# A Versatile DIY Laser Power Controller with Open-Source Hardware and Software Options

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# Abstract

This paper presents a design for a customizable laser power controller that empowers researchers, educators, and hobbyists to achieve precise laser light attenuation. The system offers flexibility in both hardware and software components. Users can integrate commercially available parts or leverage the open-source design to build their own control electronics, power attenuator, shutter, and laser power meter sensor. The paper details the functionalities of the control electronics built around the Teensy family of microcontrollers (Teensy 3.1/3.2 and 4.0), with an Arduino version under development. 3D printed parts and readily available electronic components facilitate the construction of the DIY hardware modules. Gerber files and CAD models further streamline the building process. The open-source front-end software, currently implemented in LabVIEW with Python in development, provides intuitive control over the entire system and integrates seamlessly with various power meters. In-built calibration routines ensure accurate laser power control at the sample plane. This versatile and cost-effective design allows users to tailor the laser power controller to their specific needs.

# Introduction

The laser power controller presented here is a versatile tool that allows users to combine various components to achieve precise attenuation of incoming laser light. This capability has numerous applications in research laboratories, optical communication systems, and material processing, where controlling laser power is crucial.

In the most general version, we consider the controller made of a gradual light attenuator, a shutter, a power meter, and electronics controlling them. Each of the components can be implemented using one of the described DIY designs. Alternatively, commercial hardware can be used for some, or all of them, as long as this hardware can be controlled using predefined serial commands. For example, for the gradual light attenuator, we can use a commercially available Glan prism-based device, or Pockel cells, or a neutral density filter (if it’s rotation can be controlled electronically). In place of the described DIY designs, we could use a fast Uniblitz shutter (if the laser power isn’t too high), or nothing at all. Or we could resort to a standalone DIY implementation of the whole system described here. The power meter in the current software implementation can be either a standalone module for a device controllable via a serial port or provide a direct input to the DIY MCU board described in this paper.

The complexity of building a particular version of the power controller depends on the chosen components. However, in general, it should not require special skills. The DIY hardware components described here require 3D printed parts, which can either be done manually or ordered from a vendor. The electronics controller board is made of a PCB board and electronic components which must be soldered. While soldering skills required here are minimal, this step can also be outsourced to a vendor. Installing various commercial components obviously depends on the choice of components, but it’s usually a straightforward process. And incorporation of the commercial serial devices into the front-end software requires only the provision of the map between the required commands and the commands provided in the manual for the installed device.

This controller provides an in-built calibration capability implemented both on the MCU and in the front-end software. The calibration can be done both automatically and manually and allows controlling the laser power by providing the desirable power at the sample, rather than via the units used by the power attenuation device. It also allows clamping the power at the sample to the required level so that it’s maintained even if the laser output changes.

The front-end software is implemented as the Module Conductor (MC) module, making readily incorporable into the MC assembly, or to be controlled remotely via the ZMQ interface.

In the next sections, we …

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| A diagram of a computer system  Description automatically generated  Figure 1. a) Various parts and communications allowed in the laser power controller, b) two common setups for controlling the laser power supported by our power controller: in the diverted light measurement version, the power meter measures the power ‘spilled’ by the gradual power attenuator, while in the through setup the measured power is proportional to the power delivered to the sample. |

# Control Electronics

As was mentioned in the introduction, the laser power controller can be built from a diverse combination of commercial and DIY components. If a hardware component is controlled directly by the computer (connected via a serial port), it should be equipped with its own device controller and only requires the mapping of serial commands described in the Frontend software section to be integrated into the system. However, if the hardware component is one of the DIY components described in this paper, or a voltage-controlled device, they can be controlled using the DIY electronics described here.

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| A computer screen shot of a circuit board  Description automatically generatedA green circuit board with blue and yellow squares and black text  Description automatically generated  Figure 2. PCB control boards of the DIY electronics. |

## DIY electronics and firmware.

The DIY control board was designed to support different modes of operation, from a fully integrated all-in-one solution for changing, measuring, and displaying the laser power to using this board for controlling just one of these features. We designed the solutions based on a popular Teensy USB microcontroller development system. Here, we present the PCB boards and associated firmware for two boards from the Teensy family: Teensy 3.1/3.2 and Teensy 4.0. We also have the control board based on Arduino platform in development.

## PCB boards

Designed in KiCad.

The repository contains Gerber files which can be uploaded to a facility for printing.

Alternatively, one can order the board directly from the facility by the provided stock number.

The interfaces / connectors. USB micro for the Teensy board. All the connectors are designed in the 0.1" pitch DIP format. The shutter, polarizer and display connectors have 4 pins, while the TEC connector has 2 pins. The output to the voltage-controlled hardware is optional and designed in the form factor of a Teensy board shield expansion.

## Electronic components

The electronic components used for controlling different aspects of the controller are described in the Excel file. If not all the controller’s features are necessary for the build, the corresponding components can be omitted.

A .csv file is provided for a simple drop-in order at Digikey and Mouser vendors. However, should these components become obsolete, the Excel file contains links for general searches of the replacement components satisfying the criteria necessary for the successful built.

## Firmware

Asynchronous, based on interrupts – low power, doesn’t freeze, can run multiple operations concurrently (e.g., servo, half-wave-plate and servo)

Utilizes the library facilitating the development of asynchronous firmware which we will present elsewhere.

The commands for communication with the front-end software are given in the .h file (which is capable of parsing it).

The compiled version of the firmware can be found in the firmware/bin folder, and can be easily uploaded to the MCU board using the Teensyduino software: Instructions…

Designed to be able to operate in a standalone fashion. At the moment, however, it’s made to operate only in mode in which it communicates with the computer.

# Hardware

As discussed earlier, the power controller can operate with different kinds of hardware capable of attenuating the laser power or blocking the laser light. The hardware should either be connecting to the serial port on the computer directly (e.g., using a USB or RS-232 connector), or to a corresponding connector on the DIY board (including the voltage-controlled devices). Below, we present examples of some of the commercial devices which can be incorporated into our laser controller (with the associated files containing the communication commands), as well as the family of DIY devices which combine high quality and low construction cost for scenarios when changing power in dozens of milliseconds is sufficiently fast. For each of the DIY devices, we present step-by-step instructions for building them.

## Power attenuator

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| A close-up of a small silver device  Description automatically generatedA close-up of a camera  Description automatically generatedA drawing of a machine  Description automatically generated  Figure 3. Example of the power attenuation devices which can be used with our power controller. a) The DIY device which can be both, used as a standalone device, and be integrated into the 40 mm cage system, b) an assembly made of commercial components, with a Newport rotational stage, c) Conoptics Pockels cell |

There are different types of gradual power attenuators: neutral density filters, combinations of polarizers and waveplates, acousto-optic modulators (AOMs), ?MEMS?. They differ in the possible rate of attenuation, requirements to the attenuated light (e.g., the maximum allowed power, incoming light polarization, etc.), physical dimensions, etc. However, as long as a device can connect either to our controlling board, or to a serial port on the computer, it can be fully integrated in the power controller.

Here we present a series of DIY laser power attenuators which are based on a combination of a Glan-Taylor prism and a rotating half-wave plate, and allow changing the power of high-energy polarized laser light. The rate of power control depends on the speed at which the half-wave plate can be rotated, and is dozen of milliseconds when a fast servo motor is used in the design. It should be noted that in principle it is also possible to rotate the Glan prism and skip the half-wave plate altogether. However, due to the gap between the two prisms comprising the calcite Glan prism, the outcoming light is shifted slightly in the interference plane. Since this plane is rotating along with the prism, the output of such a system will be shifted differently, depending on the power output, preventing the alignment of sensitive systems, s.a. microscopes. However, if the shifts of light within hundreds of microns is not an issue, omitting the half wave plate allows the simplification of the power attenuator with an accompanying reduction in cost.

The presented DIY attenuator works for beams of the diameter up to … , but can be easily modified for larger beams if necessary. We present several versions which allow for different positioning of the attenuators in optical setups. We also describe DIY setups with varying amount of commercial components. For details and build instructions, see Supplementary Material 1.

## Shutter / Beam block

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| A green and black robotic arm  Description automatically generatedA black and silver circular object with wires  Description automatically generatedA green machine with a black square on it  Description automatically generated  Figure 4. Example of the laser blocking devices which can be used with our power controller. a) A slim DIY device design to be integrated on top of the 60 mm cage system, b) a DIY device which can operate in a standalone fashion, or be integrated into the 40 mm cage system, c) Uniblitz shutter, which can be used for fast blocking of the light pass in low power laser light applications. |

The purpose of a shutter is to safely dump the light by either blocking or redirecting it into a block. So, in most cases it can be considered as all or none power attenuator. Figure 4 shows a few examples of the shutters which can be integrated into our power controller. As for the attenuator, the main requirement here is that it should be possible to either control the shutter via out DIY controller, or via a serial port commands. The DIY shutter presented here divert light into a beam block and can handle high power lasers. The Uniblitz shutter offers much faster blocking time, but by absorbing the incoming light and being thin, it works only for low power applications. Other methods for redirecting the light ….

We developed DIY shutters which can be placed as standalone devices, or incorporated into the 40 mm and 60 mm cage systems. Most of them depend on parts which have to be 3D printed, but a couple can also be made with a laser cutter. For details and build instructions, see Supplementary Material 2.

## Laser Power Meter/Sensor (LPM)

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| A black square device with a wire  Description automatically generatedA green light on a metal box  Description automatically generated  Figure 5*.* The power meter sensors options which can be used with our power controller. a) DIY sensor based on the TEC (Thermoelectric Cooler) element painted with a selected black paint to be connected directly to the DIY power controller described here, b) S405C Thorlabs sensor (at the moment, has to be equipped with one of the Thorlabs’ power meter controllers). |

Our DIY controller board allows connecting any power meter which reports its measurements as differential voltage pair. This includes the DIY power meter based on a Thermoelectric Cooler (TEC) element which is presented in Supplementary Material 3. (Also, see Figure 5). Integrating a commercial power sensor with a custom board is complicated as they typically rely proprietary protocols, but we have one in development as a shield for the control board. However, if the laser power controller is not to be operated as a standalone device, the commercial power sensors can be connected to the computer via a serial port and easily integrated in the front-end software. See Supplementary Material 4 for an example of such an integration.

# Front-end software

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| A screenshot of a computer  Description automatically generatedA screenshot of a computer  Description automatically generated  Figure 6. The front panels of the Labview/compiled versions of the a) power controller and the b) power meter software. |

The developed front-end software allows for the integration of the various parts of the laser power controller and fully implements the logic of its operation. The currently fully implemented solution is written in Labview and can also be used as a compiled executable file. We also have Python code in development. The code is complemented with necessary hooks to be used as the MC module, which also includes the logging ability. It is written based on asynchronous events, and thus requires minimal resources to operate.

The main panel of the software shows the control and feedback (if present) from the power attenuator hardware on top. Depending on whether the power controller has been calibrated, the units of measurement will either be the AU of the connected attenuator controller, or the power at the sample in mW.

The second line of controls is for the shutter. If the shutter controller allows, the controls allow to move the shutter gradually in between the closed and opened states and to introduce an intermediate position, which we found to be useful when we want a rough, but quick partial blocking of the laser beam, independent of the power attenuator. A toggle next to the slider allows to switch between the continuous and discrete regimes of operation. And a button under the slider allows saving the current position in the continuous slider to the controller board as the intermediate position.

The settings of the power controller can be set in the settings window, accessible via the cog-wheel button, or by settings them in the MC configuration file. The calibration sub-window … Inbuild, easy

calibration to allow control by the power at the sample rather than the AU of the controller. Works with both, Diverted and Through designs.

The power meter can be run in a separate, MC-module application, which can send the readings to the laser power controller, which can use it instead of internally obtained readings.

# Discussion

# Supplementary Materials.

## Supplementary Material 1.

Here we present the details on integrating different power attenuators into the power controller and instructions on building the DIY power attenuators.

### DIY Power Attenuator 1.

This power attenuator is driven by a servo. There are two bracket choses: for the standard HS-422 servo which shared dimensions with many other servos with different characteristics, or a smaller … servo. However, for a servo of a different size one has to simply modify the dimensions of the parametrically configured bracket in the design.

## Supplementary Material 2.

Here we present the details on integrating different laser light shutters into the power controller and instructions on building the DIY shutters.

## Supplementary Material 3.

Here we present the details on building the DIY power meter using a painted TEC element.

## Supplementary Material 4.

Here we present an example on combining different elements in a fully functioning power controller with the MC integration.