

# OzturkLab Report

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# Contents

<b>1 Self-recovering Wired Ethernet Connection</b>	<b>2</b>
1.1 Preparation and Software Installations . . . . .	2
1.1.1 Chrome Installation . . . . .	2
1.1.2 Anaconda Installation . . . . .	2
1.1.3 Selenium Library Installation . . . . .	3
1.1.4 Selenium WebDriver Installation . . . . .	5
1.2 Implementation-Coding . . . . .	6
1.3 Implementation-Automatization . . . . .	7
<b>2 Photoluminescence (PL) Setup</b>	<b>12</b>
2.1 Reflecting Light Microscopes Overview . . . . .	12
2.2 Confocal Systems Overview . . . . .	14
2.3 Confocal Reflecting Light Microscope for PL Measurements . . . . .	16
2.3.1 Excitation, Zone 1 . . . . .	18
2.3.2 Emission, Zone 2 . . . . .	19
2.3.3 Brightfield, Zone 3 . . . . .	20
2.3.4 Objective, Zone 4 . . . . .	21
<b>3 Mask Design Instructions for ODMR Antenna</b>	<b>21</b>
3.1 ODMR Antenna manufacturing with a mask . . . . .	21
3.1.1 Mask Design . . . . .	21
3.1.2 Lithography on Copper Laminate . . . . .	33
<b>4 Optically Detected Magnetic Resonance (ODMR)</b>	<b>34</b>
4.1 Data acquisition and initial processing . . . . .	34
4.1.1 Spectrometer properties and dark background removal . . . . .	34
4.1.2 Fluorescent background removal . . . . .	39
4.2 CW-ODMR measurement and calculation of parameters . . . . .	39

# 1 Self-recovering Wired Ethernet Connection

This is a software based workaround for our lab's computers to keep the in the wired network. To implement the solution, following software is required to be installed;

- **Chrome** web browser
- **Anaconda** or another Pyhton distribution.
- **Selenium** libraries for Anaconda to be able to interface with Selenium.
- **Selenium** Web Driver

## 1.1 Preparation and Software Installations

### 1.1.1 Chrome Installation

To install Chrome, go to following web page and download the suitable installer version for your operating system (OS).<sup>1</sup>

### 1.1.2 Anaconda Installation

To install Anaconda, go to web page and download Anaconda installer suitable for your OS.<sup>2</sup>. During the installation, at some point installer will give you an option to add Anaconda to system path (\$PATH) as shown in Figure1.

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<sup>1</sup><https://www.google.com/chrome/>

<sup>2</sup><https://www.anaconda.com/products/individual>

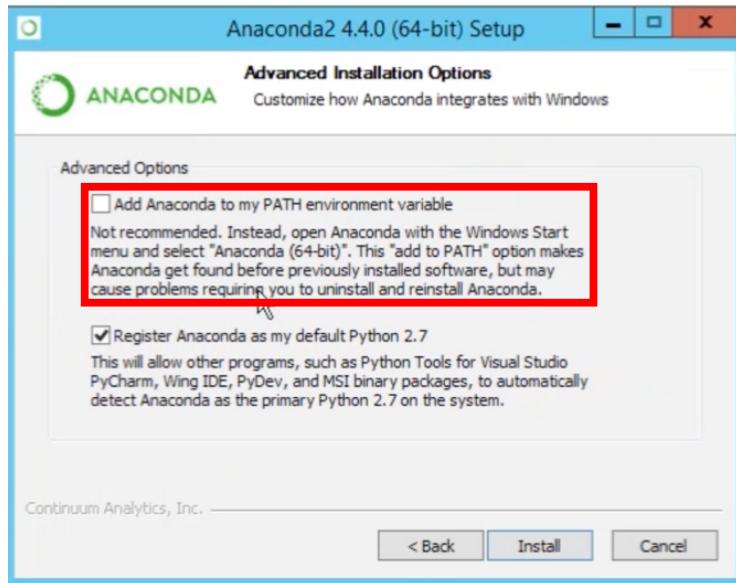


Figure 1: Installation step for adding Anaconda to system path.

Here, go ahead and click the box on the left to add Anaconda to system path. This will make Anaconda your system-wide Python library. Its issues are not going to be discussed here for simplicity.

### 1.1.3 Selenium Library Installation

To install Selenium libraries for allowing Anaconda to interface with Selenium web driver you can use Anaconda Prompt as shown in Figure2.

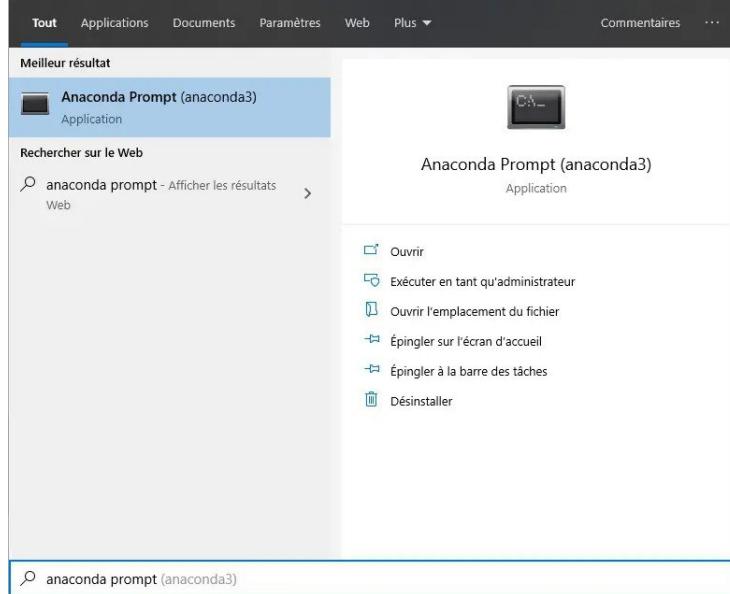


Figure 2: Opening up Anaconda Prompt.

In Anaconda Prompt, you can simply type **conda install -c conda-forge selenium** and click **Enter**, as shown in Figure3.

```
(base) C:\Users\j-c.chouinard>conda install -c conda-forge selenium
Collecting package metadata (current_repodata.json): done
Solving environment: done

## Package Plan ##

environment location: C:\Users\j-c.chouinard\AppData\Local\Continuum\anaconda3

added / updated specs:
- selenium

The following packages will be downloaded:
  package          build
  conda-4.7.12      py37_0      3.0 MB  conda-forge
  selenium-3.141.0  py37hf6e62cd_1000  858 KB  conda-forge
  -----
  Total:           3.8 MB

The following NEW packages will be INSTALLED:
  selenium          conda-forge/win-64::selenium-3.141.0-py37hf6e62cd_1000

The following packages will be SUPERSEDED by a higher-priority channel:
  conda                  pkgs/main --> conda-forge
```

Figure 3: Selenium library installation for Anaconda.

Once Anaconda figures out where Selenium library is and possible additional required libraries, it will ask your confirmation as shown in Figure 4. Here you can type **y** and click **Enter**.

```

Proceed ((y)/n)? y

Downloading and Extracting Packages
conda-4.7.12          | 3.0 MB    ######|####|####|####| 100%
selenium-3.141.0       | 858 KB   #####|#####|#####|#####| 100%
Preparing transaction: done
Verifying transaction: done
Executing transaction: done

(base) C:\Users\j-c.chouinard>

```

Figure 4: Selenium library installation confirmation screen.

#### 1.1.4 Selenium WebDriver Installation

To install Selenium WebDriver for allowing Selenium-Anaconda library to control the web browser (**here we use Chrome!!!**), go to the following web page, <https://sites.google.com/a/chromium.org/chromedriver/> as shown in Figure 5.

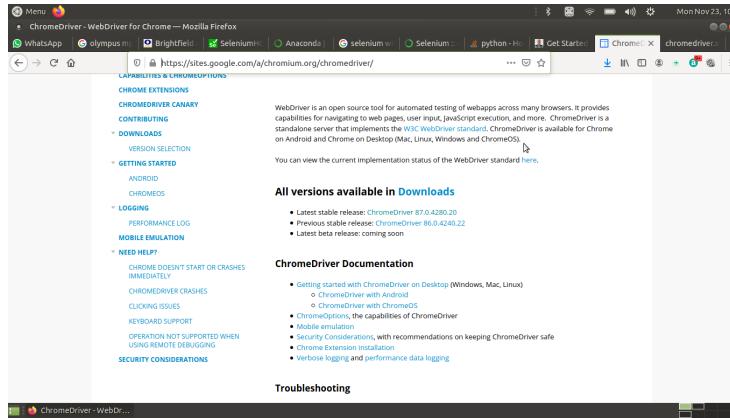


Figure 5: Selenium library installation confirmation screen.

Within other options, click on the **Latest Stable Release**. This will direct you another web page with multiple files you can download as shown in Figure 6. **Here, you have to download 32-bit driver!!!**

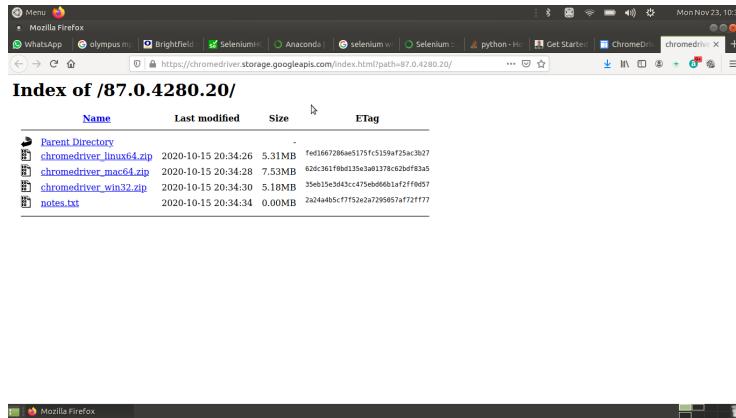


Figure 6: Selenium library installation confirmation screen.

Once download finishes, you can unzip the webdriver file with any software you desire.

## 1.2 Implementation-Coding

To invoke Selenium I wrote Python Script. An overview of the code is as following;

1. **Lines 1-4:** Imports essential libraries.
2. **Lines 6-8:** Pings Google's DNS server to check whether the PC is connected to wired network.
3. **Lines 10-11:** If output of lines 6-8 are both indicating connection proceed to the end of the code.
4. **Lines 12-27:** If PC is not connected; **Line 13:** Run Chrome driver  
**Line 14:** Send Chrome to university's Log-In page. Here "https://secure-access.morgan.edu/guest/ngnauth.php?" is a fixed string. "&mac=f8:b1:56:b3:7a:0a&\_browser=1" is the MAC address of our machine and browser number which is the default browser.
5. **Lines 17-20:** Fill out the form on university's Log-In page using your username and password.
6. **Lines 21-22:** Click the box to accept the terms.
7. **Lines 23-24:** Click on the Accept button to Log-In.
8. **Lines 25-27:** Wait for the webpage to load to university's homepage then close the browser.
9. **Line 28:** Kill python.exe to stop the process cleanly.

```

1  from selenium import webdriver
2  from selenium.webdriver.common.keys import Keys
3  import time
4  import os
5
6  temp = os.popen("ping 8.8.8.8").read()
7  test_connection1 = temp.find('PING: transmit failed. General
    ↪   failure.')
8  test_connection2 = temp.find('Request timed out.')
9
10 if (test_connection1 < 0 and test_connection2 < 0):
11     print("Already connected. Exiting!!!")
12 else:
13     driver = webdriver.Chrome()
14
15     ↪   driver.get("https://secure-access.morgan.edu/guest/ngnauth.php?
16                 &mac=f8:b1:56:b3:7a:0a&_browser=1")
17
18     elem1 =
19         ↪   driver.find_element_by_id('ID_formcd662c6a_weblogin_user')
20     elem1.send_keys("Peker.Milas")
21
22     elem2 =
23         ↪   driver.find_element_by_id('ID_formcd662c6a_weblogin_password')
24     elem2.send_keys("Onder1981")
25
26     elem3 =
27         ↪   driver.find_element_by_id('ID_formcd662c6a_weblogin_visitor_accept_terms')
28     elem3.click()
29
30     elem4 =
31         ↪   driver.find_element_by_id('ID_formcd662c6a_weblogin_submit')
32     elem4.click()
33
34     time.sleep(10)
35
36     driver.close()
37 os.system("taskkill /F /im python.exe")

```

### 1.3 Implementation-Automatization

As I have indicated above, the provided Python script is meant to execute once. Therefore, to first sense a loss in wired connection and invoke the Selenium for automatic Log-In, we use Windows' **Task Scheduler**. This is done as following;

1. Click on the Windows search bar and type Task Scheduler. This will pop a widow above Windows logo to let you run Task Scheduler which is shown in Figure7

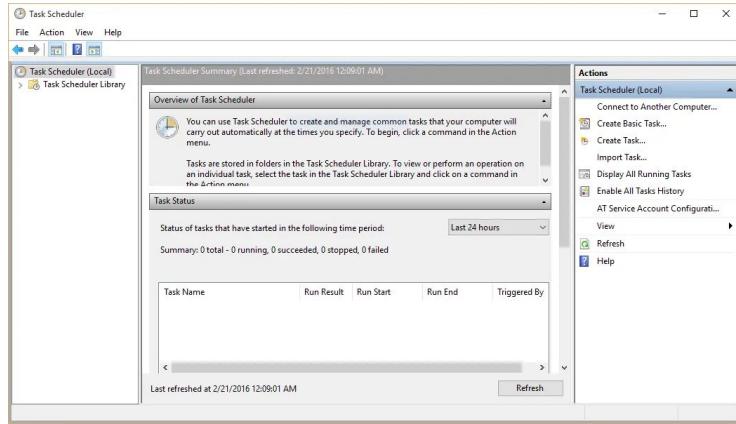


Figure 7: Windows10 Task Scheduler.

2. Click on the "Action→Create Task", as shown in Figure 8

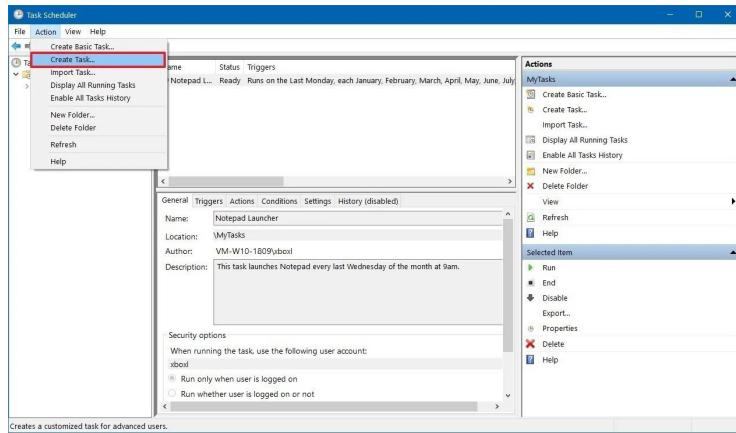


Figure 8: Create a task in Task Scheduler.

3. In popped-up window, on General tab, as shown in Figure9, give a unique name to your task and describe it for future reference.

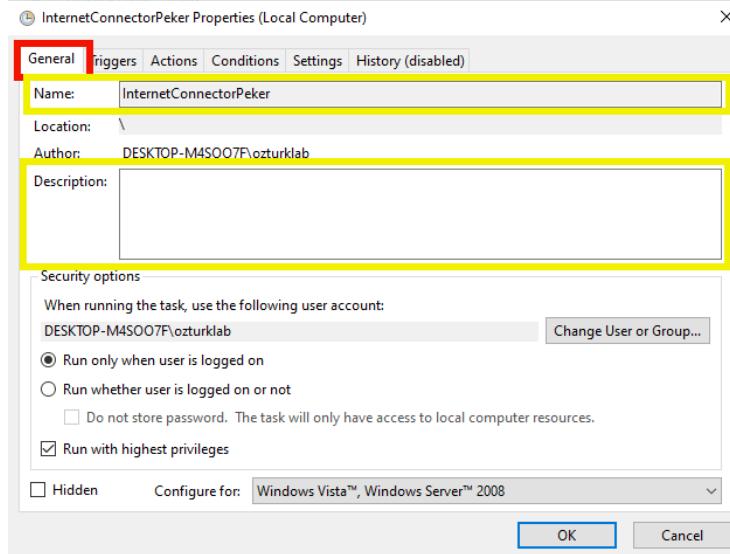


Figure 9: Name and Description fields under General tab.

4. On the Triggers tab, as shown in Figure10, click on New. In popped-up window, set the Start time and date. Also make your task runs for One time. Let the task repeat at specified times (here every 30 minutes) and keep it run indefinitely.

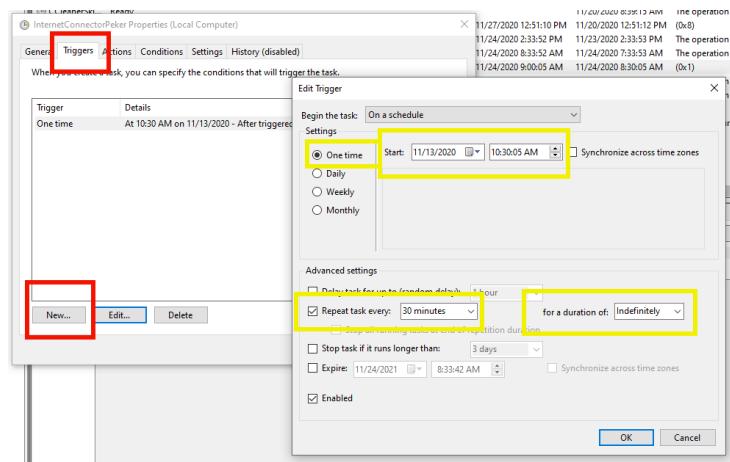


Figure 10: Timer and repetition related fields under Triggers tab.

5. On the Actions tab, as shown in Figure11, click on New. In popped-up window, make Action Start a program. In Programs/script field, add the

location of your python executable (python.exe). In Arguments field, add your python script's name. In Start in (Optional) field, add the location of your python script.

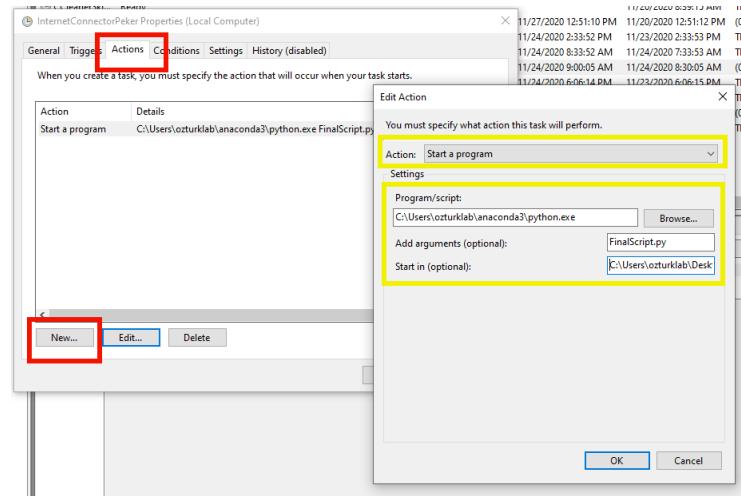


Figure 11: Script and arguments related fields under Triggers tab.

6. On the Conditions tab, as shown in Figure12, most of the fields are related with hardware such as whether you have a laptop which can run on battery or not. Therefore you can simply keep it as shown in Figure 12

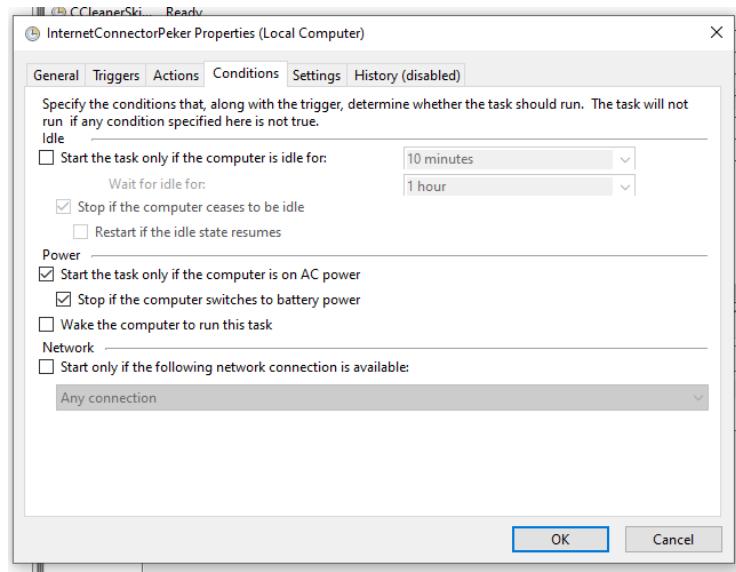


Figure 12: Already prepared Conditions tab.

7. On the Setting tab, as shown in Figure13, you can again set relevant fields as shown in Figure13.

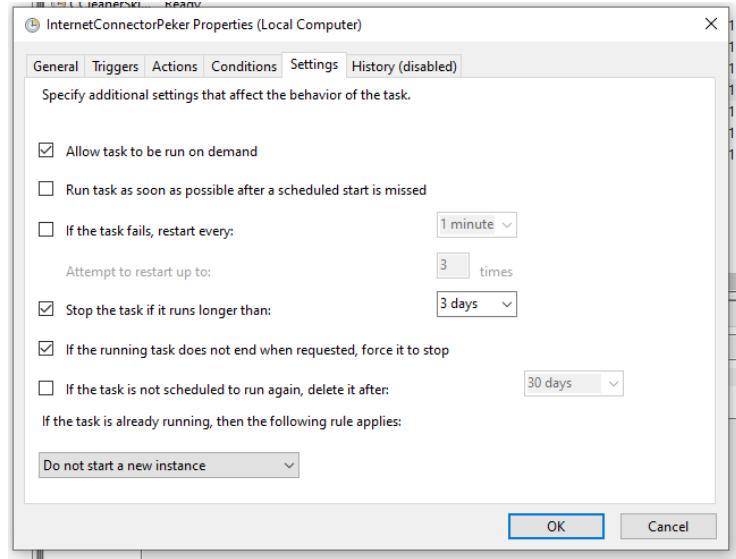


Figure 13: Already prepared Settings tab.

8. Once you are done with setting up your scheduled task, save it and close

its window. This will add your new task to default windows tasks as shown in Figure14. Right-click on your task and run it for the first time. After that point, it can run by itself.

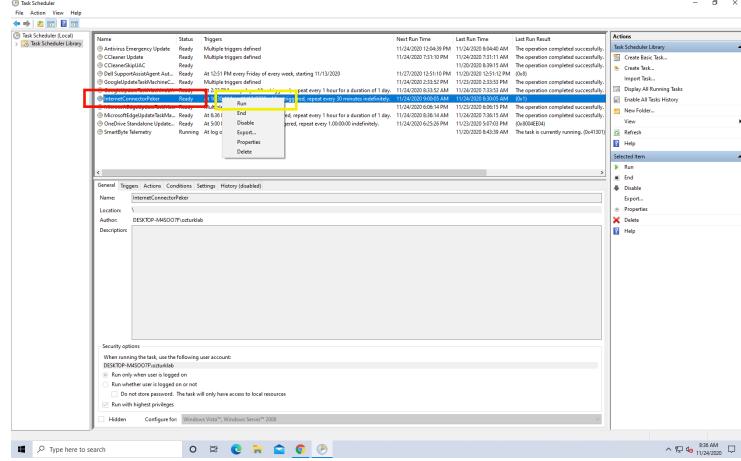


Figure 14: First run of the new task.

## 2 Photoluminescence (PL) Setup

**Photoluminescence** is the emission of light by the excited molecules and/or molecule clusters. Here we are intended to observe photon emission from the defects within crystalline structures such as diamond and cubic boron nitride. Given that these materials known to be opaque in visible light range, we are building a **reflecting light microscope**[refhere]. Although wide-field excitation (similar to epifluorescence [refhere]) based emission measurements from an ensemble of defects have their own importance in characterization, we pursue investigating properties of individual defects/ emitters. This requires our reflecting light microscope to be a **confocal system**.

### 2.1 Reflecting Light Microscopes Overview

On typical an upright or inverted microscope, illumination light comes from a direction relative to sample surface, while the collection or imaging is done in the opposite direction. Therefore in terms of optical components, illumination and imaging sides differ in those systems. For example in illumination side a special lens called **Condenser** focuses the light on to the sample while in the imaging side another special lens called **Objective** lens collects the light coming from the sample. These special lenses and the typical upright and inverted microscope configurations are shown in Figure15.

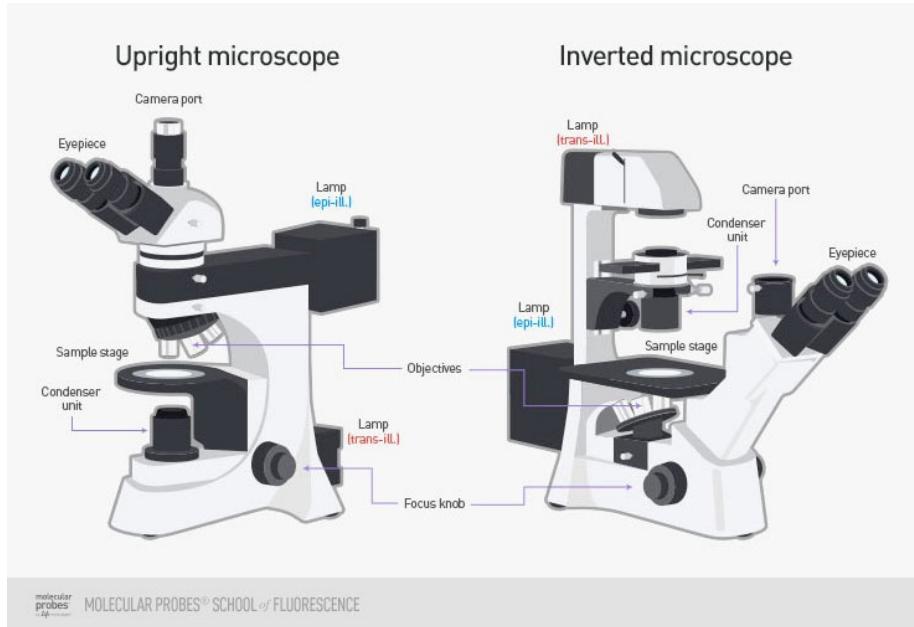


Figure 15: A typical upright (**left**) and an inverted (**right**) microscope structures indicating the positions of special lenses (**Condenser and objective**).

On the other hand, in a reflecting microscope illumination and imaging are done through the same optical path or by same optics. As it is shown in Figure 16, shared optical path allows one (1) additional port for imaging and/or illuminating the sample on a typical reflecting microscope. This port is very frequently assigned to white-light (**bright-field**) imaging through a camera, so it is called the camera port. As a result any additional illumination and/or imaging on top of the default system, require a custom design optical system with the ability to finely couple with the existing microscope.

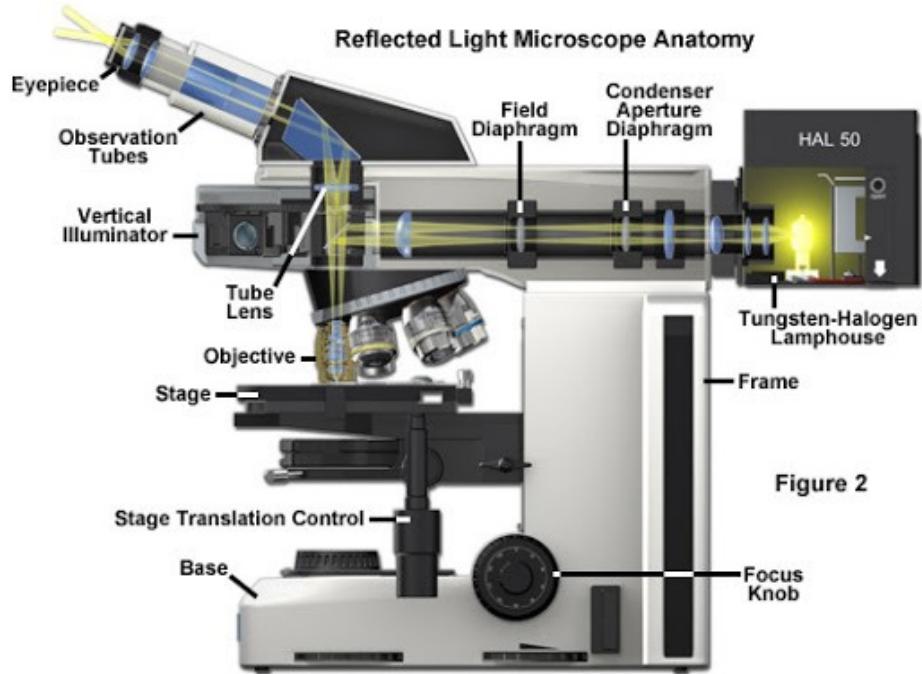


Figure 16: Schematics of a typical reflecting microscope with light path and internal optical components.

## 2.2 Confocal Systems Overview

A **confocal system** is an imaging system that utilizes a spatial filter (or simply a pinhole) before the imaging component for strictly matching the illumination volume with the observation volume as it is shown in Figure17. Because of very likely chromatic aberrations<sup>3</sup> through the imaging components, usually illumination is done by a single color light source such as a laser. The pinhole suppresses the out-of-excitation volume light dramatically, so it increases the resolution of imaging system, Figure18. REF HERE!!!!

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<sup>3</sup><https://www.microscopyu.com/tutorials/chromatic>

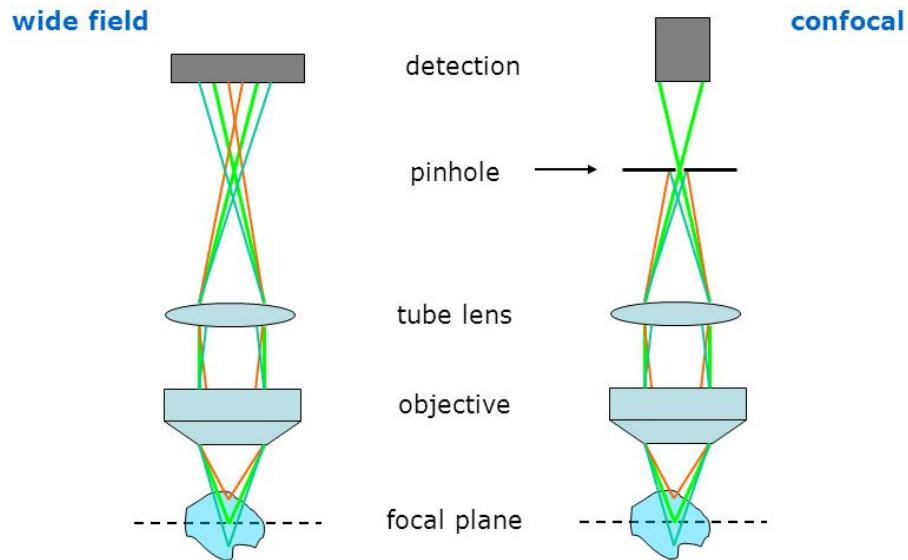


Figure 17: Simplified structure of a typical widefield (**left**) and a confocal (**right**) imaging system with spatial filter. ADD REF-FOOTNOTE HERE!!!

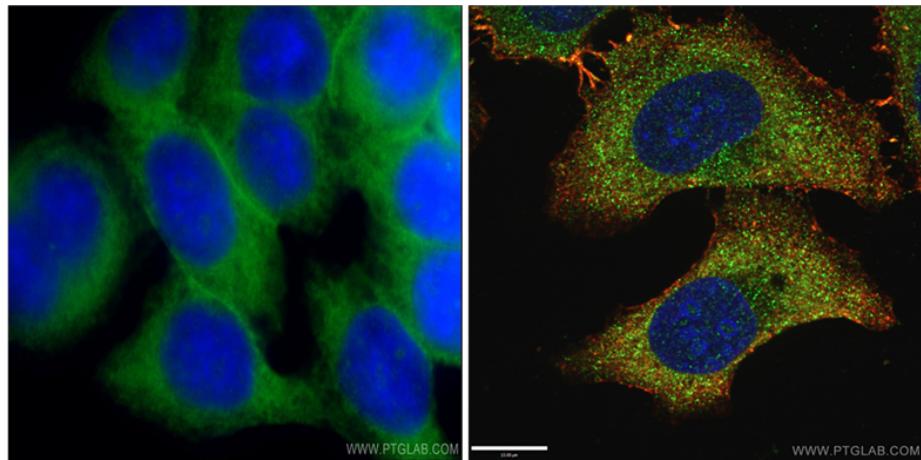


Figure 18: Imaging of HeLa cells with a typical widefield (**left**) and with a confocal (**right**) imaging system. ADD REF-FOOTNOTE HERE!!!

Microscope manufacturers very frequently incorporate additional openings (called **microscope ports**) on sides, front and even at the bottom of microscope bodies which allows the operator to couple additional imaging and illumination

systems into the microscope. Although this is a very common practice in the case of transmission microscopes (upright and inverted as well), reflecting microscopes usually don't have these additional ports, Figure16. Because of missing ports, turning a reflecting microscope is considerably harder into a confocal system compared to transmission microscopes.

### 2.3 Confocal Reflecting Light Microscope for PL Measurements

Our goal is to observe emission from excited lattice-defects in solids like boron nitride(BN) and diamond[REF HERE!!!]. These materials are not particularly transparent to visible light<sup>4</sup>. Moreover defect formation (particularly in the case of BN) is induced by ion bombardment, so neither the density nor spatial distribution of defects are known prior to a PL measurement. The lack of information on defect positions introduces the requirement of active search for defects within the sample volume, so a confocal imaging system with the capability of scanning. To overcome the refractive index issue and satisfying the confocality in imaging, we built a confocal reflecting light microscope as shown in Figure19.

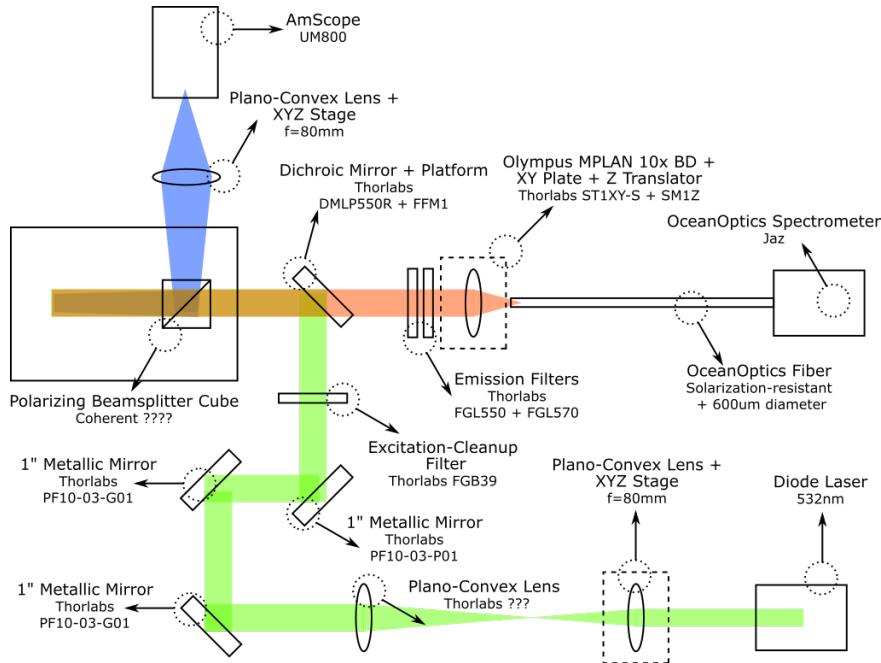


Figure 19: Our homemade confocal reflecting microscope for PL measurements.

Although the purpose of individual parts can not be explained accurately by

<sup>4</sup>[https://en.wikipedia.org/wiki/Boron\\_nitride](https://en.wikipedia.org/wiki/Boron_nitride)

ignoring their interactions with the remaining system components, it is a common practice to divide the whole system into 4 essential zones for educational purposes as in Figure20.

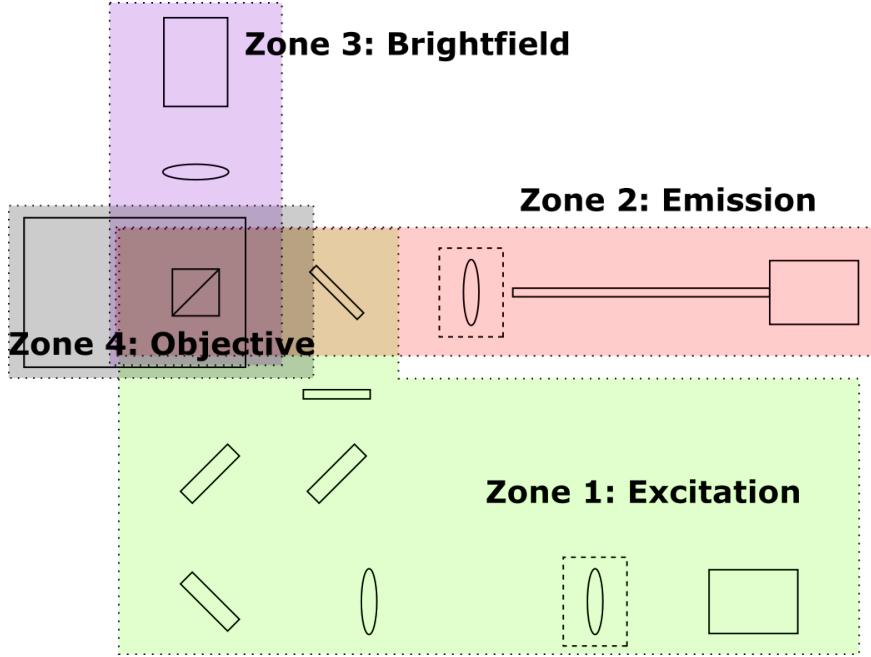


Figure 20: Zones in PL microscope.

To briefly describe these zones;

1. **Excitation, Zone 1 :** This is the zone where the excitation light is directed into the microscope. The excitation source is frequently a laser, but there are systems which prefer broadband light sources such as UV lamps. In this zone, beam characteristics of excitation light (i.e. size, divergence, polarization, etc.) are adjusted to match the requirements imposed by other zones.
2. **Emission, Zone 2 :** This is the zone where the emission or reflection from the sample is collected and analyzed by a detector. The detector can be any photon sensitive device (i.e. PMT, APD, CCD camera, etc.). Based on the preferred coupling mechanism in the sensory device, characteristics of the emission from the sample are adjusted similar to the case the adjustment of excitation light.
3. **Brightfield, Zone 3 :** This is the zone responsible to visual inspection of the sample surface and excitation/emission light profiles on the sample. Its mere purpose is to create an image of the sample surface and everything in near proximity on a camera and allow guided tracking.

4. **Objective, Zone 4 :** This is the zone where the primary imaging lens called objective lens resides. As a result, it is the core of the whole optical system and couples with all other zones. In other words, optical components in other zones are chosen/built essentially for matching the objective lens to utilize the whole measurement system at its maximum efficiency.

As in any other optical system, efficiency of imaging in this system is strongly correlated with match ratio of all these zones. Although it appears to be the Objective (Zone) 4 is the central piece that all other zones required to be matched, there are matching requirements for among other zones too. As a result, proper description of the microscope require deeper understanding of all zones.

### 2.3.1 Excitation, Zone 1

In terms of the structure, this zone directly couples into Objective (Zone 4) and indirectly couples into Emission (Zone 2). In terms of the alignment, it directly couples into Brightfield (Zone 3). These couplings and the required matching conditions are as following;

#### 2.3.1.1 Direct structural coupling between Excitation and Objective Zones

This coupling is dictated by the three essential **optical design rules**;

1. Excitation light going into the Objective has to be collimated, so it should not be converging or diverging in free space for a long enough distance. On the other hand, the level of collimation is very frequently not perfect, because of the real/non-ideal objective lenses. To address this we placed a telescope in the path of excitation light as shown in the Figure 19. In addition, the first lens in the telescope is positioned on a XY-stage to finely tune the convergence/divergence of the excitation light.
2. Propagation direction of the incoming light to the objective lens has to be parallel with the surface normal of the objective lens. A well aligned excitation beam removes undesired distortions in the structure of focused light after the objective lens. This is addressed by introducing two 1" mirrors to the light path right before the excitation- cleanup filter. As it is shown in the Figure19, the mirror closest to the filter is responsible for angular change while the one before that mirror is responsible for translation of the excitation beam, both relative to the objective lens' surface normal.
3. The ratio of the diameter of excitation light and the diameter of back-aperture of the objective lens (**aperture filling ratio**) has to be known and fixed to a value depending on the experimental needs (i.e. tight focus, scanning beam, etc.). previously mentioned telescope not only sets the angular dispersion of the laser but it also adjusted the beam diameter. By using a 200mm focal lens in the telescope, we set the beam diameter slightly larger than the back-aperture of the objective lens.

### **2.3.1.2 Indirect structural coupling between Excitation and Emission Zones**

This coupling is dictated by the confocality of the system. To be more precise, while excitation zone is describing the input excitation beam, it also defines the distance and size of the focused beam on the front-focal plane of the objective lens. As it was indicated in Section 2.2, spatial filter (pinhole) position and its size has to be adjusted according to the focus position and size.

### **2.3.1.3 Direct alignment coupling between Excitation and Brightfield Zones**

In the case of a conventional microscope, optics in the brightfield zone need to be aligned prior to sending additional input light. This is called Köhler illumination<sup>5</sup> which is not fully implemented in our microscope. Instead we illuminate the sample surface with a ring of LEDs around the objective lens housing and collect the reflecting light either with a camera or with an additional long focal length lens. Purpose of the long focal length lens is for the adjustment of field of view (FOV<sup>6</sup>). Therefore before adjusting the focal position of the laser in the front focal plane of the objective lens, we try to see the image of the sample surface. Once a clear image is observed, we adjust the convergence/divergence of the laser beam to place the laser focus on to the image plane.

## **2.3.2 Emission, Zone 2**

In terms of the structure, this zone directly couples into Objective (Zone 4) and indirectly couples into Excitation (Zone 1). In terms of the alignment, it directly couples into Brightfield (Zone 3). These couplings and the required matching conditions are as following;

### **2.3.2.1 Direct structural coupling between Emission and Objective Zones**

This coupling is dictated by the objective lens being non-ideal or real. [ADD A PICTURE!!!]. Even though microscope objectives are called infinity-corrected<sup>7</sup>, like all real lenses they have two focal planes namely back (BFP) and front (FFL) focal planes<sup>8</sup>. A confocal system uses BFL of the objective lens or its image to spatially filter the emission. In our system the fiber optics cable is used to spatially filtering the emission at a proper position where there is the first image of BFL is formed.

### **2.3.2.2 Indirect structural coupling between Emission and Excitation Zones**

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<sup>5</sup><https://www.olympus-lifescience.com/en/microscope-resource/primer/anatomy/kohler/>

<sup>6</sup><https://www.edmundoptics.com/knowledge-center/application-notes/imaging/understanding-focal-length-and-field-of-view/>

<sup>7</sup><https://www.olympus-ims.com/en/microscope/terms/feature15/>

<sup>8</sup>[https://en.wikipedia.org/wiki/Cardinal\\_point\\_\(optics\)](https://en.wikipedia.org/wiki/Cardinal_point_(optics))

Although this coupling is explained in Excitation section, it is worth mentioned that apart from the coupling through objective lens' focal plane positions Excitation Zone sets the operable size range for spatial filter by defining the excitation beam profile. The coupling considered to be crucial for the resolution of the whole microscope, so a very detailed work is provided in literature.[REF HERE!!!]

### **2.3.2.3 Indirect alignment coupling between Emission and Bright-field Zones**

Although this coupling is explained in Excitation section, it is worth mentioned that apart from the coupling through objective lens' focal plane positions Excitation Zone sets the operable size range for spatial filter by defining the excitation beam profile. The coupling considered to be crucial for the resolution of the whole microscope, so a very detailed work is provided in literature.[REF HERE!!!]

### **2.3.3 Brightfield, Zone 3**

Given that this zone's couplings with Excitation and Emission zones are already presented in sections 2.3.1 and 2.3.2, its remaining coupling is with the Objective (Zone 4).

#### **2.3.3.1 Direct structural coupling between Brightfield and Objective Zones**

A proper brightfield image of the sample plane means that an image formed on the CCD camera chip with minimal optical aberrations<sup>9</sup>. Among which chromatic aberration, field curvature, distortion, and defocus are the ones frequently observed in homemade systems.

- There is not a perfect solution for chromatic aberration because it is related with the objective lens' response to excitation and emission wavelengths. Objective lenses are quite a bit expensive instruments and it is highly unlikely that a research group can effort purchasing unique objective lenses for individual experiments. As a result, a partial solution for chromatic aberration is to image the excitation light focus and the sample surface within the range of operable wavelengths.
- Defocus and distortion are the ones related with the relative axial positions of the objective lens, camera lens, and the camera. These aberrations are required to be corrected by altering lens and camera positions in an ad-hoc fashion on the light propagation axis. It is also useful to have an imaging lens of similar focal length to tube lens of objective lens was designed for.
- Field curvature occurs by the mismatch between objective lens and the remaining lens(es) in the imaging pathway. It is highly likely that the

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<sup>9</sup><https://www.edmundoptics.com/knowledge-center/application-notes/optics/comparison-of-optical-aberrations/>

image forming lens for camera is not exactly same as actual tube lens in a commercial microscope. As a result it is very likely that outer edges of the image will be distorted in a homemade system. As long as the desired portion of the image around center is good enough, there is no need to put extra effort to find an exact copy of tube lens.

#### 2.3.4 Objective, Zone 4

Coupling of Objective (Zone 4) with other zones are covered in sections 2.3.1, 2.3.2, and 2.3.3.

### 3 Mask Design Instructions for ODMR Antenna

This is a walkthrough on antenna design and manufacturing for **Optically Detected Magnetic Resonance** (ODMR) setup we have in the lab. Two methods, both relying on the photo-lithography, will be covered here in detail.

#### 3.1 ODMR Antenna manufacturing with a mask

##### 3.1.1 Mask Design

At the moment we are using the design given in an article <sup>10</sup>. To replicate the design and manufacture the antenna, we used the given parameters in the article and followed these steps;

1. Replicate the design in AutoCAD.
2. Convert the AutoCAD design to a high resolution .pdf file.
3. Process the .pdf file in Inkscape for removing unwanted features like watermarks etc.
4. Print the mask on to a heat resistant acetate sheet with max resolution.

Some of the feature dimensions are not provided in the article. These dimensions are required to be estimated by carefully inspecting the real antenna image given in the article, Figure21.

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<sup>10</sup>Efficient microwave radiation using broadened-bandwidth coplanar waveguide resonator on assembly of nitrogen-vacancy centers in diamond; Zongmin Ma, et al.; *Japanese Journal of Applied Physics*; 2019, Vol:58, p:050919

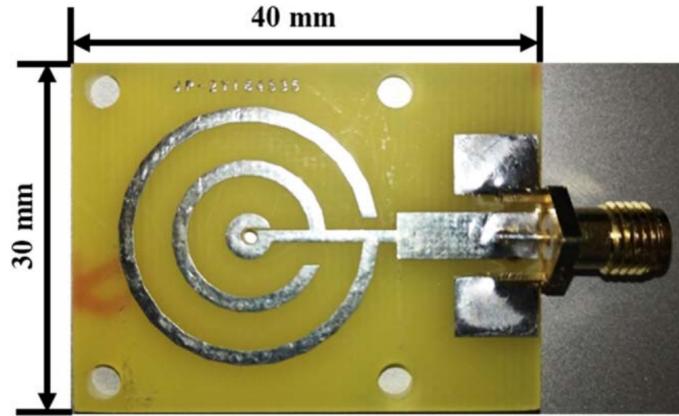


Figure 21: An image of the real antenna used in the reference article. Here **the thickness of the central line, and its length** are not given. The thickness and the length of the central line (up to the outer edge of the largest circle) are estimated to be 1.12mm, 1.57mm respectively.

Upon estimating the missing dimensions, antenna can be replicated in AutoCAD. It is important to note that the line thicknesses in the drawing has to be zero (0). Also all the line segments, arcs, etc. have to be connected so that the final drawing has to have only polylines for disconnected objects. You can test the polyline behavior by hovering the over lines in the drawing. Once the mouse is hovered AutoCAD generates a shade throughout polylines, Figure22.

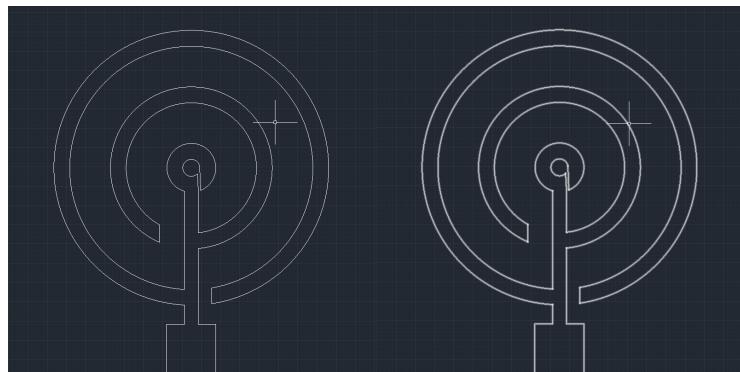


Figure 22: A screenshot from AutoCAD showing the finalized antenna design (**left**), and the shade on polyline when the mouse/cursor is hovered on a line (**right**).

It is important to note that AutoCAD's printing mechanism is a bit complicated. It does not simply print the drawing in 1:1 scale, neither I recognizes the

which paper size is suitable for the design. Specific to the "Student Version", it also creates watermarks near the side edges of the print area. These are all required to be handled manually. The conversion of design to .pdf format needs to be done in following steps;

1. Click on the "Print" button, Figure23. This will open up "Plot - Model" window for you, Figure24.

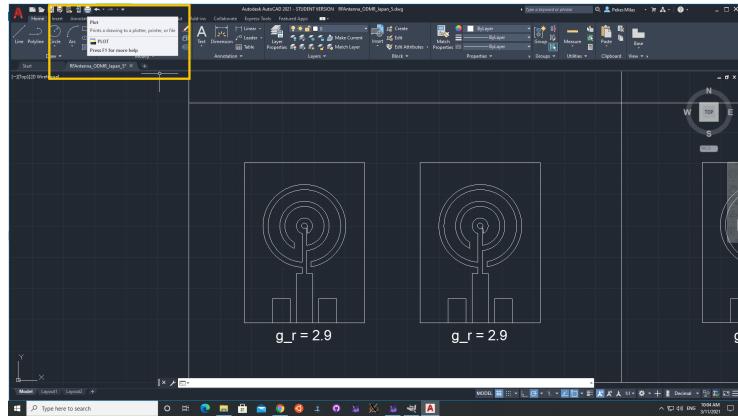


Figure 23: "Print" button on AutoCAD top menu.

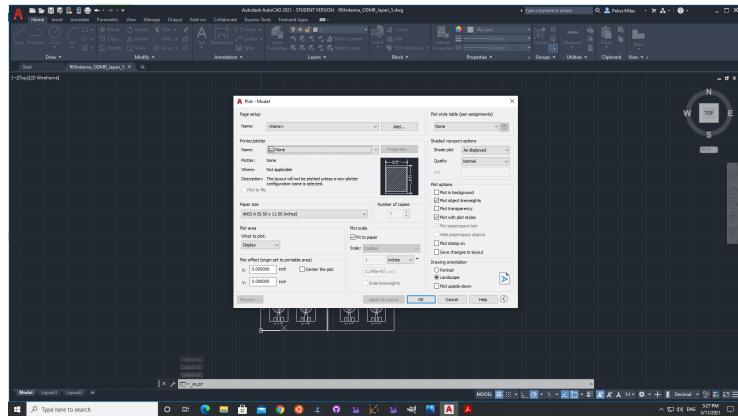


Figure 24: "Plot - Model" window in AutoCAD.

2. In "Plot - Model" window, select proper "Drawing Orientation" (Portrait), Figure25.

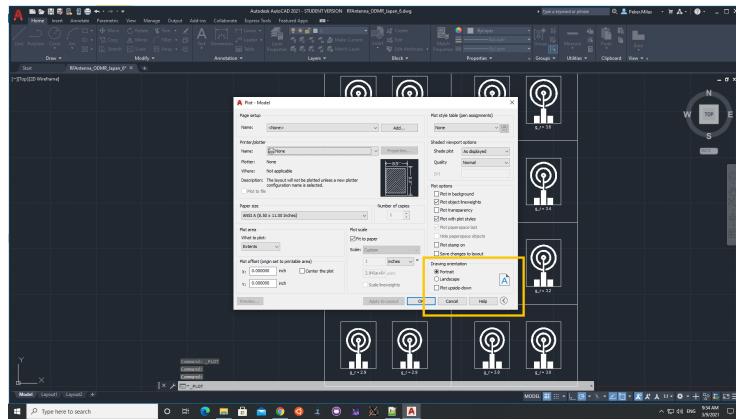


Figure 25: Drawing Orientation section in "Plot - Model" window in AutoCAD.

3. In "Plot - Model" window, under Printer/plotter section, select AutoCAD PDF (High Quality Print).pc3, Figure26.

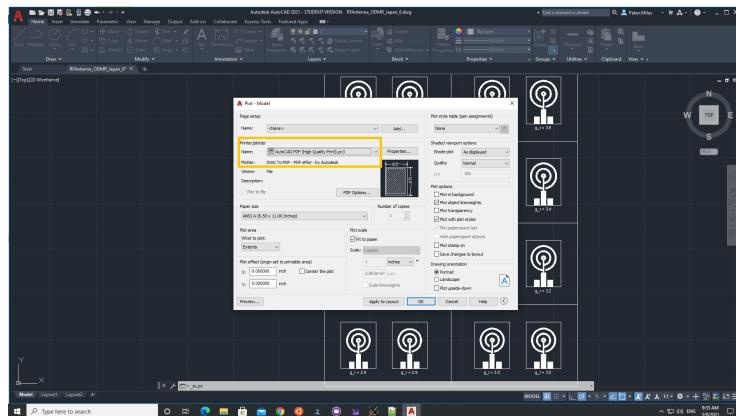


Figure 26: Selection of AutoCAD PDF (High Quality Print).pc3 in Printer/plotter section of "Plot - Model" window in AutoCAD.

4. In "Plot - Model" window, under Printer/plotter section, select click on PDF Options button, Figure27. This will open up "PDF Options" window, Figure28.

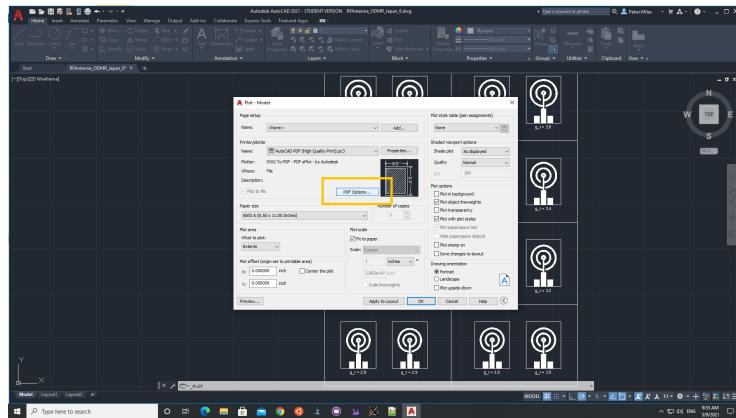


Figure 27: PDF Options in Printer/plotter section of "Plot - Model" window in AutoCAD.

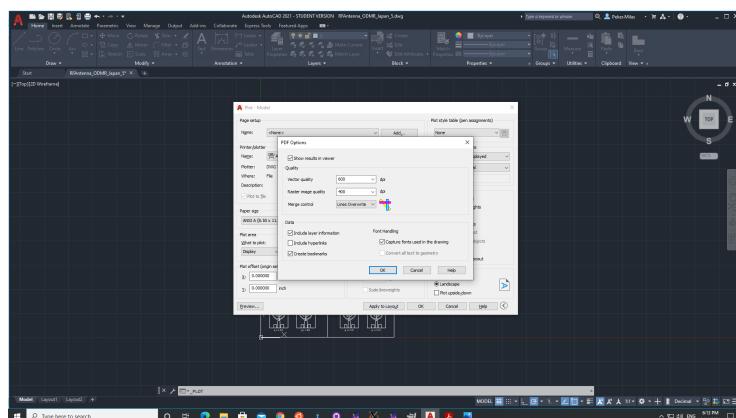


Figure 28: "PDF Options" window in AutoCAD.

5. In "PDF Options" window, under "Quality" section, change both "Vector quality" and "Raster image quality" to maximum (4800 dpi), Figure29. Then click on "OK" to close the window.

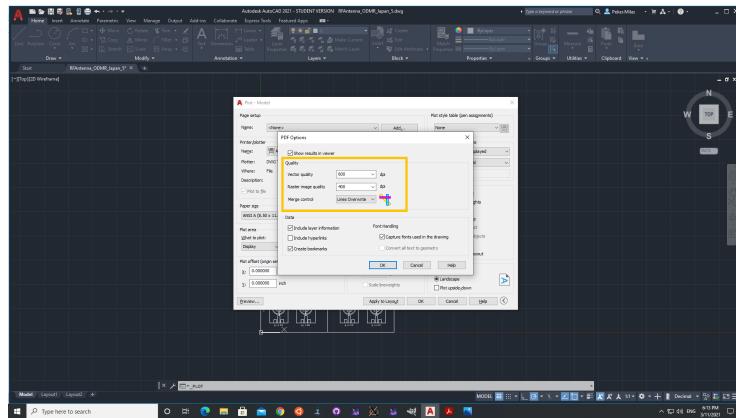


Figure 29: "PDF Options" window in AutoCAD.

6. In "Plot - Model" window, under Printer/plotter section, click on the "Properties" button. This will open up "Plotter Configuration Editor", Figure30.

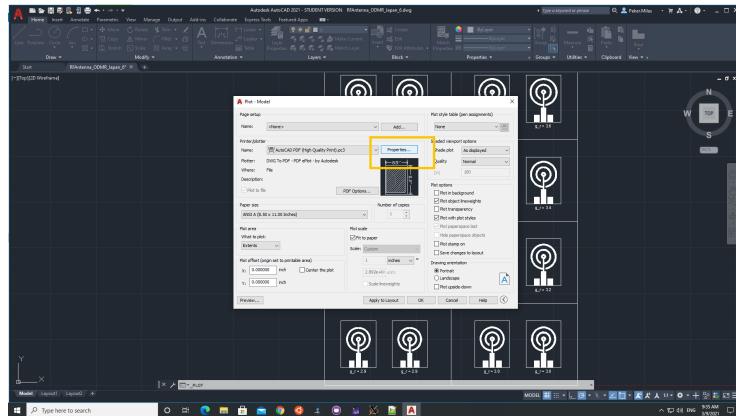


Figure 30: "Properties" button in Printer/plotter section of "Plot - Model" window in AutoCAD.

7. In "Plotter Configuration Editor" window, select "Modify Standard Paper Sizes", Figure31 and select proper paper type (here ANSI A (8.50 x 11.00 Inches)), Figure32 in the "Modify Standard Paper Sizes" section.

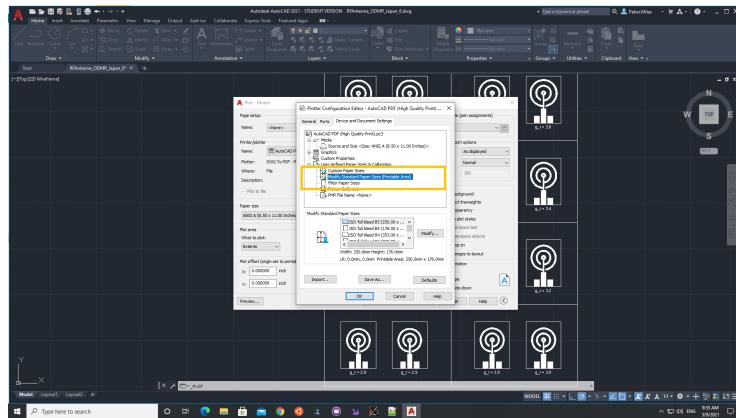


Figure 31: In "Plotter Configuration Editor", selection of "Modify Standard Paper Sizes" in AutoCAD.

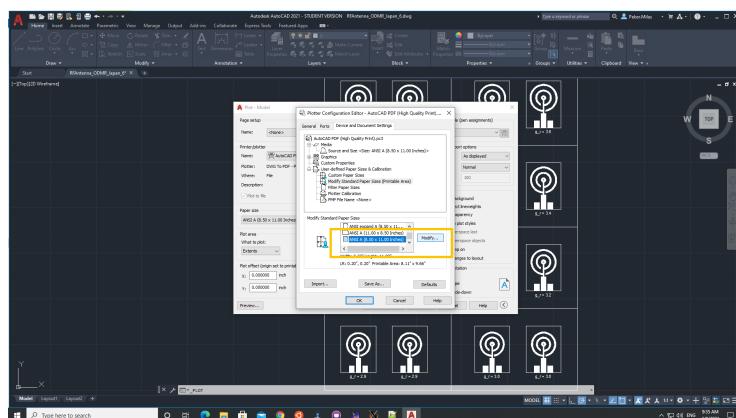


Figure 32: In "Plotter Configuration Editor", paper type selection in AutoCAD.

8. Click on the "Modify" button in "Modify Standard Paper Sizes" section. This will open up "Custom Paper Size - Printable Area" window for you, Figure33.

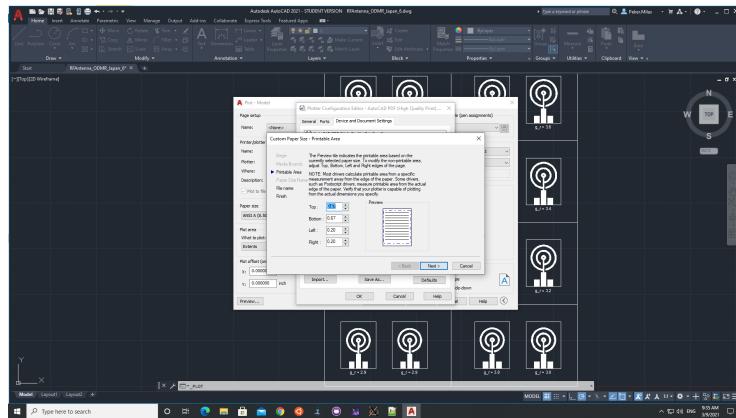


Figure 33: "Custom Paper Size - Printable Area" window in AutoCAD.

9. In "Custom Paper Size - Printable Area" window, change the values for Top-Bottom-Right-Left to zero (0), Figure34.

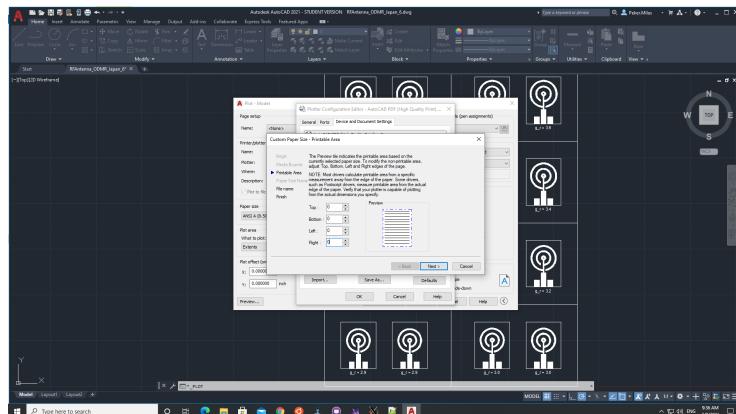


Figure 34: Setting print margins to zero in "Custom Paper Size - Printable Area" window.

10. Click on "Next", then "Next", and finally "Finish". This will change the plotter settings and create a new file in AutoCAD/Plotters/PMP files directory, Figure35. Once conversion to .pdf is done, it is a good practice to delete this file.

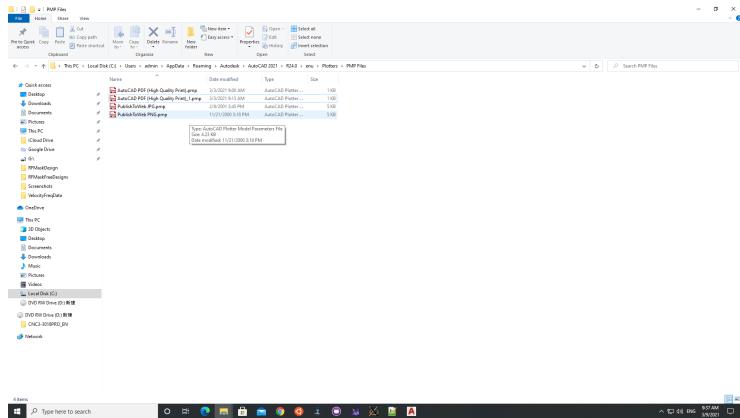


Figure 35: Customized plotter file in AutoCAD Plotters folder.

11. Click on "OK" in "Plotter Configuration Editor" window to close it.
12. In "Plot - Model" window, under "Plot Area" section, change "What to Plot:" to "Extents", Figure36.

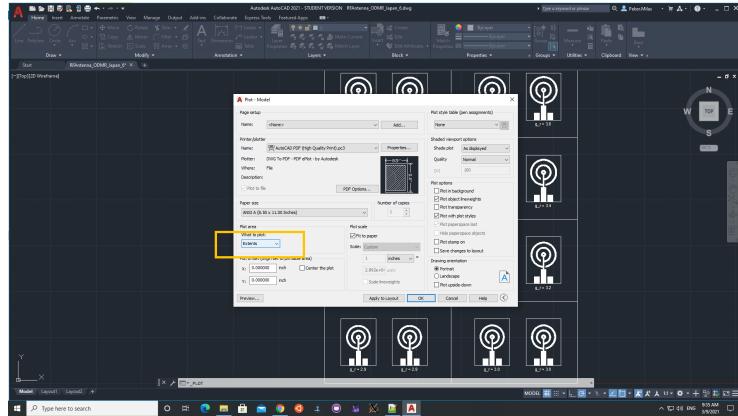


Figure 36: Selection of plot area in "Plot - Model" window.

13. In "Plot - Model" window, under "Shaded viewport options" section, change "Quality" to "Maximum", Figure37.

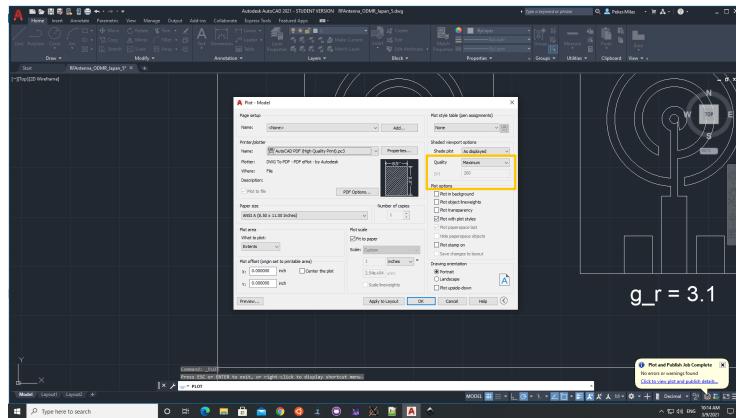


Figure 37: Setting plot quality in "Plot - Model" window.

14. In "Plot - Model" window, under "Plot options" section, un-click "Plot object lineweights" box, Figure38.

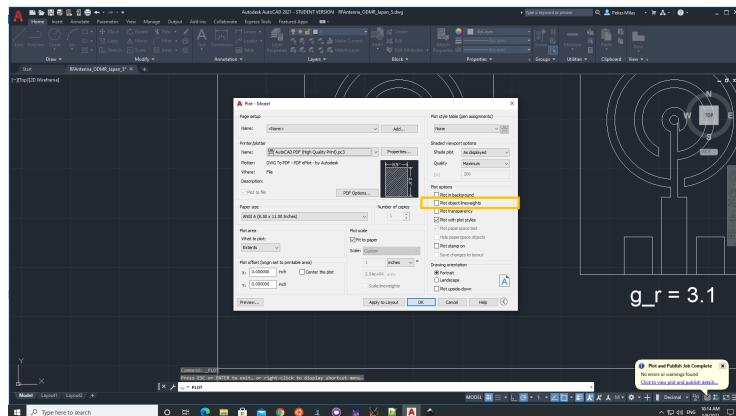


Figure 38: Setting the plot line thicknesses to zero in "Plot - Model" window.

15. Now the drawing can be plotted/converted to a .pdf file.

Following the conversion of the drawing, the resultant .pdf file needs to be post-processed with Inkscape. This has to be done in following steps;

1. Open the .pdf file in Inkscape. In "Import" window select Poppler/Cairo option, Figure39.

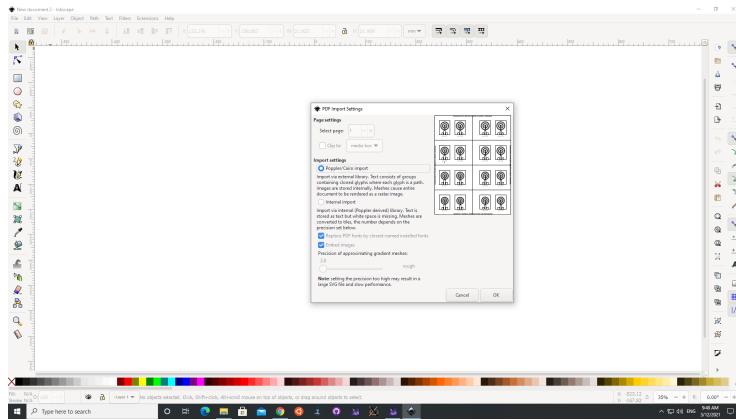


Figure 39: Opening/Importing pdf version of the mask in Inkscape.

2. Select everything and un-group, Figure40.

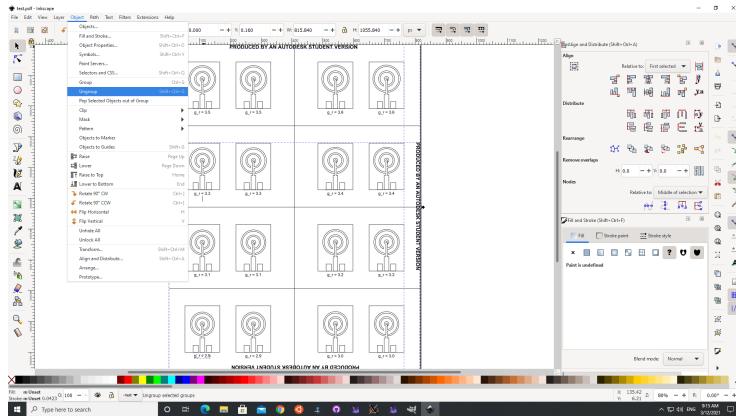


Figure 40: Ungrouping the selected elements in Inkscape.

3. Click on "Edit nodes" and select disconnected line segments. Selection of disconnected line segments can be done by left-clicking on a line segment while holding "Shift" button, Figure41.

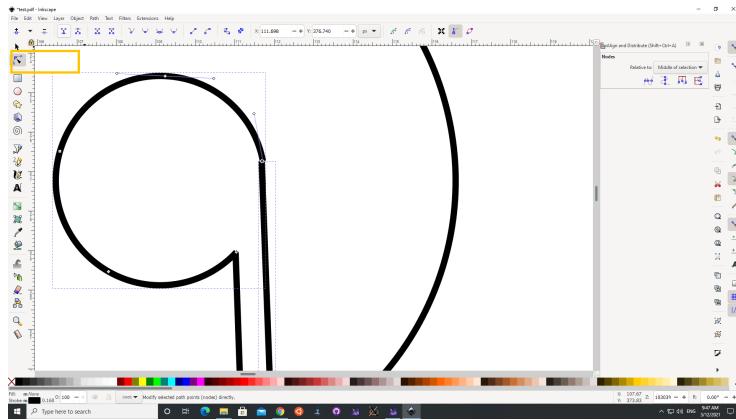


Figure 41: Selection of Edit Nodes and the two disconnected line segments in Inkscape.

4. By looking at the zoomed in images, disconnected line segments' ends will be obvious. Here select these line segment ends and "Join" them. This has to be done for all disconnected line segments, Figure42.

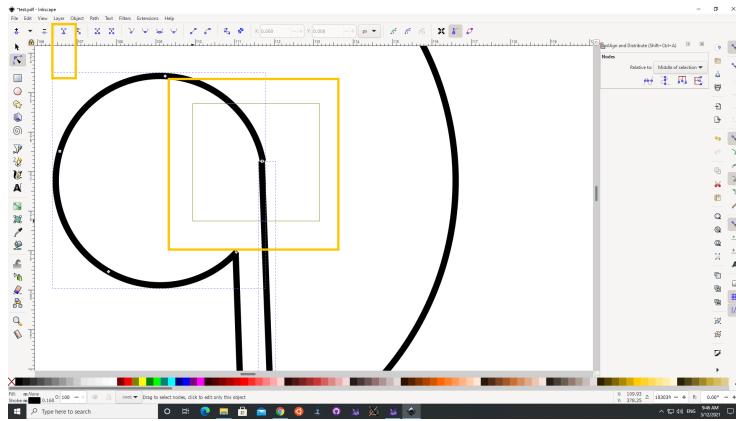


Figure 42: Joining the end nodes of two disconnected line segments in Inkscape.

5. Processing fully connected structures is very easy in Inkscape, so additional changes in the document without disturbing the original design can be done at this stage. One example to these changes can be increasing the number of structures or repositioning them with respect to the page.
6. Select the fully connected structure and open up "Fill and Stroke" dialog, Figure43.

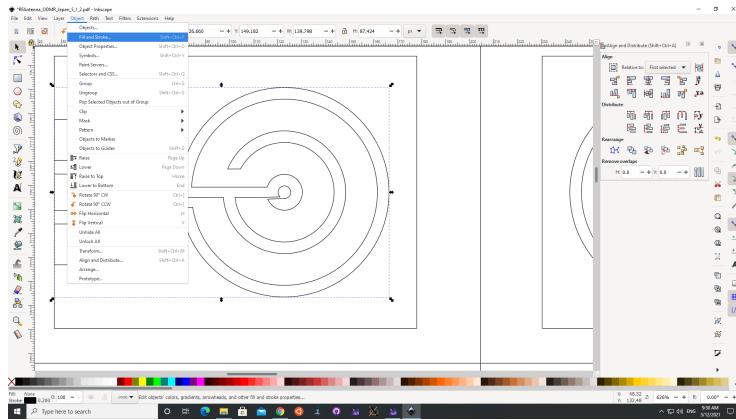


Figure 43: Fill and Stroke dialog in Inkscape.

7. In "Fill and Stroke" dialog, Fill with a solid color, Figure44.

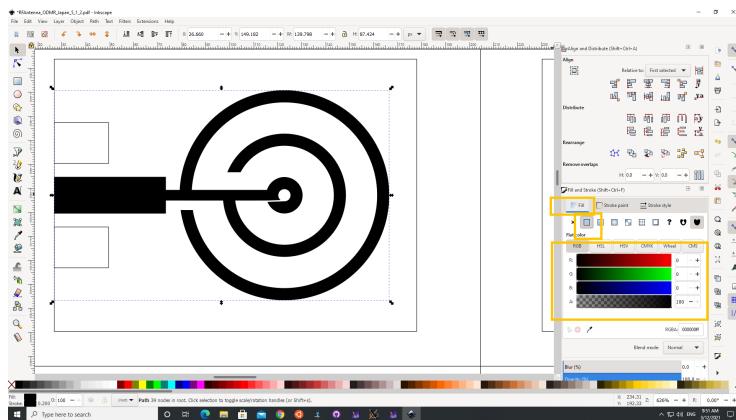


Figure 44: Filling structures with a solid color in Inkscape.

8. Select everything on the page and group them this time from the menu that was used for un-grouping, Figure40.
9. Save the final design as .svg file first. Then save it again as .pdf file.

### 3.1.2 Lithography on Copper Laminate

AAA

## 4 Optically Detected Magnetic Resonance (ODMR)

**ODMR** is a resonance technique by which the electron of a crystal defect may be optically excited and its spin state will initialized by the spin selection and readout. Among other materials this a method most frequently used on diamond has nitrogen vacancy defects (NV). Yet, it is quite hard to find a comprehensive and clear explanation of the method including application details. Here, I will provide detailed information on our measurement and data processing methods for measuring the ODMR contrast.

### 4.1 Data acquisition and initial processing

Since ODMR method relies on the observation of changes in the PL emission spectra of the target material defects, it requires either a spectrometer or a photon counting unit like PMT or APD. Our setup utilizes a relatively low-profile and low-cost spectrometer from ASEQ Instruments[ref here!!] for the collection of PL emission. The PL emission from NV diamond is basically coupled in to the spectrometer through an optical fiber as it was shown in Figure19. This is the raw PL data which depending on the setup includes dark background counts produced in the detector chip, fluorescence background emission produced by the buffer media where the actual sample resides, and the actual PL emission from the target material, here NV defects in the diamond. Identification of these emissions from different sources and isolation of the PL from NV defects are imperative for proper quantification ODMR data.

#### 4.1.1 Spectrometer properties and dark background removal

A spectrometer is a charge coupled device (CCD) which reads out photon counts based on their wavelengths. An input light coupled into a spectrometer either through air or an optical fiber, shines on to a grating within the device and diffracted. The diffraction grating separates the wavelength components of the light by directing each wavelength into a unique output angle. Hence each pixel on the CCD accepts only the photons from a particular wavelength range. These photons create electrons on the CCD chip units/pixels and the electron counts reported as the photon counts acquired per pixel.

In our experiments we utilized a low-cost portable spectrometer from ASEQ Instruments, since these devices are very common and easy to operate. Our ASEQ spectrometer has a line detector (CCD) TCD1304DG from Toshiba as its sensor. This is a 3694 pixel detector and 3654 of them are set to be used in a measurement. Currents from CCD are converted to photon counts per pixel through a 16 bit analog to digital converter (ADC). Therefore the maximum counts per pixel is limited to 65535 (a.k.a. maximum 16 bit unsigned int). Analog-to-digital conversion of the CCD's output creates a noise called **read noise** in the measurement. In a typical experiment, at relatively integration/exposure times the read noise realized as background counts in CCD pixels in the absence of input light. This background counts often measured

and reported by CCD manufacturers by averaging them throughout the whole chip. Yet every pixel has its unique read noise, so contribute the background in a different way.

A common method for cleaning up the actual spectra from background is subtracting a snapshot of the these counts which was measured in the absence input light. In Figure45, an example of background counts we acquired in our system is given as a function of exposure times. This is an easy to execute and fast method, and it serves well the qualitative analysis of emission/absorption spectra. In case of quantitative analysis, a better understanding of the background counts in statistical sense is required. To achieve a statistically sound description of background counts at the pixel level, one can sample them and attempt to fit a model to count distribution of each pixel. Since at the short exposure times the counts expected to be read noise dominated, a Gaussian model is usually good enough for fitting the distribution. Background count distributions of a random pixel in our spectrometer given in Figure46, is a good example of this behavior. Nevertheless, both by unknown sampling amount of counts per pixel and by the requirement of manual parameter estimation per fit, this approach is not practical nor it is straightforward to execute.

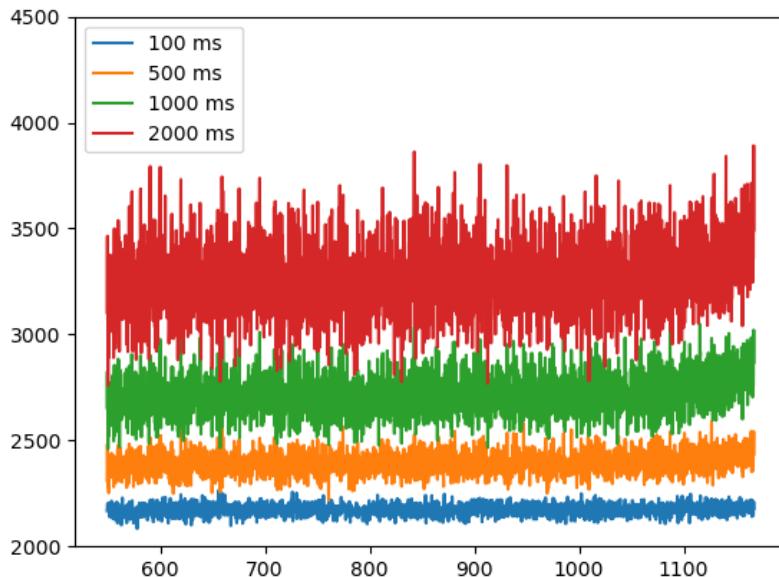


Figure 45: Typical background counts from ASEQ spectrometer as a function of exposure/integration times.

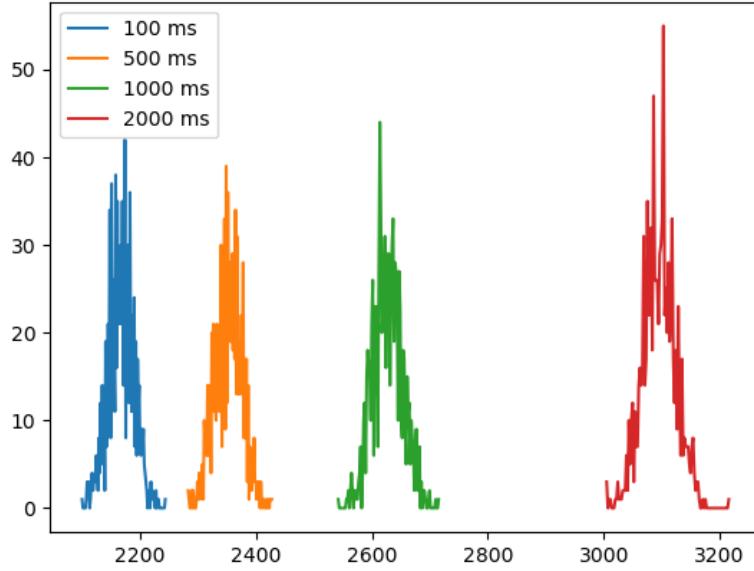


Figure 46: Count histograms of a random pixel on the CCD as a function of exposure/integration times.

To circumvent both problems, we employed a machine learning method called expectation-maximization (EM) algorithm to describe background counts of our CCD at the pixel level. Under the assumption of Gaussian distributed counts per pixel, the algorithm learns the parameters of a Gaussian Mixture Model (GMM) from the sampled background data via Bayesian inference. Calculated distributions by GMM algorithm on the background data of a randomly selected pixel for 5000 shots and the normalized histograms of the actual counts at various exposure times are shown in Figures 47, 48, 49, and 50.

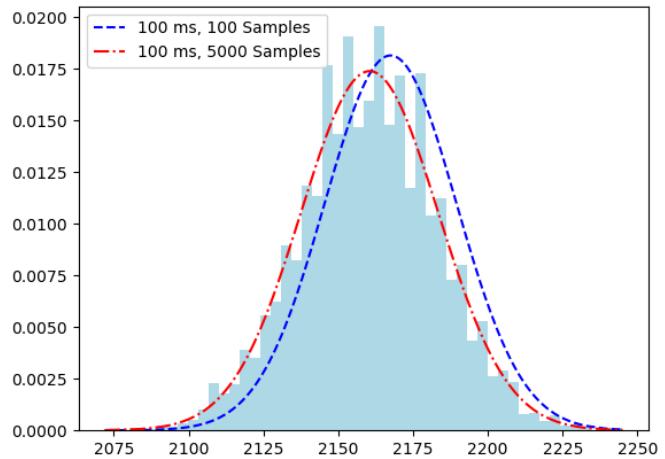


Figure 47: Count histograms of a random pixel on the CCD at the 100ms exposure time and GMM fits for low and high sample rates.

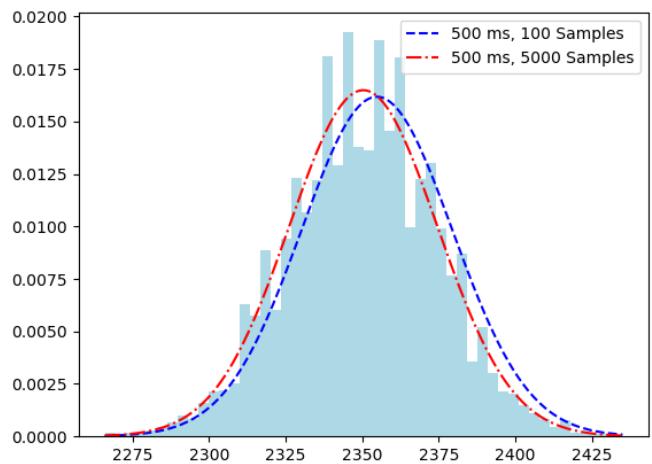


Figure 48: Count histograms of a random pixel on the CCD at the 500ms exposure time and GMM fits for low and high sample rates.

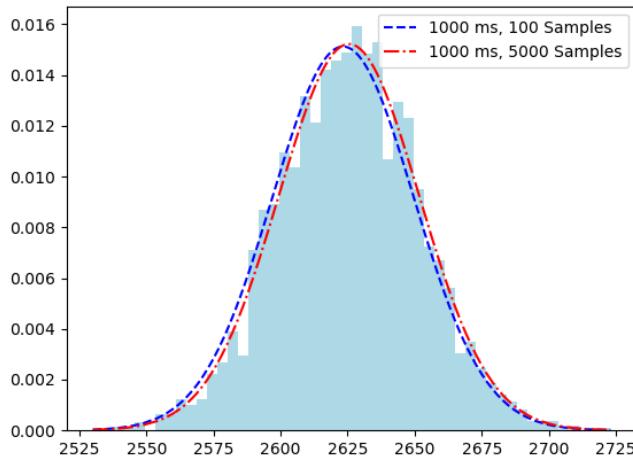


Figure 49: Count histograms of a random pixel on the CCD at the 1000ms exposure time and GMM fits for low and high sample rates.

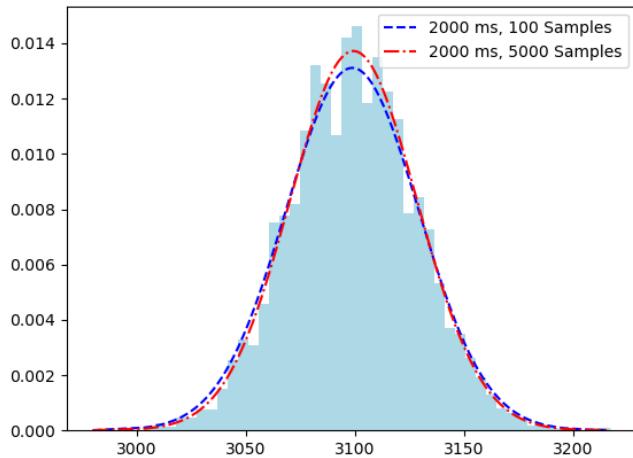


Figure 50: Count histograms of a random pixel on the CCD at the 2000ms exposure time and GMM fits for low and high sample rates.

As it is shown in the Table1, estimated GMM parameter values change minimally between the sampling size of 100 and 5000 on a data of 10000 shots.

According to the data the worst case estimate occurs for shorter exposure times not exceeding 7 counts in 2160 for the mean value and 1 count in 22 for the standard deviation. This indicates that parameters of background counts can be estimated as efficiently by using sample sizes of 100 or larger for at least two decades in exposure times (i.e 100ms to 10000ms).

Exposure (ms)	100 Samples		5000 Samples	
	$\mu$	$\sigma$	$\mu$	$\sigma$
100	2167.5	22.0	2160.5	23.0
500	2355.0	24.7	2350.0	24.2
1000	2623.3	26.4	2625.5	26.2
2000	3098.8	29.1	3099.3	30.4

Table 1: GMM parameter estimates for large and small sampling sizes as a function of exposure times.

#### 4.1.2 Fluorescent background removal

Studies on the PL emission of NV defects can be divided into main groups in terms of the material used. First group is the bulk experiments which utilizes a solid piece of diamond with desired defect densities. The second group nano or micro diamond, depending on the experiment, embedded in a solid or liquid media. Although the optical measurement systems in these experiments spatially filter most of the emission from the environment, some fluorescence couple and contaminate the PL spectra in this group of experiments.

The essential difference between the dark background<sup>4.1.1</sup> and the fluorescent background is that while the counts from the former follow a Gaussian distribution, counts from the latter follows Poisson distribution. In other words, the total background in a PL measurement is composed of counts in each pixel drawn from statistical distribution which is the convolution of a Gaussian and a Poissonian. Since there is no analytical expression for this distribution, we facilitate an approximation for cleaning up the PL data. In our method, we first define the dark background as explained in Section<sup>4.1.1</sup>, then we remove the mean counts from the PL data taken in the absence of NV defects at the pixel level. The remaining counts at each pixel are supposed to be emitted by the environment. We sample these counts to find out the parameters describing their distribution at pixel level. In this analysis, we use Poisson Mixtures instead of GMM.

## 4.2 CW-ODMR measurement and calculation of parameters

In the context of fluorescence, intersystem crossing (ISC) refers to non-emissive transitions pathways that the emitter goes through to return from the excited state to its ground state. It is known that the NV centers' excited state is a spin

triplet, so the excited electron can be in a spin state of  $m_s = 0$  or  $\pm 1$ . Among which only the electrons with spins of  $m_s = \pm 1$  can undergo ISC. It is also known that ISC is not a spin conserving transition, so once an electron experiences ISC it does not follow the spin selection rules. It should also be noted that there are no reported bleaching pathways for NV diamond. Hence, in contrast to typical fluorophores, ISC creates blinking but the defect emission does not stop by a chemical transition.

Application of microwave field (MW) to NV defects is a well-known method for manipulating the relative populations of electrons in  $m_s = 0$  and  $m_s = \pm 1$  states. When the applied MW field resonates with the defect centers' frequency, it increases the electron population in  $m_s = \pm 1$  states, so it promotes ISC and reduces the PL intensity. In other words, one can monitor PL intensities of NV defects as a function of applied MW field frequencies and observe the ratiometric reduction around the resonance frequency. The ratiometric change in PL called the **ODMR contrast**.

In diamond, individual NV defects can be in either of two charge states, neutral  $\text{NV}^0$  and  $\text{NV}^-$ , with the ability of conversion to one another. Since the emission spectra of these states overlap, they both contribute to the PL of a diamond sample. On the other hand, it has been shown that only  $\text{NV}^-$  is sensitive to applied MW field.

the is The PL of NV centers in diamond is

Continuous-wave ODMR is an ODMR method which

Since ODMR method relies on the observation of changes in the PL emission spectra of the target material defects, it requires either a spectrometer or a photon counting unit like PMT or APD. Our setup utilizes a relatively low-profile and low-cost spectrometer from ASEQ Instruments[ref here!!] for the collection of PL emission. The PL emission from NV diamond is basically coupled in to the spectrometer through an optical fiber as it was shown in Figure19. This is the raw PL data which depending on the setup includes dark background counts produced in the detector chip, fluorescence background emission produced by the buffer media where the actual sample resides, and the actual PL emission from the target material, here NV defects in the diamond. Identification of these emissions from different sources and isolation of the PL from NV defects are imperative for proper quantification ODMR data.