Mar 17, 2020

# Illuminated Orbital Shaker for Microalgae Culture V.3

Jakub Nedbal[1]

[1]King's College London

In Development dx.doi.org/10.17504/protocols.io.bdtyi6pw

Jakub Nedbal
King's College London

ABSTRACT

Microalgae are grown for the research on photosynthesis, biotechnology, and water-environment ecology. Specialized laboratories typically use calibrated commercial equipment, which agitates the microalgae culture by shaking or bubbling, controls the irradiance, temperature, and $CO_2$ content. Such commercial incubators may be out of reach for some laboratories, like those not specializing in microalgae research, teaching laboratories, or laboratories in low resource settings. Our research uses microalgae cultures during the development and validation of advanced microscopy techniques. We lacked access to and the budget for a commercial incubator. We solved the problem by building a stand-alone orbital shaking incubator with an in-built variable light source and a 24-hour timer. The shaker features a homogeneously illuminated growth area of 20 cm × 15 cm, which is suitable for three T75 tissue culture flasks or four 100 ml Erlenmeyer flasks. The overall material cost was around £300 and assembly time of about two days. We tested the shaker with fresh-water microalgae *Desmodesmus quadricauda* and *Chlorella vulgaris*. Both microalgae cultures have been grown continuously for seven months in the incubator. We studied their growth under different light conditions to validate the function of the shaker. The protocol outlines the step-by-step process to the building of this microalgae shaker.

Here, we describe an illuminated orbital shaker designed for culture of microalgae suspensions. It was optimized for production cost, simplicity, low power consumption, design flexibility, and consistent and controllable growth light intensity. The instrument agitates and illuminates microalgae suspensions grown inside flasks. The agitation speed is variable while the light intensity is both variable and programmable (24-hour light/dark diurnal cycle).

The instrument offers a vastly cheaper alternative to commercial instruments for many laboratory applications, making it especially well suited for teaching and poorly-resourced research laboratories. It improves on home-built microalgae growth systems by offering consistent and well characterized illumination light intensity, low power consumption and heat dissipation. The illuminated growth area is 20 cm × 15 cm, which is suitable for three T75 tissue culture flasks or six 100 ml Erlenmeyer flasks. The photosynthetic photon flux density, measured inside an Erlenmeyer flask, is variable in eight steps (26–800 $\mu mol \cdot m^{-2} \cdot s^{-1}$). The overall material cost is around £300 (including an entry-level orbital shaker). The build takes about two days, requiring electronics assembly and machine workshop skills. The instrument build is documented in a set of protocols, design files, and source code. Its design can be readily modified, scaled, and adapted for other orbital shakers and specific experimental requirements.

The illuminated orbital shaker is ideal for growing small volumes of microalgae for research and teaching. It can readily replace commercial systems in many common microalgae culture application for a fraction of their cost. It outperforms typical home-made systems by offering consistent and predictable illumination light intensity and low power consumption.

EXTERNAL LINK

https://app.labstep.com/sharelink/221d4460-8591-4ab5-ac0c-70b54c93532a

GUIDELINES

This document brings an overview of the steps required to build and assemble the algal shaker. It is a high-level document that explains the process and links to more detailed protocols, which describe the step-by-step procedures.

SAFETY WARNINGS

The work on this project involves a number of hazards. The risks are low with appropriate safety precaustions in place. The warnings are discussed in details in the individual protocols. In general, the hazards involved in electronics soldering, mechanical workshop tools use, and optional laser cutter and 3D printer use. The risks include exposure to fumes, solvents, hot surfaces, electrical current, and potentially lead during soldering; cutting or bruising and dust during mechacial workshop works; exposure to fumes, hot surfaces, and potentially solvents during optional 3D printing; and exposure to fumes and laser irradiation during optional laser cutting.

BEFORE STARTING

**Project Steps**

Building the algal shaker requires the following major steps:

- Procuring Parts for Algal Shaker
- Assembling LED Controller Electronics
- 3D Printing Case for LED Controller
- Assembling Cooled LED Illuminator
- Cutting and Drilling Clear Acrylic Sheet
- Assembling Algal Shaker

The steps outlined above are superficially described in this protocol. Detailed step-by-step description of each is in the linked protocols.

**Required Skills**

Building requires electronics assembly skills, including soldering of surface mount components. Basic mechanical workshop skills and equipment are also required. Optional 3D printer and laser cutter simplify the process. The custom printed circuit board needs to be ordered from a suitable supplier.

**Time to Build**

Once all the parts are secured, the assembly should take a day or two in total. The lead time of the parts will depend on their local availability and price. Custom-made printed circuit boards and the orbital shaker are likely to be the components with the longest lead times.

**Cost**

We found the overall cost to be about £300. The price will vary according to local prices and fluctuate with time.

## 1 Procurement of Parts

The components for the algal shaker can be sourced from four types of suppliers.

- Laboratory equipment supplier
- Electronics parts distributor
- Printed circuit board manufacturer
- 3D printing service (or in-house 3D printer)

The orbital shaker can be sourced from laboratory equipment suppliers. The orbital shaker described in this protocol was bought on ebay.

All electronics components and mechanical fixings can be bought from electronics parts distributors. In the described case, it was Farnell. The clear acrylic sheet can be bought from specialist local supplier of sheet plastic or can be ordered laser cut to size and shape local laser-cut service providers.

The custom-made printed circuit board (PCB) simplifies and speeds up the assembly and results in a smaller, more robust circuit. Here, Seeed Technology was used for their low-cost, high-quality PCBs production service.

The electronics is housed in a custom case. It can be produced on a fused-deposition modelling 3D printer - in-house or outsourced to third-party manufacturers. An in-house Stratasys Uprint SE Plus was used here.

Procuring Parts for Algal Shaker
**by Jakub Nedbal,**
**King's College London**

PREVIEW RUN

1.1 Obtain the list of parts and tools required to build and assemble the illuminated orbital shaker by downloading the file:

OrbitalShaker_PartsList.xlsx

The content of the above spreadsheet are discussed in the steps below.

1.2 **Ordering the Orbital Shaker**

It should be possible to convert any orbital shaker by adding the illuminator and a raised clear acrylic platform to hold the algal cultures. Many labs may have spare orbital shakers that can be repurposed in this way. Second-hand ones could be found on online auction sites and spare lab equipment resellers pages. New professional orbital shakers start at around £700 (2019).

It is essential the orbital shaker platform is larger than than 22 cm × 20 cm. Otherwise, the heatsink, fans and stand-offs holding the acrylic platform might not fit.

For this project, we bought a basic orbital shaker imported from China. It can be found on ebay. It retailed for £95.30 in May 2019 - including shipment, import duties and VAT. The protocol will always refer to this particular orbital shaker, which is still on sale on ebay (Nov 2019). The shaker worked continuously during the past 6 month without any glitches. The major drawback of this orbital shaker is the loud noise it produces, compared to high-end orbital shakers, which are barely audible.


The seller image of the KJ-201BD orbital shaker.

Below is a table listing the orbital shaker. It is the only laboratory equipment required for this project. The orbital shaker is also listed in the "Laboratory Parts" tab of the OrbitalShaker_PartsList.xlsx spreadsheet.

| Item | Qty | Description | Distributor | Manufacturer | Order Code | Part Number | Unit Price [£] | Total [£] |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | Orbital Shaker | eBay | | 283712826465 | KJ-201BD | 95.30 | 95.30 |
| **Total** | | | | | | | | **95.30** |

Table of laboratory parts used in the build of the illuminated orbital shaker.

## 1.3 Ordering Electronic Parts

Electronic parts for the illuminated orbital shaker can be sourced from various suppliers worldwide. Farnell was chosen for its comprehensive offer, competitive price and fast delivery. Any other suitable supplier could be used instead. Many of the standard components can be substituted for different parts. This includes the 0603-size resistors, the BSS138W transistor, and the pin header, shunt jumper, and the fuse. The capacitors can also be swapped for equivalent kind, bearing in mind that the rated Voltage and dielectrics must not be lower specification than theose listed.

The electronics parts are listed in the table below and in the "Electronics Parts" tab of the OrbitalShaker_PartsList.xlsx spreadsheet:

| Item | Qty | Value | Description | Distributor | Manufacturer | Order Code | Part Number | Unit Price [£] | Total [£] |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 10u/50V | 10µF/50V X5R 1206 ceramic capacitor (pack of 5) | Farnell | Murata | 2672214 | GRT31CR61H106KE01L | 0.525 | 2.625 |
| 2 | 1 | 47u/63V | 47µF/63V electrolytic capacitor | Farnell | Panasonic | 2326166 | EEE1JA470UP | 0.679 | 0.679 |
| 3 | 2 | 100n | 100nF/50V X7R 0603 ceramic capacitor (pack of 10) | Farnell | Multicomp | 1759122 | MC0603B104K500CT | 0.0341 | 0.341 |
| 4 | 1 | MAX6006 | 1.25V shunt reference | Farnell | Maxim Integrated | 2511278 | MAX6006BEUR+T | 1.29 | 1.29 |
| 5 | 1 | LDU2430S1000 | 24V/1A adjustable LED driver | Farnell | XP Power | 1738296 | LDU2430S1000 | 8.23 | 8.23 |
| 6 | 1 | Fuse Holder | 5x20mm fuse holder (pack of 10) | Farnell | Schurter | 2309093 | 751.0052 | 0.103 | 1.03 |
| 7 | 1 | T1.25A | 1.25A slow-burning fuse (pack of 10) | Farnell | Eaton Bussmann | 1123242 | S506-1.25-R | 0.836 | 8.36 |
| 8 | 1 | 2.1mm DC Jack | 2.1mm 2A/16V DC power jack | Farnell | Cliff Electronics | 2450496 | FC681478 | 1.84 | 1.84 |
| 9 | 6 | 2way Screw Terminal | 2way 3.81mm screw terminal | Farnell | Multicomp | 2007985 | MC000018 | 0.481 | 2.886 |
| 10 | 1 | 3way Shunt Header | 3way 2.54mm header (pack of 50) | Farnell | Multicomp | 1593412 | 2211S-03G | 0.0156 | 0.78 |
| 11 | 1 | Shunt Jumper | 2.54 mm shunt jumper (pack of 50) | Farnell | Multicomp | 2834673 | MC-2228CG | 0.0262 | 1.31 |
| 12 | 1 | BSS138W | 50V 200mA N-channel MOSFET (pack of 5) | Farnell | Diodes | 1713833 | BSS138W-7-F | 0.265 | 1.325 |
| 13 | 3 | 27k | 27kΩ 0603 1% SMD resistor (pack of 10) | Farnell | Multicomp | 2447315 | MCWR06X2702FTL | 0.0038 | 0.038 |
| 14 | 1 | 1k0 | 1kΩ 0603 1% SMD resistor (pack of 10) | Farnell | Multicomp | 2447272 | MCWR06X1001FTL | 0.0038 | 0.038 |
| 15 | 1 | 560R/500mW | 560Ω 1206 1% 500mW SMD resistor (pack of 10) | Farnell | TE Connectivity | 2332136 | CRGH1206F560R | 0.0447 | 0.447 |
| 16 | 1 | 6k8 | 6.8kΩ 0603 1% SMD resistor (pack of 10) | Farnell | Multicomp | 2447427 | MCWR06X6801FTL | 0.0034 | 0.034 |
| 17 | 1 | 2k7 | 2.7kΩ 0603 1% SMD resistor (pack of 10) | Farnell | Multicomp | 2447324 | MCWR06X2701FTL | 0.0034 | 0.034 |
| 18 | 3 | 820R | 820Ω 0603 1% SMD resistor (pack of 10) | Farnell | Multicomp | 2447437 | MCWR06X8200FTL | 0.0035 | 0.035 |
| 19 | 1 | 390R | 390Ω 0603 1% SMD resistor (pack of 10) | Farnell | Multicomp | 2447353 | MCWR06X3900FTL | 0.0037 | 0.037 |
| 20 | 1 | 270R | 270Ω 0603 1% SMD resistor (pack of 10) | Farnell | Multicomp | 2447314 | MCWR06X2700FTL | 0.0038 | 0.038 |
| 21 | 1 | 100R | 100Ω 0603 1% SMD resistor (pack of 10) | Farnell | Multicomp | 2447227 | MCWR06X1000FTL | 0.0034 | 0.034 |
| 22 | 1 | 220R | 220Ω 0603 1% SMD resistor (pack of 10) | Farnell | Multicomp | 2447298 | MCWR06X2200FTL | 0.0034 | 0.034 |
| 23 | 1 | 150R | 150Ω 0603 1% SMD resistor (pack of 10) | Farnell | Multicomp | 2447255 | MCWR06X1500FTL | 0.0035 | 0.035 |
| 24 | 1 | 180R | 180Ω 0603 1% SMD resistor (pack of 10) | Farnell | Multicomp | 2447267 | MCWR06X1800FTL | 0.0034 | 0.034 |
| 25 | 1 | 47R | 47Ω 0603 1% SMD resistor (pack of 10) | Farnell | Multicomp | 2694082 | MCWF06P47R0FTL | 0.0083 | 0.083 |
| 26 | 2 | 100R/500mW | 100Ω 1206 1% 500mW SMD resistor (pack of 10) | Farnell | TE Connectivity | 2332126 | CRGH1206F100R | 0.0423 | 0.423 |
| 27 | 1 | DPDT Switch | DPDT On-Off-On toggle switch | Farnell | Multicomp | 9473556 | 1MD4T1B1M1QE | 2.60 | 2.60 |
| 28 | 1 | 6pos Rotary Switch | 6-position rotary switch | Farnell | Nidec Copal | 2854809 | SS-10-16NP-LE | 2.48 | 2.48 |
| 29 | 1 | DIP-8 Socket | DIP-8 socket for rotary switch | Farnell | Multicomp | 2668408 | SPC15494 | 0.133 | 1.33 |
| **Total** | | | | | | | | | **38.45** |

Table of electronics parts used in the build of the illuminated orbital shaker.

### Availability of Components in the Bill of Materials

Some of the above components may be already available in local electronics workshops and do not need to be purchased. Items 3, 7, 10-14, and 16-25 are most likely to be broadly available and could save £13 off the bill of materials.



**Citation:** Jakub Nedbal (03/17/2020). Illuminated Orbital Shaker for Microalgae Culture. https://dx.doi.org/10.17504/protocols.io.bdtyi6pw

## 1.4 Ordering Mechanical Parts and Fixings

There are several different types of mechanical parts and fixings required to build the illuminated orbital shaker. Most of them are common and may well be locally available. The only less usual component is a 50 mm-long M4 standoff. The mechanical parts are listed in the table below and in the "Fixings" tab of the OrbitalShaker_PartsList.xlsx spreadsheet:

| Item | Qty | Value | Description | Distributor | Manufacturer | Order Code | Part Number | Unit Price [£] | Total [£] |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 4 | M4 Nut | M4 zinc-plated steel nut (pack of 100) | Farnell | TR Fastenings | 1419449 | M4-HFST-Z100- | | 1.59 |
| 2 | 8 | M4 Washer | M4 zinc-plated steel washer (pack of 100) | Farnell | TR Fastenings | 2506009 | DM4-FASTWAZ100DIN125 | | 1.14 |
| 3 | 4 | M4×12 Screw | M4 12mm zinc-plated pan head screw (pack of 100) | Farnell | TR Fastenings | 1419994 | M4 12 PRSTMC Z100 | | 2.08 |
| 4 | 4 | M3×10 Screw | M3 10mm countersunk zinc-plated screw (pack of 100) | Farnell | TR Fastenings | 1420398 | M3 10 KRSTMC Z100 | | 1.64 |
| 5 | 4 | 50mm M4 Standoff | 50mm M4 standoff male-female | Farnell | Ettinger | 1466738 | 05.14.501 | 0.73 | 2.92 |
| **Total** | | | | | | | | | **9.37** |

Table of mechanical parts and fixing used in the build of the illuminated orbital shaker.

### Note for Imperial Thread Size Users

*The table above includes a several M4 and M3 fixings. here imperial thread are used, swap #8-32 UNC thread for M4 and #4-40 UNC thread for M3:*

- *4× #8-32 UNC nuts*
- *8× #8-32 UNC washers*
- *4× #8-32 UNC 1/2"-long pan head screws*
- *4× #4-40 UNC 3/8"-long countersunk screws*
- *4× 2-inch #8-32 male-female standoff (1964, Keystone).*

### Availability of Components in the Bill of Materials

The washers, screws and nuts are likely to be available in local workshops and not buying them could save £6 off the bill of materials.

## 1.5 LED Illuminator Parts

The LED illuminator consists of LED strips attached to a heatsink, cooling fans and wires that connect all components together and the LED controller electronics circuit. The list also includes a wall socket plug-in power supply and a 24-hour time switch to control the daily sequence of the LED illuminator. The components required to build the LED illuminator are listed in the table below and in the "LED Illuminator Parts" tab of the OrbitalShaker_PartsList.xlsx spreadsheet:

| Item | Qty | Value | Description | Distributor | Manufacturer | Order Code | Part Number | Unit Price [£] | Total [£] |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 1m LED Strip | LED strip, 1m, cool white, 24VDC, 14.4W | Farnell | Ledxon Modular | 2214009 | 9009079 | 25.84 | 51.68 |
| 2 | 4 | 40mm Fan | 12 VDC Fan, 60mA, 40mm | Farnell | Multicomp | 2816685 | MC002106 | 2.11 | 8.44 |
| 3 | 1 | 30V/1A AC Adaptor | 30V/1A 2.1mm DC power supply | Farnell | Ideal Power | 2771453 | 15DYS624-300100W-K | 23.37 | 23.37 |
| 4 | 1 | LED Heatsink | Heatsink, 200 mm x 150 mm x 40 mm, 0.5 °C/W | Farnell | Fischer Elektronik | 4621906 | SK 47/150 SA | 35.71 | 35.71 |
| 5 | 2 | Black Cable | 0.5 mm2 black cable for LED strip connection | Farnell | Pro Power | 2528081 | PP001185 | 0.315 | 0.63 |
| 6 | 2 | Red Cable | 0.5 mm2 red cable for LED strip connection | Farnell | Pro Power | 2528174 | PP001269 | 0.315 | 0.63 |
| 7 | 1 | Clear Acrylic | 4 mm clear acrylic sheet (any make, > 30cm×20cm) | RS | RS Pro | 824-660 | 824-660 | 32.72 | 32.72 |
| 8 | 1 | 24H Time Switch | Programmable 24-hour socket time switch (any make) | Farnell | Pro Elec | 2777066 | PEL00407 | 2.01 | 2.01 |
| **Total** | | | | | | | | | **155.19** |

Table of electrical parts used in the build of the LED illuminator for the orbital shaker.

### Note for Non-UK Regions

The power supply and the 24-hour timer (items 3 & 9) are for UK sockets. Other parts of the world have different line Voltage and sockets. Find a 30V/1A power supply with a 2.1mm DC connector and a programmable 24-hour socket timer that are suitable and certified for use in your region.

### Note for Non-Metric Regions

*Items 6 & 7 are cables with 0.5 mm$^2$ cross-section. This is roughly equivalent to AWG 21 cables. Choose a suitable cable, which is close to this gauge. Thicker cables can force the LED strips to lift off from the heatsink and thinner gauges may be insufficient to support the current.*

### Note on the Clear Acrylic Sheet

Here, an off-the-shelf clear acrylic was used. The 4 mm (5/32") thick clear acrylic is ideal. A thinner one might be to weak and a thicker one might be impossible to fix to the stand-offs. However the exact make and size of the sheet are irrelevant. Polycarbonate could also be used instead of acrylic. It may be easier to drill and cheaper, but absorb more light.



**Citation:** Jakub Nedbal (03/17/2020). Illuminated Orbital Shaker for Microalgae Culture. https://dx.doi.org/10.17504/protocols.io.bdtyi6pw

## 1.6 Checking Local Availability of Tools

To assemble the orbital shaker several tools are required. Hopefully most of these tools will be available in local workshops or office, saving most of the listed costs.

The tools parts list in the table below and in the "Tools" tab of the [OrbitalShaker_PartsList.xlsx] spreadsheet is divided into five sections:

- Workshop Tools
- Stationaries
- Soldering Equipment
- 3D Printing
- Cutting and Drilling Tools

| Item | Qty | Value | Description | Distributor | Manufacturer | Order Code | Part Number | Unit Price [£] | Total [£] |
|---|---|---|---|---|---|---|---|---|---|
| | | | **Workshop Tools** | | | | | | |
| 1 | 1 | M3 Tap Set | M3 thread tap set (any make, #4-40 for imperial threads) | Farnell | Ruko | 375238 | 230-030 | 8.77 | 8.77 |
| 2 | 1 | Tap Wrench | Tap Wrench (any make) | Farnell | Ruko | 376395 | 241 001 | 10.71 | 10.71 |
| 3 | 1 | Tool Kit | Mechanical workshop tool kit (any make) | RS | RS Pro | 829-6561 | 829-6561 | 108.59 | 108.59 |
| 4 | 1 | DMM | General digital multimeter (any make) | RS | RS Pro | 123-1930 | 123-1930 | 30.00 | 30.00 |
| | | | **Stationaries** | | | | | | |
| 5 | 1 | Multipurpose Glue | All purpose clear adhesive (any make) | Amazon | Bostik | B0001OZI48 | All Purpose | 1.58 | 1.58 |
| 6 | 1 | Scissors | Common scissors (any make) | Amazon | Helix | B00XP1V0UU | Oxford 13cm | 1.39 | 1.39 |
| 7 | 1 | Pen | Fine tip permanent marker pen (not black, any make) | Amazon | Staedtler | B005DPPQAG | 733449 | 1.66 | 1.66 |
| 8 | 1 | Ruler | Ruler 30 cm (any make) | Amazon | Q Connect | B000NMBTUK | Ruler | 0.59 | 0.59 |
| | | | **Soldering Equipment** | | | | | | |
| 9 | 1 | Tweezers | Watchmakers tweezers (any make) | Farnell | Duratool | 3127692 | 1PK-125T-F | 3.22 | 3.22 |
| 10 | 1 | Solder Flux | Solder flux (any make) | Farnell | Chip Quik | 1850220 | SMD291NL | 11.94 | 11.94 |
| 11 | 1 | Solder Wire | Thin solder wire (any make) | Farnell | Duratool | 3262209 | D03341 | 5.18 | 5.18 |
| 12 | 1 | Soldering Station | Soldering station suitable for SMD (any make) | Farnell | Metcal | 1560738 | PS-900 | 187.00 | 187.00 |
| 13 | 1 | Electrical Tape | PVC Electrical Insulation tape (any make) | Farnell | Pro Power | 152346 | PVC TAPE 1920B | 1.18 | 1.18 |
| 14 | 1 | IPA | Isopropyl alcohol for cleaning (any make) | Amazon | Hexeal | B079YVPZDF | IPA | 6.79 | 6.79 |
| 15 | 1 | Small Tub | Margarine tub or something similar | | | | | | |
| 16 | 1 | Brush | Old toothbrush or stiff paintbrush | | | | | | |
| | | | **3D Printing** | | | | | | |
| 17 | 1 | 3D Printer | FDM 3D Printer with build material (any make, or outsource) | | Stratasys | uPrint SE Plus | uPrint SE Plus | | |
| | | | **Cutting and Drilling Tools (Either tools or laser cutter, both not required)** | | | | | | |
| 18 | 1 | Drill | General hand or pillar drill (any make) | Amazon | Skil | B00IINANZ8 | 6221AB | 44.99 | 44.99 |
| 19 | 1 | 4mm Drill Bit | HSS drill bit 4 mm (any make, ideally spur-point bit for plastic) | Farnell | Ruko | 378124 | 201 040 | 0.44 | 0.44 |
| 20 | 1 | Hacksaw | 300 mm hacksaw (any make) | Farnell | Duratool | 2103261 | D02166 | 7.32 | 7.32 |
| 21 | 1 | P150 Sandpaper | P80-P180 sandpaper (any make) | Amazon | 3M | B001PNBC0I | 20150 | 4.49 | 4.49 |
| 22 | 1 | Laser Cutter | Optional laser cutter for plastics (any make) | | | | | | |
| **Total** | | | | | | | | | **435.84** |

Table of tools and stationaries used during the build of the illuminated orbital shaker.

#### Note for Imperial Thread Size Users

*Replace the 4 mm drill bit (item 18) with a #16 or #18 drill bit.*
*Use a #4-40 UNC thread tap instead of the M3 thread tap (item 1).*

#### Note Regarding Multipurpose Glue

The listed multi-purpose glue worked well. This particular brand may not be widely available outside of the UK. Choose any trasparent solvent-based multi-purpose glue. It is important it is a glue that retains some flexibility and cures through evaporation of the solvent. Do not use PVA or superglue.

#### Note Regarding 3D Printing

Item 17 is a 3D printer to produce the case for the LED controller electronics. We used a locally available FDM printer. However, other 3D printers should work equally well. Both locally available 3D printers or commercially outsourced 3D printing service can be used. 3D printing by laser sintering would offer a better finish, but this 3D printing technology is less widely available and not required.

#### Note Cutting and Drilling Tools

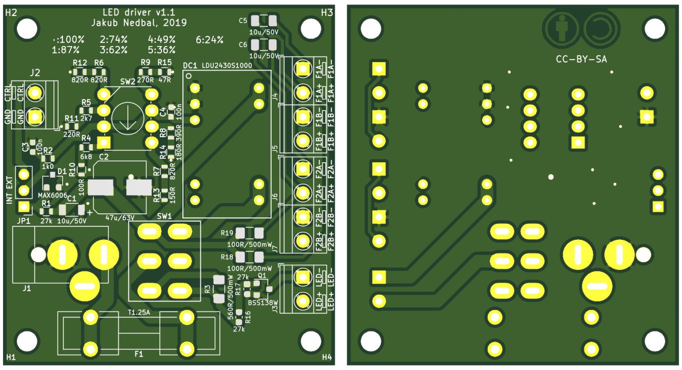
Here, mechanical tools (items 18-21) have been used to cut and drill the clear acrylic sheet to build the illuminated shaker platform. However, with laser cutters widely available these days, a better and quicker job could be done by using a laser cutter instead. In that case, the drill, drill bit, hacksaw, and sandpaper will not be required.



**Citation:** Jakub Nedbal (03/17/2020). Illuminated Orbital Shaker for Microalgae Culture. https://dx.doi.org/10.17504/protocols.io.bdtyi6pw

## 1.7 Ordering the Custom Printed Circuit Board

The printed circuit board (PCB) has been designed specifically for the LED controller circuit. It is a double sided PCB with plated through-holes. All components are mounted to the top side only for ease of assembly. The assembly of the components on the board is described in the document Assembling LED Controller Electronics. The top and bottom view of the PCB are in the picture below:

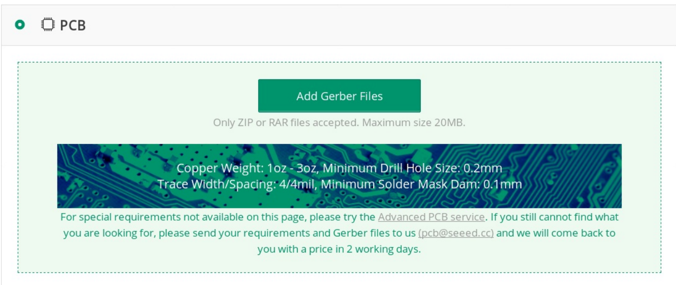



2D rendered image of the top and bottom views of the printed circuit board for the LED controller.

The PCB design has been done in KiCAD, which is a cross platform and open source electronics design automation suite. The source files are available for download from the project GitHub page.

Any PCB manufacturer should be able to produce the PCB from the Gerber files available in the board folder on the project GitHub page. We used Seeed Technology Fusion PCB service to produce the PCB. The ordering process is described below.

- Get the archive LEDregulator.zip
- with Gerber files from the project GitHub page
- Go to the Fusion PCB order page
- Upload the LEDregulator.zip file using the **Add Gerber Files** button:




Snapshot from the Seeed technology website, which is used to upload the Gerber files for PCB production.

- Select the options for the board manufacture. All settings can be left at their default values. Decreasing the order amount to five PCBs does not lower the final price, but could minimize waste and environmental impact.
- Confirm the order, provide shipping and billing details, choose the preferred shipping service and pay the manufacturer.
- Wait a few weeks for the PCBs to arrive.

## 1.8 Summary

This document described the procurement of the components for the build of the illuminated orbital shaker for algal cultures. It listed the electronics parts, the tools and fixings required for the assembly, and it explained the process to order the printed circuit boards. The next document explains how the obtained components are used to build a functioning LED regulator:



**Citation:** Jakub Nedbal (03/17/2020). Illuminated Orbital Shaker for Microalgae Culture. https://dx.doi.org/10.17504/protocols.io.bdtyi6pw

1.9 **References**

- OrbitalShaker_ElectronicsPartsList.xlsx: Excel document listing all electronics and electrical parts, and fixing required in the assembly of the illuminated Orbital Shaker.
- GitHub Project Page: Electronics design files for KiCAD.
- LEDregulator.zip: Gerber files for PCB manufacture.
- Seeed Technology Fusion PCB order page: Website to order the PCB production.
- KiCAD: Cross platform and open source electronics design automation suite.

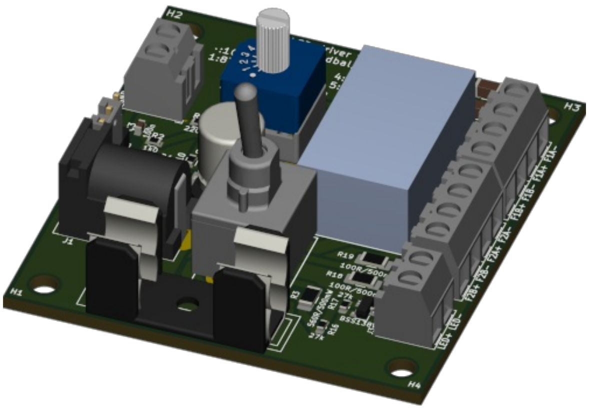
1.10 **This document is part of the Illuminated Orbital Shaker for Microalgae Culture project:**

- Procuring Parts for Algal Shaker *(this document)*
- Assembling LED Controller Electronics
- 3D Printing Case for LED Controller
- Assembling Cooled LED Illuminator
- Cutting and Drilling Clear Acrylic Sheet
- Assembling the Algal Shaker

## 2 Assembling the LED Controller

The LED controller electronics regulates the LED current, adjusting the irradiance of the sample according the experimental needs. It also powers the fans cooling down the LEDs. The electronic circuit assembly requires surface-mount component soldering equipment and skills. The smallest parts used are in 0603 package. This size allows soldering with a decent soldering station, flux, watch-makers tweezers, an a bit of experience. The soldering should take no more than 1-2 hours. It is followed by testing the circuit and finally cleaning any excess flux.

*Consider the safety of the soldering process and observe local regulations. Soldering creates risks of fire, exposure to hazardous fumes, and skin exposure to the soldering flux. Take all necessary precautions. Keep the work area tidy, especially devoid of any combustible materials. Never leave the soldering iron unattended while hot. Use fume extractor during soldering and laboratory gloves when handling the flux-stained PCB.*



Assembled LED controller printed circuit board

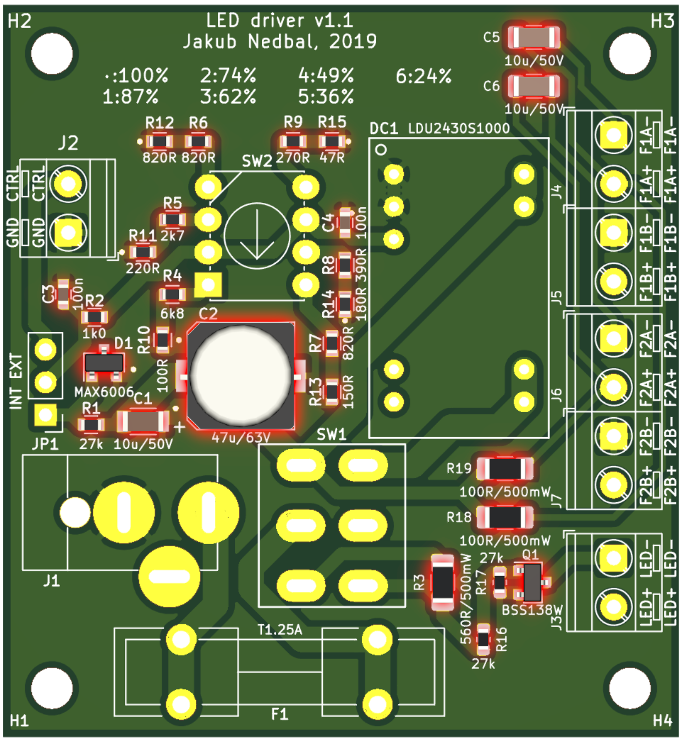
Assembling LED Controller Electronics
**by Jakub Nedbal,**
**King's College London**

PREVIEW RUN

## 2.1 Assembly of SMD Components

Start the assembly with all the SMD components first.

Use a thin solder wire, solder flux, and watchmaker's tweezers to help with the soldering. The SMD components that need to be soldered are highlighted in the image below:

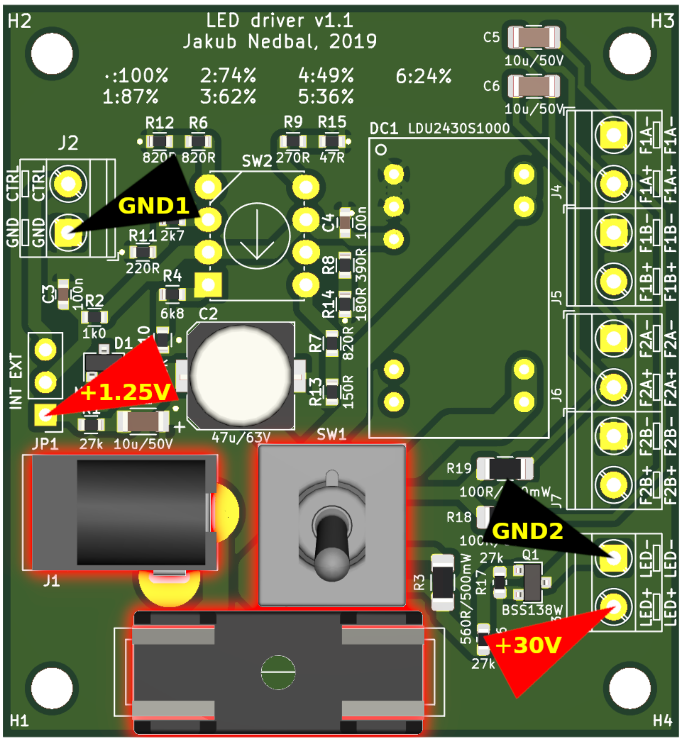



SMD components, highlighted in red, are assembled first. This way the larger through-hole components do not restrict the access to the soldering pads.

## 2.2 Adding the Power Supply Connection

In this step, the power supply connection is added and the first test of the circuit is performed.

Solder the power supply connector (J1), toggle switch (SW1), the fuse holder (F1), and insert T1.25A fuse into the fuse holder according to the image below:




The DC power supply connector, fuse in a fuseholder, and toggle switch are soldered next. The partial circuit functionality is tested by connecting the power supply to the DC power supply connector and ensuring the expected voltages are measured at the test points highlighted by the black and red arrows in the diagram.

With the components soldered in place, connect the +30V power supply to DC power jack (J1). Make sure the T1.25A fuse is in the fuse holder (F1). Use a digital multimeter in the DC Voltage mode to probe the Voltages on test points of the board.

Make sure the toggle switch (SW1) is in the position as shown in the image above. Connect the multimeter ground lead (black) to the test point labelled **GND1** in the image above. Connect the positive lead (red) to the test point labelled **+1.25V** in the image above. The multimeter should show a value close to 1.25 V on the display. If it does not, check the soldering. On an occasion, we found the shunt reference D1 (MAX6006) failed after assembly and had to replace it. It may be that this component is quite sensitive to mishandling and so you may need to replace it if it does not work before proceeding to the next steps.

Switch the toggle switch (SW1) to the opposite position to the one shown in the image above. With the multimeter ground lead connected to the **GND2** test point, probe the Voltage at the testpoint labelled **+30V**. Make sure the measured Voltage is close to +30 V. If not, check the soldering. The only component that may be susceptible to failing due to mishandling is Q1. Check if it works and replace it if required.

Do not proceed to the next steps, until you verified the circuit works as described above. Replacing components will become hard or impossible once the remaining large through-hole components are soldered to the PCB.

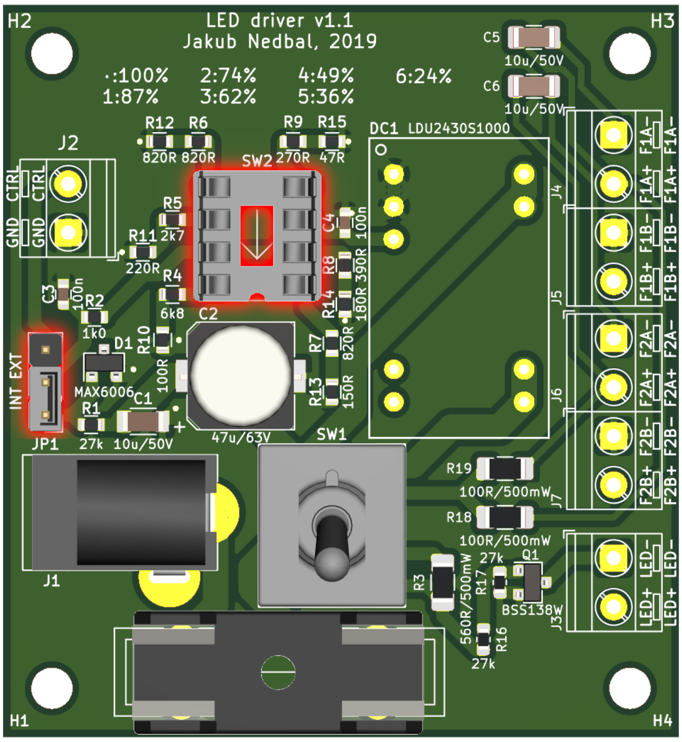
## 2.3 Adding the LED Current Regulation

In the next steps, the rotary switch and the input control jumper will be installed and tested.

Solder in the 3-way header (JP1). Insert a jumper shunt across onto the two lower pins of the three way header (JP1) labelled **INT**. Solder a DIP-8 socket into the place for the rotary switch SW2, according to the image below (**do not** solder the rotary switch directly into the PCB):

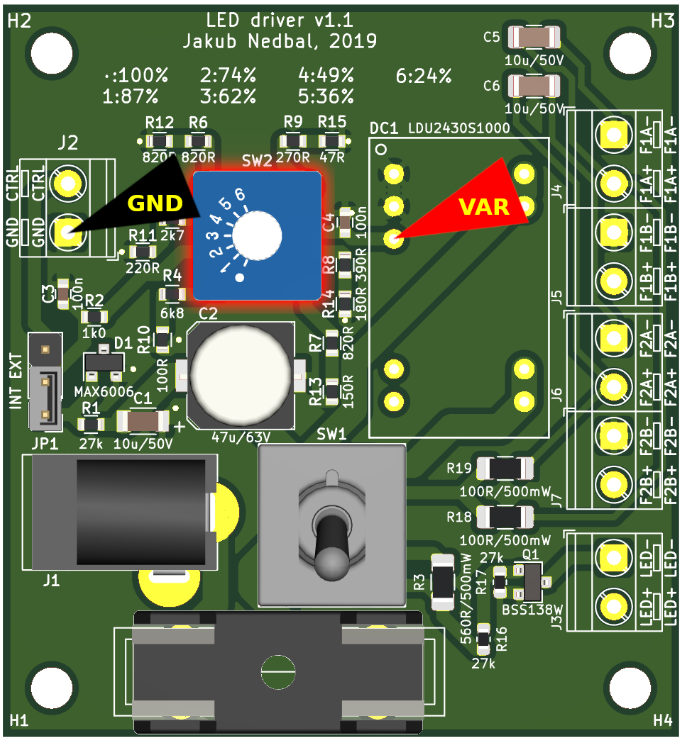



**Citation:** Jakub Nedbal (03/17/2020). Illuminated Orbital Shaker for Microalgae Culture. https://dx.doi.org/10.17504/protocols.io.bdtyi6pw




Solder a DIP-8 socket and a 3-pin header with to the PCB. Connect a jumper shut to the lower two pins of the 3-pin header.

Now, insert the rotary switch into the DIP-8 socket that has just been soldered to the PCB, according to the figure below:




Plug a 6-position rotary switch into the DIP-8 socket. Connect the power supply into the DC power supply connector. Check the voltage between the test points highlighted by the black and red arrows. The voltage should change with the rotary switch position.

With the switch in place and the +30V power supply connected to DC jack (J1), use a multimeter to test the Voltage between test points labelled **GND** and **VAR**. The Voltage measured should vary in steps of 1.25 V, 1.09 V, 0.93 V, 0.78 V, 0.62 V, 0.46 V, and 0.30 V, which are respective to rotary switch positions of •, 1, 2, 3, 4, 5, and 6. Check these Voltages for every rotary switch position. If any vary significantly, check the soldering and measure the resistances of the SMD resistors. Fix any loose soldering joints or erroneous component placement. If no Voltage can be measured at any position, make sure there is a jumper shunt in the correct position on the 3-way jumper (JP1), as described above.



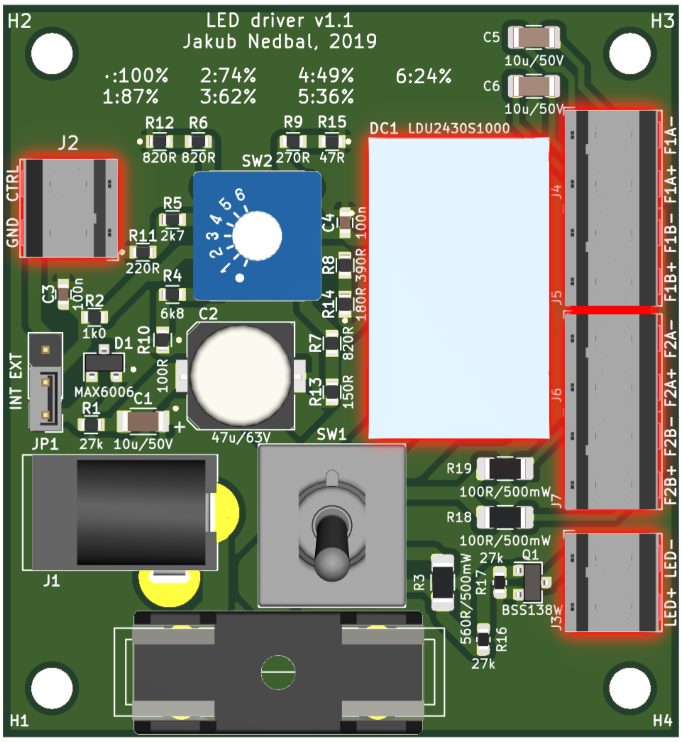
**Citation:** Jakub Nedbal (03/17/2020). Illuminated Orbital Shaker for Microalgae Culture. https://dx.doi.org/10.17504/protocols.io.bdtyi6pw

Do not proceed to the next steps, until you verified the circuit works as described above.

## 2.4 Adding the LED Controller

In the final assembly step, the adjustable LED driver (DC1) is added together with the screw terminal connectors (J2–J7).

Solder in all these components according to the image below:




Solder the last through hole components to the PCB. These include the screw terminal connectors and the adjustable LED driver.

This completes the circuit assembly. Do not test the function of the circuit with the LEDs just yet. The LED strip needs to be mounted onto the heatsink first, to avoid overheating of the LEDs at full power.

## 2.5 Cleaning the PCB

Cleaning the PCB from residual flux is important to avoid long-term corrosion and possible future reliability issues. There are professional PCB cleaners in spray, which dissolve the flux that can be wiped off together with the solvent.
Instead, I use a widely available solvent **isopropanol** (isopropyl alcohol, IPA, propan-2-ol) for cleaning. Get a small tub just about fitting the PCB with a lid (an old margarine tub works fine).

- Place the PCB into the tub and cover it completely with the solvent (the parts do not need to be completely submerged).
- Close the lid and let it soak for at least 10 minutes (or even overnight). This should soften the flux.
- Use a toothbrush and a toothpick to rub and scrape off any flux deposits from the PCB.
- Empty the tub with the solvent according to local waste disposal regulations.
- Place the PCB back into the tub, cover it with fresh isopropanol, close the tub lid and let the board soak for additional 10 minutes.
- Brush and pick any residual flux.
- Flick any residual solvent from the board and let it dry.

The above steps explained how to clean the flux from the printed circuit board for long-term reliability of the LED regulator circuit.

## 2.6 Summary

This document described the assembly process for the LED controller electronic circuit. The assembly took place in steps, each followed by test instructions to verify the function of the circuit before embarking on the next assembly steps. By the end, the circuit board is ready to be installed into a custom case, which is described in the 3D printing case for LED controller document.

2.7 **References**

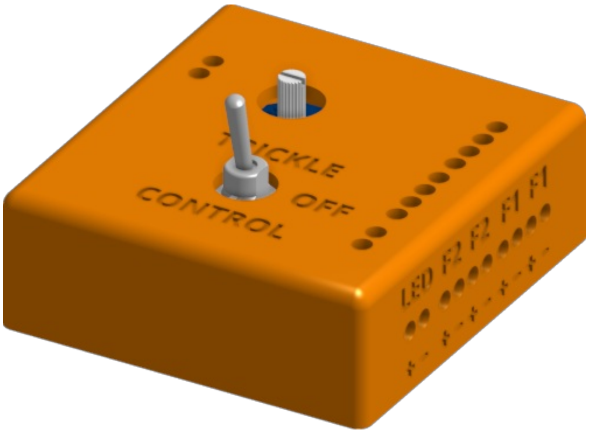
- LEDregulator Circuit: KiCAD files with the circuit diagram and PCB design files.
- OrbitalShaker_ElectronicsPartsList.xlsx: Excel document listing all electronics and electrical parts, and fixing required in the assembly of the illuminated Orbital Shaker.
- KiCAD: Cross platform and open source electronics design automation suite.

2.8 **This document is part of the Illuminated Orbital Shaker for Microalgae Culture project:**

- Procuring Parts for Algal Shaker
- Assembling LED Controller Electronics *(this document)*
- 3D Printing Case for LED Controller
- Assembling Cooled LED Illuminator
- Cutting and Drilling Clear Acrylic Sheet
- Assembling Algal Shaker

3 **3D Printing the Case**

The electronics circuit is housed inside a case, which protects the circuit from damage and the users from exposure to live voltage. The case for the LED controller can be 3D printed in-house or outsourced to a specialist supplier. I used Stratasys Uprint SE Plus, a fused-deposition modeling printer. The finishing is rough, but serves the purpose. A laser-sintering printer would produce a more detailed and premium finish.




Assembled case for the LED controller

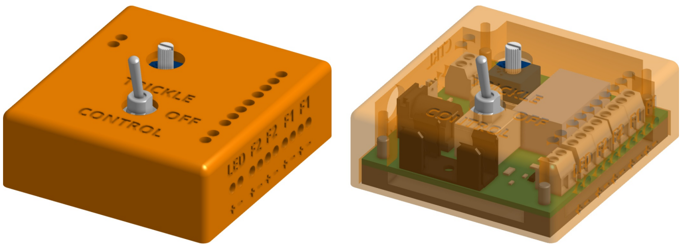
3D Printing Case for LED Controller
**by Jakub Nedbal,**
**King's College London**
PREVIEW RUN



**Citation:** Jakub Nedbal (03/17/2020). Illuminated Orbital Shaker for Microalgae Culture. https://dx.doi.org/10.17504/protocols.io.bdtyi6pw

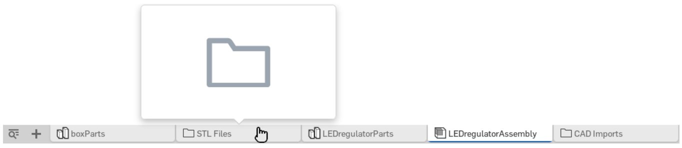
3.1 **Obtain Source Files**

The electronics circuit has been designed in [KiCAD](). KiCAD PCB files can be opened in [FreeCAD](). This in turn allows exporting the 3D render of the PCB into an industry-standard STEP file format. The STEP file can then be imported into [Onshape](), which is a 3D CAD tool. [Onshape]() was then used to create a 3D model of a case to hold the electronics printed circuit boards with all its components. The case consists of two parts, the Top and the Bottom, which are fixed together by screws during the final assembly. The model of the case with the embedded electronics circuit is openly available on the [LED regulator case]() project page.



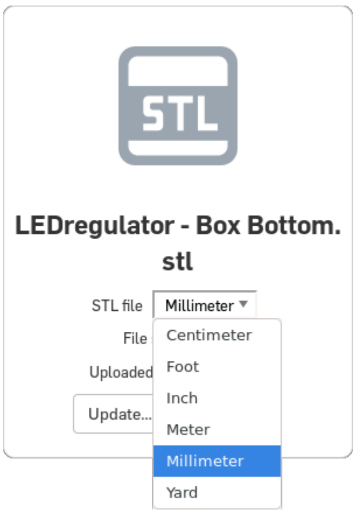
Assembled case for the LED controller circuit. (Left) the outside view of the case, (right) a transparent rendering of the case to show the electronics within.

3D printing, whether done in-house or outsourced, requires STL files to work from. The STL files can be found on the [LED regulator case]() project page in a subfolder named **STL Files**, as shown in the screenshot below:




Click the STL Files tab on the LED regulator case project to access the STL files for 3D printing.

There are two files in this folder, named **LEDregulator - Box Top.stl** and **LEDregulator - BoxBottom.stl**. Download these files. During the download phase, ensure you select the desired units, matched to those specified for the 3D printing. In my case, that would be **Millimeter**, as in the image below:




Download the files scaled to the units used by your 3D printer.

Use the two downloaded files **LEDregulator - Box Top.stl** and **LEDregulator - BoxBottom.stl** to 3D print the two case parts.



**Citation:** Jakub Nedbal (03/17/2020). Illuminated Orbital Shaker for Microalgae Culture. https://dx.doi.org/10.17504/protocols.io.bdtyi6pw

3.2 **3D Printing**

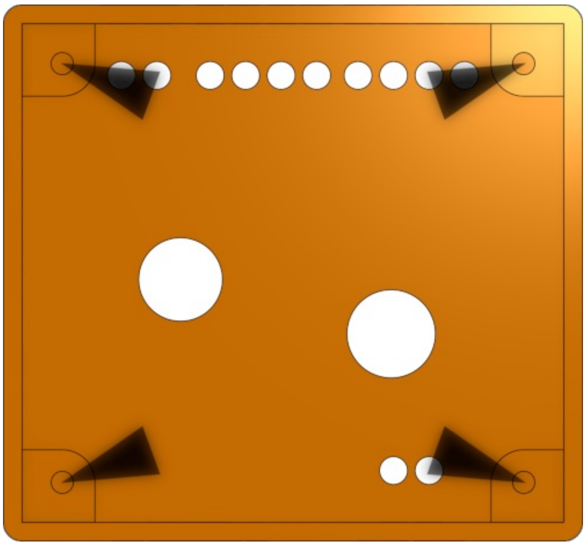
There is no general instruction on how to run a 3D printer. We used an in-house [Stratasys uPrint SE Plus] fused deposition modelling printer with printed support according to manufacturers instructions. The support material was subsequently dissolved by immersing the 3D printed parts in a warm hydrogen peroxide bath.

*This step is potentially hazardous. All local regulations and procedures were observed and personal protection equipment was used.*

Finally, the two parts were thoroughly washed with copious amounts of water and dried prior to further processing.

3.3 **Tapping Threaded Holes in the 3D Printed Case**

The Top part of the case is printed with four blind holes in each corner, highlighted by the black arrows in the image below:



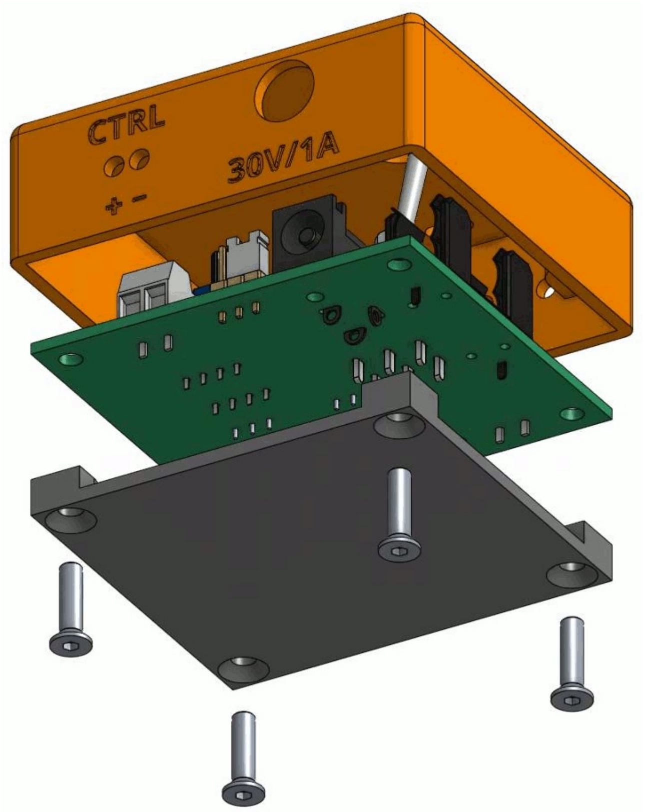
Four holes to be tapped with M3 (or#4-40 UNC) threads for screws holding the case closed.

Use an M3 thread tap to create M3 threaded holes in each corner. In areas, where Imperial thread sizes are in use, swap the M3 threads for locally common #4-40 UNC threads instead. They have similar diameter and due to their courser thread spacing, they are better suited for soft materials like plastic.
The thread is typically created in three steps using three thread taps with progressively deeper cutting threads. Start with the shallowest thread tap and finish with the deepest thread tap. Some tap manufacturers help identifying the order of taps by the number of engraved lines (see image below). First comes a tap with one line, followed by a tap with two lines, and finished with a tap with no lines. Use a tap wrench to do the thread tapping. An illustrative image of an M3 thread tap set and a tap wrench are in the image below:

Image of a set of M3 thread taps and a tap wrench.

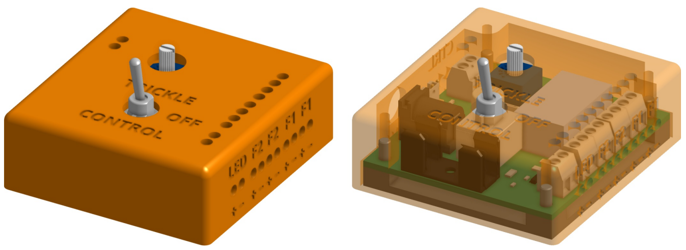
3.4 **Assembling the Case**

The document Assembling LED Controller Electronics explains how the electronics is assembled onto a printed circuit board (PCB). The PCB fits into the printed 3D case. The case is held together by four M3×10 mm counter sunk screws. Where imperial threads are common, four #4-40 UNC 3/8"-long countersunk screws should be used instead. The assembly is really trivial and only takes a screwdriver or an Allen key, depending on which screw head type is available. The image below should be sufficient to explain the assembly procedure:




Assembly steps for the LEC controller case. The PCB slides into the case. The bottom of the case goes over the PCB and is fastened with four M3×10 mm (#4-40 UNC × 3/8") screws.

The assembled LED Controller is shown as 3D render in the image below:




Assembled case for the LED controller circuit. (Left) the outside view of the case, (right) a transparent rendering of the case to show the electronics within.

3.5 **Summary**

This document described how to obtain STL files to print a case for the LED regulator electronics circuit. It explained the assembly steps. Once the electronics is inside the case, it is ready for use with the Cooled LED Illuminator, described in the next protocol.

3.6 **References**

- LED regulator case: Onshape project with STL files available for download for 3D printing the case for the LED regulator electronics.



**Citation:** Jakub Nedbal (03/17/2020). Illuminated Orbital Shaker for Microalgae Culture. https://dx.doi.org/10.17504/protocols.io.bdtyi6pw

3.7 **This document is part of the Illuminated Orbital Shaker for Microalgae Culture project:**

- Procuring Parts for Algal Shaker
- Assembling LED Controller Electronics
- 3D Printing Case for LED Controller *(this document)*
- Assembling Cooled LED Illuminator
- Cutting and Drilling Clear Acrylic Sheet
- Assembling Algal Shaker

## 4 Assembling Cooled LED Illuminator

The LED illuminator is built from LED strips mounted on top of a heatsink. The heat sink is passively cooled when the LEDs are operated at low current. It is actively cooled by small fans at higher current to avoid overheating the algal cultures. The assembly of the cooled LED illuminator consists of glueing the LED strips to the underside of the heat sink and soldering them in a daisy-chain fashion for connection to the LED controller. The fans are also glued to the heatsink and connected to the LED controller.

Cooled LED illuminator

Assembling Cooled LED Illuminator
**by Jakub Nedbal,**
**King's College London**
PREVIEW RUN

## 4.1 Fixing LED Strip to Heatsink

Prepare two meters of the LED strip.

Self-adhesive LED strip to be fixed to the heatsink.

Cut the LED strip into ten 200 mm (8") long segments using scissors. Cut along the designated lines going through the solder pads.

Prepare the heatsink. The recommended heatsink features a 200 mm × 150 mm flat surface area, 40 mm height, and 0.5 °C/K thermal resistance. Other heatsink may be used, but it must be sufficiently large to accommodate the LEDs and the axial fans fixed to its side. Any heatsink of this size should have sufficiently low thermal resistance.

Heatsink to hold the LED strips and fans.

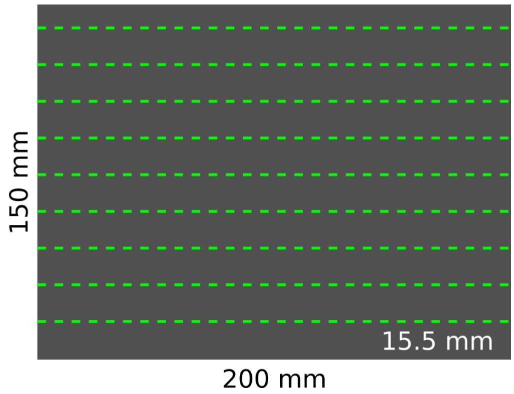
Use a permanent marker and ruler to draw lines, along which the LED strip will be glued to the adhesives. For ten ($N_S$ = 10) parallel LED strips, each $w_S$ = 10 mm wide, there are nine ($N_G$ = 9) gaps of unknown width ($w_G$). The width of the heatsink is $w_H$ = 150 mm. The spacing of the lines ($w_L$) can be calculated using the following equation:

$N_S \times w_S + N_G \times w_G = w_H$

$w_G = (w_H - N_S \times w_S) / N_G$ = (150 mm - 10 × 10 mm) / 9 ≅ 5.5 mm

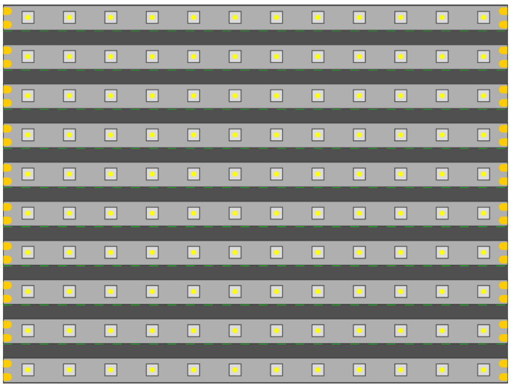
$\boldsymbol{w_L}$ = $w_G + w_S$ ≅ 5.5 mm + 10 mm = **15.5 mm**

Lay the heatsink on a table with the flat surface facing the top. Draw nine lines with a permanent marker onto the heatsink surface. The lines are parallel to the longer edge of the heatsink. The first one starts 15.5 mm from the heatsink edge and they are spaced 15.5 mm apart, as in the image below:




Sketch of the heatsink surface with green lines spaced 15.5 mm, starting from the bottom. Draw these lines using a permanent marker onto the actual physical heatsink. They will be used as guides for attaching the self-adhesive LED strips.

Peel the backing foil from the LED strip one-by-one and stick it along the drawn lines onto the heatsink surface. Make sure that the orientation of all the strip segments is the same to avoid confusion later. Once all the LED strip segments are attached, the surface of the heatsink will be covered with the LED strip segments as in the image below:



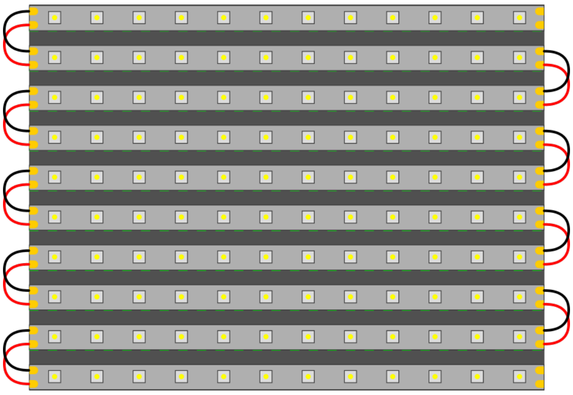
Sketch of LED strips stuck to the heatsink surface. The LED strips are attached along the green lines shown in the picture above to produce equal spacing across the entire surface of the heatsink.

### 4.2 Soldering LED Strips Together

Prepare the soldering equipment.

Cut the red and black 0.5 $mm^2$ wires into nine 30 mm (1") long segments of both colors. Strip the insulation from both ends of each segment.

Solder the neighboring LED strip segments together, with the red cable segments connecting the anodes (+) and the black cable segments connecting the cathodes (–), as in the image below:

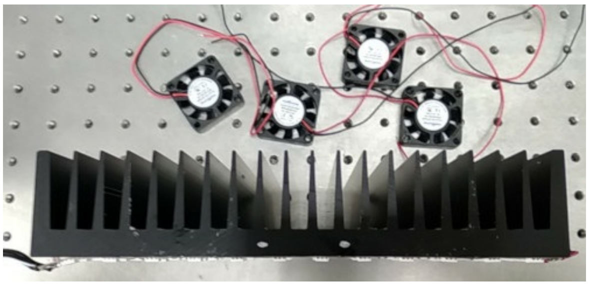


Sketch of LED strips on the heatsink with short cable segments connecting their electrodes. The red cables connect the anodes (+) and the black cables connect the cathodes (–).

**Note:** The soldering may be problematic if the soldering iron does not have sufficient power to heat up the solder pads of the LED strips attached to the heatsink. In that case, lift the ends of the LED strips by peeling them off the heatsink temporarily. Reseal the self-adhesive backing to the heatsink once finished soldering.

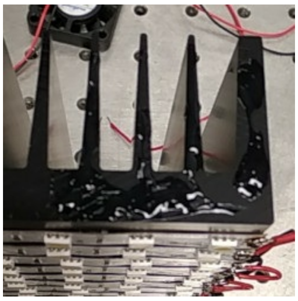
### 4.3 Fixing Axial Fans to Heatsink

The heatsinks are attached to the side of the heatsink using general purpose solvent based glue. Prepare the glue, the heatsink with the LED strips attached, scissors, electricians tape, and four axial fans:



Four axial fans prepared to be glued to the heatsink with the LEDs already attached.

Deposit the general purpose glue onto the side of the heatsink, where the fans will go:



Glue is liberaly applied to the edge of the heatsink. The fans will be fixed to the heatsink with the glue. The fans are oriented such that the frame is touching the heatsink and the rotor with the blades is facing the outside.

Press the axial fan into the glue with the sticker facing the heatsink. Do not glue the rotor with the blades, but the frame of the fan.



**Citation:** Jakub Nedbal (03/17/2020). Illuminated Orbital Shaker for Microalgae Culture. https://dx.doi.org/10.17504/protocols.io.bdtyi6pw

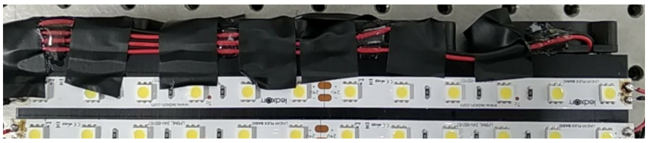
Glue all four fans side-by side with the supply cables facing the side, where LEDs are attached:

All four fans have been glued to the edge of the heatsinks. Notice the fans are oriented such that their power leads face up, the same way the LED strips face.

The glue dries quite quickly and if the fans are handled carefully, you can proceed immediately to the next steps. Dab a bit of glue onto the side of the fan near its power supply cables. Push the cables into the glue blob and fix them with electricians tape in place. Cover the glue patch with more glue, which will reliably fix the cables to the side of the fan:

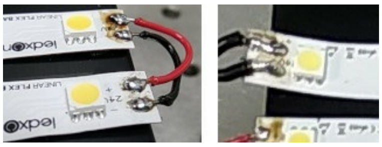
The heatsink leads are glued along the fan top using the multipurpose solvent-based adhesive. The leads are temporarily fixed using electricians tape to the fan - holding the leads in place while the glue dries and solidifies.

Do this for all fan leads and fans to tidy up the cables using more glue and more electricians tape:



Gradually fix using a multipurpose solvent-based adhesive all supply leads to the fans along the heatsink to the fan bodies. Use electricians tape to temporarily hold the leads in place while the glue sets.

The LED strips tend to peel off from the heatsink, especially near the edges. The peeling process is gradual, however pushing the strip back down does not fix the problem and the strip will peel off over time as seen in the pictures below:



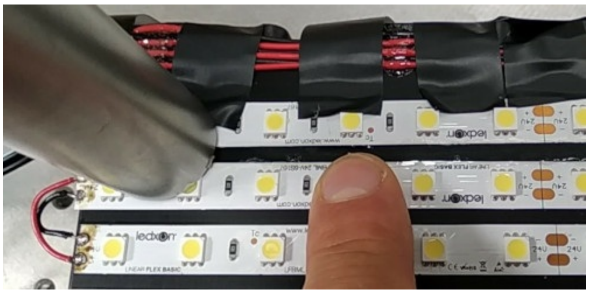
The LED strips tend to peel off from the heatsink. The peeling is most obvious near the ends of the strips.

The self-adhesive backing can be reinforced with the general purpose glue. Push down the LED strip segments to stick flat to the heatsink. Dispense the all-purpose glue in between and along the edges of the LED strip segments. Push again on all the LED down with finger to make sure the strip is adhered to the heatsink before the glue dries. If any part of the LED strip does not hold adhered, weight it down with a suitable object while the glue is setting.

The image below shows glue between the top to segments of the strip (not clearly visible, due to its transparent look), the finger pushing down on the LED and a steel post weighting down end of a strip, which kept bulging up without the weight:



**Citation:** Jakub Nedbal (03/17/2020). Illuminated Orbital Shaker for Microalgae Culture. https://dx.doi.org/10.17504/protocols.io.bdtyi6pw



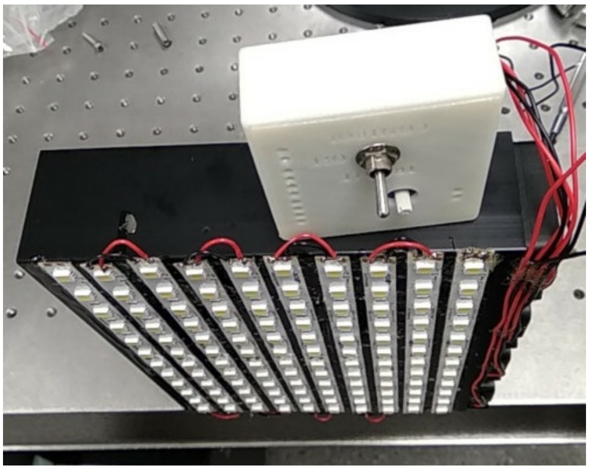
Deposit glue onto the heatsink surface, covering the edges of the LED strips. This way the glue will bond the LED strip thoroughly to the heatsink. Use a heavy weight (1" stainless steel post in the photo) to hold any lifting LED strips while the glue is drying. Use gloves and not a bare finger, unlike shown in the photo.

Leave the glue dry out. The drying time will depend on the type of the glue and the environmental conditions, but could take an hour or more. Glue all strips in one go, if in rush, or glue them in batches of a few strips at a time.

4.4 **Fixing LED Controller to the Heatsink**

The LED controller can be left lying next to the heatsink on the shaking incubator. The fixing does not need to be done at this point and could be postponed until everything is tested and working. The primary reason to fix the LED controller to the heatsink is to keep the wiring tidy and reliable in the long-term by minimizing risk of snapping of the cables.

Position the heatsink on the edge of a table to have it standing sideways. Make sure the LED controller can be mounted sideways, as in the image below:

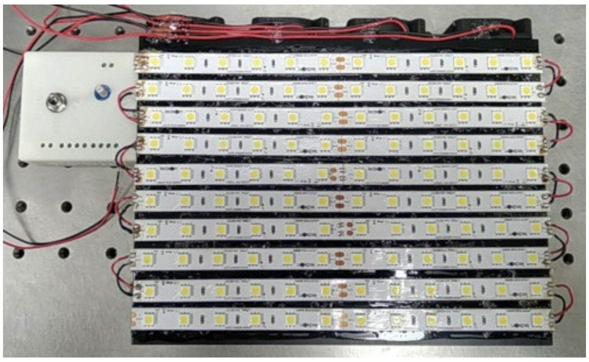


Heatsink placed on the edge of a table on its side. The LED controller is positioned standing on the other side of the heatsink.

Apply the general purpose glue to the side of the heatsink, where the LED controller is to be mounted. Press the LED controller into the glue and make sure that the bottom of the heatsink and the bottom of the LED controller are spaced at least 6 mm (1/4") apart. This is to ensure that the LED controller stays above the rim of the orbital shaker platform. The rim is about 6 mm high. If you have a different orbital shaker, make sure that either the heatsink with the LED controller fit entirely onto the platform, or check for minimum clearance required to accommodate the platform rim.

Fix the LED controlled to the side of the heatsink with the general purpose solvent-based adhesive. Make sure there is enough space (6 mm) between the bottom of the heatsink and the bottom of the LED controller, so the rim of the orbital shaker platform is no in the way of the LED controller.

Let the glue dry for 10-30 minutes, depending on the type of the glue and environmental conditions. Even once the glue is partially set, handle the unit with care, as the glue will initially be quite weak. Once happy with the strength of the glue, lay the heatsink back on its back:

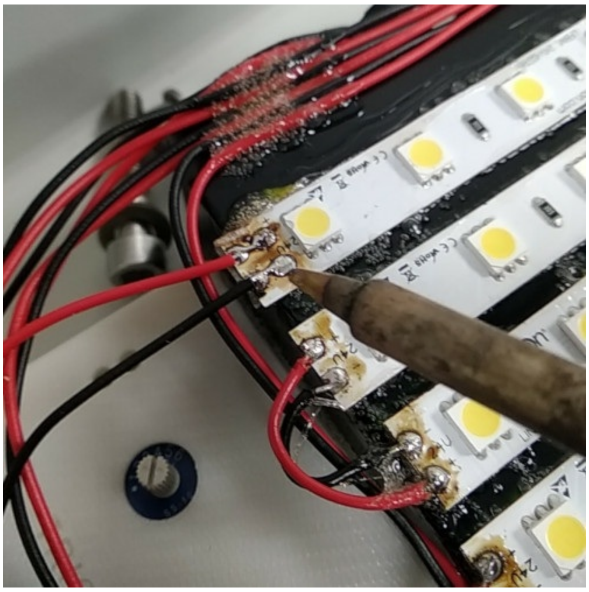


This photo shows the heatsink with the LED controller glued to its side.

Solder short lengths of red and black 0.5 $mm^2$ cables to an unconnected end of the LED strip. Connect the red cable with the (+) labeled solder pad and the black cable to the (−) labeled solder pad.

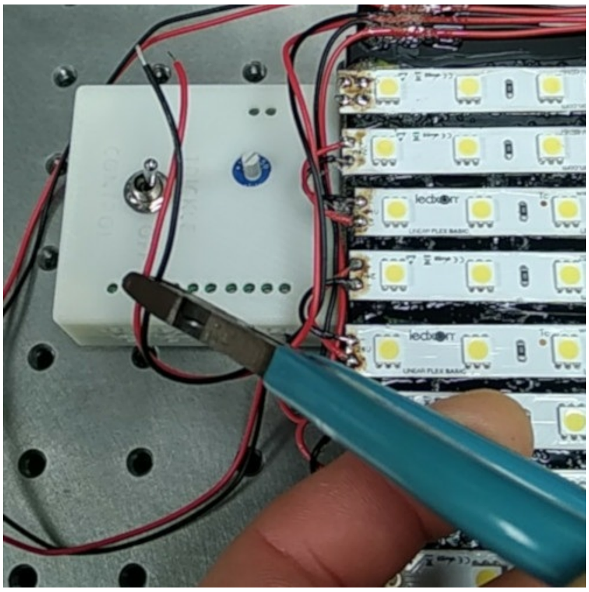


**Citation:** Jakub Nedbal (03/17/2020). Illuminated Orbital Shaker for Microalgae Culture. https://dx.doi.org/10.17504/protocols.io.bdtyi6pw



Solder the power supply leads to the first LED strip. Connect a black cable to the cathode (−) and the red cable to the anode (+).

Trim the fan cables to length suitable for connecting to the LED controller. Make sure to connect the pairs of red and black cables coming from each fan to the two neighboring terminals in the LED controller. Connect the red cable to the (+) labeled terminal and the black cable to the (−) labeled terminal. It does not matter which fan connects to which pair of terminals.



Trim the fan power supply leads to a length long enough to comfortably reach the screw terminals in the LED controller.

Strip the ends of each lead and connect them to the LED controlled terminals. As explained above, ensure the cables to one fan go into the neighboring pairs of terminals. The LED is connected to the terminal labelled LED. Observe the polarity signs printed on the side of the LED controller or follow the labeling in the image below:


The cables are connected to the LED controller. The two leftmost terminals connect the LED strips. The four pairs of terminals are for the four cooling fans.

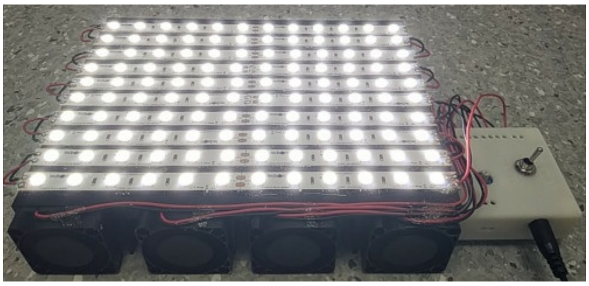
4.5 **Testing the LED controller**

Connect the 30V/1A Power Supply to the LED controller and plug it into the socket. Flick the toggle switch between the 3 positions: TICKLE CURRENT - OFF - CONTROLLED CURRENT. In the OFF mode, the LEDs and fans should be off. In the TRICKLE mode, the LED should glow weakly and the fans should be stationary. In the CONTROL mode, the fans should be spinning and the LEDs should be glowing bright. Use a screwdriver to adjust the LED brightness by turning the rotary switch between the end positions (•), for maximum brightness, and (6), for minimum brightness.

LEDs are in the trickle mode and fans stationary:

LEDs glow is dim in the trickle current mode. The fans are stationary.

LEDs are in the controlled current mode and the fans are spinning:



In the controlled current mode the fans are spinning and the LEDs are considerably brighter.

4.6 **Summary**

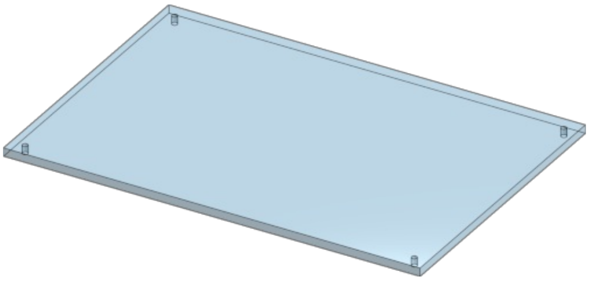
This protocol explained the procedure of mounting LED strips to a heatsink, adding axial fans for cooling, and the LED controller. It described the electrical connection of these parts and finally shown how to verify the function of the cooled LED illuminator. The next document will describe how to cut a clear acrylic sheet for the illuminated orbital shaker.

4.7 **This document is part of the Illuminated Orbital Shaker for Microalgae Culture project:**

- Procuring Parts for Algal Shaker
- Assembling LED Controller Electronics
- 3D Printing Case for LED Controller
- Assembling Cooled LED Illuminator *(this document)*
- Cutting and Drilling Clear Acrylic Sheet
- Assembling Algal Shaker

## 5 Cutting and Drilling Clear Acrylic Sheet

A clear acrylic sheet is mounted over the LEDs and serves as the platform on which the algal cultures are placed for shaking. The acrylic can be cut out and drilled using a hack saw and a drill in a workshop. Alternatively, it can be cut using a laser cutter in-house or externally.



Cut and drilled clear acryilic sheet serving as a transparent orbital shaker platform

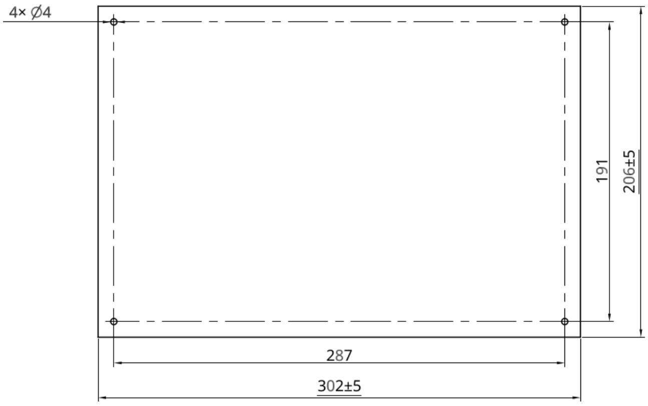
Cutting and Drilling Clear Acrylic Sheet
**by Jakub Nedbal,**
**King's College London**
PREVIEW RUN

5.1 **Technical Drawing for the Clear Acrylic Platform**

Measure the size and positions of mounting holes on your orbital shaker. There is a technical drawing file available for the orbital shaker KJ-201BD used in this project, available in Onshape:

Orbital Shaker Platform

A technical drawing of the clear acrylic platform for the KJ-201BD orbital shaker, including the four mounting holes, is in the image below. The dimensions are in millimeters. Notice, the actual dimensions of the sheet are not critical, what matters is the spacing of the fixing holes (287 mm and 191 mm). These must match the holes in the orbital shaker platform.



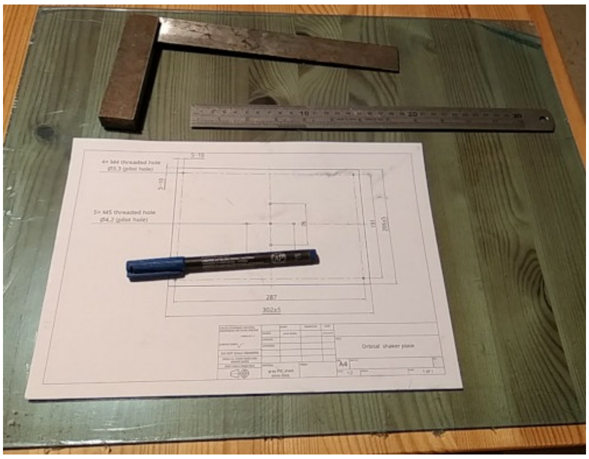

Technical drawing of a clear acrylic platform compatible with the KJ-201BD orbital shaker. The critical domensions are the spacing of the mounting holes. Other orbital shakers will require custom technical drawings to reflect the size of the shaking platform and the position of its mounting holes.

If you have a different shaker, prepare a technical drawing for the clear acrylic platform, based on the dimensions and hole placement of your shaker platform.

5.2 **Cut and Drill the Clear Acrylic Platform**

This section describes the cutting and drilling of the acrylic using workshop tools. If a laser cutter is available and will be used for cutting the acrylic, skip to the next step.

Prepare the acrylic sheet, technical drawing, fine tip permanent marker, ruler and a square or a protractor:



Clear acrylic sheet, technical drawing, carpenter square, and a ruler used to draw guidelines for the cutting and drilling.

Draw the outline of the platform onto the clear acrylic sheets and mounting holes in positions according to the technical drawings.
Use a hacksaw to cut along the drawn lines to cut out a sheet of the desired dimensions.

Cutting with a hacksaw along the guide lines drawn on the acrylic sheet.

Use a medium grit (P80–P180) sandpaper to deburr the cut edges.
Use a drill with 4 mm (5/32" or 3/16") multipurpose drill bits to drill the holes in the marked locations. Special drill bits for plastics exist and would be preferrable for drilling these holes. Their use would minimize the risk of cracking of the sheet, but they are not widely available.


Drill and a drill bit with the cut clear acrylic sheet havings marks for the holes drawn nears the corners.

5.3 **Laser Cutting Clear Acrylic Sheet**

This step has not been tested. It should be possible to laser cut the acrylic sheet, instead of cutting and drilling it by hand. The resulting sheet should have cleaner cuts and more accurate holes placement, compared to the hand-made one described above. For the KJ-201BD orbital shaker, you can use a DXF file to guide the laser cutter:

Orbital_Shaker_Clear_Acrylic_Sheet.dxf

The file has been created by exporting the drawing of the Onshape model of the Orbital Shaker Platform. The file was edited in LibreCAD to remove all unwanted text and lines, leaving the outline of the sheet and the four mounting holes only, as seen in the image below.

The outlines guiding the laser cutter to produce the transparent platform for the orbital shaker from clear acrylic sheet.

If your orbital shaker has different shaking platform dimension and/or mounting hole positions, create a custom drawing reflecting the actual dimensions.

Use manufacturer instructions to operate the laser cutter. Observe local safety rules. Allow only trained staff operate the laser cutter.

5.4 **Summary**

This document describes the steps to cut a clear acrylic sheet and drill holes into it to create a transparent shaking platform to place the culture flasks on. It offered a solution for laser cutting the sheet instead of doing it by hand. The sheet will be mounted on top of the orbital shaker, as explained in the next document on the final assembly.

5.5 **References**

- Orbital Shaker Platform: Onshape document with the model and technical drawing of the clear acrylic platform designed to fit the KJ-201BD orbital shaker.

- LibreCAD: 2D CAD program that allows editing the technical drawing in DWG or DWF formats exported from Onshape to remove unwanted details for laser cutting.

- Orbital_Shaker_Clear_Acrylic_Sheet.dxf: DXF file for laser cutter to produce clear acrylic platform designed to fit the KJ-201BD orbital shaker. Different file will be needed for orbital shakers of different sizes and mounting hole positions.

5.6 **This document is part of the Illuminated Orbital Shaker for Microalgae Culture project:**

- Procuring Parts for Algal Shaker
- Assembling LED Controller Electronics
- 3D Printing Case for LED Controller
- Assembling Cooled LED Illuminator
- Cutting and Drilling Clear Acrylic Sheet *(this document)*
- Assembling Algal Shaker



**Citation:** Jakub Nedbal (03/17/2020). Illuminated Orbital Shaker for Microalgae Culture. https://dx.doi.org/10.17504/protocols.io.bdtyi6pw

## 6 Assembling the Algal Shaker

Assembling the Algal Orbital Shaker is the last an most rewarding step. The acrylic sheet is mounted on top of the orbital shaker on metal stand-offs. The cooled LED illuminator is laid underneath the acrylic. The antislip silicon mat supplied with the orbital shaker is placed on top of the acrylic. The LED controller is connected to a socket through a 24-hour timer with the day/night cycle programmed. Once powered, the algal shaker should be working.


Assembled and functioning illuminated orbital shaker

Assembling Algal Shaker
**by Jakub Nedbal,**
**King's College London**
PREVIEW RUN

6.1 Prepare a tidy workbench with sufficient space and illumination to minimize risk of accidents.



**Citation:** Jakub Nedbal (03/17/2020). Illuminated Orbital Shaker for Microalgae Culture. https://dx.doi.org/10.17504/protocols.io.bdtyi6pw

6.2 Fix the four M4×50 mm male-female standoffs to the orbital shaker platform using nuts and washers.
*Where Imperial threads are preferred, use #8-32×2" stand-offs instead.*

Fix stand-offs to the holes in each corner of the orbital shaker platform using nuts and washers.

Use wrenches snd/or pliers to fasten the stand-offs by tightening the nuts.

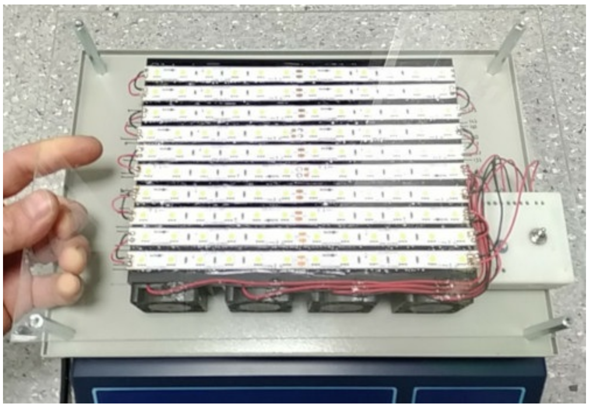
6.3 Lay the cooled LED illuminator onto the orbital shaker platform, between the standoffs.


Lay the LED illuminator onto the shaker platform between the four stand-offs.



**Citation:** Jakub Nedbal (03/17/2020). Illuminated Orbital Shaker for Microalgae Culture. https://dx.doi.org/10.17504/protocols.io.bdtyi6pw

6.4 Place the clear acrylic sheet over the standoffs.



Align the clear acrylic sheet mounting holes with the stand-offs.

6.5 Place the antislip mat delivered with the orbital shaker over the clear acrylic sheet. Orient it with the antislip face facing up.
Pierce small holes through the antislip mat using a needle or a sharp blade in the locations of the mounting holes.

Pierce the antislip mat at the positions of the mounting holes.



**Citation:** Jakub Nedbal (03/17/2020). Illuminated Orbital Shaker for Microalgae Culture. https://dx.doi.org/10.17504/protocols.io.bdtyi6pw

6.6 Use M4×12 mm screws and washers to fix the clear acrylic sheet with the antislip mat to the orbital shaker platform.

*Where Imperial screws are preferred, use #8-32 UNC×1/2" screws and washers instead.*

Fix the acrylic sheet with the antislip mat on top using screws and washers.

6.7 Program the 24 hour timer to the desired day/night cycle. In our case the day starts at 6 AM and finishes at 8PM. Set the current time on the 24 hour timer.


Program the 24-hour timer. Different timers will look differently. The manual ones, like in this picture, are programmed by pushing in or raising the switches along the dial. Digital ones will be programmed on the screen, according to manufacturer's instructions.



**Citation:** Jakub Nedbal (03/17/2020). Illuminated Orbital Shaker for Microalgae Culture. https://dx.doi.org/10.17504/protocols.io.bdtyi6pw

6.8 Connect the 30V/1A power supply into the LED controller power input and plug it into the 24 hour timer.

Plug the orbital shaker and the 24 hour timer to the mains socket.

Plug the orbital shaker into one mains socket. Plug the 30 V power supply into the 24-hour timer and plug that timer into another socket.

6.9 Turn on the LED to the desired power setting using the toggle switch and the rotary switch on the LED controller. This may require temporarily pulling out the cooled LED illuminator to reach these switches. Set the spin speed on the orbital shaker to the desired speed (100 rpm, in our case) and turn it on.


The assembled an working illuminated orbital shaker.

6.10 With the above steps complete, the orbital shaker should keep shaking 24-hours a day and cycle the light with the interval set on the 24 hour timer.

6.11 **Summary**

This protocol finished the assembly of the illuminated orbital shaker for microalgae culture. The cooled LED illuminator has been installed onto the shaker platform and a new light-transmissive antislip platform was built over the illuminator.

6.12 **This document is the final part of the Illuminated Orbital Shaker for Microalgae Culture project:**

- Procuring Parts for Algal Shaker
- Assembling LED Controller Electronics
- 3D Printing Case for LED Controller
- Assembling Cooled LED Illuminator
- Cutting and Drilling Clear Acrylic Sheet
- Assembling Algal Shaker *(this document)*



**Citation:** Jakub Nedbal (03/17/2020). Illuminated Orbital Shaker for Microalgae Culture. https://dx.doi.org/10.17504/protocols.io.bdtyi6pw

**Citation:** Jakub Nedbal (03/17/2020). Illuminated Orbital Shaker for Microalgae Culture. https://dx.doi.org/10.17504/protocols.io.bdtyi6pw