QSD Monitoring Network

Measuring Laser Beam Powers

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Laser beam power is measured with a photodiode - a device which produces electron-hole pairs when photons of sufficient energy fall on the depletion region of the p-n junction semiconductor. Because there is a separation of charge either side of the depletion region, there is also an internal electric field across it. Therefore, when light falls on the active area the electrons move towards the cathode and holes towards the anode, leading the generation of an electrical photocurrent. To convert the photocurrent into a measurable voltage signal, a *transimpedance amplifier* can be used, shown schematically in Fig. 1.

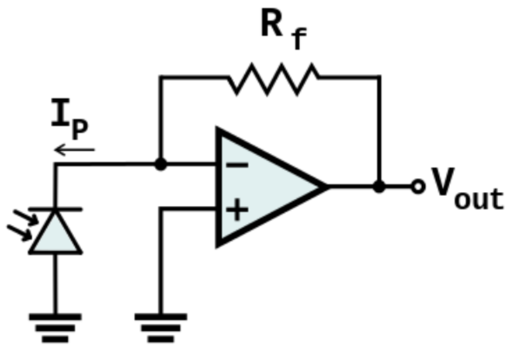

FIGURE 1: Schematic of a photodiode connected in photovoltaic mode with a transimpedance amplifier configuration, which gives an output voltage proportional to the incident light power that can be scaled using the feedback resistor.

Photodiodes can be operated in either of two modes: *photoconductive* (with an external reverse bias applied across it), or *photovoltaic* (with zero bias across it). In general, photovoltaic mode reduces dark current, but is less optimal for bandwidth and response time. An excellent source of information on photodiode circuits and configurations is the book *Photodiode Amplifiers - Op Amp Solutions*, by J. Graeme [1]. In the particular application described in this document bandwidth is not a priority, and the photovoltaic arrangement is employed as shown in Fig. 1. Here, the op amp acts to make both its inputs equal to each other, which is zero volts due the non-inverting input being explicitly grounded. Since the photocurrent I_{p} is forced to flow through the feedback resistor R_{f}, the voltage drop across this resistor is

$$\Delta V = (V_{\mathrm{out}} - 0) = I_{\mathrm{p}} \times R_{\mathrm{f}}, \tag{1}$$

and so the output voltage V_{out} is simply linear with the photocurrent. The amount of photocurrent generated is also linear with incident optical power through a factor known as the *responsivity* (measured in $\mathrm{A\,W^{-1}}$), and so this configuration provides a measurable output voltage that is linear with laser light power, which can be conveniently scaled by changing the gain of the transimpedance amplifier using the feedback resistor.

It was decided to use the *Thorlabs FDS100*, shown in Fig. 2 a), which is a standard silicon photodiode with a large active area of $13\,\mathrm{mm}^2$, and costing £10 each. The responsivity at $780\,\mathrm{nm}$ is $\sim 0.5\,\mathrm{A\,W^{-1}}$, as can be seen in Fig. 2 b).

For the transimpedance op amp, the MCP604X series from *Microchip* is used, which is available with either one, two, or four op amps in a single chip. This is a low power op amp, designed for battery powered applications. It has a relatively low bandwidth, but this isn't an

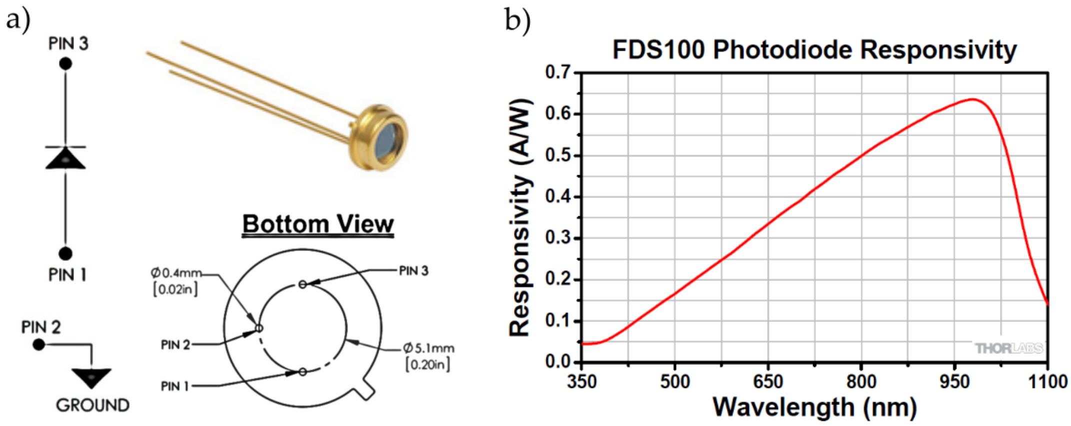

FIGURE 2: Thorlabs FDS100 Photodiode. a) Photograph and pin connections. b) Responsivity of the diode as a function of wavelength.

issue here. The main reason for using this op amp is that it is a single-supply *rail-to-rail* type, which means that its output voltage can get very close (to within $\sim 10\,\mathrm{mV}$) of the power supply rails, in contrast to regular op amps which typically have a headroom of $\sim 1\,\mathrm{V}$ or more. This means that if the op amp is powered with $0\,\mathrm{V}$ (VSS) and $+5\,\mathrm{V}$ (VDD), then its output signal will be able to get very close to $+5\,\mathrm{V}$, but not any higher. This is important because it provides a convenient way to protect the analog input pins of the Arduino microcontroller.

To be able to mount the FDS100 photodiodes and allow them to be integrated easily into the setup on the optical tables, several components were purchased from *Thorlabs*, as shown in Fig. 3. An $8\,\mathrm{mm}$ circular hole is drilled into the centre of a 1 inch *SM1CP2* threaded cap, and the photodiode is then attached using a hot glue gun. This threaded cap then screws into a *SMR1/M* lens mount, which allows a neutral density filter to be attached if necessary (for example, *NE01A-B*. Everything can then be mounted to the optical table using standard posts. The photodiode is connected to wires using a removable socket with solder tail (*STO5S*).

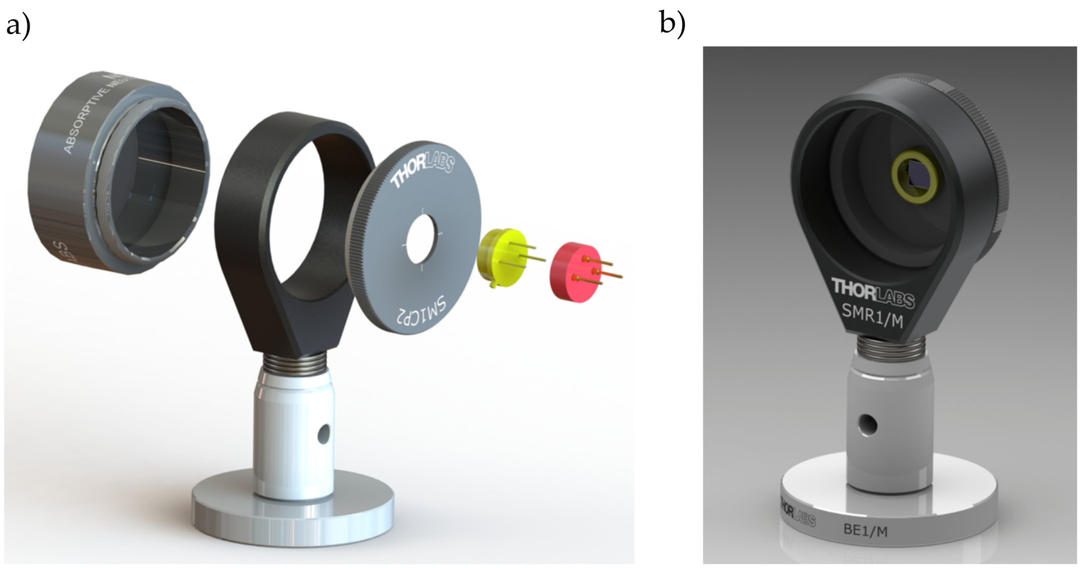

FIGURE 3: Exploded view a) and fully assembly b) photodiode with standard Thorlabs components.

For testing, the circuit was assembled and the output voltage was measured as a function of the incident laser light power, having a wavelength of 780 nm, with the results displayed in Fig. 4. Three different ranges with maximum powers of 100 µW, 1 mW, and 10 mW were achieved by inserting appropriate values of R_f, and are shown in (a), (b), and (c), respectively. In this case, the op amp was powered with 0 V→+3.3 V. It can be seen that the output voltage is nicely linear with input light power, and never exceeds +3.3 V, meaning that the microcontroller will be safe.

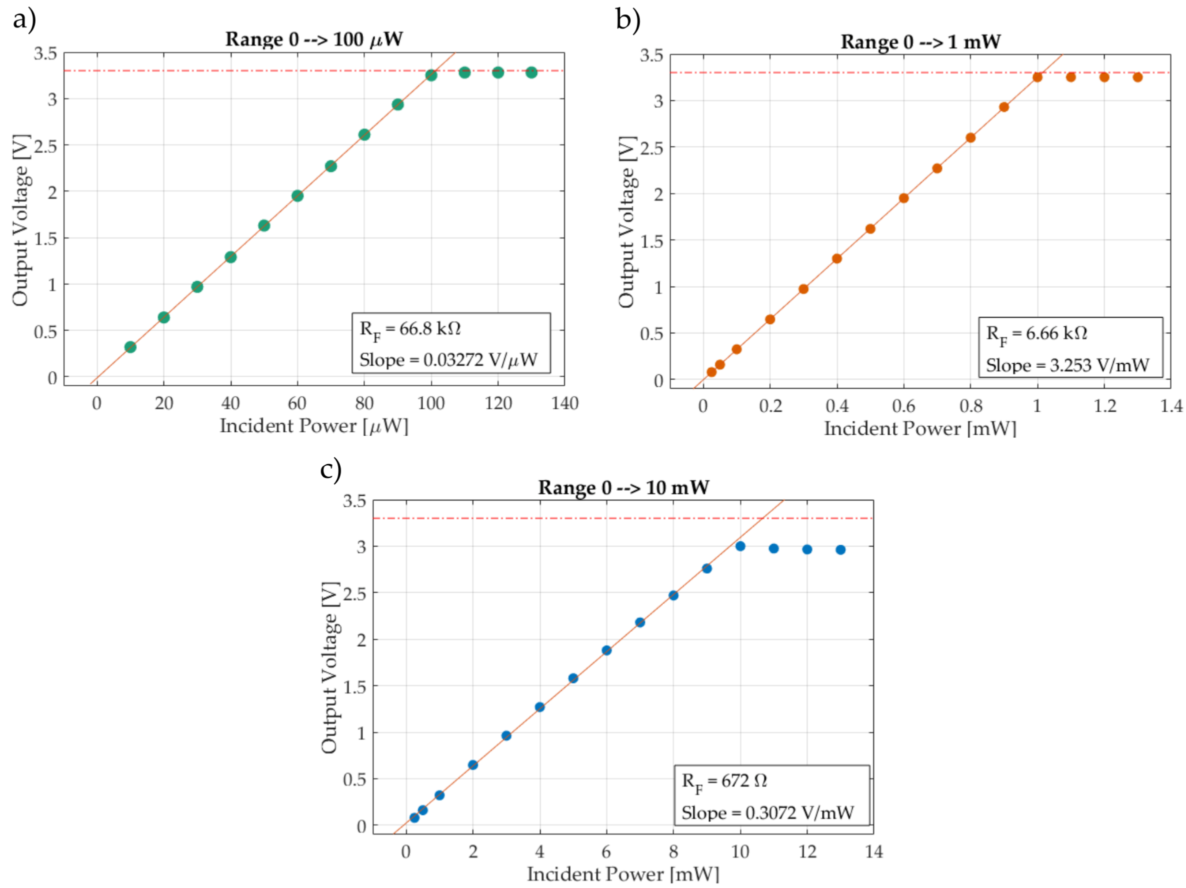

FIGURE 4: Measurements of the output voltage signal from a photodiode with a transimpedance amplifier as a function of incident laser light power. Three different ranges are shown in a), b) and c), corresponding to feedback resistors of 66.8 kΩ, 6.66 kΩ, and 672 Ω, respectively.

Arduino Code

The analog voltages can be read very easily using the following code, which reads x6 inputs. The ADC resolution is 10-bit on most Arduinos, giving possible values from 0 to 1023 as outputs from the *analogRead()* function.

```
/* 02_MultipleAnalogVoltageReadr
 * Code for measuring multiple analog voltages.
*/

// Analog input channel sensor ADC values
unsigned int sensorValueA0 = 0;
unsigned int sensorValueA1 = 0;
unsigned int sensorValueA2 = 0;
unsigned int sensorValueA3 = 0;
unsigned int sensorValueA4 = 0;
unsigned int sensorValueA5 = 0;
String payloadStr;

void setup() {
  Serial.begin(9600);
}

void loop() {

    sensorValueA0 = analogRead(A0);
    sensorValueA1 = analogRead(A1);
    sensorValueA2 = analogRead(A2);
    sensorValueA3 = analogRead(A3);
    sensorValueA4 = analogRead(A4);
    sensorValueA5 = analogRead(A5);
    payloadStr = "";
    payloadStr = payloadStr + sensorValueA0 + "," + sensorValueA1
                 + "," + sensorValueA2 + "," + sensorValueA3 + ","
                 + sensorValueA4 + "," + sensorValueA5;

    Serial.print("Analog Voltages: ");
    Serial.println(payloadStr);
    delay(1000);
}
```

The output from the Serial Monitor is shown in Fig. 5.

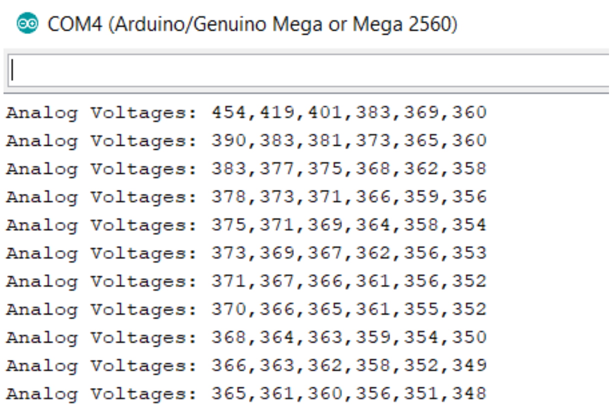

FIGURE 5: Serial Monitor output from reading multiple analog voltages.

1 References

[1] J. Graeme. *Photodiode Amplifiers - Op Amp Solutions*. McGraw-Hill Education, 1995.