OPTIX Module 3 – Basic

Laser Pulses and Pulsed Lasers

Shelby Merrill, Dane Tippett, Michaela Kleinert

1 Objectives:

In this module you will learn about

- how to use an oscilloscope;
- pulsed lasers;
- pulse energy, average power, and repetition rate of a pulsed laser;
- a common way to communicate with industrial lasers using *HyperTerminal*.

This module is part of our Modern Physics curriculum and prepares you for `MODULE 3 - INTERMEDIATE and ADVANCED` on diode lasers and absorption spectroscopy of rubidium, respectively, and for working on the ablation projects in the Kleinert research lab. It should take about 3 hours to complete.

Use this manual as you work through the module to keep track of your notes and thoughts. In addition, you may have to add a few printouts or refer to data tables or additional notes in your lab notebook. I'd encourage you to create a Jupyter Notebook for your calculations and plots. Make sure to add all your printouts to the folder in which you keep this manual. Lastly, note that this lab has no formal lab report. Instead, you will turn in and be graded on your notes in this manual.

2 Tests and assessment:

In preparation for this module, read through the whole manual and answer the questions that are marked with a *. You should also watch the `VIDEOs` that are posted on our website (`www.willamette.edu/cla/physics/info/NSF-OPTIX`). They are meant to accompany this manual and will show you some critical steps of the module. When you come to lab, be prepared to discuss your answers to these questions with your classmates and your instructor.

In addition, in order to assess the success of this module, you will take a short assessment test before you start ("pre-assessment"), and another one after you have successfully completed this module ("post-assessment"). At this point you will also have the opportunity to provide us with feedback about the module that we will use to improve it for the next student generation. Thank you for your support!

3 Equipment:

You can find the Fianium laser in the bottom-left drawer in the OPTIX lab. Take it out very carefully, and make sure that the silver cable that extends from the laser doesn't get bent. It contains an optical fiber, and bending it could damage the laser beyond repair. Use one person to carry the laser head, another to carry the power supply, and a third to keep an eye on everything and help out when needed. Standard equipment that is used in multiple modules will be located in other cabinets in the OPTIX lab. Please feel free to also ask your instructor for help. You will need:

- a pulsed laser from Fianium (bottom-left drawer);
- a power meter (top-right cabinet next to the door);
- a photodiode connected to an oscilloscope (the photodiodes are in the same cabinet as the box labeled 'Module 3').

4 Required background knowledge and things you need to do before starting this module:

In this module you will investigate pulsed lasers in more detail. You will learn about the average power of such a laser, its pulse energy, and its repetition rate. You will also learn how these quantities are connected, and which ones are important when it comes to laser ablation and micro-machining/structuring of metals.

Thoroughly review the *Laser Safety Material* before coming to lab; there will be a brief test about laser safety before you will be allowed to start this module. Make sure to **always wear your laser goggles unless your instructor tells you that it is safe to take them off**. Besides general laser safety, you don't need to know anything about lasers; for now, we will use them as a *tool* to study physical phenomena. You will learn more about how they work later in this semester in Modern Physics and in `MODULE 3 - INTERMEDIATE and ADVANCED`.

Make sure to read through the *whole* manual before coming into the OPTIX lab, and mark everything that you find difficult to understand. In addition, **work through all the boxes marked with a *. Be prepared to discuss your completed work with the group and your instructor before starting the lab. This counts as your pre-lab.** During your lab time, you can work through parts of the manual with your lab group and instructor, and you will get a lot of hands-on experience.

If you damage anything, please tell your instructor *immediately*. While we of course try to avoid damaging the equipment since it is rather pricey, especially in this lab, accidents can happen. Please don't try to cover up any damage; that only makes life harder for us as we try to figure out why something is no longer working. Tell us exactly what happened, and we can either fix it or replace the equipment quickly.

*** Lastly, write down everything related to lasers (pulsed lasers in particular) that you remember from a previous class. Any relations, sketches, key words that pop into your head. If you can connect them in a meaningful way, even better! And now - have fun in the lab!**

5 Laser Pulses and Pulsed Lasers:

In this module we will explore a type of laser that is different from the ones you have used so far: A *pulsed* laser. In contrast to the helium-neon lasers, which emit laser light continuously (so-called *continuous-wave* or *cw* lasers), a pulsed laser emits bursts of laser light with distinct amounts of time between each pulse. You can picture this as taking the continuous beam of light from a HeNe laser, chopping it into segments of the same length, and then squeezing these segments, thus shortening the duration of each segment, to create very sharp bursts of light. This not only makes the laser pulses very short and sharp, it also forces all the energy into a very brief burst. You can easily imagine that these lasers are quite powerful! In fact, they are used in the Kleinert lab to drill holes into metallic surfaces, or to otherwise change the surface of metals (so-called micro-structuring and micro-texturing).

The duration of these laser pulses is called the **pulse width** τ and is measured in seconds (or fractions of a second). Most industrial lasers have pulse widths in the nano- to femto-second range. That's pretty short!

*** To get a feeling for how short this really is, let's calculate how far light, the fastest thing ever!, travels in 1 ns, 1 ps, and 1 fs:**

$d_{1ns} =$ $d_{1ps} =$ $d_{1fs} =$

Find examples of everyday objects for each of the lengths you calculated.

The frequency of these pulses - how often they occur - is called the **repetition rate** R, and it is measured as one-over-time (between two pulses). Typical industrial lasers have repetition rates ranging from a few hertz to several mega-hertz. Let's think about the effect the repetition rate has on the average power output of such a laser.

*** To do this, compare two lasers, one with a low and one with a high repetition rate, each producing pulses with the same (constant) energy per pulse. How do their average power outputs P_{avg} compare? A sketch in which you show the pulses (and define both the pulse width and repetition rate) may be helpful.**

For most lasers, especially those with repetition rates in the kHz or higher range, it is not possible to measure the power of each individual pulse since the power meter is not fast enough. Instead, the power meter *averages* over many pulses. Mathematically, we can describe the relation between this **average power** P_{avg} and the actual energy per pulse (the **pulse energy** E_{pulse}) by $P_{avg} = R \times E_{pulse}$, where R is the repetition rate. Note that the two quantities on the right hand side of this equation, R and E_{pulse}, are determined by the laser you are using: The pulse energy is an inherent property of the laser determined by the exact laser medium and overall setup. The repetition rate is often fixed by the manufacturer (although there are lasers that allow you to vary it over a certain range). Thus, these two quantities are properties of the particular laser you are using, and the average power is really just a result of the combination of these two properties. Solving this relation for E_{pulse} is a great way to determine the pulse energy since measuring it directly is a bit more difficult. Measuring the average power and repetition rate is quite easy, though, as you will see in a moment.

6 A home-built "pulsed laser":

Remember the chopped HeNe beam analogy we used earlier to describe laser pulses? We're going to create a "pulsed laser" doing just that, by using a HeNe laser and a chopper wheel! You'll also get a refresher on how to use an oscilloscope and a photodiode, which you will use with the actual pulsed laser. We encourage you to review MODULE 1 - BASIC (LAB EQUIPMENT) to learn in more depth how to use this fundamental piece of lab equipment.

First, set up a HeNe laser just as you did in MODULE 1 - BASIC (Optics Basics - I) and attach it safely to the table. Attach the photodiode to a post and post holder and connect it safely to the table. The active area of the photodiode (the sensor) is the small square in the middle underneath the glass cover, and it should be at approximately the same height as the laser beam. A photodiode is a small semiconductor device that takes incident photons and converts them into an electrical current that is typically converted into a voltage (hint: Ohm's Law). This voltage can then be read by a multimeter or displayed on an oscilloscope. It is proportional to the number of incident photons as long as the photodiode is not saturated with light, thus allowing you to measure light intensity as an electric signal. For the photodiodes you will use today, the signal is linear and not saturated as long as the voltage is below 12 V. Once you reach this voltage, increasing the amount of light hitting the photodiode will not further increase the voltage (we say that it "plateaus" (i.e. saturates) at that voltage).

Operation of the photodiode is pretty straight forward: connect the photodiode to its power supply (check that the toggle switch is set to 110 V!) and flip both, the switch on the power supply and the switch on the photodiode, to turn on the photodiode. A green LED on the photodiode should light up, indicating that the photodiode is indeed on and working correctly. In order to read the voltage outputted by the photodiode, connect it to channel 2 of the oscilloscope via a BNC cable by pushing the cable into one of the channels of the oscilloscope and rotating the outer ring until it snaps into place. Please review the paragraph about BNC cables in MODULE 1 - BASIC (LAB EQUIPMENT) to refresh your memory of what's special about them.

The photodiode is pretty sensitive, so you want to place it slightly off to the side of the laser beam, so that only part of the laser beam hits the sensor. Observe the signal on the oscilloscope and make sure that it is less than 12 V. If not, move the photodiode to the side some more. Once you have a signal somewhere between 5 and 10 V, lock it down onto the table and double check that all the screws holding the laser and photodiode in place are thoroughly tightened.

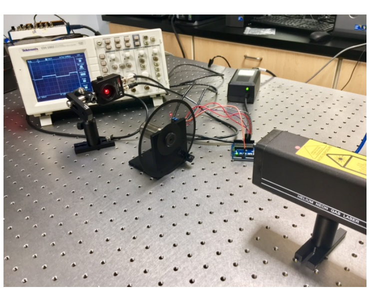
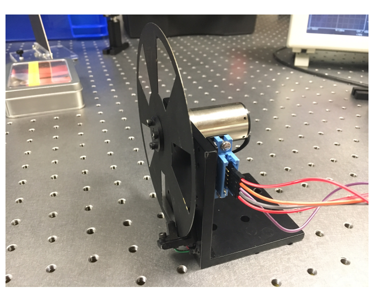
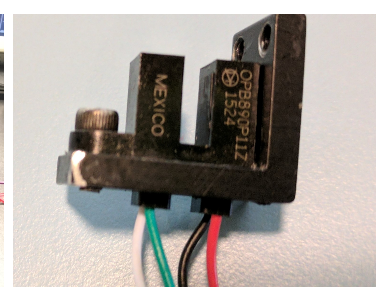
Record the voltage reading: $V_{initial} =$

Also comment on whether this reading is stable or changes over time. If it changes, record an estimate for how much and over what time period.

To "chop" the HeNe laser beam and create "laser pulses", you will use a circular blade with large spokes attached to a small motor called a **chopper wheel**. When you turn on the motor and place the wheel in the path of a cw laser, the spokes and the space between the spokes block and unblock the laser beam, which essentially creates a "laser pulse" that we can measure.

The mount of the chopper wheel also contains an optical sensor, a photogate that is shaped like a rectangular horseshoe (it is shown on the right hand side of the photo sequence below). One leg of the horseshoe sends out a (non-visible) laser or LED beam that is detected by a small photodiode on the opposite end of the horseshoe. Much like the photodiode you just set up, the optical sensor's photodiode converts the detected photons into a voltage of around 5 V when the sensor is unblocked and 0 V when the sensor is blocked. The rate at which the sensor reading changes from 0 to 5 V and *vice versa* correlates to the rotation frequency of the chopper wheel.

Insert the chopper wheel between the laser and the photodiode without moving either of the two. The chopper wheel should be placed such that the spokes block the beam and the spaces between the spokes allow it to propagate toward the photodiode. The final setup should look like the figure below on the left. The right hand side of this figure shows you a close-up of the chopper wheel. Note the black horseshoe-shaped photogate at the bottom and the golden-colored cylinder (the motor).

Please watch the VIDEO called HOW TO CONNECT THE CHOPPER WHEEL AND OPTICAL SENSOR on our website to learn how to set up the chopper wheel correctly. Take the two wires from the motor and connect them to a power supply; the current carrying wire and the ground wire can be connected to either side of the power supply as reversing the voltage only changes the direction of rotation of the motor. To turn on the chopper, set the voltage to 5 V. Try this briefly to confirm that the motor is rotating the wheel, then turn it off again.

Read the next paragraph slowly and carefully to ensure that all of your electrical connections are correct. Double check them at least once before you turn on the power supplies! Connect the red and the white wire on the sensor together (these two wires power the switch) and connect a 220 Ω resistor in series with these two wires. Connect the other end of the resistor to another power supply (you will set it to 3.3 V in a moment, but don't do it just yet!). Connect the black wire (= ground) to the more negative side of *both* power supplies by using alligator clips. Also connect it to the black end of a break-out BNC cable. Lastly, connect the green wire to the red end of the break-out BNC cable and connect the other end of the BNC cable to channel 1 of the oscilloscope.

The best way to get the optical sensor to work reliably is to work under the green light only (turn off all the other lights), because photons from the bright ceiling lights will interfere with the optical sensor, and you will get noisy or inaccurate data.

Turn on the oscilloscope, the laser, and both power supplies (set to 5 V for the motor and 3.3 V for the sensor). The motor should rotate the chopper wheel and the oscilloscope should display a signal that oscillates between 0 V and 5 V on channel 1, indicating that the optical sensor is working correctly. Use the trigger function of the oscilloscope to trigger on either a rising or falling slope of this signal. If you are unsure how to correctly operate the oscilloscope, you can refresh your memory by reviewing **MODULE 1 - BASIC (Lab Equipment)** and the links therein.

Observe the photodiode signal on channel 2 of the oscilloscope. Adjust the settings for the voltage and time per division on the oscilloscope until you see several discrete "laser pulses".

Record the frequency of these laser pulses and compare this frequency to the frequency of the chopper wheel.

$f_{pulses} =$ $f_{chopper} =$

What can you conclude?

You probably noticed that your "pulses" are pretty broad.

Zoom into one of those pulses and measure this *pulse width* of a single pulse. Record it here:

$\tau_{meas} =$

We will now compare this measured width to the one we would expect based on the rotation frequency of the chopper wheel, $f_{chopper}$, and the spacings in the chopper blade (i.e. the available space between two spokes).

[Note: this box counts as two boxes.] Calculate the expected pulse with, τ_{exp}. Show your work! Note: there are actually five spokes in the chopper wheel. Hint: Think about how the rotation frequency and the spacing are related, and what other measurement you need to calculate an "illumination time". Then compare your measured and predicted pulse width. Are they in agreement?

Repeat these exercises for 3 V and 10 V applied to the chopper motor, which will make it rotate more slowly or faster, respectively. How do the pulse width and frequency change? Show your work and explain.

7 The Fianium laser and HyperTerminal:

If you have time, you can use a real pulsed laser, the "Fianium". This laser is similar to the pulsed lasers used in the Kleinert research lab to study laser ablation, but it is much weaker. For comparison, the Kleinert lasers have pulse energies of up to 20 μJ. You will measure the pulse energy of the Fianium laser in a moment, and compare it to this benchmark.

The Fianium is located in the bottom drawer on the far left side of the OPTIX lab. **Move it very carefully and avoid excessive bumping when you place it on the table. Handle with care! Also make sure to protect the fiber (the silver metal cord extending from one end of the laser). In particular, prevent any kinks or strong bends while moving the laser. Move it with two people and have a third one stand ready to ensure that none of the attached cables catch on anything.**

Start by plugging the power supply of the laser into the wall socket and connecting the USB cord to the right lab computer. Make sure that the interlock DB15 pin is safely plugged in (see the photo below). Otherwise the laser won't turn on.

Interlocks are common safety features of industrial lasers. The DB15 connector simply shorts out two of the pins, which then connects two halves of a circuits, which in turns allows the laser to turn on. Before continuing, please watch the `VIDEO` called `HOW TO OPERATE THE FIANIUM LASER` on our website. Then turn on the laser power supply by pushing the red toggle switch at the back of the power supply. You have to wait for about ten minutes to allow the laser to warm up (it has a built-in timer).

During this time, log into the lab computer and find the **Fianium folder** (located directly on C:\\). Inside it should be an application called **`hypertrm.exe`**. This is *`HyperTerminal`*, and you will use it to communicate with the laser. Double click it and hit run. You will see a popup window. Hit cancel, then click `file` and open the `Laser comms using Hyperterminal.ht` file from within HyperTerminal (it is located in the same folder as the hypertrm.exe). Go to `file` and `properties`, and make sure the laser is connected to `COM3`. If it isn't, change the port to `COM3` and close `HyperTerminal`. Then reopen `HyperTerminal`, hit cancel, and open the `Laser comms using Hyperterminal.ht` file once more. Now you should be ready to use `HyperTerminal`.

`HyperTerminal` is a tool used to communicate between the laser and the computer with a few key commands that you need to know. The first is **`h?`**. Type it in and press enter (Note: Type in both the lower-case 'h' and the question mark). This will give you a list of all the commands that are available. Most of them are letters followed by a question mark. The question mark tells the laser to display the value of the parameter on `HyperTerminal`. When you instead put an equal sign after the letter followed by some number, you change the parameter's value.

The laser's startup defaults it to a **`q`** value of zero, which means that the laser is off. Type in **`q?`** and press enter. The laser should return that `Amplifier DAC Level = 0`, which means that **`q`** is zero. Mount the power meter to the table and place the laser's output aperture located at the end of the silver fiber cable such that it is pointing directly at the power meter. The distance between the aperture and the power meter should be just about an inch or less. Be careful not to touch the aperture with your hands. Check the laser temperature and confirm that the laser is ready to go by typing **`o?`**, which should return that the laser is ready. Turn off the room lights and adjust the range of the power meter until you see a very small reading (check the power meter manual or ask your instructor to learn how to do this).

This is your background measurement, i.e. the amount of light that is still present in the lab (even when the room lights are off), and that the power meter reads. Record it here, including an uncertainty: $P_{back} =$

Can you think of any sources of this background light?

Press the green `oscillator on` button and tell the laser to go to full power by typing `q=3800` and pressing enter. Note: Don't go higher than `q = 3800`; this is the maximum allowed value! Also, the key on the far right of the laser power supply and the big knob don't do anything; just make sure that the `oscillator on` button is pressed and lit up.

Record the reading on the power meter again (it should be slightly higher than your background measurement). Make sure to include an uncertainty!

$P_{on} =$

Then subtract the background measurement from the measurement with the laser on:

$P_{on} - P_{back} =$

Is this value equal to the individual pulse energy, the average pulse energy, the individual pulse power, the average power, or the repetition rate? Explain!

Turn off the laser by typing `q=0` and hitting enter. Then replace the power meter with the photodiode you used in the first half of this module. It should still be connected to the oscilloscope. Make sure the horizontal zero line is located at the center of the screen of the oscilloscope. To ensure that you will see the signal, **set the voltage to 5.00 mV per division and the time to 25 ns per division. This is a good starting point, however, you will have to adjust these values for each of the following tasks. Always make sure that you want to use the available screen as best as possible.** For example, if you are interested in a single pulse, you want to zoom in more. But if you are interested in the spacing between pulses, you want to zoom out more to see more pulses and average over multiple measurements.

Turn on the laser (type `q=3800` and hit enter). Gently move the photodiode until you maximize the signal you see on the oscilloscope. Make sure that the oscilloscope is set to trigger on the channel that is connected to the photodiode. Move the `trigger` level up or down until you get a stable and stationary signal.

Sketch the trace you see on the oscilloscope and/or take a photo of it and send it to your instructor. Measure the time between ten pulses as carefully as possible (you can use the oscilloscope's `cursor` function). Include an uncertainty!

$\Delta T_{10} =$

From this time, calculate the repetition rate. Show your work.

$R =$

Then zoom into one of the pulses and sketch its shape below (it's OK if it isn't perfectly symmetric; that's normal for these kinds of lasers). Measure the pulse width using the cursors on the oscilloscope:

$\tau_{fian} =$

The pulse width you just measured is actually *much* larger than the actual pulse width of the laser.

Bonus points if you can figure out on your own why that is! [Hint: It has to do with the 'bandwidth' of the equipment you are using.]

Lastly, use the data you have collected so far to calculate the pulse energy of this Fianium laser:

$E_{fian} =$

Compare it to the pulse energy of the lasers in the Kleinert lab. Do you think the Fianium laser is powerful enough to destroy metal? How about paper? Feel free to try it!

And that's it! You made it successfully through the first module and are now qualified to perform the more advanced modules. Please leave us any comments, suggestions, or concerns in the box below, so that we can optimize this module for future student generations. Thanks!