

2 Watt laser driver

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April 24, 2019

Abstract

A variable power output 2 watt laser driver built for professor Jean Hertzberg's Flow Visualization class. This paper serves to discuss lasers in general and the laser I built to assist in flow visualization image and video capture

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1 Types of lasers

Lasers are designated primarily by the material in which the light is derived. All lasers work off of a principle called *population inversion*. The basic idea of light emission comes from changing an atom's energy level from a high state to a low. For the atom to make this transition, it has to release a photon. Naturally, the population of energy levels exists in lower states rather than higher states. To create amplification of the incident wave in which lasing can occur, atoms need to be pumped into a metastable level and stay long enough to store energy. This is what allows for a larger production of stimulated photons. Because the population is now higher in the higher energy levels, it is contrary to its original state. Thus the term of *population inversion*. [1] The method in which electrons are excited to higher energy levels is called *pumping*, typically with something like a semi-conductor laser or arc-lamp. One last important term with lasers is the *gain medium*. The *gain medium* is the energy levels in which the electrons get excited to. Typically, you may find a level 3 or level 4 gain medium. For the *population inversion* event to occur, at least more than half of the electrons must fall in the level 2 excitement category. Here are a few common laser types. [2]

1.1 Solid-state

Solid-state lasers use a gain-medium that is solid (versus something like a gas). They are usually made out of a crystal or glass that is doped with some kind of rare-earth mineral (like Neodymium). Remember, a gain medium is the material and method in which an atom transitions from a high energy state to a lower energy state, thus resulting in a stimulated emission (similarly to how a fluorescent bulb works). You might think of a solid-state laser to be more akin to a light-saber from Star Wars as they generally use crystals. Solid-state lasers are typically known to be optically pumped, allowing for very high power outputs for very short time periods, from milliseconds down to femtoseconds (1×10^{-15}). [3]

1.2 Gas

Emission that is derived from gas, commonly Helium-Neon. CO2 lasers are also common in laser cutting hard materials. Gas lasers have been widely replaced by alternative methods, but there are a few reasons that they remain in use. They can offer special wavelengths that are hard to achieve via other methods, as well as being able to achieve high optical power outputs. They can also provide much higher quality beams compared to solids. The most common example of this is CO2, which offers both a unique long wavelength and high power. [4] Below is an image of a Helium-Neon gas laser



Figure 1: A helium neon laser [5]

1.3 Excimer

A type of gas lasing that stems from mixing reactive gases with inert gases. When excited, a pseudo molecule is created called a *dimer*. This dimer will produce light in the ultra-violet range. These lasers are commonly found in use with the following applications.

- Microelectronic devices
 - Semiconductors
 - Integrated Chips
 - Eye surgery
 - Scientific research
-

1.4 Dye

Dye lasers are known for their versatility. They can have a very broad range of producible wavelengths, from the near infrared to the near ultraviolet. Typically made from an organic dye as a liquid solution. They use a pump laser to effectively pump the dye into a fluorescent state where it can radiate.

These types of lasers can be used for very high power output applications. Some of these applications include [6],

- Astronomy
- Atomic vapor laser isotope separation
- Manufacturing

- Medicine
- Spectroscopy

Below is an image of the relatively complicated setup that is involved with these lasers.

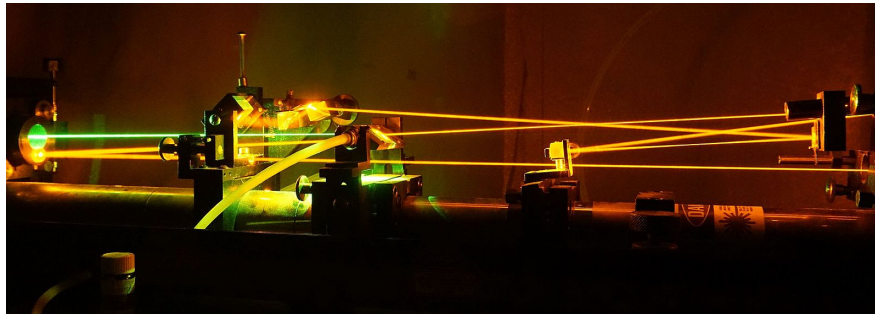


Figure 2: A dye laser setup [7]

1.5 Semiconductor

The more well known laser is the semiconductor laser, also referred to as a diode laser. They are similar to solid-state lasers in that they both use a solid medium. That is where the similarities end. Solid-state lasers have to be optically pumped, whereas semiconductor lasers are excited by the movement of electrons through them. These are the kinds of lasers you find in pointers and hand-held devices. They directly convert electricity into light by a doped transistor. Basically, an electron is allowed to drop in energy level through a hole (via doping) which results in the emission of a photon. This process creates light with the same wavelength and phase. In addition, this type of laser is often used to act as the optical pump for other types of lasers too (such as solid-state).

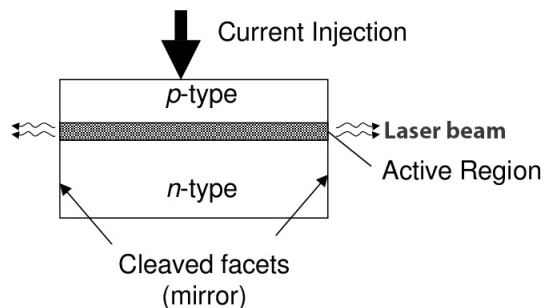


Figure 3: Example illustration of a semiconductor laser [8]

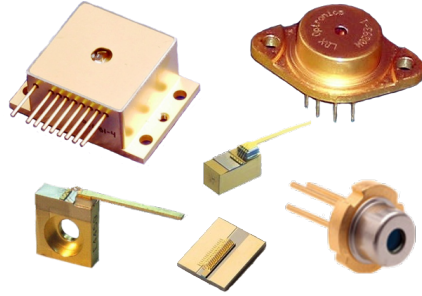


Figure 4: Typical packaging of semiconductor lasers

2 The laser (M-140)

This paper is the result of an independent study the purpose of which was to build an adjustable high-power vertical sheet laser that better captured slices of flow phenomenon. The requirements were:

- Power control
- Cylindrical lens
- Adjustable and secure stand
- High power output
- Capable of further application (such as turning the laser on/off with an external micro-controller).

The circuitry I envisioned required that I create a custom circuit. I determined the necessary components to meet the design parameters, then designed a circuit board based on those components. A commercially available adjustable light stand was adapted for the parts. See Figure 6 and Figure 7 (pages 6 and 7).

The laser used is originally built and sold for engraving purposes. It has a maximum power output of 2 Watts which is enough to burn wood within a second. The laser is fixed into an adjustable fixture with an adjustable G2 collimating lens, which then feeds into an adjustable cylinder lens in order to achieve a vertical sheet. This vertical sheet can be used to slice smoke and capture on camera the flow phenomenon. The diode itself is sold by numerous distributors though I could not locate a specific manufacturer. The aluminum heat sink and built in lens are also separate products, and can be all found together from the Ebay distributor listed in the citations [9].

2.1 The Apparatus

A few pictures of the device are below.



Figure 5: M140 laser



Figure 6: The laser in action

The control box is external to the laser. It has an optional input to control the laser's ON/OFF state. An external switch can be added to control time intervals during which the laser is on. For example, an Arduino could be used with a MOSFET to connect the RCA's positive terminal, to the RCA's ground terminal. The minimum time in which you can cycle the laser on and off is 0.1ms. Be sure to connect the RCA's ground to your external circuit's ground as well. See figure 8 as an example.



Figure 7: The fixture

A closer view of the control box can be seen here



Figure 8: The control box

The laser's protective cover should be placed over the laser during operation to prevent accidental reflections from escaping.

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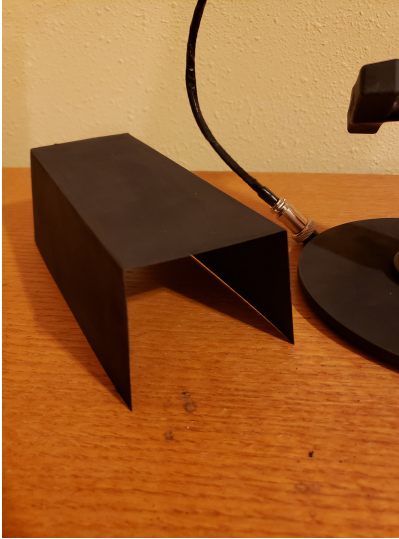


Figure 9: The protective cover

2.2 Optics

This laser is designed to cast a vertical/horizontal sheet of light. The purpose behind this is to 'slice' through a phenomenon and photograph it (or video). This slice allows us to see the complex activity of physical flow. A few examples can be found on Professor Jean Hertzberg's website, <http://www.flowvis.org/category/flow-vis-techniques/marked-area/laser-sheet/>. Here's an example image:

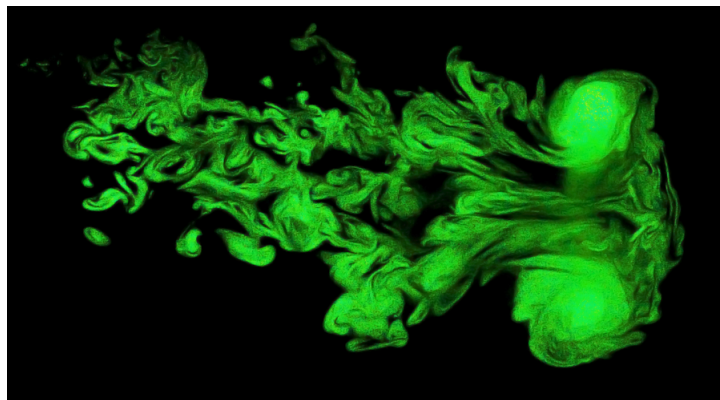


Figure 10: An image of smoke captured by slicing it with a vertical line from a laser [10]

The laser is a diode laser operating at 445nm (blue). The light is immediately collimated through a $G2$ [11] lens. It is a single element aspherical lens. This lens is also suitable for other lasers in the visible spectrum (not all lenses can work with different wavelengths/colors).

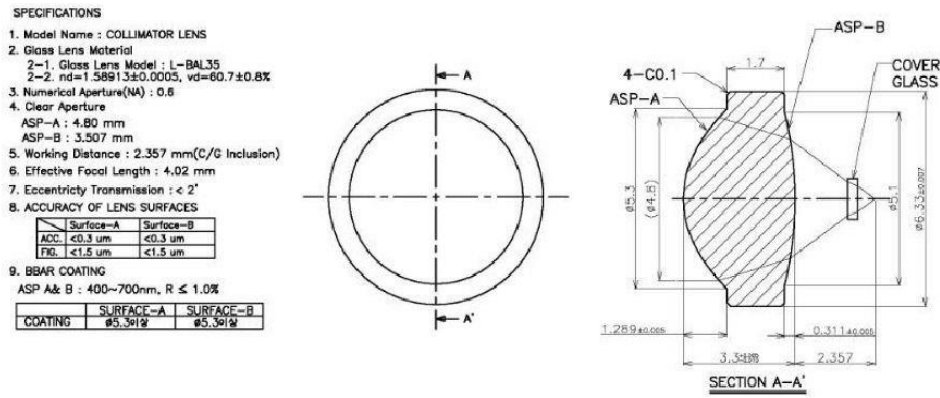


Figure 11: Specifications of G2 lens [12]

The light that enters this lens is not focused. When it passes through the G2 lens, it guides the photons to go straight instead of fan out, as in Figure 12:

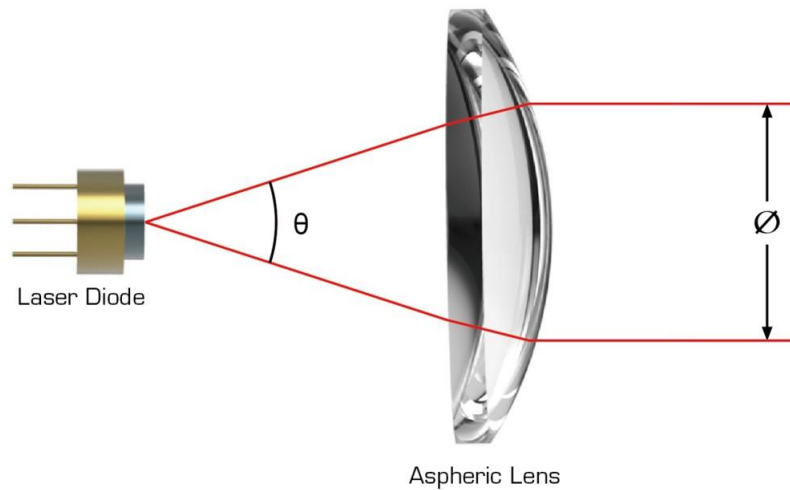


Figure 12: Example of lens collimation [13]

Once the light is collimated, it passes through a cylindrical lens that converts it from what would be a dot on the wall, to a line, as shown in Figure 13.

Not all lenses are created equal! Quality of lens is an important factor, as is the structure of the lens. Different lens structures can produce results of differing refinement. As stated, the structure of the lens will alter the beam. The Powell lens, as an example, will disburse the beam more accurately. You can see this in Figure 14 below.

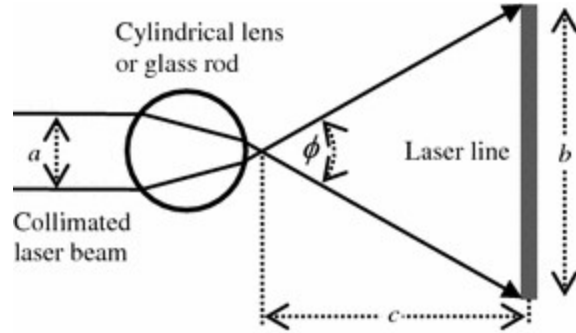


Figure 13: Example of collimation to vertical sheet [14]



Figure 14: Cylindrical lens vs Powell lens [15]

The Powell lens is, of course, much more expensive, and is not necessary for our purpose. A cheap cylinder lens can be found on ebay for \$1, while a cheap Powell lens can be found for \$30. It may serve as a great modification to this apparatus for a future experiment — to alter the setup to incorporate a Powell lens instead of a cylinder lens and compare the results.

2.3 The fixture

All the components used for this project can be found in the table in section 3.2, aside for a few parts. The fixture employs a round steel base to provide stability. This steel base was found in the scrap in the engineering building. Alternatively, one could have cut this base using a lathe. The mounting plate for the laser and cylinder lens was machined out of aluminum in the Duane physics machine shop on campus. The RAM adjustable mount can be adjusted at the head of the fixture, or at the base as well. The whole unit weighs approximately four pounds.



Figure 15: T-clamp for adjusting the fixture



Figure 16: Screws for holding the lens holder down



Figure 17: The G2 lens can be adjusted by turning the barrel

2.4 Specs

The laser diode is of a M140 M-Type. It's known as a multi transverse mode M140 laser diode. Do note this laser IS DANGEROUS, it can ENGRAVE, and will cause blindness if handled incorrectly.

Absolute Maximums		
Item	Absolute Maximum Ratings	Unit
Forward Current (Tc=25°C)	1.7	A
Allowable Reverse Current (Tc=25°C)	85	°C
Operating Case Temperature	50	°C

Electrical/Optical Characteristics				
Item	Min	Typ.	Max	Unit
Typical Optical Output Power @1 amp		1.2	1.4	W
Typical Operating Current		1	1.7	A
Dominant Wavelength	435		455	nm
Threshold current	80		220	mA
Operating Voltage	3.7		5.5	V
Focused Spot size	0.006	0.0008		Inch
Beam Divergence Full Angle (1/e ²)//	5	14	25	deg.
Beam Divergence Full Angle (1/e ²) - Perp	30	44	50	deg.

-Above specifications are for reference only. [16]

3 The circuit

This circuit was designed to drive the M-140 laser diode to near the specifications listed in the tables above. It is capable of over driving the diode and care should be taken to not exceed the physical stop on the potentiometer that is mounted to the circuit board's box. The circuit to drive the laser relies on the LM25085 chip from Texas Instruments. It is a Constant On-Time PFET Buck Switching Controller. A buck switching controller refers to the notion of down-stepping a DC voltage, known as *bucking*. The opposite is called *boost* (stepping up voltage). The controller aspect means that it can be configured to control the current and voltage to some programmed limit. Programming in this case refers to calculated external components. The data-sheet for this device can be found bundled in the folder that this document is found. The data-sheet for that also describes the calculations necessary to determine the component specs I designed the board around.

The board takes a 24v input and outputs 4.6 volts. The output's current can be adjusted via a potentiometer located on the board. This current limit is an analogue limit so that photography or videography would not have issues with flickering. This means that the laser is always on, contrary to pulse-width-modulation (PWM). PWM turns a device on and off very quickly, unseen to the human eye. Cameras on the other hand can pick this phenomenon up unintentionally. A fan is connected and can be turned on to aid in heat dissipation whilst the laser is under a high output. The fan is not always necessary and may be turned off but care must be taken as to not let the laser overheat under such a circumstance. It is advisable to always leave the fan on.

Bundled in this folder is a schematic, BOM (Bill of Materials), and a GERBER file.

You can upload the BOM and order the components to <https://www.mouser.com>. The circuit board can be ordered from <https://www.jlpcb.com> by uploading the GERBER.zip file.

- The Schematic can be used to reproduce a new design. Note the orientation of the MOSFET because of the use of a PFET.
- The BOM may have parts that are out-of-stock. This is common and a similar replacement is usually easy to find. Parts are no more than \$20 in total.
- The GERBER file is currently for V1.1. This can be submitted to any PCB manufacturer to have more circuit-boards made. www.jlpcb.com is a cheap and easy to use manufacturer with typical return times of about five days. This board in particular is a small \$2 + shipping.

3.1 How the circuit works

Below are images of the schematic and layout of the driving circuit board.

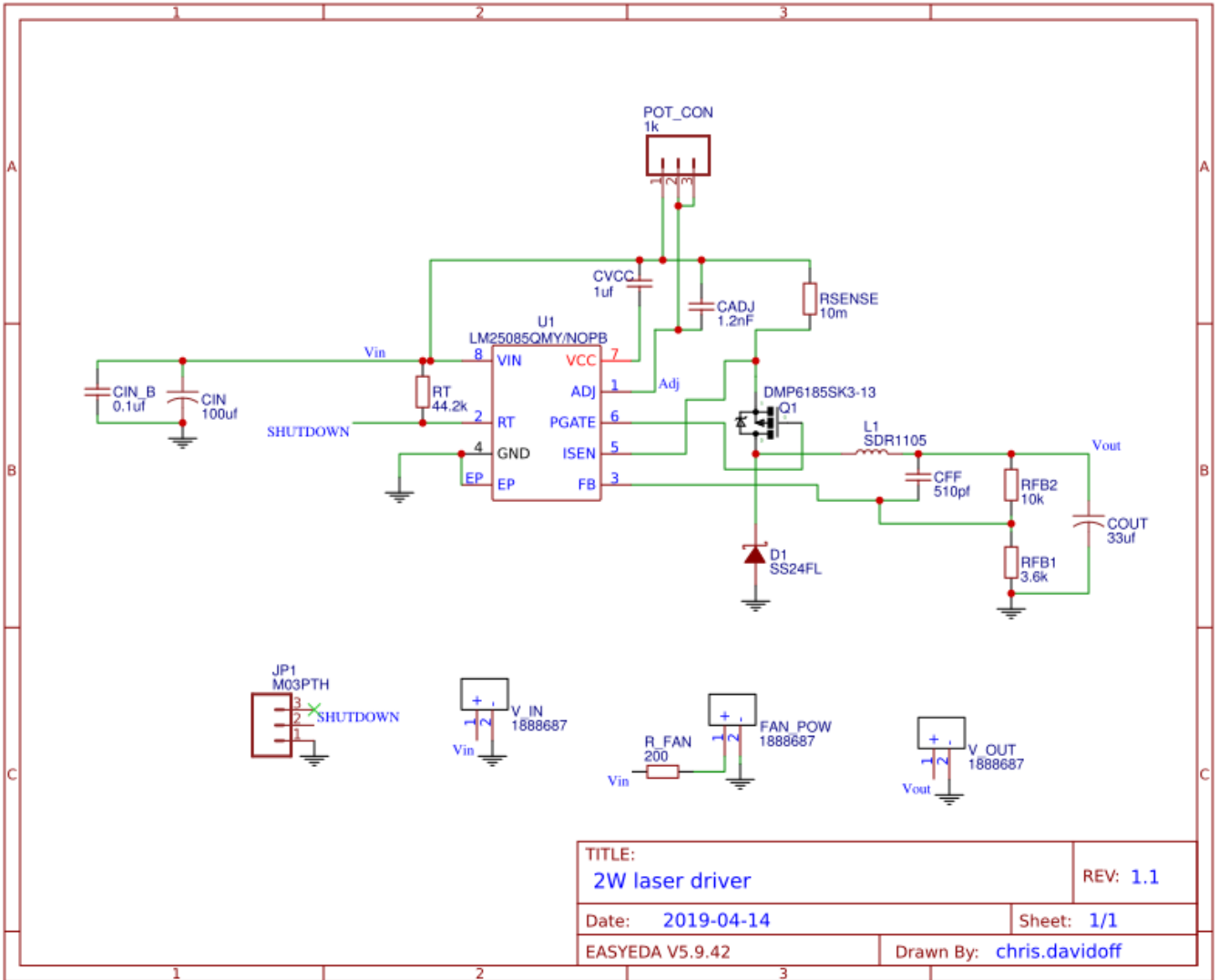


Figure 18: Full schematic

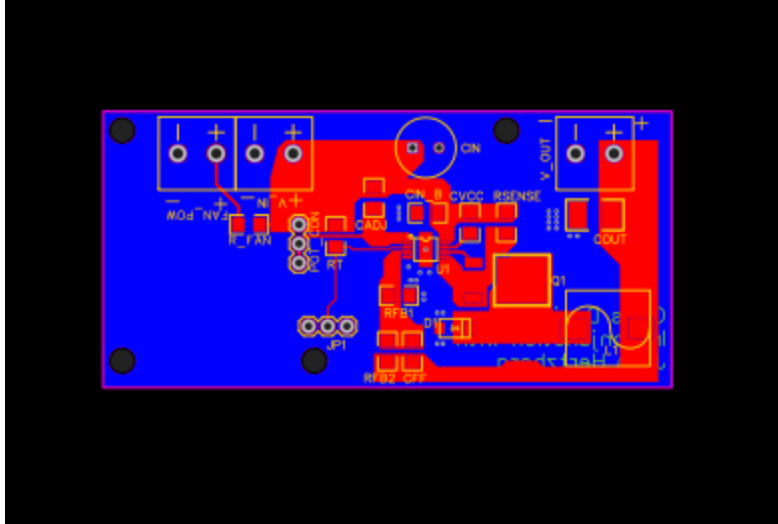


Figure 19: GERBER view of circuit board

Let's take a closer look at what's going on in this schematic. First and foremost with any integrated circuit, we need capacitors to smooth out the voltage and allow for on-demand current draws.

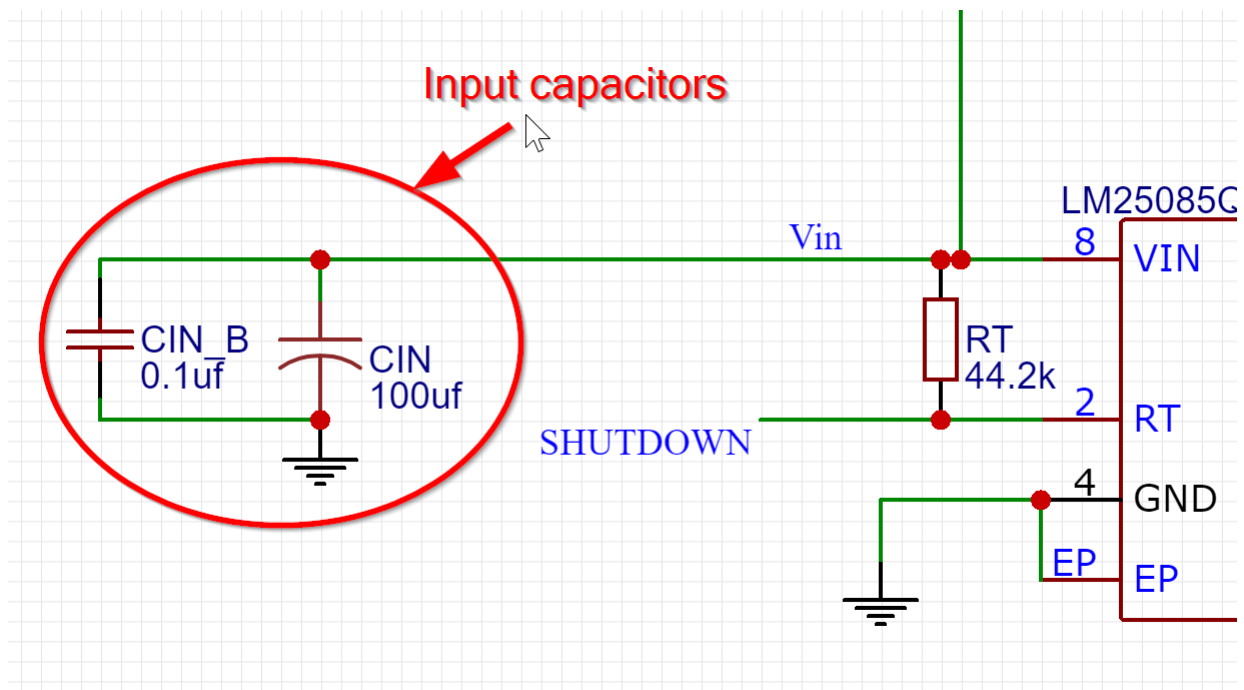


Figure 20: Input capacitor in schematic

Next up we have the resistor labeled as *RT*. This resistor is what programs the LM25085

chip to operate at a specific frequency. In this case, that frequency is about 650Khz. That number can be found for F_s

$$F_s = \frac{V_{out} \times (V_{in} - 1.56V + R_t/3167)}{V_{in} \times [(1.45 \times 10^{-7} \times (R_t + 1.4)) + (t_D \times (V_{in} - 1.56V + R_t/3167))]}$$

Where F_s is the frequency, V_{out} is the output voltage (4.6v), V_{in} is the input voltage (24v), and t_D is 50ns + the mosfet's delay (15ns). More information on this can be found in the datasheet [17].

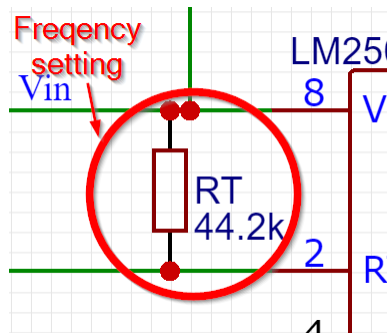


Figure 21: RT sets the frequency

At the top of the schematic we see something called *POT_CON*. This is where the external potentiometer is soldered into the board. This potentiometer acts as a varistor in order to adjust the current being delivered to the laser. Beneath it is a capacitor labeled *CADJ*, which simply helps smooth the signal out and reduce noise.

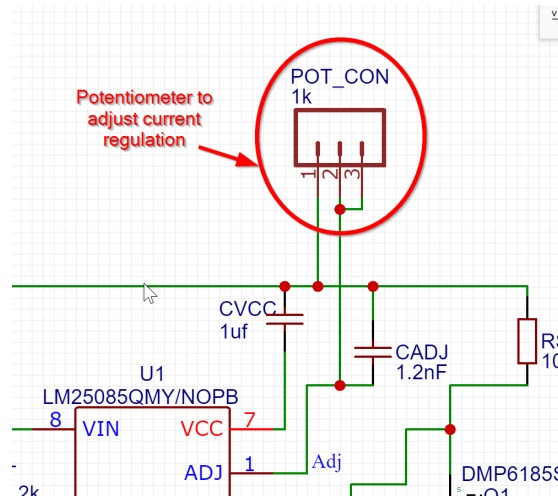


Figure 22: Connection to a potentiometer

To make for accurate current control, it's best to use a current sense resistor. Typically,

these resistors are very low in resistance and purchased with tight tolerances (0.1%). The equation to set the current is (solve for R_{SEN}):

$$I_{cl} = 40\mu A \times \frac{R_{ADJ}}{R_{SEN}}$$

Where R_{ADJ} is the potentiometer. Below is an image of R_{SEN}

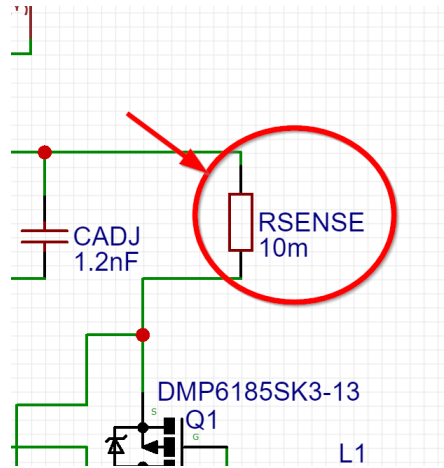


Figure 23: Rsense sets the maximum current capability

Now for the real bread and butter of the circuit. The DC-DC buck converter! This portion of the circuit relies on the properties of an inductor, denoted by $L1$

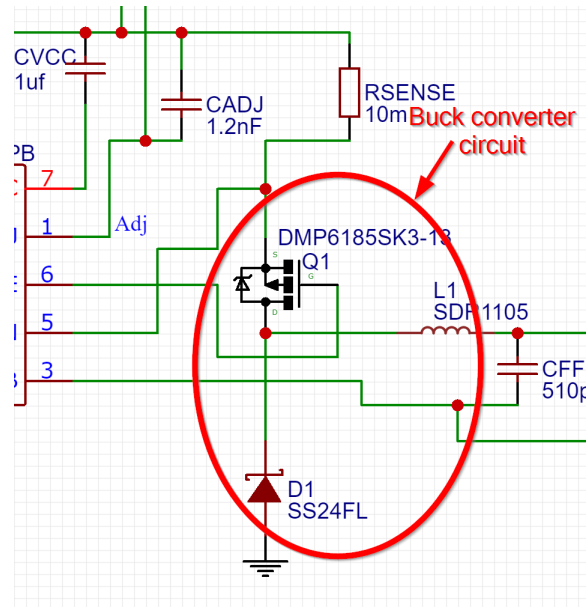


Figure 24: Primary elements of the buck-converter circuit

The other 2 primary components of a buck converter circuit is the switch and diode. The switch in this case is a mosfet, denoted by $Q1$ and the diode as $D1$. When the mosfet/switch is turned on (closed switch), current passes through the inductor and to the output. Because of physics, inductors do not like to change amperage. This is because current through an inductor creates a magnetic field. Technically speaking, the inductor is just a bunch of copper wire and can also be seen as nothing more than a wire. Based on this schematic, that would mean that when the mosfet turns on, the input voltage is directly connected to the output voltage. This would be bad, since our input voltage is 24 volts and we are designing this power supply to output less than 5 volts. It is because of the inductor that the output is not 24 volts.

So, when the inductor receives a voltage potential, it has its own reverse potential that resists the flow of current. Over time this breaks down as the magnetic field changes, allowing the voltage to rise on the output. This is where the LM25085 IC chip comes into play, as it senses when the voltage and/or current hits a certain threshold as designed into the circuit. When that happens, it shuts the mosfet off, thus opening the switch. At this point the load on the output will draw energy from the output capacitor and the collapsing magnetic field in the inductor, causing the output voltage to drop. The LM25085 chip will sense this, and will activate the mosfet again. Refer to the image below to see a schematic that shows this more clearly.

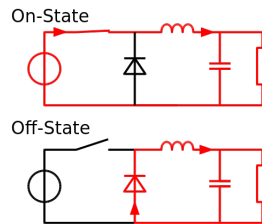


Figure 25: Buck-converter circuit illustration

Lastly, we can set the output voltage by choosing the values of $RFB1$ and $RFB2$. These resistors create a voltage divider that the LM25085 chip senses. The middle of the divider connects to the feedback pin on the IC as seen in the image below:

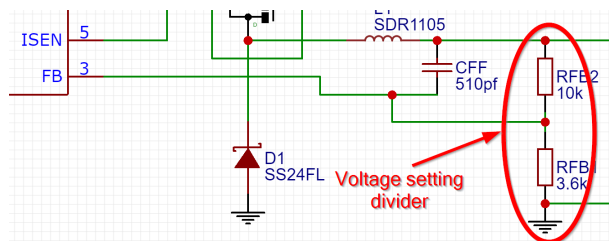


Figure 26: Voltage divider acts as a voltage setting

Testing the circuit suggests that the laser could be brighter. A fix to the circuit would be to increase the voltage to something greater than 5 volts. To do this, simply change resistor $RFB2$ from $10k\Omega$ to $14k\Omega$. I mistakenly set the output voltage lower than it should be resulting in the voltage drop across the laser's diode to not be high enough to achieve full current power.

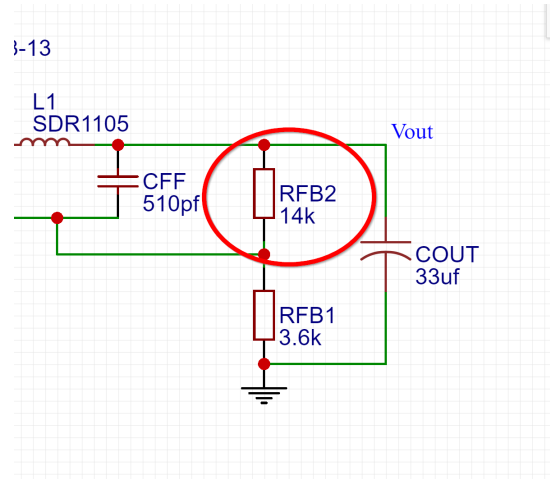


Figure 27: Voltage output change

If this is done, then the $RSEN$ resistor should be changed to $25m\Omega$ too, so that the maximum current is restricted to $1.6A$

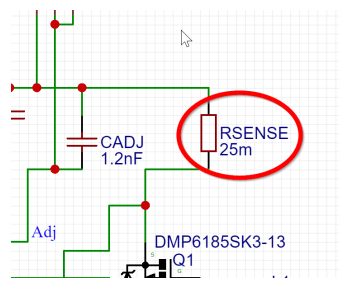


Figure 28: Current maximum change

An even more detailed analysis of how the IC chip and related circuits work can be found by reading its data sheet [17]

3.2 Items used

Purchased Items		
Item	Cost (\$)	URL
Laser module	65	https://www.ebay.com/itm/2W-Laser-Engraving-Module-M140-Diode-w-G-2-Lens-445nm-EZ-F-323187975206
Cylindrical lens	4	https://www.ebay.com/itm/120-Cylinder-Line-Glass-Lens-Laser-Optical-Lenses-%CE%A65-11mm/192581732842?ssPageName=STRK%3AMEBIDX%3AIT&_trksid=p2057872.m2749.12649
Laser diode (extras)	15	https://www.ebay.com/itm/M140-M-Type-Laser-Diode-445nm-5-6mm-2W-2-Watt-Blue-Beam-TO-323126349867?ssPageName=STRK%3AMEBIDX%3AIT&_trksid=p2057872.m2749.12649
DIN connector	7	https://www.amazon.com/CESS-Aviation-Socket-Cable-Connector/dp/B01ASF5HR2
BLACK 2.0 paint	20	https://www.amazon.com/Stuart-Semple-mattest-flattest-acrylic/dp/B0758GKKGZ
Potentiometer scale sheet	8	https://www.amazon.com/Taiss-Rheostat-Variac-Transformer-Potentiometer/dp/B07F24TT59
Chicken head knob	7	https://www.amazon.com/2-pack-Potentiometer-Knobs-Black-Chickenhead/dp/B0077RKJ32
Project box	10	https://www.amazon.com/Waterproof-Plastic-Electronic-Junction-Enclosure/dp/B07M5SZNR9
RCA terminal	7	https://www.amazon.ca/Eightnoo-Connector-Chassis-Amplifier-Terminal/dp/B076QD8VJZ
RAM mount	42	https://www.amazon.com/RAM-Mount-Surface-Humminbird-Helix/dp/B00TJ5JQI4/ref=sr_1_7?keywords=helix+5+mount&qid=1556997888&s=gateway&sr=8-7
Power switch	8	https://www.amazon.com/FBApayipa-Solder-Rocker-Switch-Toggle/dp/B01N2U8PK0
Circuit components	17	Excel spreadsheet

Total: \$210

This leaves you with a lot of extra little parts

4 Troubleshooting

This section is meant to be updated with fixes to any problems that occur while using the device.

4.1 Burnt out diode

It is possible to burn out the laser diode. As of this writing, the laser module costs around \$65 and is not desirable to have to replace due to accidental misuse. The diode itself however, only costs \$15 and is relatively easy to replace. Those diodes can be found readily on ebay:

<https://www.ebay.com/itm/M140-M-Type-Laser-Diode-445nm-5-6mm-2W-2-Watt-Blue-Beam-T0-18-323126349867>.

If that link fails, a google search for "M-140 laser diode" should find plenty.

Symptoms of a burnt out laser diode include

- No emission
 - Poor focusing capability
 - Poor output power
1. Unplug the laser
 2. The laser should be removed from its mounting location.
 3. Unscrew the fan off of the back
 4. Unscrew the front lens piece
 5. With a wide flat-head, unscrew the diode from the inside of the heatsink
 6. Cut the wire leads
 7. Solder leads onto the new wire leads (MAKE NOTE OF POLARITY OR LOOK IT UP)
 8. Screw the diode back into place
 9. Screw the front lens back on
 10. Screw fan back on
 11. Mount laser
 12. Set laser to lowest power setting
 13. Plug laser back in and turn on
 14. Adjust front laser lens to achieve correct collimation at 3 feet

5 Future Improvements

A number of improvements can be made to this apparatus. As it is, the G2 lens is not doing a great job at collimating the laser. On top of that, the Cylinder lens is not very high quality. There are alternative types of cylinder lenses that could do a better job, or even better, a Powell lens would be even better. Other improvements can be made to where the laser mounts, a new machined plate for adjustability would be great, especially if a new lens is to be added. The power output of the laser has been identified to max out at $0.4W$. The problem was identified and the output voltage was not correctly configured. Necessary changes can be found at the bottom of section 19. In addition, a more accurate voltage output (which is not necessary in this case, as current control is the primary goal) can be configured. To do so, section 8.2.2.6 depicts the three components that help reduce output ripple. Again, this is not necessary as it will not affect current regulation.

6 Bibliography

References

- [1] popinversion, https://www.redbrick.dcu.ie/~lickylip/laser/basic_principles_of_lasers.htm
- [2] <https://science.howstuffworks.com/laser7.htm>, <https://science.howstuffworks.com/laser7.htm>
- [3] Solid state reference https://www.rp-photonics.com/solid_state_lasers.html
- [4] Gas laser RP Photonics https://www.rp-photonics.com/gas_lasers.html
- [5] Gas laser picture <https://n.ethz.ch/~kluszczyk/index.php?page=lasers/hene>
- [6] wikipedia https://en.wikipedia.org/wiki/Dye_laser
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- [9] Distributor for the M140 laser package <https://www.ebay.com/itm/2W-Laser-Engraving-Module-M140-Diode-w-G-2-Lens-445nm-EZ-Focus-Burning-/323187975206>
- [10] Photo by Jeffrey Pilkington and Alex Meyer
- [11] g2 lens <https://www.sanwulasers.com/product/lenses>
- [12] G2 specifications <https://www.aliexpress.com/item/G2-Focal-Lens-6-33mm-Collimation-Lens-Coated-Glass-Lens-f-RGB-Laser-FL-4-02mm/32622608238.html>
- [13] Image <http://www.hypoptics.com/lens-assembly/collimating-lenses.html>
- [14] Laser diode beam manipulations https://link.springer.com/chapter/10.1007/978-94-017-9783-2_3
- [15] Cylinder vs Powell https://www.google.com/search?q=powell+lens+vs+cylinder&newwindow=1&rlz=1C1MSIM_enUS555US555&source=lnms&tbm=isch&sa=X&ved=0ahUKEwig9YW0mfThAhUEWaOKHeAbDIcQ_AUIDygC&biw=1920&bih=937#imgrc=aEwaR-yYVHTL5M:
- [16] *Diode data*, available at <https://jtechphotonics.com/wp-content/uploads/2013/05/Instruction-Manual-2W-445nm-Laser-Diode-Component-V6.pdf>
- [17] LM25085 datasheet, <http://www.ti.com/lit/ds/symlink/lm25085.pdf>