Wisconsin Photoreactor Platform
Fabrication and Operation Guide

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Contents

1 Introduction

The Wisconsin Photo-Reactor (WPR) is made to be easily assembled. This document is meant to help chemists accomplish this assembly. Each reactor has two major components requiring detailed custom assembly:

- The 3D printed enclosure, described in subsection 2.2
- The drive electronics, described in subsection 2.3

With these two major components complete, assembly of the WPR is relatively straight-forward. Details of final assembly are described in subsection 2.4.

Throughout this document we refer to an online repository containing source and design files. This repository appears at https://github.com/uw-madison-chem-shops/wisconsin-photoreactor. This repository contains everything including the source for this very document.

A working WPR is made up of many separate commercially available parts. This guide assumes that you have already done the work of procuring those parts. The online repository contains several README files with detailed part numbers and suggested vendors.

The WPR is a living project. We welcome and encourage duplication and modification of our designs and documentation. If you notice problems or omissions within this assembly document, please consider opening an issue or pull request.

TODO: FIGURE 1 FROM OPERATION GUIDE

A WPP device consists of a base, reaction module and reactor driver (Figure 1). The base houses the photon source and cooling fan. The reaction module is comprised of a reflective reaction chamber and rigid vessel holder. A digital driver board, analog driver board or simple circuit integrating a commercial light emitting diode (LED) driver can be fitted to the base to drive the reactor. Each component is highly versatile, and apparatus assembly is fully modular (Figure 1B).

Through variation of each component, one can quickly produce bespoke WPP devices to meet specific research needs. Configurational variations are easily documented for later reproduction. Detailed below are instructions for configuration and documentation of each component in a WPP apparatus.

2 Fabrication

2.1 Photon Source

TODO: FIGURE 2 FROM OPERATION GUIDE

The WPP architecture utilizes industry standard 20 mm LED star circuit boards mounted with 3 high-intensity LEDs to deliver photons to photoreactions (Figure 2A). These LED star boards are commercially available or can be easily fabricated (see fabrication guide). The range of wavelengths provided by a LED star depends upon the emission profile of the mounted LEDs. Through variation of the LED star integrated into a base (Figure 2B), the user can control the wavelengths of light delivered by the photon source to a reaction vessel. See fabrication guide for LED star installation instructions.

2.2 3D Printed Enclosure
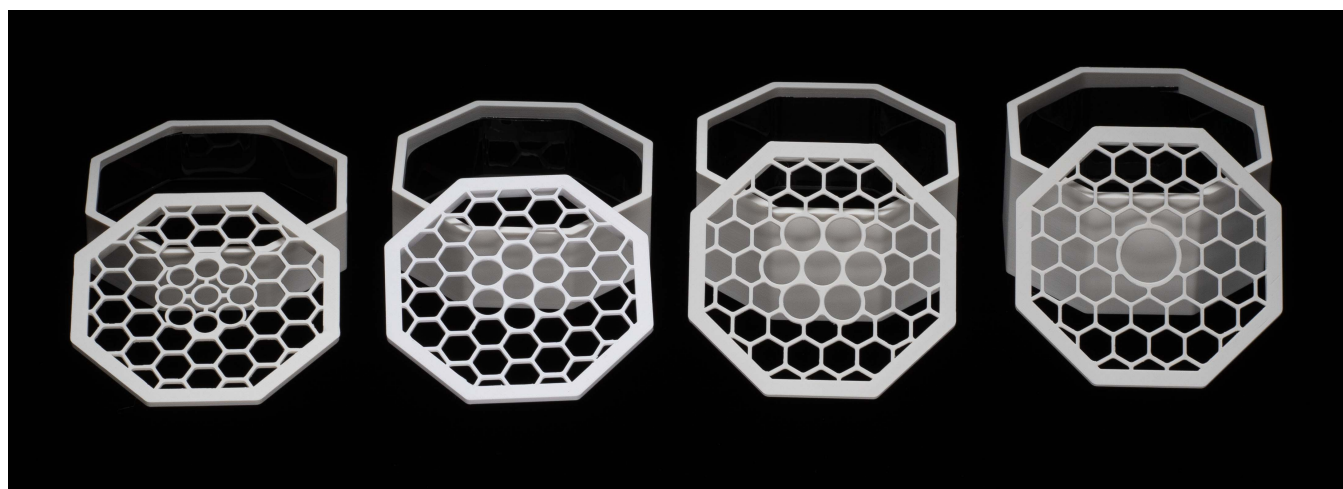
A WPP reaction module consists of a reaction chamber and vessel holder. By modifying chamber height and adjusting holder geometry, one can produce modules compatible with reaction vessels of various types and sizes. Template reaction chamber and vessel holder CAD designs are provided in the project repository. CAD designs and 3D-printable models for modules compatible with 1-, 4-, 8- and 24-mL vials are also provided in the repository (Figure 3A—B).

A single reaction module can offer multiple layouts for reaction vessel placement. For the provided modules, two vessel placement configurations exist. First, the single reaction configuration, where one vessel is placed in the center of the module directly above the photon source (Figure 3C). This configuration exposes one vessel to maximum light intensity. Second, the multiple reaction configuration, where multiple vessels are placed in a circle around the photon source (Figure 3D). This configuration exposes each vessel to less light relative to the single reaction configuration but provides equivalent exposure to each vessel. Through variation of the reaction module, the user can configure the reaction vessel type, size and placement within a WPP apparatus.

The body of the WPR is made up of three main pieces:

- Base, containing LEDs, fan, and drive electronics.
- Top plate accepting reaction vials.
- Chamber walls spacing the top plate at the appropriate distance away from the base.

The WPR base is the same for all reactors. Look within the repository in the subdirectory "photoreactor-base" to find design and production files to produce the WPR base. You will also need to print a cable anchor, see files in that same directory.

The top plate and chamber height must be specified for the particular reaction vessels used. Four examples for different vial sizes are pictured above. Look within the repository in the subdirectory "photoreactor-tops" to find existing designs. We encourage you to design your own if none of these suit your application. Consider adding your new designs to repository so that others may benefit from your design efforts.

When interacting with the design files in our online repository you will see several different filetypes. We have designed the WPR enclosure using Fusion 360, and have included those f3d design files for those that wish to extend or modify the designs. Interacting with f3d files will require a Fusion 360 license. You will also find stl files in the online repository. These are common 3D-model exchange files which can be viewed using any 3D modeling program. In fact, GitHub itself has a built in stl viewer which you may use to inspect our designs.

There are many options for getting your enclosures printed. We recommend white PLA as a material, although any white material should work—we have also used ABS. If you are printing yourself, follow the instructions provided by your printer to produce slices and program your printer. Note that you will need support material for the base. Any company or shop offering 3D printing as a service should be able to accept our stl files without further modification.

We have succesfully printed using the following printers:

- Ender 3
- Stratasys uPrint SE Plus
- Ultimaker 3

Once your parts are done you may need to remove extra bonding material with a razor blade or exacto-knife. The three pieces of your reactor should fit together snugly and securely.
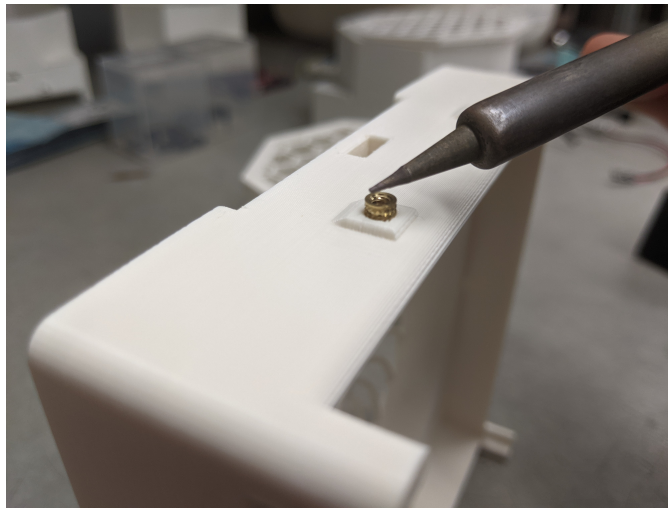
Each WPR base contains seven threaded heat inserts. These allow components such as the drive circuit board to rigidly attach to the base via machine screws. Use a soldering iron to carefully heat these while pushing them into their cavities.

2.3 Electronics

The WPR incorporates small circuit boards controlling the incorporated LED and fan. We refer to these small boards as "drivers". There are two types available: the "analog-driver" and "digital-driver". Refer to the associated directories in the online repository for design files for each of these.

Both drivers are built around Mean Well's LDD-1000L LED driver module. This module delivers constant current up to one amp. The current delivered can be controlled electronically in several different ways. WPR

users wishing to understand this design should refer to Mean Well's datasheet.

The analog-driver circuit is made to be as simple as possible. The circuit accepts DC 12 V through a barrel jack. A small knob is used to adjust light intensity. Fan speed is not adjustable. Refer to subsubsection 2.3.1 for analog-driver assembly instructions and further explanation.

The digital-driver circuit is made to be incorporated into an I^2C-based digital control system. In addition to power, these boards have 4-pin connectors to carry the I^2C serial data. The digital-driver is pictured above, without any connectors attached. Refer to subsubsection 2.3.2 for digital-driver assembly instructions and further explanation.

When interacting with the design files in our online repository you will see several different filetypes. These circuit boards were designed using KiCad, a free and open source electronics CAD software. All KiCad files are contained within the "kicad" subdirectories. You may modify and extend these designs however you like.

Those wishing to reproduce our designs should refer to the gerber subdirectory. Within the gerber directory you will find zip files for each separate version of the PCB. You may upload these zip files to PCB manufacturers when ordering copies of our designs.

A WPP device can be driven using a digital driver circuit board, an analog driver circuit board or a simple electronic circuit with a commercial LED driver (Figure 4). Digital and analog driver board fabrication instructions are provided in the fabrication guide. All provide power to the cooling fan and constant current to the LEDs. All utilize 1000 mA forward current LED drivers. Each driver provides different configurational abilities.

2.3.1 Analog Driver

The analog driver circuit is meant to be as simple as possible while still allowing for reproducible LED intensity control. To this end, the number of components has been minimized as much as possible. A full schematic of the analog circuit appears at the end of this section. A bill of materials appears within the README of the online repository.

Through use of the analog driver board, one can control WPP device light intensity. This control is achieved through adjustment of the board-mounted potentiometer. No software is required, and multiple WPP reactors can be connected in series to a single power source (Figure 6A). However, fan speed isn't adjustable and is maintained at maximum. Relative light intensity can be determined using the analog driver board test points and a multimeter (Figure 6B-D). The measured voltage can then be converted to relative light intensity using the values in Table 3. These values are derived from the manufacturer's datasheet for the analog board's LED driver. See the fabrication guide for more details.
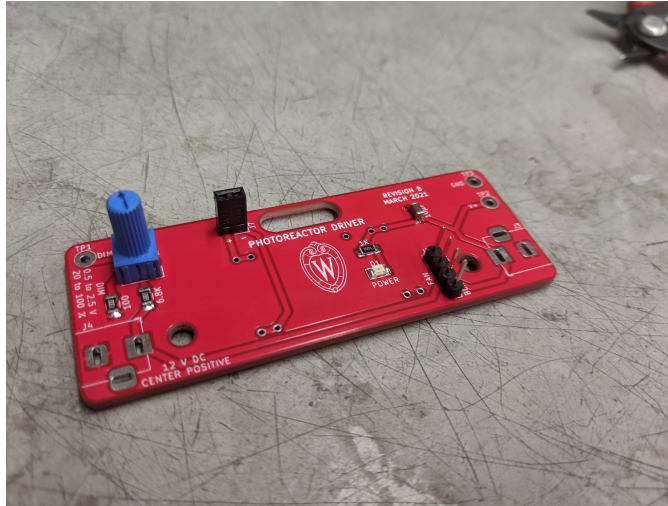
TODO: TABLE 3 FROM OPERATION GUIDE
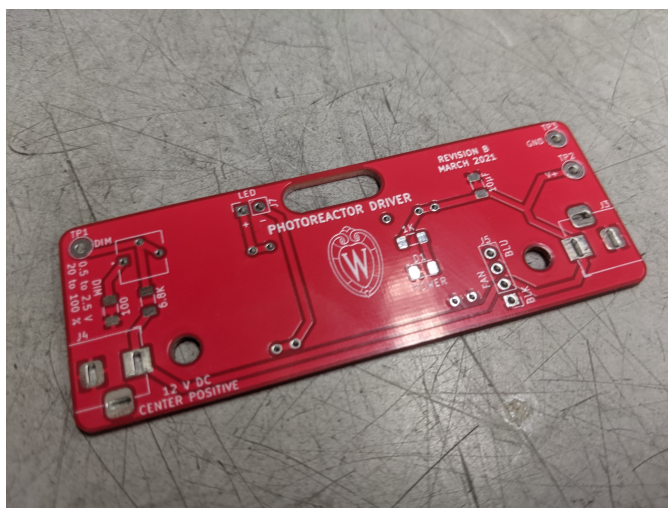
Your PCB manufacturer will send you a bare board, as seen above.
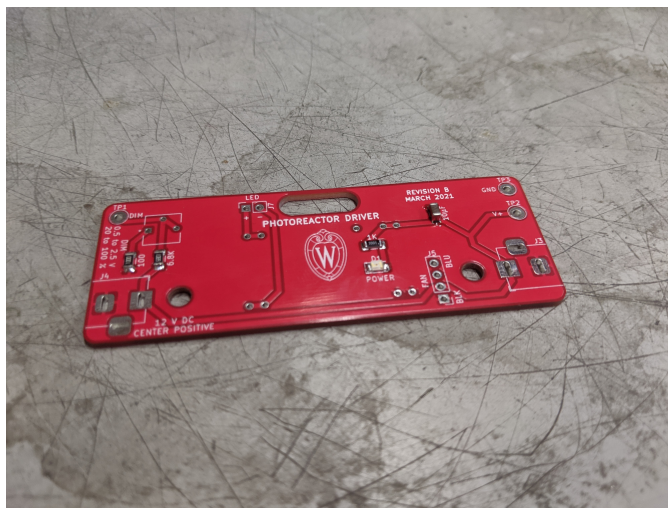
Begin by adding the surface mount components. Recommend thin solder, e.g. 0.015''. The LED does have a polarity—ensure that the small green line points towards ground (left). Once done your board should look like the above.


Next, add the connectors and the potentiometer knob. From now on we recommend standard gage solder, e.g. 0.031''. Once done your board should look like the above.
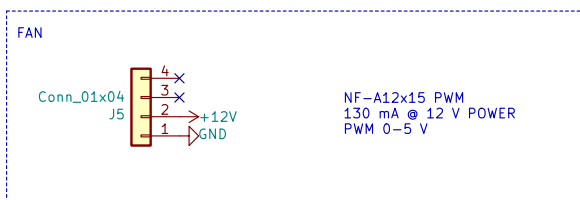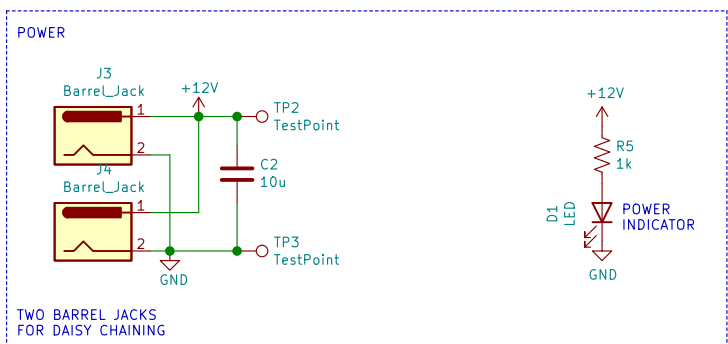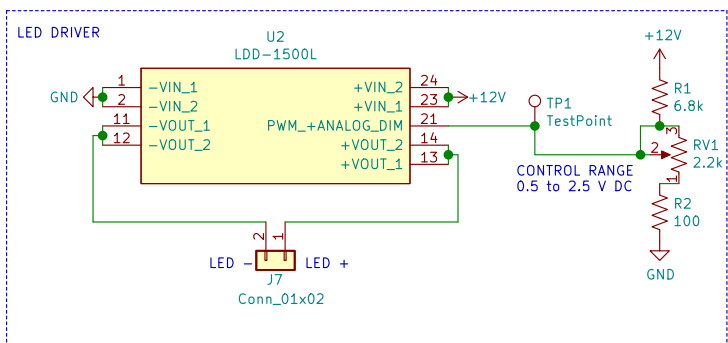

Next, add the barrel jacks and the test points. With these added you may plug in your board for the first time.

You should see your power indicator LED illuminate. You should also be able to adjust the DC control voltage relative to ground by turning the knob, as shown above.
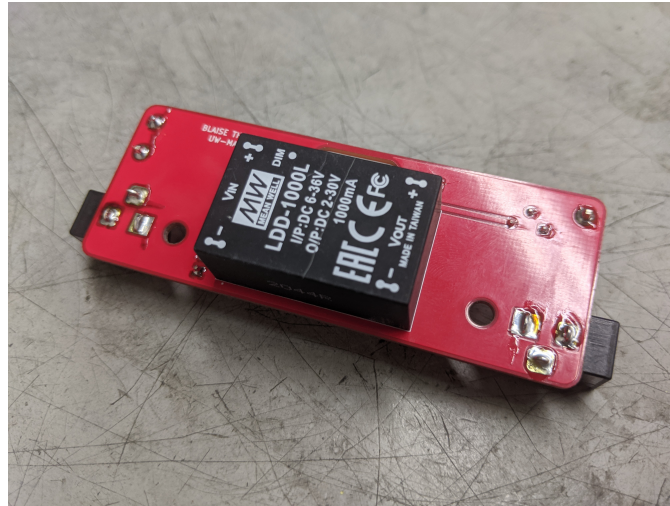
Finally, add the Mean Well LED driver. Note that this component goes on the back of the PCB, as shown above.

LED DRIVER

U2
LDD-1500L

GND
1 -VIN_1   +VIN_2 24
2 -VIN_2   +VIN_1 23   +12V
11 -VOUT_1 PWM_+ANALOG_DIM 21
12 -VOUT_2   +VOUT_2 14
                    +VOUT_1 13

+12V

R1
6.8k

TP1
TestPoint

CONTROL RANGE
0.5 to 2.5 V DC

2 RV1
   2.2k

R2
100

GND

2 1
LED - J7 LED +
Conn_01x02

POWER

J3
Barrel_Jack

1   +12V
2

J4
Barrel_Jack

1
2

TP2
TestPoint

C2
10u

GND

TP3
TestPoint

+12V

R5
1k

D1
LED

POWER
INDICATOR

GND

TWO BARREL JACKS
FOR DAISY CHAINING

FAN

Conn_01x04
J5

4
3
2   +12V
1   GND

NF-A12x15 PWM
130 mA @ 12 V POWER
PWM 0-5 V

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Sheet: /
File: driver.sch

Title: Analog Photoreactor Driver

Size: USLetter | Date: 2021-03-05 | Rev: B
KiCad E.D.A. kicad 5.1.8+dfsg1-1+b1 | Id: 1/1

2.3.2 Digital Driver

The digital driver circuit can be controlled from a computer or some other digital device. We built our driver to work over I2C, consistent with an emerging standard for many "maker" products. While the physical connectors may be different, our digital circuit is compatible with the following systems.
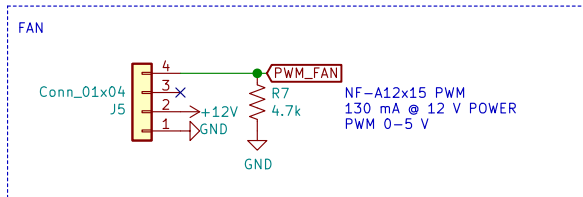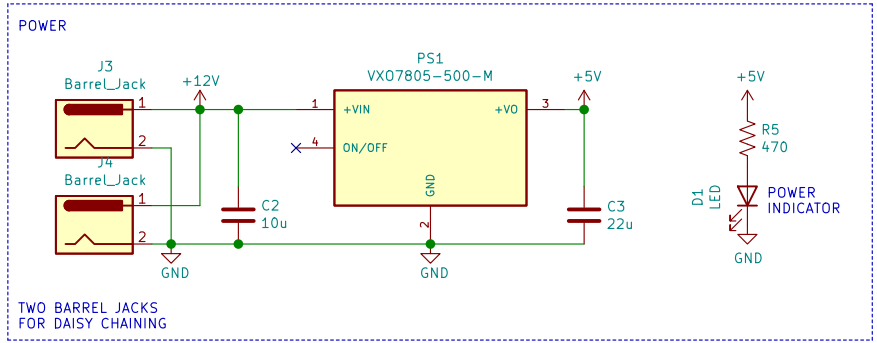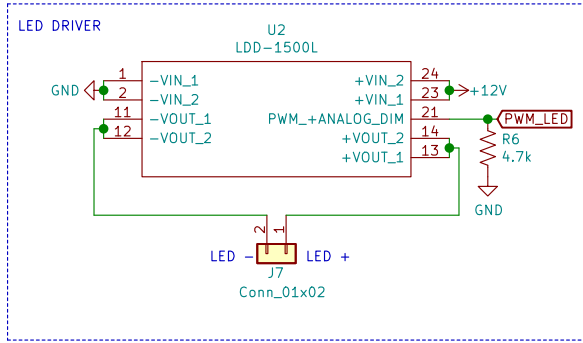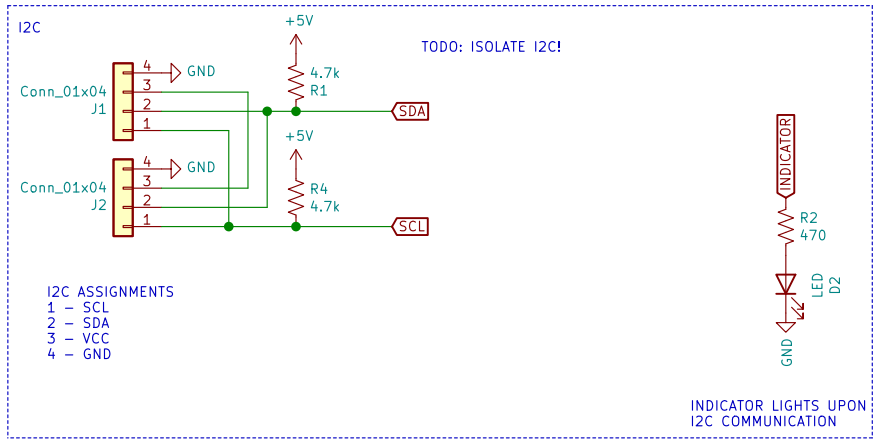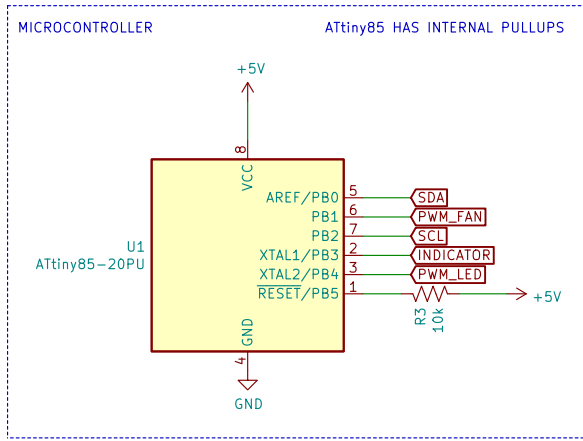
- Adafruit STEMMA
- Sparkfun Qwiic
- Seeed Grove

Through use of the digital driver board, one can control WPP device light intensity and fan speed. This control is achieved by connecting a control unit, like an Arduino Uno, to the digital driver board using custom software. Multiple WPP devices with digital driver boards can be connected to a single control unit and power supply (Figure 5). Open-source software for interfacing digital driver boards and Arduino Uno control units is provided in the project repository. Instructions for implementing this software and controlling WPP devices using it are in the fabrication guide. Other I2C peripherals can be connected to digital driver boards to expand functionality, but software must be produced to interface with them.
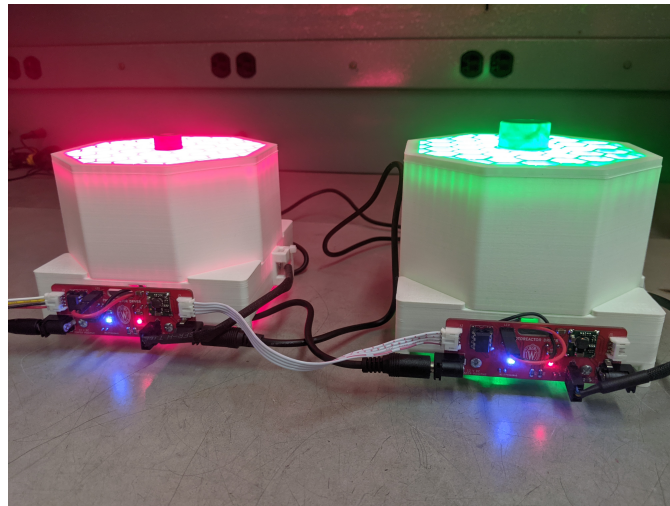
Each digital driver is based around an ATtiny85 microcontroller acting as an I2C peripheral. Multiple digital driver boards may be "networked" together onto one I2C bus by simply daisy-chaining the boards together, as shown above. In such a use-case you must choose a unique I2C address for each ATtiny85 peripheral.
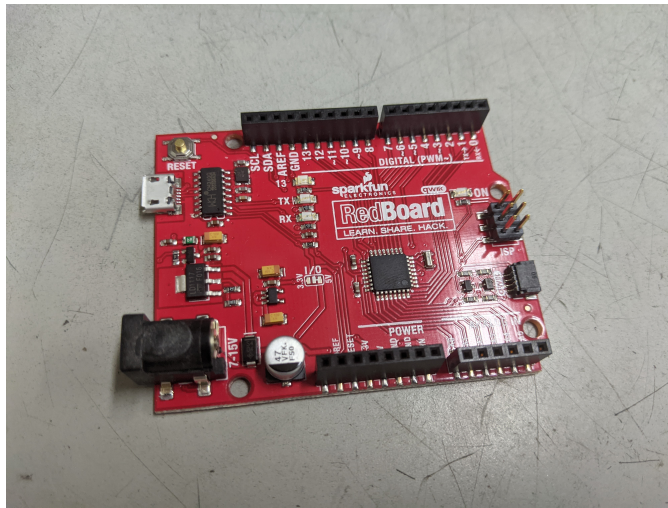
There are many ways to interface with the I2C bus. We have used a SparkFun RedBoard, pictured above. You may find an example within the online repository that dynamically controls both the LED intensity and fan speed.

MICROCONTROLLER — ATtiny85 HAS INTERNAL PULLUPS

+5V
VCC 8
AREF/PB0 5 — SDA
PB1 6 — PWM_FAN
PB2 7 — SCL
XTAL1/PB3 2 — INDICATOR
XTAL2/PB4 3 — PWM_LED
RESET/PB5 1 — R3 10k — +5V
U1 ATtiny85-20PU
GND 4
GND

I2C — TODO: ISOLATE I2C!

+5V
Conn_01x04 J1
4 — GND
3
2
1
4.7k R1
SDA

+5V
Conn_01x04 J2
4 — GND
3
2
1
R4 4.7k
SCL

I2C ASSIGNMENTS
1 — SCL
2 — SDA
3 — VCC
4 — GND

INDICATOR
R2 470
LED D2
GND

INDICATOR LIGHTS UPON
I2C COMMUNICATION

LED DRIVER
U2 LDD-1500L
GND — 1 -VIN_1   +VIN_2 24
      2 -VIN_2   +VIN_1 23 — +12V
     11 -VOUT_1   PWM_+ANALOG_DIM 21 — PWM_LED
     12 -VOUT_2   +VOUT_2 14 — R6 4.7k
                  +VOUT_1 13
GND
J7 Conn_01x02
LED −   LED +
2   1

POWER
J3 Barrel_Jack
1
2
+12V
J4 Barrel_Jack
1
2
GND
C2 10u
PS1 VXO7805-500-M
1 +VIN   +VO 3 — +5V
4 ON/OFF
GND 2
GND
C3 22u
+5V
R5 470
D1 LED
POWER INDICATOR
GND

TWO BARREL JACKS
FOR DAISY CHAINING

FAN
Conn_01x04 J5
4 — PWM_FAN
3
2 — +12V
1 — GND
R7 4.7k
GND
NF-A12x15 PWM
130 mA @ 12 V POWER
PWM 0-5 V

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File: driver.sch
Title: Digital Photoreactor Driver
Size: USLetter   Date: 2021-01-22   Rev: 1.0.0
KiCad E.D.A. kicad 5.1.8+dfsg1-1+b1   Id: 1/1

2.3.3 Simple Driver

TODO: FIGURE 7 FROM OPERATION GUIDE

The LED driver circuit shown in Figure 6 is the simplest way to drive a WPP apparatus. Neither light intensity nor fan speed can be configured when using the simple LED driver circuit. Both are maintained at maximum power. However, no circuit board fabrication is required, and any commercial 1000 mA LED driver can be used.

2.4 Assembly

Once 3D printing is done and PCBs have been filled, WPR assembly is fairly straight-forward. The various electronic components must be installed into the base (pictured above), as described in subsubsection 2.4.1. Reflective coating must be added to the chamber walls, as described in subsubsection 2.4.2. After these final steps, your WPR is ready for synthesis!

2.4.1 Base
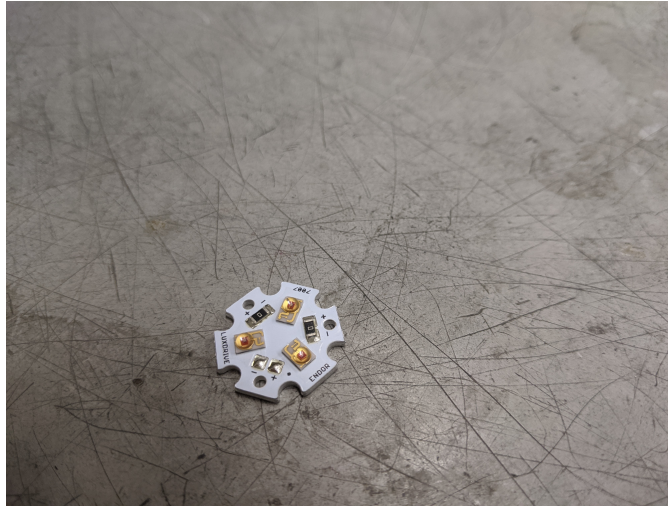
If possible, it's best to order your LEDs pre-attached to an "LED star" heat sink. Otherwise you may order bare LED stars and discrete LEDs. Either way, you will have a filled LED star as pictured above. In this example we are using LED Supply part number 07007-PL000-F.
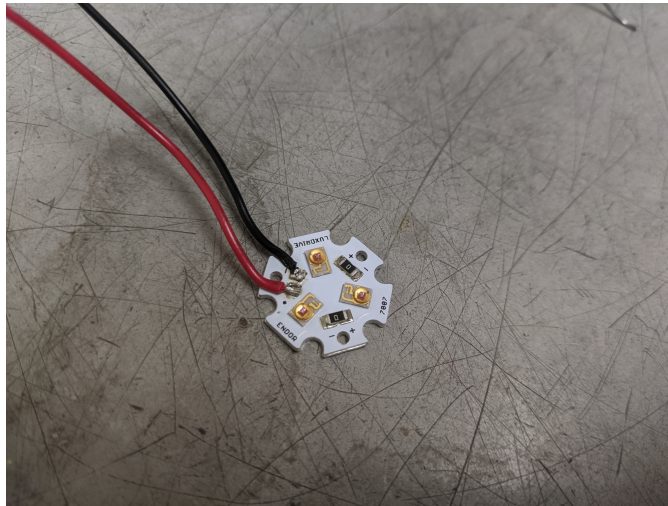

Start by soldering leads onto your LED star, using the red positive black negative convention. Soldering here may be challenging, as the LED star itself will resist your efforts to heat it. Adding some lead-based solder may help, due to the lower melting point.
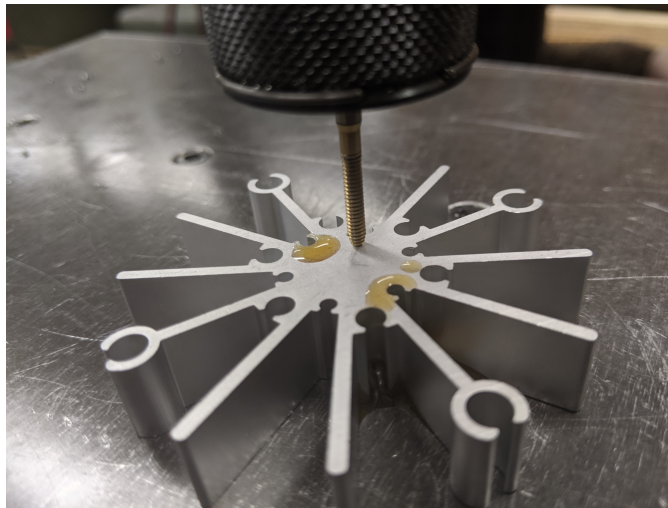
The aluminum heatsinks arrive preformed but without any tapping. Tap the heatsink for imperial 4-40 machine screws. We used thread-forming tap: OSG 1400105300 with a pneumatic "air-tapper" (pictured above), but you may do this by hand if you wish. You will need to tap just two of the innermost holes.
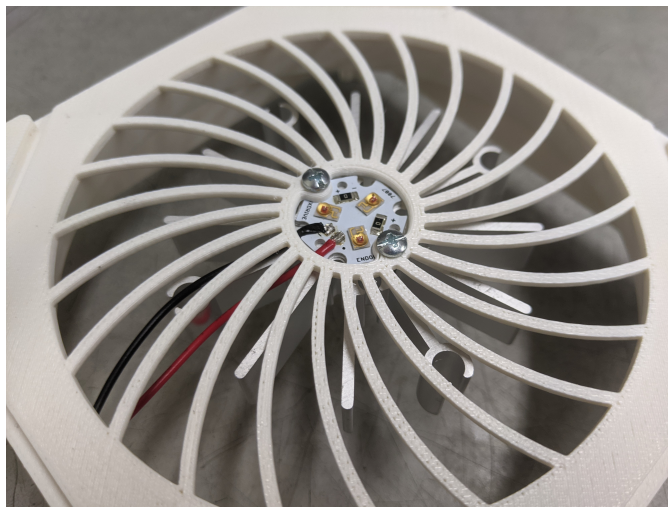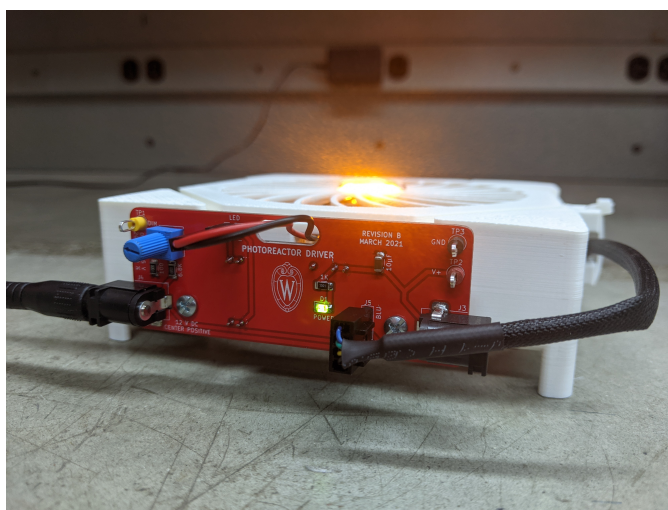

Install the LED star and heatsink with wires facing towards printed hole. Use 1/4" screws.

Install the fan. Pay special attention to the orientation of the fan, including the location of the cord. Use 3/4"
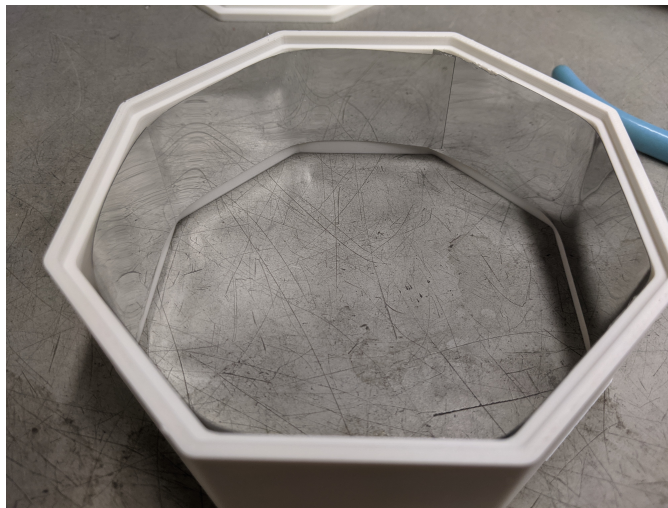screws here.

Install the cable anchor using a 1/4" screw. Use a zip tie to capture the fan cord, as shown above.

Install the driver board using the threaded standoffs. Plug the LED and fan into the board. Pay special attention to the orientation of the fan connector. You should now be ready to test your base—remember to use proper eye protection!

2.4.2 Top

Simply cut the reflective material to line the chamber. It's good to leave overlap around the interior, as shown. Remove the backing and stick the material to the chamber walls.

3 Operation

Once a WPP apparatus is configured with the desired photon source, reaction module and reactor driver, it can be used to drive photoreactions.

TODO: FIGURE 8 FROM OPERATION GUIDE

To conduct a photoreaction using a WPP device, an assembled apparatus should be placed on a lab stir plate, to provide reaction mixture stirring, and reaction vessels should be inserted into the apparatus in the desired layout (Figure 8). The 130 by 130 mm footprint of the WPP architecture is compatible with typical stir plates. A standard 12 V power supply can then be plugged into the reactor driver to turn on the device and start reaction. A single 12V 2 A power supply is sufficient to drive 2 WPP devices simultaneously. A switch can be installed between the WPP apparatus and power supply to provide power switching.

Reaction and photon source cooling is provided by the computer fan integrated into the base. Additional cooling can be achieved through placement of fans above the WPP apparatus or by placing a WPP device on a stir plate within in a refrigerator or cold room.

Once finished, the WPP apparatus can be switched off by simply unplugging it and disassembled for storage.

4 Documentation

Users should report the following for each photon source used:

(1) Max emission wavelength for LEDs. (2) Manufacturer and part number for LEDs. (3) Supplier and part number for LED star (if commercial).

This information enables precise reproduction of WPP photon sources. Characterization of a photon source's emission profile using a spectrometer is recommended but not required for reproduction. Emission profiles for commercial LEDs are supplied in part datasheets provided by manufacturers. A list of WPP-compatible LED stars exhibiting emission profiles across the visible range is provided in the project repository.

Users should provide and report the following for each module used:

(1) Original CAD designs for both module parts. (2) 3D-printable models for both module parts. (3) Photos of each reaction vessel placement configuration. (4) Manufacturer and part number for reaction vessel.

These provisions enable precise reproduction of reaction modules. Documenting the height a vessel is held above the photon source is recommended but not required for reaction module reproduction. All reaction modules provided in the project repository hold vessels a standardized 7 mm above the photon source.

Users should report the following when an analog driver board is used:

(1) Measured test point voltage. (2) Relative intensity at which LEDs are driven (0 to 100

These provisions enable precise reproduction of reaction conditions for transformations carried out using WPP devices fitted with analog driver boards.

Users should provide and document the following when a digital driver board is used:

(1) Software used to operate the digital driver board, control unit and any other peripherals. (2) Relative intensity at which LEDs are driven (0 to 100(3) Relative fan speed (0 to 100

These provisions enable precise reproduction of reaction conditions for transformations carried out using WPP devices fitted with digital driver boards

Users should report the following when a simple LED driver circuit is used:

(1) Manufacturer and part number for LED driver.

This information enables reproduction WPP devices fitted with the simple LED driver circuit.

5   Safety

WPP reactors utilize high-intensity light emitting diodes (LED) that can cause eye damage if proper safety precautions are not observed. Light-filtering safety glasses should be worn whenever a WPP apparatus photon source is powered. Care must be taken to use safety glasses protective against the specific emission wavelengths of the photon source.