This page documents the design process behind a hypothetical custom projector designed specifically for a lithography stepper.

Motivation

Existing versions of Hackerfab's lithography steppers all use off-the-shelf DLP projectors (V1 uses a standard consumer projector, and V2/V2.1 uses a development evaluation module). The issue with this is that our use-case is very far outside of what these projectors were designed for, which leads to all sorts of issues - many of the design considerations of our existing steppers specifically work around these issues:

- Stepper V1 has to replace the consumer projector's hot mirror with a UV-passing one
- Both projectors have to very jankily mount their optics to a frame that is only ever designed to have its stock lens mounted
- Both steppers have some… *creative* mounting solutions to get around the fact that both projectors are not designed to be conveniently mounted to things.

Furthermore, there's a lot of annoyances that come with the existing setups.

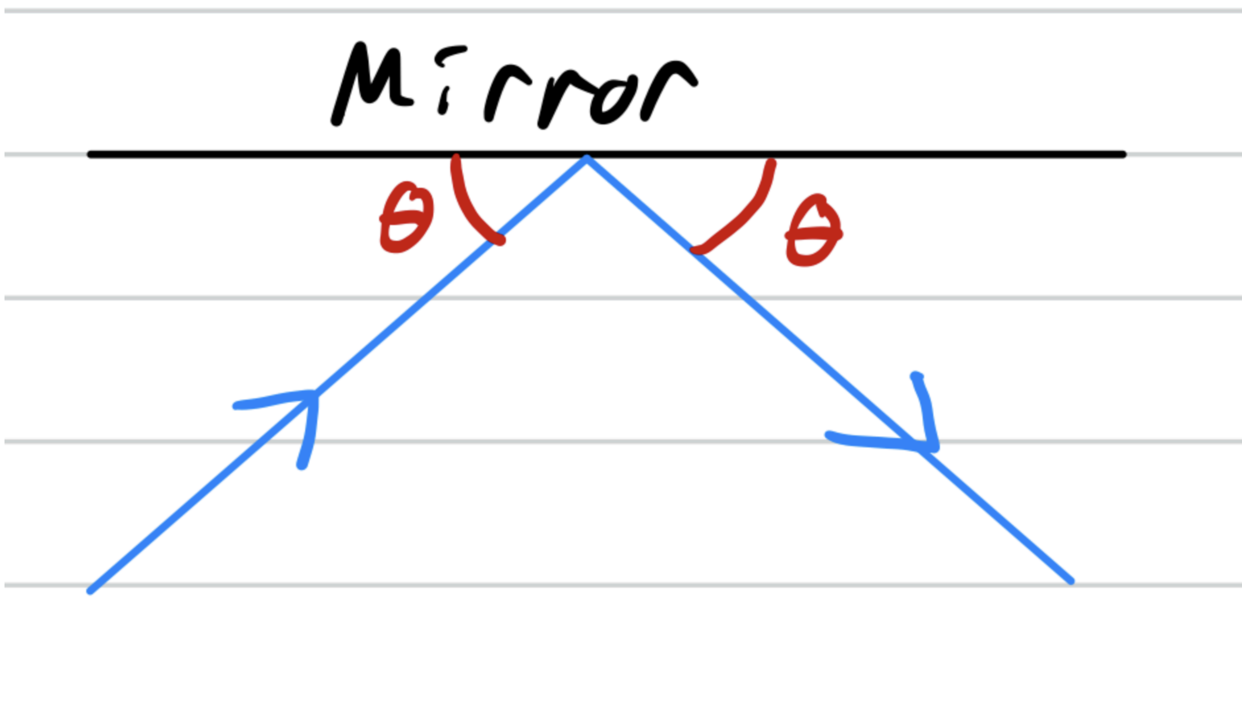
- Both projectors are driven by a computer's HDMI output, which means that the operating system will do fun things like put UI elements on the litho output. There's not really a convenient way to generate an actual HDMI signal without it being controlled by the OS…
- The projector used on Stepper V2/2.1 is currently (as of writing, May 2025) completely out of stock everywhere, with Mouser expecting a mere *3* to be restocked by August. This isn't great for anyone who wants to build a stepper now!
- While the projector used on Stepper V1 is still widely available because it's a standard consumer projector, there's no real guarantees on its continued availability.

The latter two points were part of the reason for making Stepper V2.1 use a design that will much more easily allow adapting different projectors, but also point toward a need for a projector solution that will have a longer shelf life.

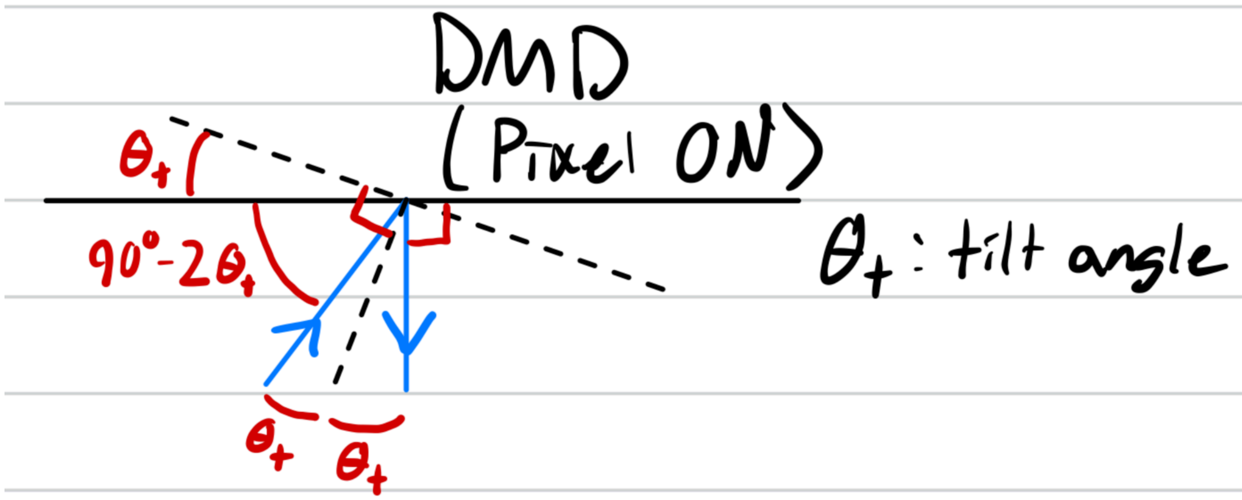
How DLP actually works, optically

DLP projectors have a whole load of stuff in them. The thing is, it's pretty hard to find proper documentation on how the light actually travels through a projector. This presentation from TI is particularly er, *illuminating*: https://www.ti.com/tool/download/DLP-OPTICAL-DESIGN.

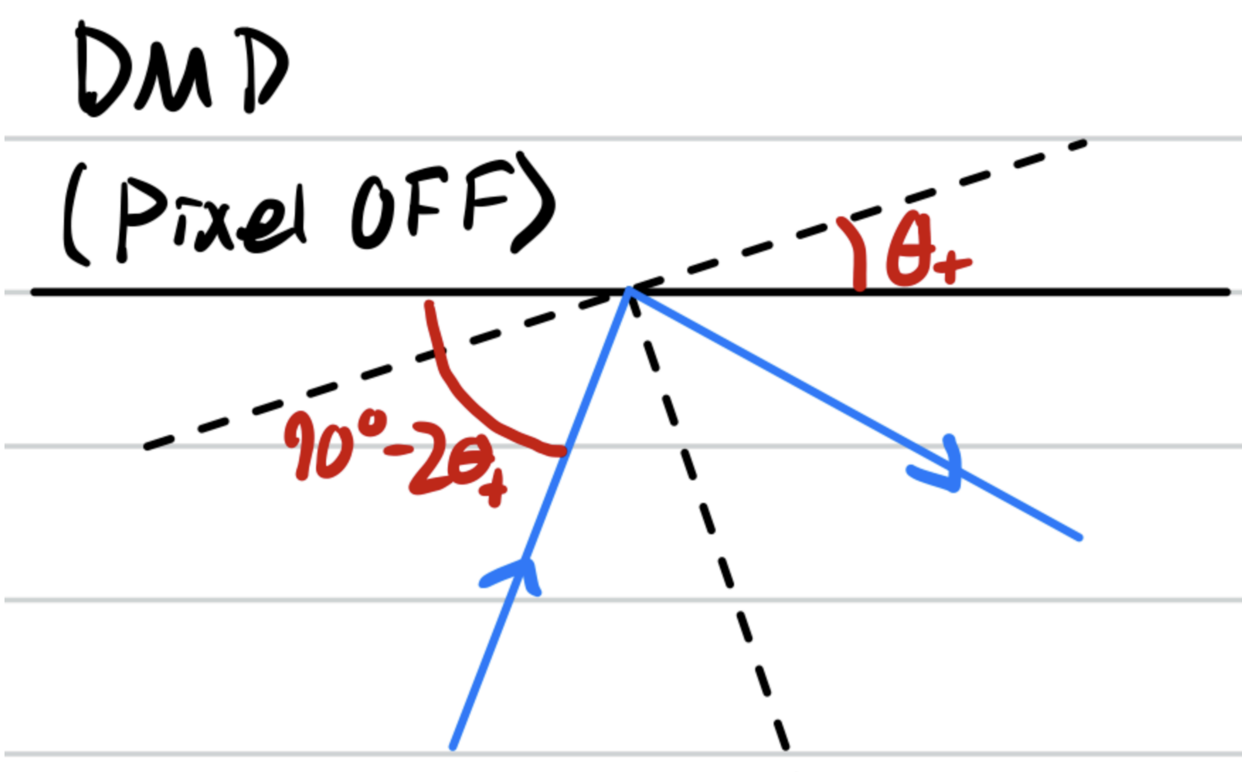
In summary, you can treat the DMD in a DLP system as a reflective plane with strange properties. Let's first talk about a normal mirror and then compare.



In an ideal mirror, a beam of light which strikes the mirror at a point will reflect and leave the mirror at an angle equal to the angle at which it entered. This is pretty intuitive. We can model the DMD as a very similar device, where an incident beam of light is reflected, but with one fundamental difference: the beam *does not leave at the same angle at which it entered*. Instead, depending on the state of the pixel which the beam strikes, it leaves at one of two different angles. I think of it this way: instead of reflecting off of the actual plane of the DMD, it reflects off of one of two mirrors which intersect with the DMD at the point at which the light strikes, but which are tilted from the plane of the DMD by a certain angle, the *tilt angle*. The tilt angle is around 12 or 17 degrees, specified in the DMD's datasheet.



In this drawing, the "invisible mirror" is the dotted line, with its normal indicated. If the pixel is turned on, then an incident beam that strikes the DMD at 2 times the tilt angle relative to the normal of the DMD, will be reflected to leave the DMD exactly normal to it. On the other hand, if the pixel is turned off, an incident beam at the same angle will instead be reflected off to the side.



That’s pretty much it. If you illuminate a DMD with a homogenous light source at an angle of 2 times the tilt angle from the normal, then an image is formed on the surface of the DMD.

The real silliness

So what is all that other *stuff* in a projector actually doing?

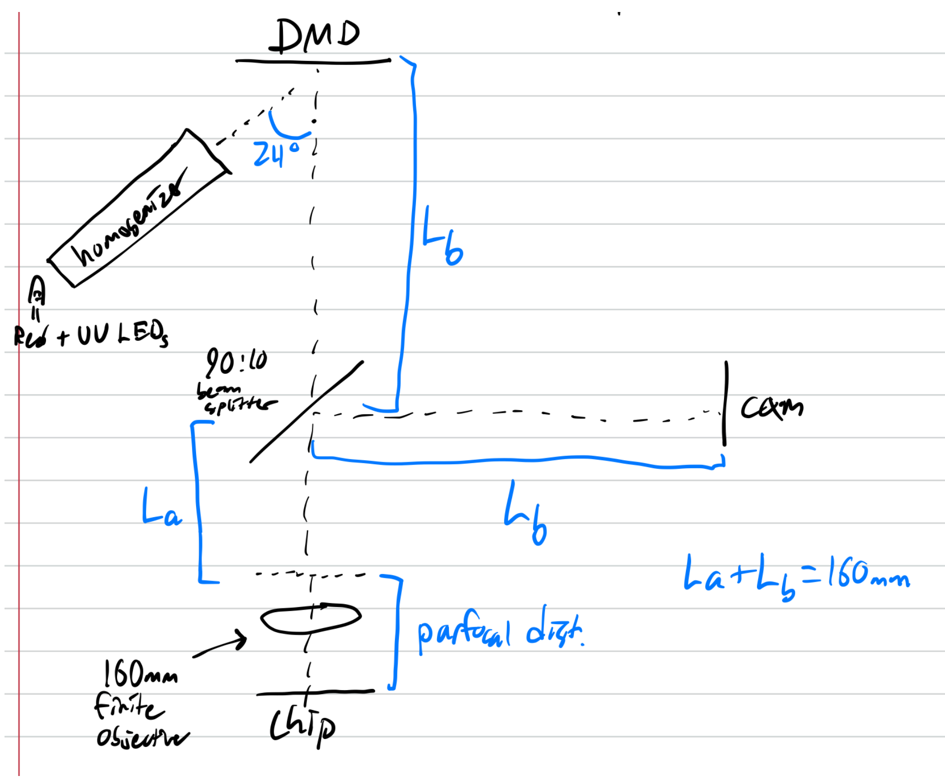
What I learned through my research on this project is that 90% of the complications that exist in off-the-shelf DLP projectors are there to solve problems that only exist in *normal* projectors, and simply do not exist for us! Let me break down the optical elements in a standard LED-illuminated DLP projector like the one used on Stepper V2:

- **Dichroic mirror array**: LED DLP projectors have a set of mirrors/filters which mix the light from the three separate RGB LED sources into a single optical path. In our case, we are not displaying a full color image, but instead two separate red and UV images at separate times. This means that we can avoid this and do something much simpler such as placing the UV and red LEDs next to each other before homogenizing, or even physically moving them between modes.
    - Lamp-based DLP projectors like the one used on Stepper V1 have a color wheel instead of this, since all the light comes from a single white source. Same dealio though.
- **Fly’s eye lens array**: this is a light homogenizer: it takes in spatially-varying light and outputs spatially-homogenous light. There’s several different types of homogenizers, but projectors tend to use fly’s eye lenses, with the only reason being size as far as I can tell. We don’t really care about size, so we can use a much less expensive homogenizer such as a light pipe.
- “**Interface optic”**: this is an interesting one. This is an optical element which “interfaces” the DMD with the illumination light and outgoing light. The TI presentation I linked presents 4 separate designs for this: TIR (total internal reflection) prism, RTIR (reverse total internal reflection) prism, field lens, and a shifted projection lens (the last one isn’t really an optic, more of a design

choice not to have one). The presentation spends a huge amount of time discussing these and all of their various differences, but here's the thing: the only real purpose of these optics is to allow the projection lens to not physically collide with the illumination optics. The last one (shifted lens) actually shows this: for the cost of having an image that's not centered on the optical axis, it's perfectly possible to avoid having an extra optic entirely. The thing is.... we aren't using a projection lens. We're using a microscope objective, the closest part of which is a whole 160mm away from the DMD! That means there is no chance of the illumination stuff physically getting in the way here, even without shifting the lens off the axis. As far as I can tell, there's no reason for us to have extra optics here.

In summary: the optical design

Based on these learnings, this is, to my understanding, the minimal set of optics needed to drive a DLP system with UV: **light source, homogenizer, DMD, and objective lens**. Together with the existing beamsplitter / camera setup from our other steppers, that means that this is the whole setup **(NOTE: La+Lb should be 150mm, not 160mm)**:



The hard part: electronics

Doing a custom design makes the optics side of this simple, but it makes the electronics a lot harder. The core reason for this is because we're no longer able to use an existing driver board for driving the DMD like is included in our other projectors and must design that board ourselves - and this is not a simple PCB.

The DLP chipset consists of 3 components: the DMD (part number starting with DLP), the DLP controller (part number starting with DLPC), and the power management IC (PMIC, part number starting with DLPA).

- The DMD contains the actual physical micromirrors and takes in a set of device-specific signals.
- The controller outputs the signals needed by the DMD and takes in a video signal and various. It also signals the PMIC for controlling the DMD state and toggling the LEDs.
- The PMIC regulates the weird voltages needed by the DMD and also drives the LEDs.

The 3 parts of the chipset are usually designed as a set: for example, the DLP471TP used in Stepper V2 is only designed for use with the DLPC6540 and the DLPA3005, but some of the components (like the DLPA3005) work with multiple other models.

There's many different series and chipsets within the DLP family, but the one I think would be the best for us to use for a custom projector board is the **DLP301S / DLPC1438**. This chipset is designed for resin 3D printers, so it is explicitly designed to be used with 405nm UV light (notably, our existing DMD is not!), and uses the same size micromirrors as the projector on Stepper V2 (the DMD itself is smaller, but the physical resolution is the same).
Also, the DLPC1438 has several features that make controlling it easier than other models:

- It takes in video in the form of "parallel video" - this is what TI calls the extremely common raw video protocol consisting of a pixel clock, a raw pixel value in parallel, and VSYNC/HSYNC signals. This can be generated using a regular microcontroller! (This is especially nice, because during previous

discussions about designing a custom projector, most of the design work was on figuring out how to supply the video input signal)
- It is designed to be used with a single color channel, which makes driving the input signal simpler, and it has options for configuring which of the 3 LED outputs to use (it still has 3 LED outputs because it uses the same PMIC as the regular projectors)

(Note the DLP301S / DLPC1438 chipset is extremely similar in specification to the DLP3310 / DLPC3437 chipset designed for normal projectors, which may warrant some research - the latter chipset is cheaper)

The real difficulty here comes from the fact that all of these parts are extremely complex. The DLPC1438 is a 201-pin BGA package with 0.8mm pitch, and the DLP301S itself is an extremely custom LGA package. I have never designed a board using a BGA nor even soldered one onto a board, and the signal density needed is far higher than anything I've designed before. However, there's a few things that make me think this is doable:

- TI provides example board designs! They do a whole lot more than we need, so they're very complicated, but they should be good for reference: https://www.ti.com/tool/TIDA-080010
- The layout guidelines in the

Over spring break, I started with the more mechanical aspects of designing a PCB with these parts, purely out of my own interest. So far (as of writing, March 2025) I have created correct footprints and symbols for both the DLP301S and the DLPC1438. Those are in this repo: https://github.com/hacker-fab/projector-pcb/

BOM / Price estimate - for just the projector

PCB + misc electronics	$25.00	JLCPCB
DLP301S	$84.98	Mouser
DLPC1438	$29.78	Mouser
DLPA3000	$15.79	Mouser
8mm Homogenizer	$283.14	Edmund

Misc hardware	$200.00	Thorlabs
Total	**$638.69**	