Quantum Information Science

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I Abstract

A single photon count is carries out using properties of visible light. The polarizers in this experiment lower the amount of energy that enter the box. Using Malus law we were able to get the lowest amount of energy inside the box. By limiting the amount of energy in the box we were able to count very few photons. Adjusting power supply systems and the amplifier we were able the detect single photons and limit noise in the system.

II Discussion

Quantum information science is an area of study that relies on properties of quantum mechanics to work. The main idea in this field of study is to understand the bizarre properties of quantum mechanics and to apply them to be used as technology. As our society studies this we proceed into having a better understanding with this field and further develop information science. Just like every development in human history, progress takes time. As the material becomes increasing harder to research the cost of also becomes disproportionate to many peoples goals and wishes. This makes funding this field incredibly hard, especially when people don't believe there are any beneficial outcomes. However, there are many subfields of study under quantum information sciences and as research continues many more might be created with material we don't currently know or understand. It is essential that people understand the astronomical advancements we might posses with this research. These subfields have endless material detailing every error and discovery. One subfield that has the potential to have a huge impact on society is quantum computing and more specifically quantum computing using optical methods.

While there is no real quantum computer the work for a full quantum computer is underway. There still is enough knowledge about quantum computers to understand all of their applications. The fields that a quantum computer would effect are extensive. Many of these applications will affect many fields of study such finance, economics, physics, medicals, and the list continues. Quantum computers have the chance to affect the world around us in ways we never thought were possible. For instance, a quantum computer could simulate advanced topics in biology, engineering or any other science. This power has the chance to create powerful drugs with a medical standpoint and also give us the ability to understand fluid dynamics to better enhance the way we transport water. This is just some examples of the possible thousands a quantum computer could achieve [**?**].

Knowing that a quantum computer is of our upmost importance, it is essential that we find a viable method for the quantum computer. There are many different ways a quantum computer can work, what many call architectures [**?**]. There are a few different physical architectures in quantum computing. One of which involves atoms and high powered vacuums so that the temperature is just above absolute zero where the atoms won't jiggle. There is also superconducting circuity and photonics systems, of which this experiment was thought out to be the beginning steps of this type of architecture for a quantum computer.

Further more, this experiment was performed to use the photonics method to create qubits with the ability to detect them. It's obvious that quantum computing isn't the simple to recreate or even understand. The idea of this experiment is to be able to get the appreciation for how hard the math is and the appreciation for how hard the physics is. There is a significant challenge when it comes to photonics quantum technologies. There are numerous variables that play a factor into the outcome of the experiment; storing photons, efficiently producing and detecting single photons, and entangling gates [**?**]. The main purpose of this experiment was to overcome one of these challenges, we found this challenge to be tedious and annoying. However, the results were successful and we were able to detect single photons.

III Introduction

Detecting a photon on its own is not an easy thing to accomplish. We are constantly surrounded by sources of light that produce thousands of photons a second. Even when it might seem that a room may be dark, light still tends to leak in. It is very hard to reduce the number of photons in a room and even harder reducing it from a device built to amplify light. The data collected in this lab was analyzed and modeled. The Fourier transfer and other methods we used to detect an individual photon.

The 2D Fourier Transform is given by

$$F(u,v)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}f(x,y)e^{(-j2\pi(ux+uy)}dxdy. \tag{1}$$

This equation is easier to code if we change the integrals to sums. This way the program is able to iterate through out rows and columns to generate a plot. The equation for this is given by

$$F[u,v] = \sum_{i=0}^{N_0-1} \sum_{k=0}^{N_0-1} f[i,k] e^{-j\frac{2\pi}{N_0}(ui+vk)}. \tag{2}$$

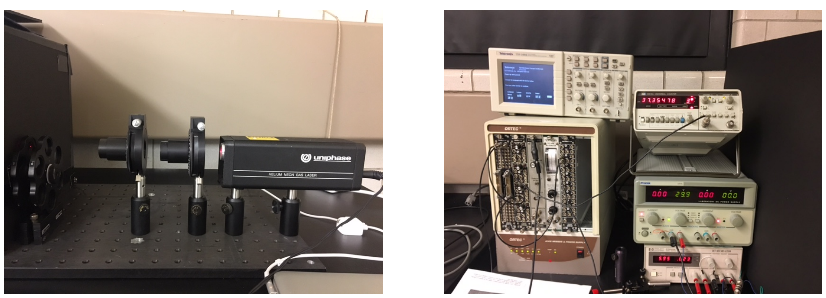
Where u is the N rows, v is the N columns, j iterates through the N rows, and i iterates through the N columns. The equation for Malus Law is given by

$$I = cos^2\theta. \tag{3}$$

Where I is intensity and θ is the angle of the polarizer. This is the only real equation used in this experiment.

IV Method

The cross polarizers and laser were set up in parallel with each other. This set up allowed the beam of light to go directly in the black box and hit a mirror to have the photons to bounce off and hit the sensor. The amplifiers and power source were controlled giving the proper amount of energy to detect a single photon. Once the energy was correct and not spiking or falling the gain on the amplifier was adjusted to reduce noise in the system. The set up of this is shown below.



(a) Cross polarizers and laser

(b) Amplifier and power source

Figure 1: The set up for the experiment.

Malus law is tested to see if the system is taking data right. A script wrote in python was created to take data picked up by the the sensor and multichannel analyzer. As the polarizer degrees increased the intensity of the beam detected by the sensor went down. Around 80 degrees the intensity of the beam was 0 and everything above 80 degrees increased in intensity. A figure from the data shows Malus law working below.

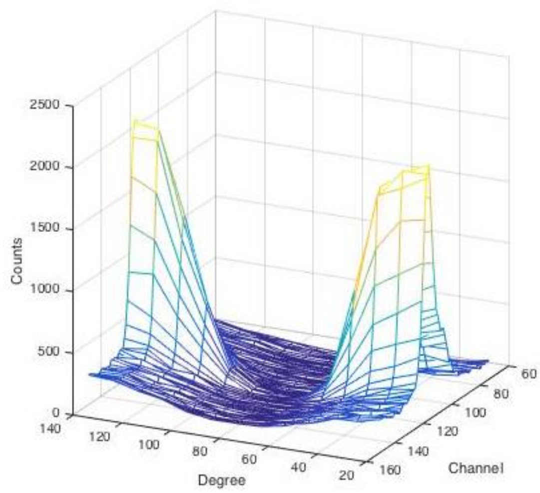
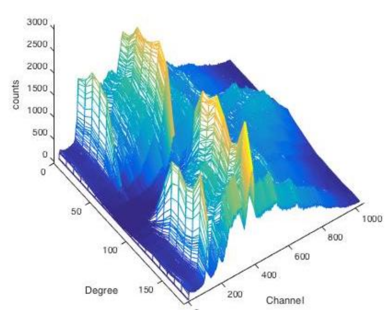


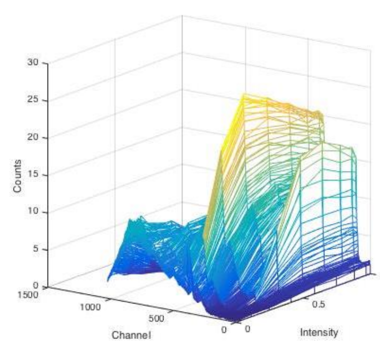
Figure 2: Malus Law

Malus law take on the shape of a parabola where the intensity decreases as the degrees on the polarizer increase. Once the intensity hits zero, as degrees on the polarizer continue to increase the intensity increases. Hence this is why it looks like a parabola. If this process is continued it will eventually look like a cosine wave, this is essentially what it is.

The primary data isn't important for what we are trying to look for. The intensity is needed for this experiment, using equation (2) the intensity is found by using degrees. The primary data can be found below along with the data for intensity.



(a) Primary data



(b) Intensity

Figure 3: Overview of the primary data as well as the intensity of the laser.

The intensity is essential to analyze since the peaks in this data will determine how many photons are counted. With the recorded voltage we are able to tell the amount of counts, we are also able to reduce the noise in the system.

The intensity plot gives us a nice peak to look and and also determine what peak the laser is. Through this we are also able to tell the noise in the peak and determine if its oversaturated and how well the polarizers worked bringing the intensity down. Another thing that can be done with this peak is to take the 2D Fourier transform. The 2D Fourier transform plot of the laser peak is shown below.

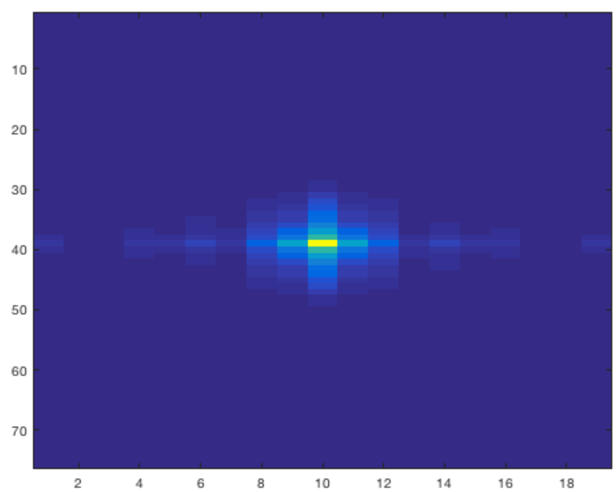
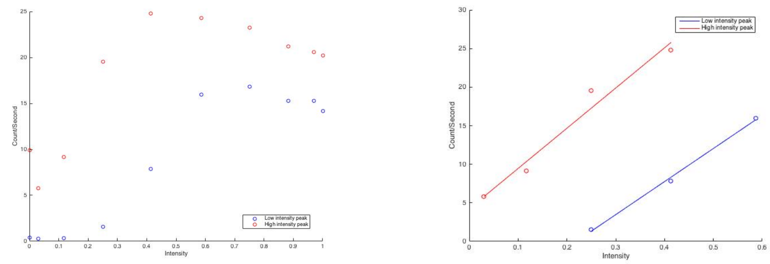


Figure 4: Truncated 2D Fourier Transformation

There are numerical scripts created to solve for the 2D Fourier transform. A lot of other work and solutions can be discovered by creating a script to understand how the Fourier transforms work. However, this is not necessary for this experiment and the Matlab command fft2(X,MROWS,NCOLUMNS), since the dimensions of the peak were already known.

Analyzing out slope allows us to understand what we are looking at.

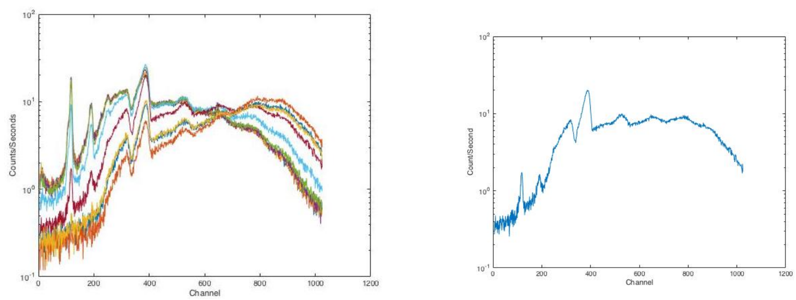


(a) Slope of photon count

(b) Curve fit of photon count

Figure 5: Linear plot of of the individual photons in blue.

In figure (5) the red data points represent multiple photon counts, notice that it closely resembles the blue data points. The blue data points represent individual photon counts. Each blue point is an individual photon count at a different intensity.



(a) Multiple semilog plots

(b) Semilog plot

Figure 6: Logarithmic plot in y to increase the view of the photon counts.

Figure 6 is the view of the peaks from the front of the intensity plot. Where the x-axis is channel and the y-axis is count per second. The purpose of this plot is to amplify the peaks. Thus, if there were any peaks we previously couldn't see the peaks would be amplified out of the noise and we could distinguish how high the peak is.

V Conclusion

We found that this method for counting an individual photon is possible. The set up for this experiment is tedious but possible. It might not also always result with how you want it to. From a computation standpoint, this might be hard to repeat. This type of computing requires extreme accuracy with minimal error and minimal noise. If this does become a problem the system will not work right because it will not be receiving the correct information. When it comes to using photonics a large optical set up is required. Thus, a lot of adjusting and time goes into setting this process up. The quantum computing field is becoming a larger field each day as new information and technology comes out. More people are willing to participate and the field is growing closer to actual solutions. It is remarkable that we have algorithms already built for these machines that are not fully quantum yet. However, it is exhilarating that we are able to run these algorithms, understand most of the math, physics, and engineering as well as understand the applications that these machines can give back to society. This is an incredibly sophisticated and powerful technology that will make for an interesting future.

VI References

References

[1] http://jubarreiro.physics.ucsd.edu/files/Kwiat-Proc.%20SPIE-5161-87-100.pdf

[2] http://www.nature.com/nphys/journal/v9/n1/full/nphys2517.html

[3] https://www.dwavesys.com/quantum-computing/applications

[4] http://www.cqc2t.org/research/photonicquantumcomputation

[5] MATLAB 2016b, The Mathworks, INC, Natick, Massachusetts, USA

Appendix

The Matlab code used to generate all the plots and calculations.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% Timothy Holmes Final Project
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [Y] = mca_data
%%%%%%%%%%%%%%%%%%%%%%%% full data mesh plot
    %%%%%%%%%%%%%%%%%%%%%%%%
clear all;
load channel.mat
load degree.mat
load mcaData.mat
degree = degree(:,:);
fullCounts = mcaData(:,:);
channel = channel(:,:);
hold on
figure(1)
mesh(degree,channel,fullCounts)
xlabel('Degree')
ylabel('Channel')
zlabel('counts')
%%%%%%%%%%%%%%%%%%%%%%% laser plot
    %%%%%%%%%%%%%%%%%%%%%%%%
clear all;
load channel.mat
load degree.mat
load mcaData.mat
counts = mcaData(75:150,:);
degree = degree(:,:);
channel = channel(75:150,:);
intensity = cos(degree*pi/180).^2;
hold on
size(counts)
size(degree)
size(channel)
figure(2)
mesh(intensity,channel,counts)
xlabel('intensity')
ylabel('Channel')
zlabel('counts')
```

```
view(-38,19)
camzoom(1)
hold off
%%%%%%%%%%%%%%%%%%%%%%truncated 2D Fourier Transform %%%%%%%%%%%%%%%%%%%%%%%%%%%
hold on
figure(9)
size counts
Y = fft2(counts,76,19);
imagesc(abs(fftshift(Y)));
hold off
%%%%%%%%%%%%%%%%%%%%%%%malus law%%%%%%%%%%%%%%%%%%%%%%%%
clear all;
load channel.mat
load degree.mat
load mcaData.mat
theta = degree(:,3:15);
chann = channel(75:150,:);
count = mcaData(75:150,3:15);
hold on
figure(3)
mesh(theta,chann,count)
xlabel('Degree')
ylabel('Channel')
zlabel('Counts')
view(-38,19)
camzoom(1)
hold off
%%%%%%%%%%%%%%%%%%%%%%%%something else %%%%%%%%%%%%%%%%%%%%%%%%
clear all;
load channel.mat
load degree.mat
load mcaData.mat
t = degree(:,:);
chann = channel(:,:);
count = mcaData(:,:);
inten = cos(t*pi/180).^2;
hold on
figure(4)
mesh(inten,chann,count)
xlabel('Intensity')
ylabel('Channel')
zlabel('Counts')
view(-38,19)
camzoom(1)
```

```
hold off
%%%%%%%%%%%%%%%%%%%%Normalized
    %%%%%%%%%%%%%%%%%%%%
clear all;
load channel.mat
load degree.mat
load mcaData.mat
load time.mat
deg = degree(:,1:10);
chan = channel(:,:);
counts = mcaData(:,1:10);
t = time(:,1:10);
int = cos(deg*pi/180).^2;
for i = 1:10
    ncounts(:,i) = counts(:,i)./time(i);
end
hold on
figure(5)
mesh(int,chan,ncounts)
xlabel('Intensity')
ylabel('Channel')
zlabel('Counts')
view(-38,19)
camzoom(1)
hold off
%%%%%%%%%%%%%%%%%%%%linear curve fit
    %%%%%%%%%%%%%%%%%%%%
hold on
figure(6)
semilogy(ncounts(:,7))
xlabel('Channel')
ylabel('Count/Second')
hold off
hold on
figure(7)
hold on
plot(int,ncounts(116,:),'bo')
hold on
plot(int,ncounts(384,:),'ro')
xlabel('Intensity')
ylabel('Count/Second')
legend('Low intensity peak','High intensity peak')
hold off
hold on
x1 = [0.25 0.4132 0.5868];
x2 = [0.03015 0.117 0.25 0.4132];
```

```
y1 = [1.568 7.869 15.99];
y2 = [5.773 9.168 19.51 24.77];
P1 = polyfit(x1,y1,1);
P2 = polyfit(x2,y2,1);
fit1 = (x1*P1(1))+P1(2);
fit2 = (x2*P2(1))+P2(2);
figure(8)
hold on
plot(x1,fit1 ,'b')
plot(x2,fit2 ,'r')
plot(x1,y1,'bo')
plot(x2,y2,'ro')
xlabel('Intensity')
ylabel('Count/Second')
legend('Low intensity peak','High intensity peak')
hold off
end
```