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The Output State of a Quantum Computer

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Abstract

This thesis examines the output state of a quantum computer from an experimental application. Additionally, this thesis looks at the output from an experimental quantum circuit and defines numerous approaches that will best be in place for future practices.

Turning our attention to experimentation. A quantum circuit was produced using a beam splitter, a 650nm red laser diode, two photo-resistors, and other various electrical equipment to produce the results. The results rendered various signatures of 0's, 1's, and 2's (experimental qubit) rendered as an output state.

Background

Quantum computing is an emerging field that applies quantum mechanics to give us solutions to questions that classical computers take more time to compute. This may be applied to solving solutions to complex calculations, simulations, or even solving challenges for climate change.

A unique way to describe how quantum computing works is by comparing it to modern-day technology. Let's look at an iPhone. An iPhone operates with the principle of binary code. Essentially, the chips found use transistors that act as a switch to give two possible values, a 0 or a 1. These strings can be encoded with data commands that tell the iPhone what to do, whether that is opening an app or sending a message through iMessage.

The basic building block for a quantum computer is known as a qubit. A qubit can be generated using either electrons or photons. For the case of this thesis, we will be applying photons. Quantum computers operate with a superposition of states. For example, imagine a coin with two sides, heads, or tails. If you flip it or spin it, in a way, it is both heads and tails at the same time. [1] This analogy can be applied to 1's or 0's to describe a superposition of states. This ability allows a larger amount of states to be encoded with data, making this more powerful than classical binary computers. [1]

Declaration

I declare that this thesis was composed by myself and that the work contained is my own except where explicitly stated otherwise in the text.

(Daniel S. Bloch, May 2023)

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Dr. Sorge, I am grateful for your guidance and advice throughout my undergraduate career. Not only have you been generous with your time whenever I needed it, but have trusted me to carry on these studies. I will always be thankful for the lessons that I have learned.

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Chapter 1

Introduction

1.1 A Brief History

The field of quantum mechanics and computer science have been prevalent in history. In World War II, computers played a critical role in solving the Enigma. Thanks to Alan Turing, who created the first digital computer to intercept German communication ultimately led us to win the war.

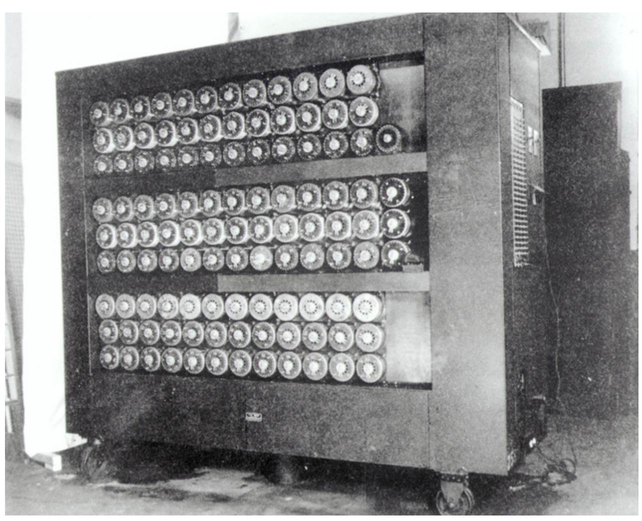

Figure 1.1: Turing Machine [6]

Additionally, quantum physics was also prevalent during World War II for the development of the hydrogen bomb used in the Manhattan Project.

Quantum computers were first proposed in the 1980s by physicists and computer scientists who pondered over the limitation of classical computing, this led to the idea of quantum computing. [2] In 1982, Richard Feynman was among those who devised this new kind of computer. [2] He constructed an abstract model to show how a quantum system could be used to do computations, especially in simulating quantum physics. [2] The fields of quantum mechanics and computer science began to converge to solve problems too complex for classical computers, swapping bits for qubits.

1.2 Current Directions

Many businesses are currently using quantum computing as an implementation of their products and services. [5] This includes IBM's partnership with, Mercedes-Bens and Exxon-Mobil. [5]

Mercedes-Benz is exploring quantum computing to create better batteries for its electric cars. [5] They are attempting to accurately simulate the chemical reactions in car batteries, which is extremely difficult for even classical computers today. [5]

ExxonMobil is using quantum algorithms to discover efficient routes to ship clean-burning fuel across the world. [5]

Just from these two utilized applications, we can see the beneficial impact quantum computing may have. Despite many ethical constraints, quantum computing does have the power to change the future for the better, including healthcare and scientific discovery.

1.3 Quantum Computing Model

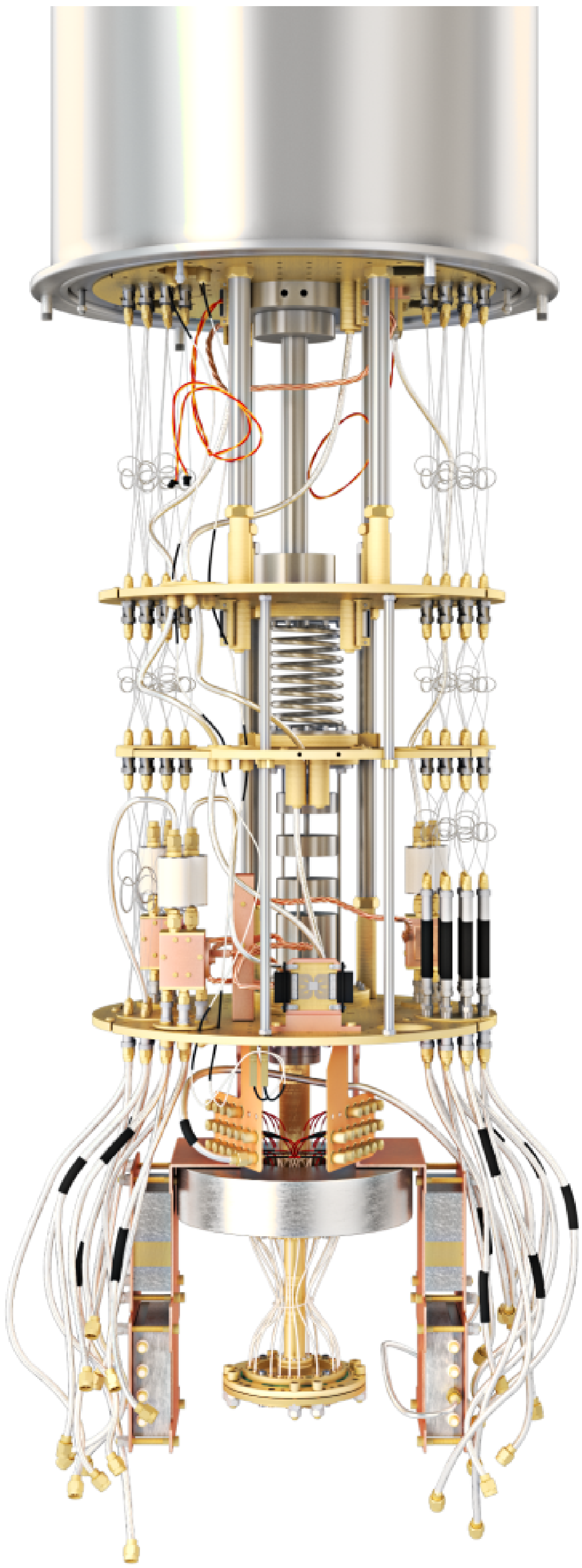

Figure 1.2: Quantum Computing Model [4]

When the computer is powered, it is encased in five casings that wrap around the entire machine. [4] A common problem known in quantum computing is decoherence, where the outside environment affects the preservation of quantum states. This problem is also quite similar to Bose-Einstein condensates. Bose-Einstein condensates are currently in the International Space Station because, on Earth, gravity will cause the Rubidium atoms to separate rather than condense. Cooling them near an absolute zero ensures the formation of the super-atom. Removing a quantum computer from the outside environment, the same way Bose-Einstein condensate is in the International Space Station can have the possibility of preserving the qubits, but that can only be found through formulation and experimentation.

Figure 1.3: The Shell [4]

This "shell" found in Figure 1.3 is vacuum-sealed and keeps the entire computer cooled to sub-zero temperatures. [4] This is to prevent decoherence, in which the environment affects the behavior of the system.

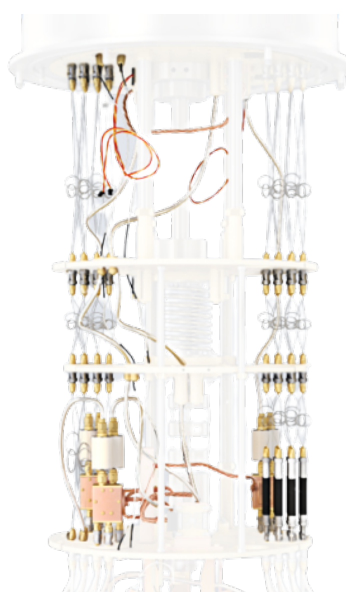

Figure 1.4: The Skeleton [4]

The gold plates separate the cooling zones. [4] In the first chamber, the temperature is just below absolute zero. [4] At the bottom, the chamber plunges to one-hundredth of a kelvin. [4]

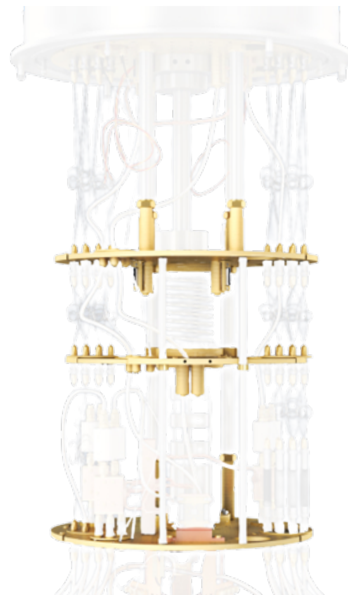

Figure 1.5: The Heart [4]

Beneath the heat exchangers sits the "mixing chamber". [4] Which houses different forms of liquid helium, helium-3, and helium-4, which together through separation and evaporation diffuses the heat. [4]

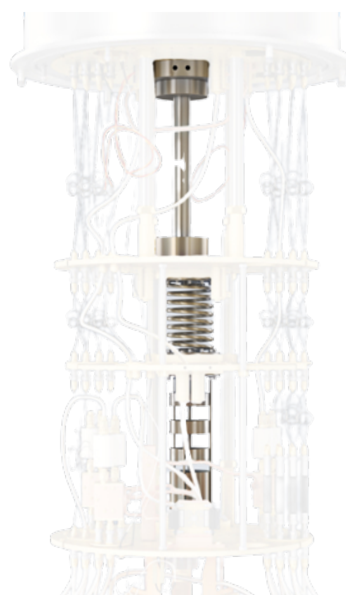

Figure 1.6: The Brain [4]

The QPU (Quantum Processing Unit) features a gold-plated copper disk with a silicon chip inside that contains the machine's "brain". [4]

Figure 1.7: The Nerves [4]

The coils in these photon-carrying cables ease the stresses that result from super-cooling the interior. [4] Without the coils, the data cables would break. [4]

1.4 The Bloch Sphere

The Bloch sphere is a geometric representation of the quantum states on the surface of a 3D unit sphere. [7] This sphere gives researchers a visual representation of the data of the given superposition of the quantum state. [7]

This is the most general form of a two-level quantum state (in this case 0 and 1, where we can represent any superposition of the two). [7]

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle \tag{1.1}$$

α and β are merely the coefficients of a quantum state describing the probability of measuring either 0 or a 1. [7] Let's examine the case of assuming the probability of measuring a 1. We can generalize the form:

$$|1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix} = \begin{pmatrix} \alpha \\ \beta \end{pmatrix}$$

$$\begin{pmatrix} 0 \\ 1 \end{pmatrix} = \begin{pmatrix} \alpha \\ \beta \end{pmatrix} = \begin{pmatrix} cos(\frac{\theta}{2}) \\ e^{i\phi}sin(\frac{\theta}{2}) \end{pmatrix}$$

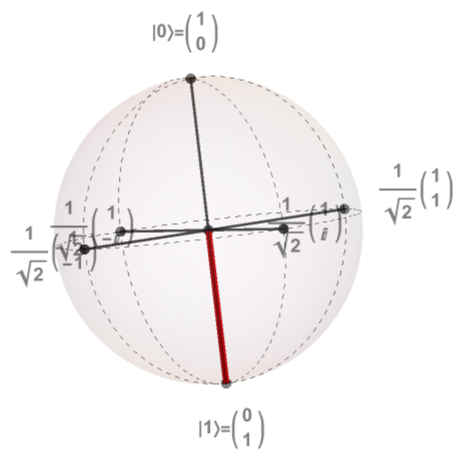

Figure 1.8: The Bloch Sphere [3]

Figure 1.8 is a visual representation of the Bloch Sphere, with a 100% probability of occurrence in the 1 state. This is denoted by the red line pointing in the negative z direction. This was produced using Wolfram's Mathematica.

Chapter 2

Experimental Application

2.1 Purpose

The purpose of this experiment was to introduce a foundation for quantum computing.

2.2 Methodology

Circuit modeling was employed as a generative study tool. The generated design was scrutinized using quantum mechanics principles to analyze the product. The criteria used to create the design are implemented with electronics and quantum mechanics to construct a "quantum circuit". This included:

- 1 × 650nm Red-Dot Laser
- 1 × 50/50 Beam Splitter
- 2 × Photo-resistors
- 2 × 10 kΩ Resistors
- 1 × Arduino Uno
- Assorted Wires

2.3 Apparatus

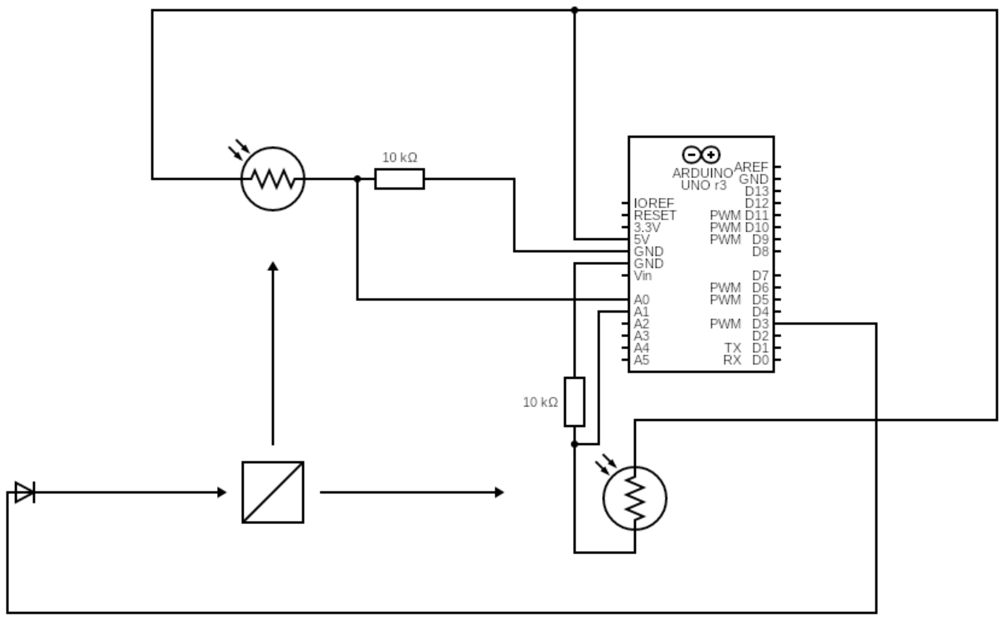

Figure 2.1: Experimental Diagram

2.4 Procedure

After the experimental setup of Figure 2.1, we receive various collections of 0's, 1's, and 2's. It is represented that a 0 is received if the intensity of H (Horizontal) is greater than the intensity of V (Vertical). A 1 is received if the intensity of V is greater than H. A 2 is received if the intensity is equal on both, this is a mere representation of a qubit, but we know from theory that a qubit is described as a superposition of selecting both with the probability of one bit being selected greater than the other. It is important to note that this experiment merely represents the impact of inducing a laser and receiving two outputs, and is an introductory quantum circuit. The readings are received on the Arduino integrated development environment through the serial monitor.

2.5 Results

The results are included with 52 characters.

Room Lights On:

0110110001101111011010010010020000002101020000000111

Room Lights Off:

2222222222222222222222222222222222222222222222222222

2.6 Discussion

What was most interesting about this experiment was seeing the system change when the lights in the room were originally turned on, then turned off. We can see when the lights were on, and how the intensity was dynamic. We received fewer numbers of qubits as compared to lights off, which is expected. This is an example of decoherence, which is a major problem in quantum computing today. Essentially, the outside environment disrupts the Hamiltonian, ruining the preservation of our energy states. Sources of error included the beam splitter. As this was one of low cost, there was some leakage appearing from the opposite side of the reflection. Additionally, the photo-resistors had a small diameter, so not all the light intensity was recorded.

2.7 Future Application

We will investigate a mixture of 0's and 1's and identify the output state from these mixtures. The study involves two inputs and two outputs that are generated with a beam-splitter. The design of the system will address important issues such as possible hardware that addresses a single photon, and probability rendering regarding the chance of a system generating a 0 or a 1. This is also done with a corresponding analog input relating to voltage and energy. We can also include another laser source to ensure frequency stability in our generated quantum circuit. This is a practice known as second-order interference. We can also use a polarizer to ensure the consistency of our outputs.

Chapter 3

Future Directions

This thesis is built on the primary infrastructure of quantum computing and is merely a building block for future research.

Applying Quantum Field Theory can extend this research topic to the creation and annihilation of quanta, and we can learn about its nature. There is also advanced research in Topological Quantum Computing and Fibonacci Anyons that is currently being studied. These are theoretical developments, but being able to match the experimental approach would lead to a future that is not yet foreseen.

3.1 Research Questions

What is Topological Quantum Computing and the theory behind it?
How can Fibonacci Anyons be experimentally created?
How can Bose-Einstein Condensate be applied to quantum computing to create a 100% polarization state in an optical circuit?
What are all the components of a quantum computer?
What is more advantageous, having a Quantum Processing Unit made out of photons or electrons?
How do you make a quantum gate?
How is a quantum circuit applied to the Quantum Processing Unit?

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