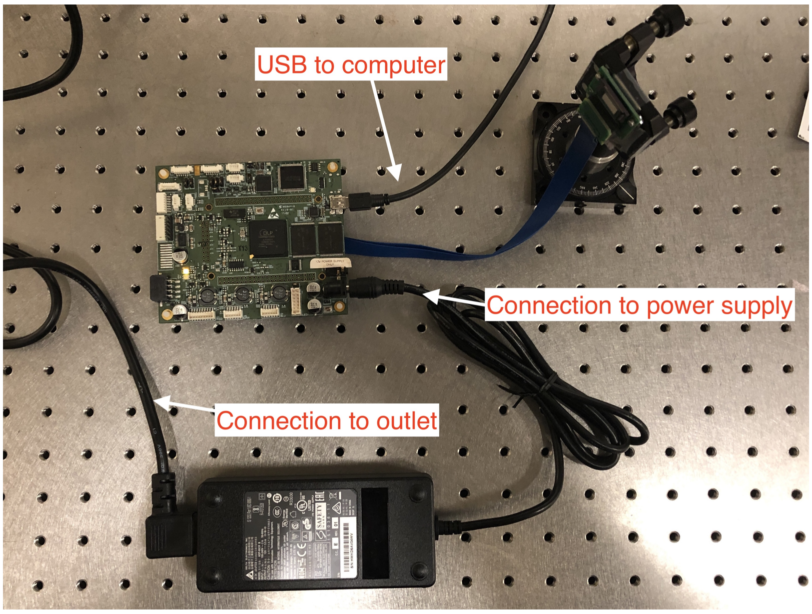

Figure 9: Connections for the LC4500 device to power supply and computer

If the device has been successfully connected, the red circle will turn green in the upper left side of the GUI.

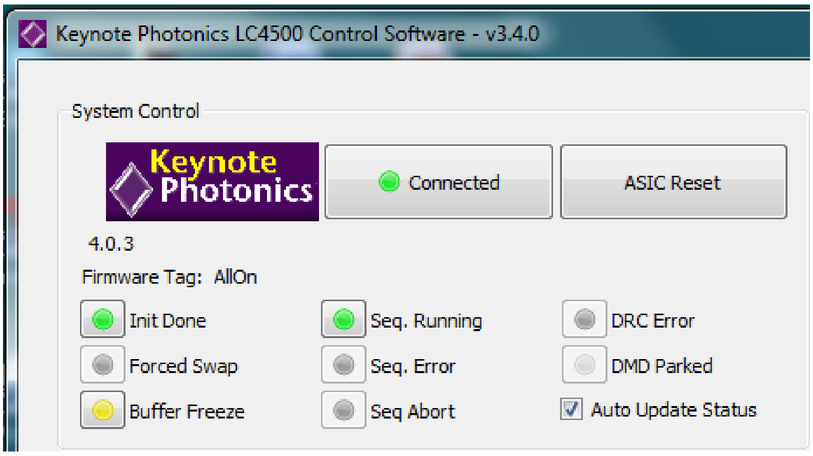

Figure 10: Indication of successful connection to LC4500 device

Now, under the firmware upload tab, upload the new firmware you built.

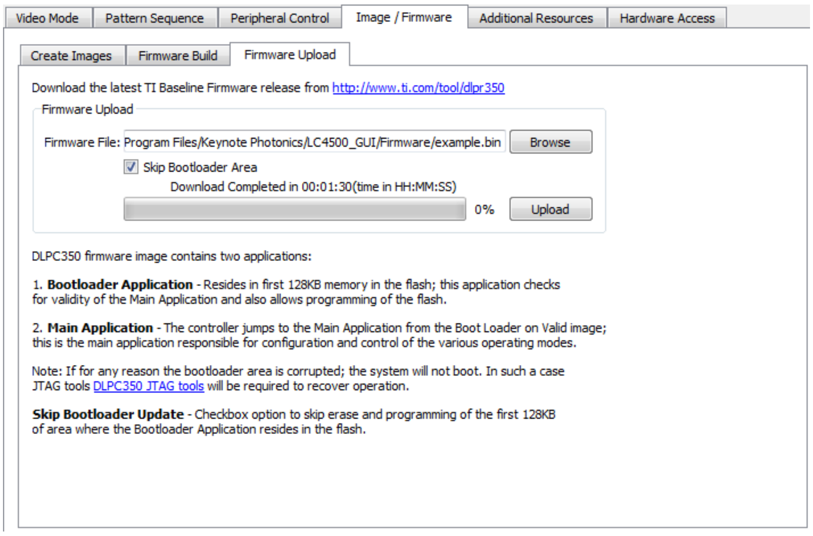

Figure 11: Uploading firmware

Once the upload is complete, turn the DMD off and on again. You can do this by either unplugging and plugging back in the power supply from the wall outlet or by pressing the small white button on the side of the DMD to turn it off and pressing again to turn it back on.

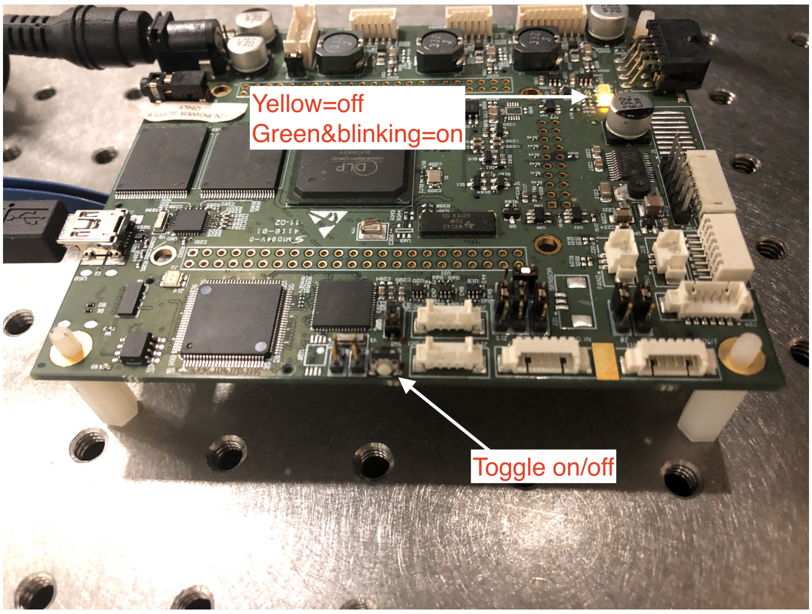

Figure 12: Location of button for turning DMD on and off

The DMD will start to buzz as it begins in video mode, probably for all of the little micromirrors rapidly flipping back and forth. To display a static image, select pattern sequence mode.

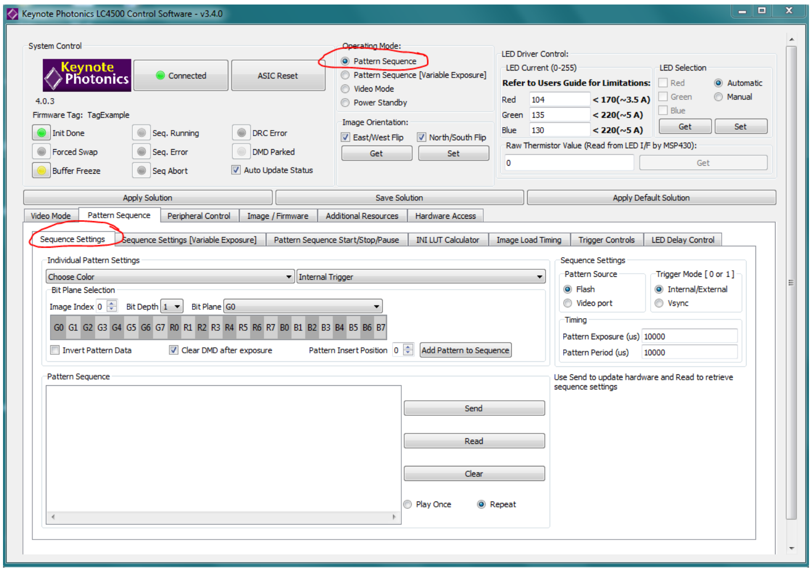

Figure 13: Selecting pattern sequence mode for displaying static images

You can display a sequence of images using this mode, but we will only display one image. You can probably use different options that will work, but these are the options that worked for me. Under "Individual Pattern Settings," select "Green." If you have multiple images uploaded, you can switch between them by changing "Image Index." Click "G0" from the available bits. Deselect "Clear DMD after exposure," as the DMD mirrors still flick back and forth if it's on. Click "Add Pattern to Sequence," and then hit "Send."

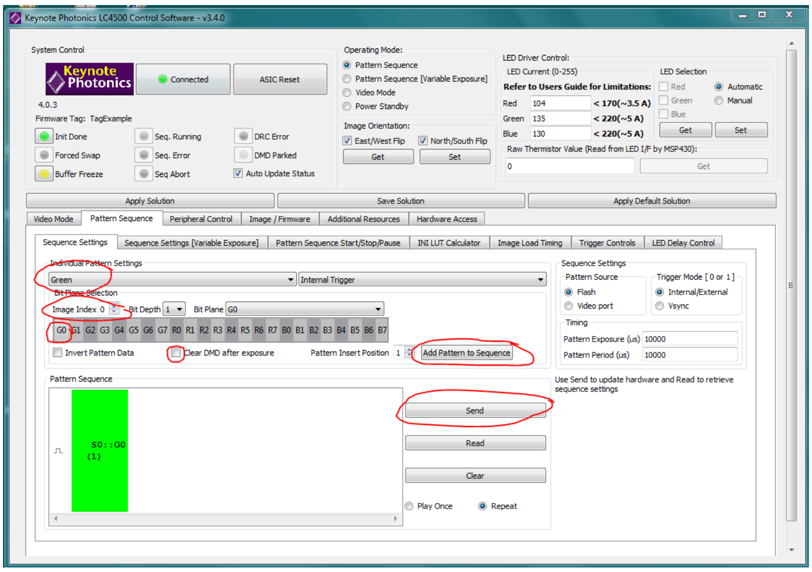

Figure 14: Adding your pattern to the sequence

Hitting send brings you to this page:

Figure 15: Displaying your image on the DMD

Click "Validate Sequence" and "Play," and the DMD will display your image! Selecting "Global Data Invert" inverts the orientation of every single micromirror.

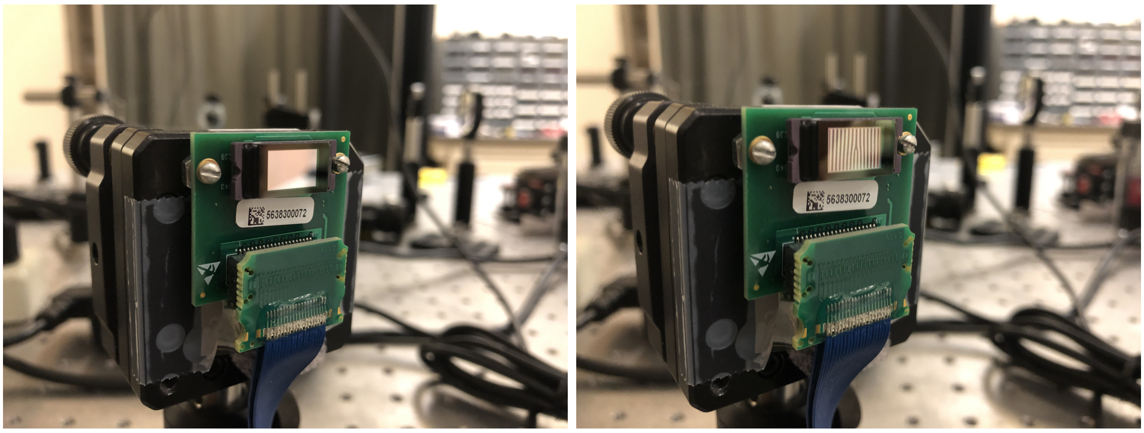

Figure 16: DMD before (left) and after (right) clicking "Play"

3 Device specifications

3.1 Micromirror geometry

The DMD used in this semester's work is the DLP4500 by Texas Instruments and is part of the LC4500 Electronics Kit created by Keynote Photonics. The DLP4500 has an array of millions of micromirrors that can individually be tilted between on and off positions, at angles of $+12°$ and $-12°$ [4]. When the DMD is turned off, all mirrors tilt to the "parked" position, at $0°$.

The dimensions of a single micromirror along with the entire array are given in Tab. 1 below:

Mirror dimensions	Mirror diagonal	Array dimensions	Array pixels
$7.637 \times 7.637 \mu m$	$10.8 \mu m$	$6161.4 \times 9855 \mu m$	912×1140 px

Table 1: DMD array dimensions

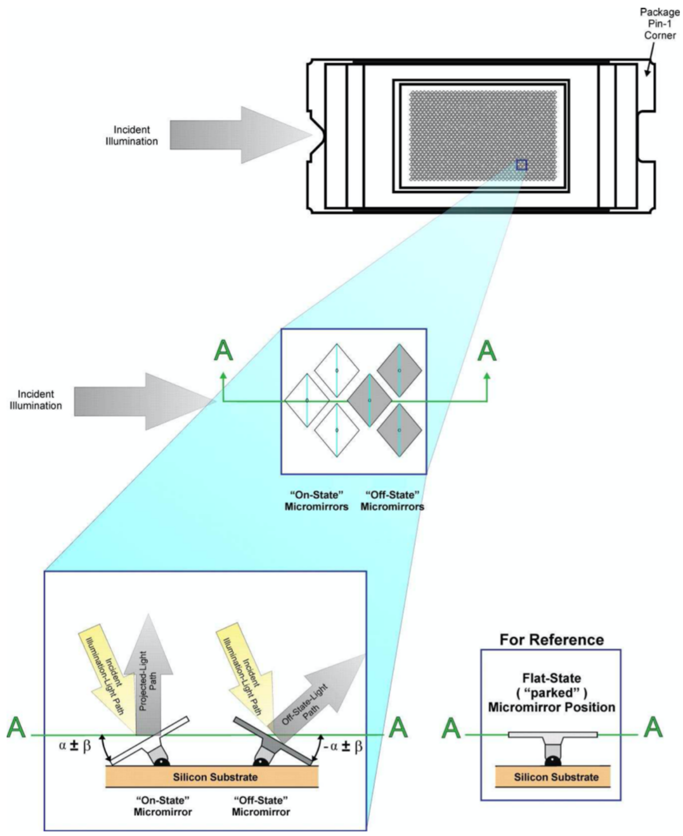

Figure 17: Diagram of the DMD included in the LC4500 Electronics Kit User's Guide [4]

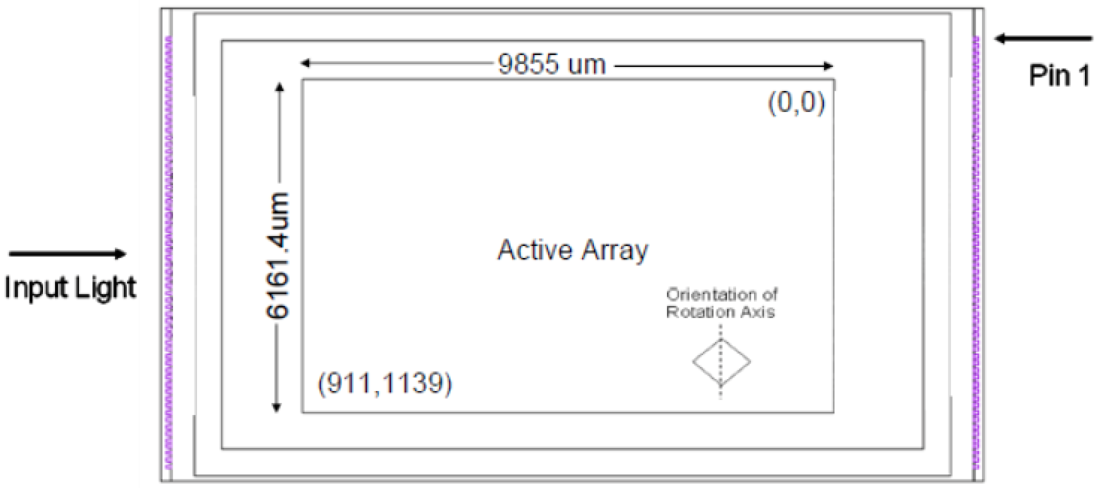

Figure 18: DMD array dimensions [1]

3.2 Displaying static images

To control each micromirror on the DMD, one can add a binary image in which each pixel corresponds to a single mirror to the device's flash memory. White pixels correspond to one of the two tilted directions, while black pixels correspond to the other.

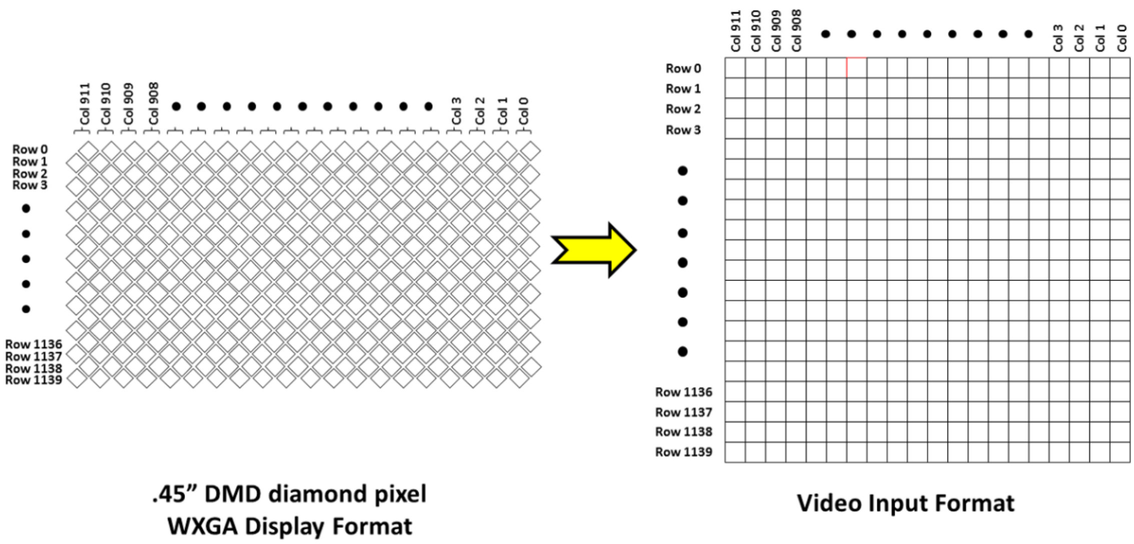

Figure 19: Diagram showing how single micromirrors in the DMD array are mapped to single pixels in an image [4]

Each mirror tilts along its diagonal. Thus, for all mirrors to tilt around a vertical axis, the mirrors are oriented in a diamond pattern. Thus, the image in pixels becomes slightly distorted when mapping to micromirrors.

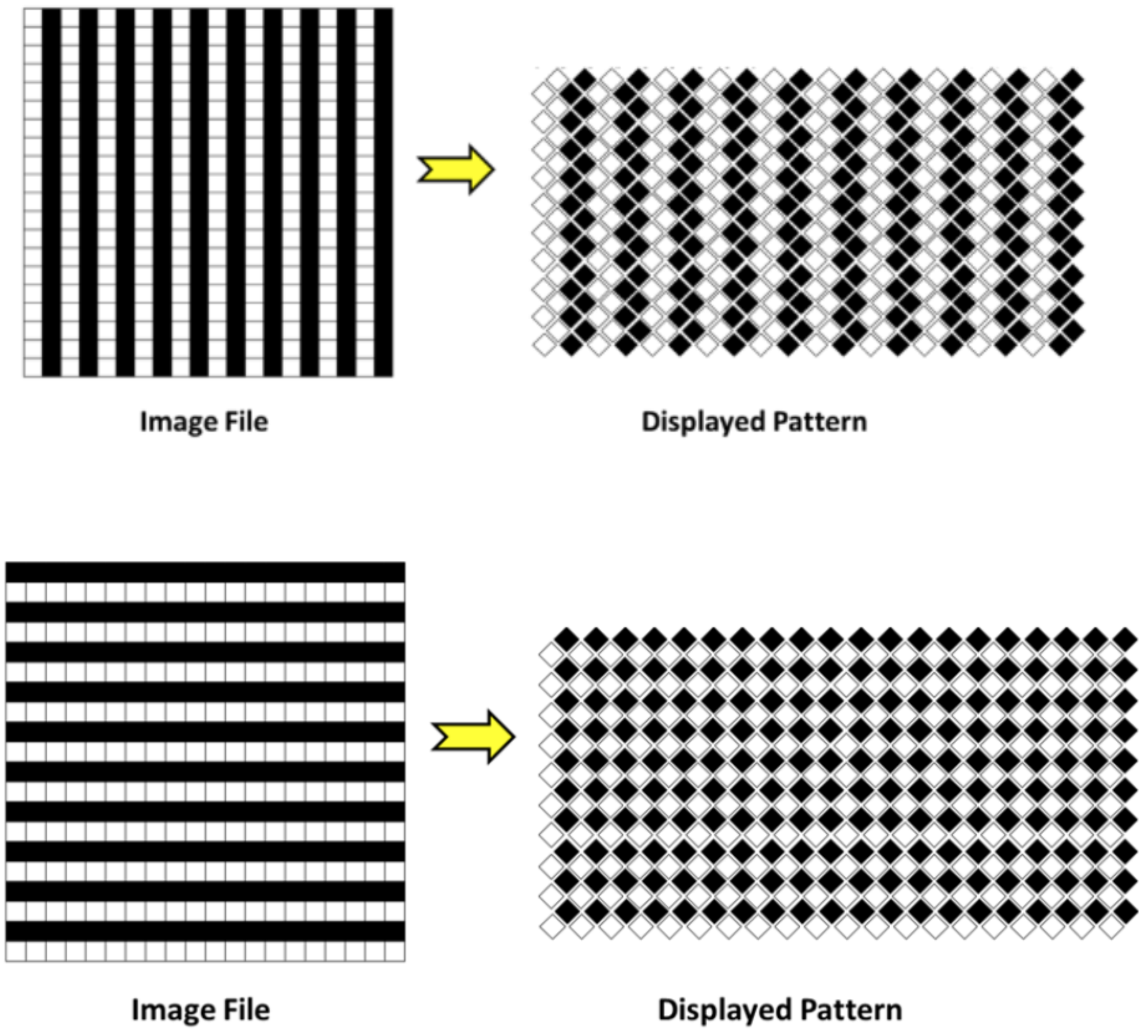

Figure 20: Difference in the way that rows and columns of pixels are displayed on the DMD [4]

Bitmaps can be created in Mathematica and Matlab. Once created, one can use the "Create Images Function" in the LC4500 GUI to ensure that the bitmap is of the proper format for uploading to the device's flash memory.

The Create Images Function has the user select colors and bitplanes when they create their image. An understanding of bitplanes is only necessary if one wants to create a sequence of images [2], and is not necessary for static images. For the easiest way to display a static image, simply add the image to all bitplanes at bitdepth of 8 on the GUI.

Once an image is created, it can be uploaded to flash memory using the GUI by following the instructions in the LC4500 User's Guide [4] or the start of this report.

3.3 Window transmittance

The micromirror array sits behind a glass window.

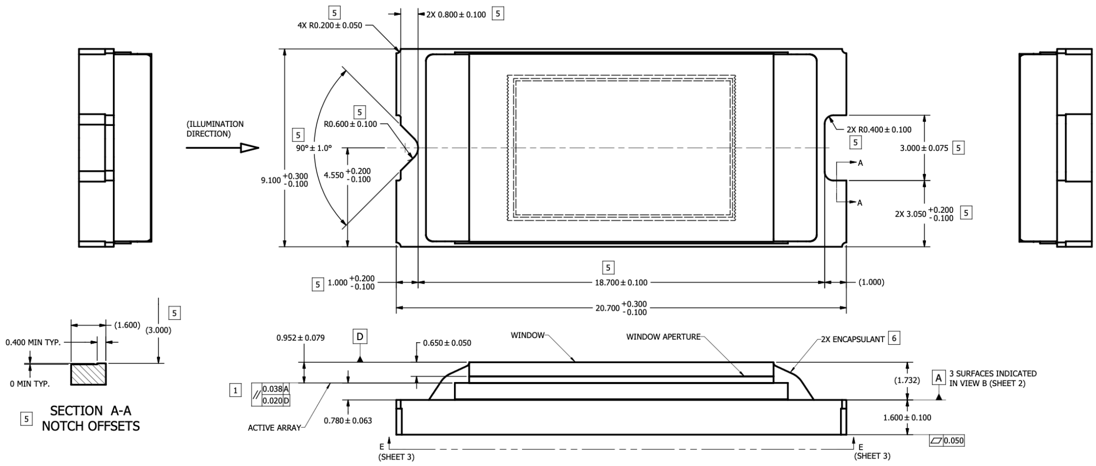

Figure 21: Schematic drawing of DMD, showing the window in front of the DMD array [2]

Some of the light is lost when passing through the window. The fraction of the light that is transmitted depends on wavelength, as shown in Fig. 22. For the intended experiment in Professor Schneble's lab, the light being used was approximately 790nm between the Rubidium D1 and D2 transition lines.

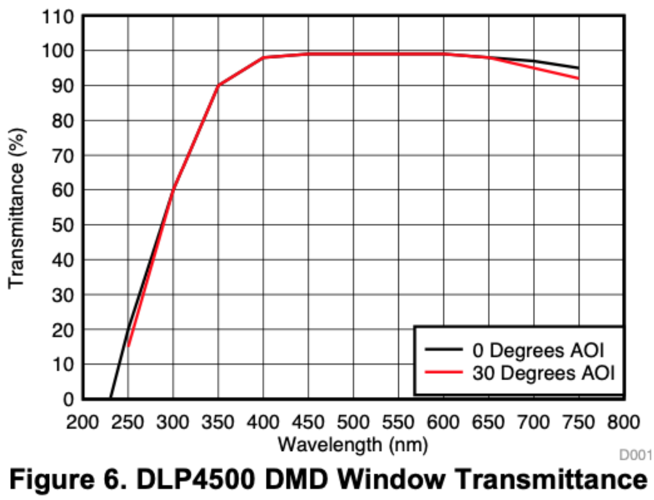

Figure 22: Graph of transmittance after single pass through two window surfaces for various wavelengths at 0° and 30° angle of incidence

An incident angle of approximately 60° was used. The outgoing angle was approximately 30°. The motivation behind this choice of angles will be discussed in Sec. 4. The transmittance for 60° is not shown in Fig. 22, and the graph does not go up to $790nm$. Thus, the transmittance for two passes through the window was estimated to be about 80%.

3.4 Recommended Incident Power

Figure 23 shows the recommended temperature rating for the DMD. For static images, the duty cycle is 100/0, and thus the recommended temperature is $40°C$. TI's documentation for the DMD recommends a maximum illumination power of $2\frac{W}{cm^2}$ [1].

I didn't end up monitoring the temperature of the device, and didn't run into any issues.

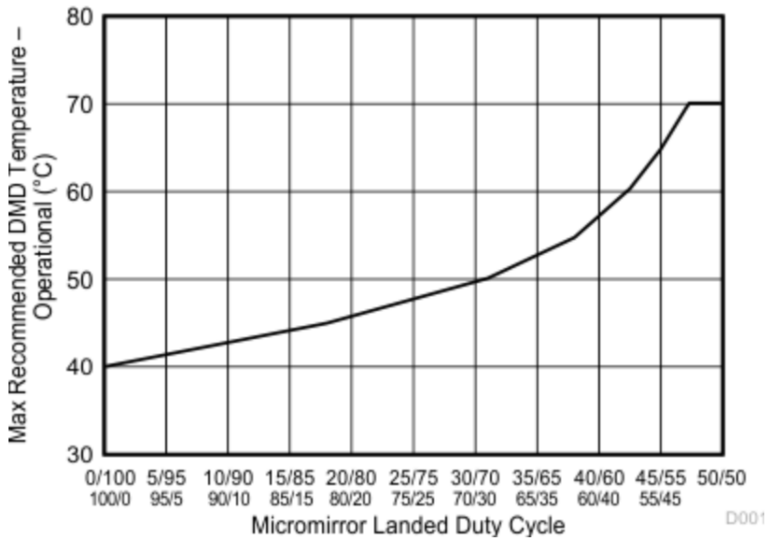

Figure 23: Recommended temperature rating for DLP4500 DMD [1]

4 DMD as a blazed grating

4.1 Description of Blazed Condition

The DMD acts as a 2D array where each micromirror acts as a slit. Reflecting light off of the DMD results in many diffraction orders, as shown in Figure 24. Intensity can be concentrated along a single order by setting the DMD up in the blazed condition [5].

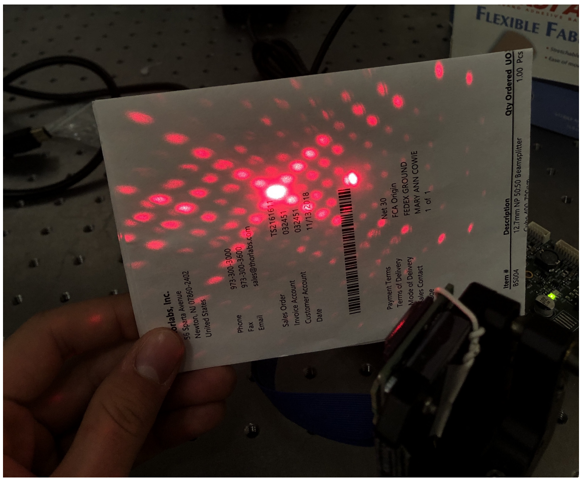

Figure 24: Observed diffraction pattern created by shining a 632nm HeNe laser onto the DMD with all micromirrors in the on position, with the 0th order being the right of the two brightest spots and the 3rd order on the left

$790nm$ light is just outside of the visible spectrum, but an IR viewer can be used to see the diffration pattern.

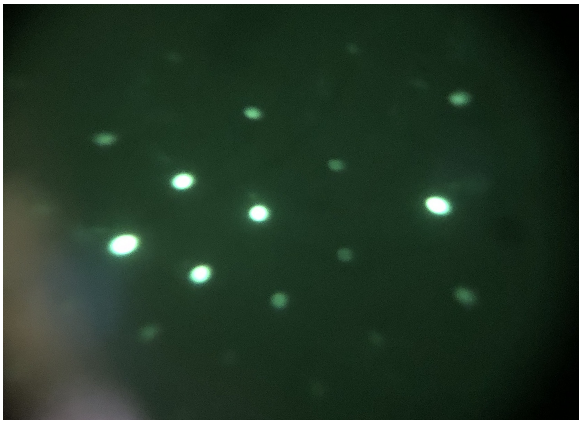

Figure 25: Diffraction pattern created by shining a $790nm$ diode laser onto the DMD at $63°$ with all micromirrors in the on position, photographed through an IR viewer.

For a 1D grating, the outgoing angle θ_{out} of diffraction peak order m is related to the grating spacing d, the wavelength of light λ and the incident angle θ_{in} by the following equation [5]:

$$\sin\theta_{in} + \sin\theta_{out} = \frac{m\lambda}{d} \tag{1}$$

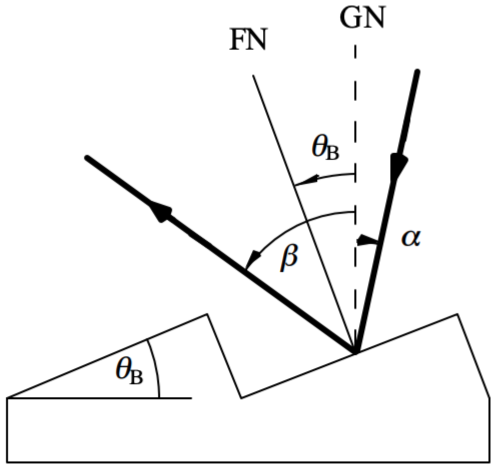

Figure 26: Littrow blaze condition [3]

The Littrow blaze condition is shown in Figure 26. It occurs when the m^{th} order peak for a grating lines up with the ray reflected off of the facet (along angle β in Figure 26). The DMD is oriented such that each mirror rotates along the vertical axis and the incident and reflected laser light both lie in the horizontal plane. The DMD is taken to act as a 1D grating where each slit is a vertical column of micromirrors. The angle θ_B is 12° for the DMD. The grating spacing is taken to be $d = 5.4\mu m$, as this is the horizontal distance between the centers of two micromirror columns.

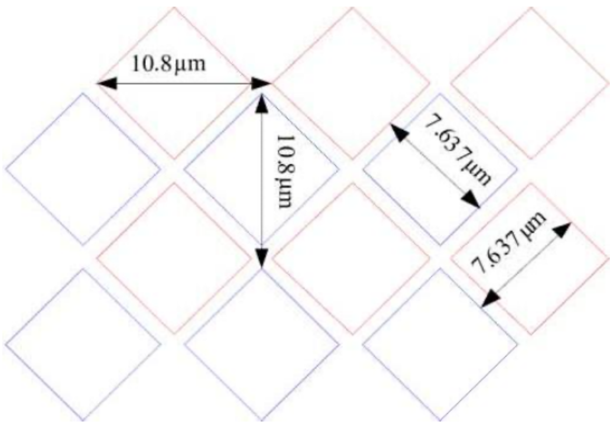

Figure 27: Micromirror geometry [4]

Using values $\lambda = 790nm$, $d = 5.4\mu m$, $\theta_B = 12°$, it was calculated that the $m = 2$ beam reflected from the DMD would be blazed at an incident angle of 57° and an outgoing angle of 33°. As the incident beam radius was chosen to be about the size of the DMD array, the 2^{rd} order was selected as it minimized the incident angle, ensuring that as much of the beam illuminated the DMD as possible. All possible blazed orders for $790nm$ wavelength and the corresponding angles have been recorded in Table 2.

Order m	Incident Angle (°)	Diffracted Angle (°)
0	102	78
1	81	57
2	57	33

Table 2: Possible blazed order and corresponding incident and reflected angle

The observed diffraction pattern in Fig. 25 verifies that the 2nd diffracted order was, indeed, the blazed order at about 57°.

4.2 Measured efficiency of the DMD

4.2.1 Window transmission

To measure the fraction of the incident power lost in transmission through the DMD window, the intensity of the incident beam and the diffracted 0th order beam with all micromirrors flat (DMD was turned off so all mirrors were "parked," see Fig. 17) was measured with a power meter.

The incident beam was produced with the LPS-785-FC diode laser, supplied with $40mA$ of current by the LDC240C Current Controller to produce a $3.25 \pm 0.10mW$ incident beam.

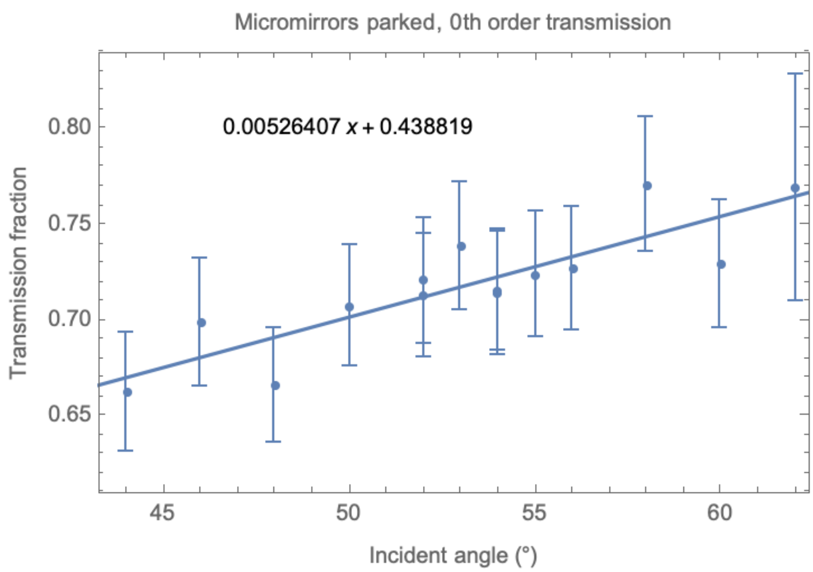

Figure 28: Fraction of the incident power transmitted to the 0th order diffracted beam with all micromirrors parked

The error bars were estimated by combining the estimated systematic error in using the power meter with the observed fluctuations of the powermeter. It was noticed that, if the beam illuminates the edge of the power meter, the measured power increased by about 3%. This estimated error was added to the estimated uncertainty due to powermeter fluctuations to obtain the error bar.

This transmittance is consistent with the expected transmittance from Fig. 22. If the transmittance for a single pass through the two windows surfaces is estimated to be 0.85, the transmittance after two passes is about 0.72.

4.2.2 Measuring diffraction order power

With all micromirrors on, the maximum efficiency measured was 0.5, and occurred at an angle of 53°. This angle is not consistent with the expected blazed angle of 57°. The discrepancy is likely due to inaccurate mounting of the DMD in the rotation stage.

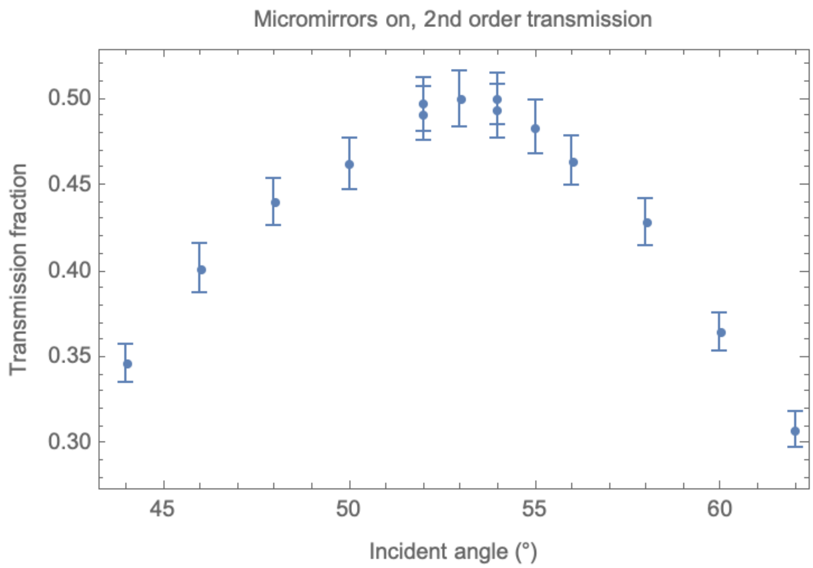

Figure 29: Fraction of the incident power transmitted to the 2nd order diffracted beam with all micromirrors on

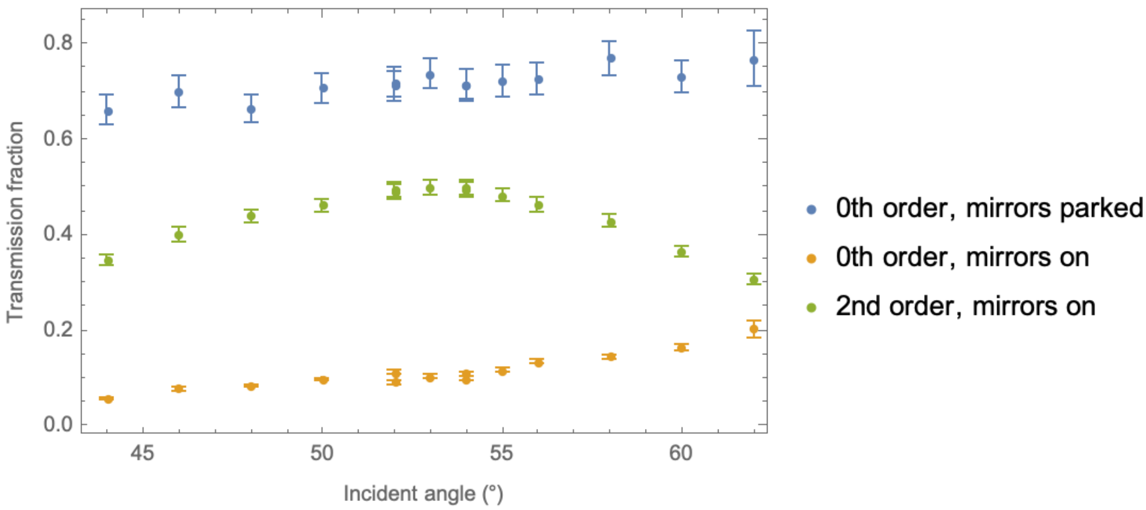

Figure 30: Comparison between the transmission fractions of the 0th and 2nd order with mirrors on and parked with various DMD angles

References

[1] Texas Instruments. *DLP4500 .45 WXGA DMD.* 2014. URL: none.

[2] Texas Instruments. *DLPC350 DLP® Digital Controller for DLP4500 and DLP4500NIR DMDs.* 2019. URL: none.

[3] Christopher Palmer. *DIFFRACTION GRATING HANDBOOK, eighth edition.* Mar. 2020, pp. 38,39. URL: https://www.researchgate.net/publication/339913143_DIFFRACTION_GRATING_HANDBOOK_eighth_edition/link/5e6ba39fa6fdccf994c637fc/download.

[4] Keynote Photonics. *LC4500 User's Guide.* 2017. URL: none.

[5] Philip P. J. Zupancic. "Dynamic Holography and Beamshaping using Digital Micromirror Devices". Master's thesis. Ludwig-Maximilians-Universitat Munchen, 2013. URL: https://greiner.physics.harvard.edu/assets/theses/zupancic_thesis.pdf.