The Power of Computing: Then, Now and Tomorrow

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Abstract- It all boils down to how quickly a computer can complete an operation in terms of processing power. Within any device's CPU is an electronic clock. The clock's job is to create a series of electrical pulses at regular intervals. This allows the computer to synchronize all its components and it determines the speed at which the computer can pull data from its memory and perform calculations. Computing power also includes how fast data is transferred from one device to another and how much time the signal takes to be rerouted back to the device. Technical innovations in the field of communications and computing power never come to a halt. In this paper, Problems with current technology and the innovations in each field will be well elucidated.
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Index Terms: 5G, Wave Polarization, Band gap, Transistors , Moore Law

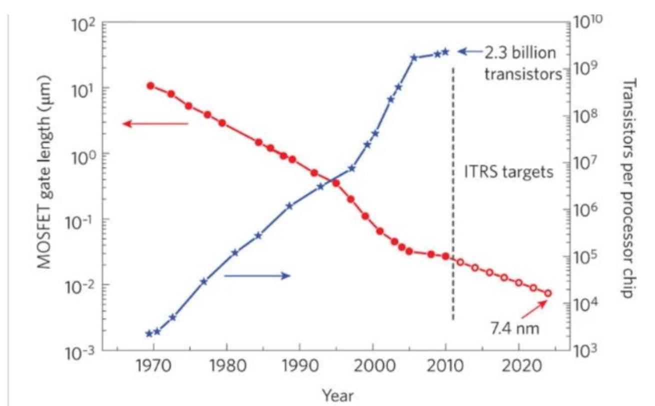
I. INTRODUCTION

We can't imagine a world without transistors. Transistors are semiconductor devices for amplifying, controlling, and generating electrical signals. They are the active components of integrated circuits, or "microchips," which often contain billions of these minuscule devices etched into their shiny surfaces. Deeply embedded in almost everything electronic, These microchips have become the nerve cells of the Information Age. As everything great began, Computer chips witnessed humble beginnings. Before the boom of superstitious computational power, Transistors, Resistors and Capacitors were separated from each other and needed to be wired to each other manually. This meant that computers possessed larger sizes and were consequentially cumbersome. From here, The integrated circuit (IC) was born, Electrical Engineer Jack Kilby paved the way for smaller devices by soldering the components into a germanium board. This allowed binary information to be transferred more quickly by using digital signals rather than analog signals. Nowadays, The size of a device is no longer considered. What matters most is the device's speed, latency and longevity.

II. IDENTIFY, RESEARCH AND COLLECT IDEA

I-Moore law and its limitations

Have you heard of Moore's law? It is the fact that the total number of transistors that manufacturers can fit into an integrated circuit doubles every two years because to technology advancements. In general, it implies that the rate of development in processing power is exponential. However, Unlike other laws like law of conservation of energy and laws of equilibrium, Moore's law has never been an immutable truth. Therefore, The future of computing is not shaped by the number of integrated transistors in the circuit. In fact, It is shaped by the conductivity and ideality of the transistor's building material. In the 1970s, Germanium was the main element for transistors. However, Germanium has high reverse bias current, which strengthens the potential barrier and therefore restricts current flow. Also, The chemistry of extracting germanium from germanium oxide is too complicated. Therefore, Silicon is used instead due to its low reverse bias current, abundance, and cheapness of its extraction from silicon oxide. That is why silicon consumes low power. Moreover, Silicon can remain a semiconductor at much higher temperatures than



germanium, especially when the transistor is overclocked, meaning that there are too much signals to process, leading to an increase in switching frequency which often generates heat. Also, Silicon conductivity is easy to change by using dopant elements like barium or aluminium.
In fact, As shown in fig.1, Moore law is coming to a halt starting from now. Intel's smallest microchips are 10nm. Below 5nm is the size of individual atoms. At this size, Intel had to deal with complex quantum tunneling issues.

II-The use of gallium nitride as a semiconductor

A new element is found to solve the silicon's low electric conductivity(relative to the rigorous tasks required in modern era), weak power handling and temperature.
It is not a new element literally, It is Gallium Nitride(GaN). Gallium nitride is a semiconductor compound commonly used in light-emitting diodes (LEDs) since the 90s. As shown in figure 1, GaN has a wider bandgap (Silicon has a 1.12 eV bandgap, while Gallium Nitride has a 3.4 eV bandgap). This means there is less energy loss as electrons move from one band to another. Gallium nitride's wider band gap allows it to sustain higher voltages and temperatures than silicon MOSFET. Due to the intrinsic properties of silicon, integrated circuits (IC) based on this material malfunction at high temperature (about 300 degrees Celsius) and operate at low frequency. GaN material is thermally robust and chemically stable, good at handling high temperature and radiation environments. Moreover, the GaN high electron mobility transistor (HEMT) technology allows monolithic integration of various GaN-based devices with ultrafast frequency response (100x) due to the two-dimensional electron gas.

	GaN	Silicon
Wafer diameter	3 - 6 inches	8 inches
Max frequency	> 12 GHz	3.8 GHz
Max temperature	600 °C	150 °C
Band gap	3.4 eV	1.1 eV
Electron velocity (peak)	2.7 x 105m/s	1 x 105m/s

Fig.1: A comparison between Si and GaN properties

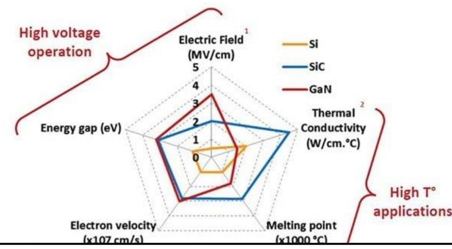
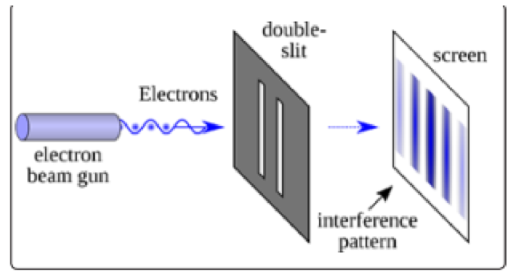


Fig.2: How GaN is better than other semiconductors

Quantum Computing

Quantum computing promises to overcome computational limitations with better and faster solutions for optimization, simulation, and machine learning problems. It is the new field of science which uses quantum phenomena to perform operations on data. The goal of quantum computing is to find algorithms that are considerably faster than classical algorithms solving the same problem. Basically a quantum computer is more powerful version of a classical computer. The key to a quantum computer's power lies in its ability to generate and manipulate qubits (Quantum Bits). Classical computers use bits. Qubits are like small switches that can either be in the on state represented by one, or in the off state represented by zero. Quantum computing uses a microscopic object (e.g., electron, photon, ion) as the medium to store and transfer digital information. Everything we do in our computer is done by the computer using this logic only. Any document, any photograph is formed from these bits only, but quantum computers use qubits. These qubits can be one or zero (on or off) and can also be in a state called superposition where they are both on and off at the same time, or somewhere between the range of these two. Quantum computing will open up a door to many areas of expertise like routers development, algorithm development, and logic gates development and what not. In coming years quantum computers are going to replace the classical computers in almost every field.
Qubits do not rely on the traditional binary nature of computing. While traditional computers encode information into bits using binary numbers, either a 0 or 1, and can only do calculations on one set of numbers at once, quantum computers encode information as a series of quantum-mechanical states such as spin

directions of electrons or polarization orientations of a photon that might represent a 1 or a 0, might represent a combination of the two or might represent a number expressing that the state of the qubit is somewhere between 1 and 0, or a superposition of many different numbers at once. A quantum computer can do an arbitrary reversible classical computation on all the numbers simultaneously, which a binary system cannot do, and also has some ability to produce interference between various different nu mbers. By doing a computation on many different numbers at once and, then interfering the results to get a single answer, a quantum computer has the potential to be much more powerful than a classical computer of the same size. In using only a single processing unit, a quantum computer can naturally perform myriad operations in parallel. As a comparison, A 30 qubit computer would equal a processing power of a conventional computer that would run at 10 teraflops (trillions of floating point operations per second).
The superposition from a quantum point of view is a fundamental principle of quantum mechanics. The Quantum Superposition (QS) states that, much like waves in Classical Mechanics (CM) or Classical Physics (CP),as shown in the figure, any two or more quantum states can be added together ("superposed"), and the result will be another valid quantum state; and conversely, that every quantum state can be represented as a sum of two or more other distinct countries. Mathematically, it refers to a property of solutions to the both Schrödinger Time-Dependent and Time-Independent Wave Equations; since the Schrödinger equation is linear, any linear combination of solutions will also be a solution.



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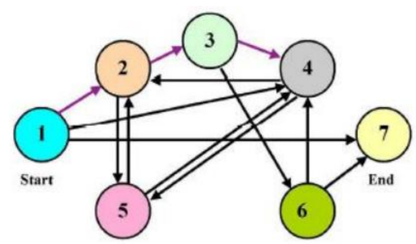
DNA Computing

Development in traditional electronic computers is restricted by hardware problems. DNA computing will solve that problem and serve as an alternative technology. DNA computing is also known as molecular computing. It is computing using the processing power of molecular information instead the conventional digital components. It is one of the non-silicon based computing approaches.
DNA has been shown to have massive processing capabilities that might allow a DNA-based computer to solve complex problems in a reasonable amount of time. DNA computing was proposed by Leonard Adleman, who demonstrated in 1994 that DNA could be applied in computations .He used DNA to solve a small instance of the traveling salesman problem, in which the objective is to find the most efficient route through seven cities connected by 14 one-way flights. Adleman solved this problem by creating strands of DNA to represent each flight and then combined them to generate every possible route The graph in Adleman's experiment is shown in Figure1. Adleman's work have set imaginations blazing throughout the world and across disciplines. It introduced a new revolutionary era in the field of computing. DNA computing is now an interdisciplinary research field where chemistry, molecular biology, computer science, mathematics, and technology come together.



Graph used in Adleman Experiment

Computing Model

DNA (Deoxyribo Nucleic Acid) is the molecule that plays an important role in DNA computing. It is found in every living cell. It is used as a medium to store the genetic information of all living beings. It consists of nucleotides which have four different bases: adenine (A), guanine (G), cytosine (C), and thymine (T). Pairs (A,T) and (G,C) are called complimentary. The amount of each nucleotide and the other of their arrangement are unique to every living organism. We define the complement operation as: A = T , T = A, C = G , and G = C . DNA strands can be regarded as a sequence represented by a combination of four symbols A, G, C, and T. DNA strands are used in encoding the problem, while biological operations are used in simulating the computation [4]. For example, a single-stranded segment consisting of the base sequence TAGCC will stick to a

section of another strand made up of the complementary sequence ATCGG. A strand of DNA bears similarity to a Turing machine's tape. DNA is usually double-stranded, consisting of two long strings twisted around each other in a helical form. DNA computers perform computations by synthesizing DNA strands and allowing them to react in test tubes. DNA can be [4]:
- Synthesized – desired strands can be created –
Separated – strands can be sorted and separated by length –
Merged – pour two test tubes of DNA into one to form union –
Extracted – extract strands that contain a given pattern –
Melted/Annealed – breaking/bonding two DNA molecules with complementary sequences –
Amplified – make copies of DNA strands –
Cut—cut DNA restriction enzymes –
Rejoined – rejoin DNA strands with ―sticky ends‖
- Detected – confirm presence or absence of DNA

DNA computing model is described in the opposite figure. The input consists of DNA fragments and some enzymes. (Enzymes are proteins that accomplish specific functions in the cell.) The output consists of DNA fragments through controllable biochemical reactions [6]. In a DNA computer both the input and output are strands of DNA. DNA computing is a form of parallel computing in that it takes advantage of many different molecules of DNA and tries many different possibilities at once. In order to accomplish DNA computing, it is necessary to have DNA libraries, which are also known as DNA codes

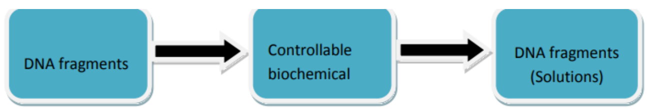


Figure 2: DNA computing model [6].

DNA vs CPU

In the cell, DNA is modified biochemically by a variety of enzymes, which are tiny protein machines that read and process DNA according to nature's design. There is a wide variety and number of these "operational" proteins, which manipulate DNA on the molecular level. For example, there are enzymes that cut DNA and enzymes that paste it back together. Other enzymes function as copiers and others as repair units. Molecular biology, Biochemistry, and Biotechnology have developed techniques that allow us to perform many of these cellular functions in the test tube. Just like a CPU has a basic suite of operations like addition, bit-shifting, logical operators, etc. that allows it to perform many complex calculations, DNA has cutting, copying, pasting, repairing, and many others. Also, as mentioned above, in the test tube enzymes do not work sequentially on one DNA at a time. Rather, many copies of the enzyme can work on many DNA molecules simultaneously

Limitations of DNA Computing

DNA computing is essentially mechanical computing using macromolecules. The computers made in this way are slower and less scalable than the electronic chips. This can be demonstrated in many ways. DNA self-assembly and other similar processes are essentially chemical reactions, much slower than switching electric current. Furthermore, DNA is a molecule that has the size bigger than the logical gates of modern computers.

The Power of Computing with respect to communication

Aside from computing power which enables a device to be extremely fast, There is also an important aspect of computing, communication. In our modern world, Our devices are connected as if they are neurons. Mobile network traffic continues to grow in a very rapid manner due to new mobile technologies, like; virtual reality applications, high resolution video streaming and cloud gaming . the 4G services would certainly not meet the speed of the rise in traffic, as well as the anticipated demands of new scientific technologies, such as Unmanned Aerial Vehicles (UAVs), virtual reality and autonomous vehicles. In a In addition, There are other devices like IOT which is basically anything with a computer chip that can decode instructions and communicate data with other devices wirelessly.

III. III-i -The Evolution of Communication networks

The evolution of communication mainly depends on the range of signal frequencies of the electromagnetic waves transmitted by the cell towers. Prior to 2G and 3G networks, 850 MHz and 1900 MHz frequency spectrums were used to provide service for the Global System for Mobile Communications (GSM) networks. The modulation method changed with the advent of 2G and 3G networks, but the frequency spectrum used was mostly the same. With the arrival of 3G, new frequency bands of nearly 2100 MHz were added. This spectrum provides a wide range of options for users, allowing them to connect to various services with ease. With the arrival of 4G, new frequency bands and spectrums were added, ranging from 600 MHz to 2.5 GHz. For 5G, the frequency spectrum of mmWave ranges between 450 MHz to 6 GHz and 24 GHz to 52 GHz.

IV. IIII-ii -The Physics and Mathematics behind 5G

Scientists and Researchers are working hard to attain mm Wave spectrum. Microwave has several unique characteristics. Firstly, the propagation mode of microwave and light is very similar, so Microwave has a strong light transfer characteristic since it has a high frequency. They are all spread in a straight line. And when the microwave encountered an object which has a large size of its wavelength, it will be reflected. When the size of the conductor is almost the same as the wavelength of the microwave, it can produce radiation effects, the antenna and radar system are designed based on this characteristic. 4G networks depend on MIMO. This is a form of antenna diversity, which uses multiple antennas to improve signal quality and strength of an RF(radio frequency) link. The data is split into multiple data streams at the transmission point and recombined on the receive side by another MIMO radio configured with the same number of antennas. The receiver is designed to consider the slight time difference between receptions of each signal, any additional noise or interference, and even lost signals.

V. IIII-iii-Advantages of MIMO

By transmitting the same data on multiple streams, the MIMO radios introduce redundancy into data transmission that classic single antenna setups (SISO: Single In, Single Out) can't provide. This gives MIMO systems several advantages over typical SISO configurations:

1-MIMO radios can utilize the bounced and reflected RF transmissions (known as multipath propagation) to actually improve signal strength even without clear line-of-site, since MIMO radios receive and combine multiple streams of the same data that are received at slightly different time intervals. This is particularly useful in urban environments, where signal degradation between single antennas without clear line-of-site is a major issue. Urban environments provide plenty of reflection paths for MIMO signals to take between the transmit and receive radios.
2. Overall throughput can be improved, allowing for greater quality and quantity of video or other data to be sent over the network.
3. By utilizing multiple data streams, issues such as fading caused lost or dropped data packets can be reduced, resulting in better video or audio quality.

IIII-iiii Use of Antenna Polarization in 5G*

MIMO radio systems can take advantage of multiple types of antenna polarization schemes to improve diversity, which is one of the key ways MIMO systems are able to provide robust connectivity even challenging environments that would prove difficult for single antenna radio systems. All antennas have a specific polarization direction, which is determined by their design and represents the oscillation direction of the electromagnetic radio waves as they propagate from the antenna's radiating element. The 'electric' portion of the electromagnetic wave is only half of the transmitted signal, with a magnetic wave

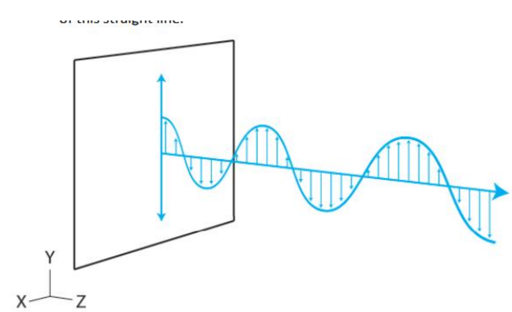


Figure 6: Example of linear polarization, with the radio wave's electrical field oscillating on a single plane, in this case vertically.

that oscillates at a 90 degree angle at the opposite timing of the electrical wave. As the electrical wave rises the magnetic wave falls, and vise-versa for each cycle. Polarization types can be broken down into two key types: "linear polarization" and "circular polarization":

• Linear polarization occurs in a straight line, and can be vertical, horizontal, or at any angle such as 45 degrees. The electrical wave of the antenna's signal oscillates up and down along the axis of this straight line as shown in the figure.

• Circular polarization, instead of occurring on a single plane, rotates as it leaves the antenna. Imagine a spiral corkscrew radiating out of the antenna. Circular polarization can either rotate left (counter-clockwise) or right (clockwise). One revolution is completed for each wavelength of the transmission. Antennas that are circularly polarized are often better suited for operating in inclement weather conditions, as they can more easily pass through rain and other atmospheric disturbances compared to linear polarized antennas as shown in the figure.

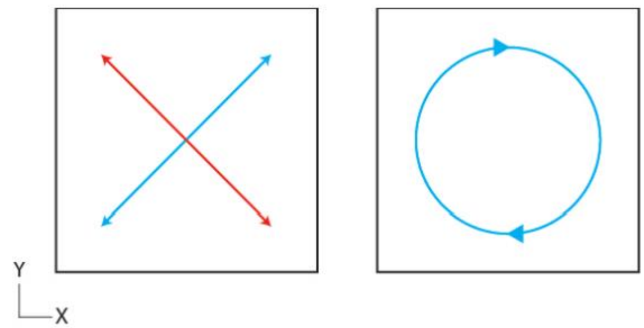


Figure 7: Examples of linear cross polarization (left) and circular polarization (right)

IIII-V Why antenna polarization is imperative?

The choice of antenna polarization is important because transmit and receive antennas need to be paired by matched polarization type. A vertically polarized antenna works best with another vertically polarized antenna, and circularly polarized antennas will work best with other circularly polarized antennas. If a polarization mismatch occurs, a loss of gain will be introduced reducing communication distance and impacting the quality of video or data transmission. While polarization matching on both sides of the RF link is still important with MIMO systems, since there are two or more sets of antennas used with every radio users can configure opposite polarizations with each set of antennas on the radio to introduce cross polarized isolation between the multiple data streams being transmitted by the radio, increasing diversity and improving transmission quality. 5G networks will be improved on the long term when implemented with MIMO. However, MIMO will need more frequencies in its electromagnetic spectrum, and researchers will need to design new antenna systems to withstand 5G traffic.

* the **polarization of electromagnetic radiation** is a characteristic of the electromagnetic waves and indicates the oscillation direction of the electric field vector during the wave propagation in space – time (the magnetic field will be polarized along the direction orthogonal to that of the electric field and to the direction of propagation).

VI. Maths between 5G Signals

Physics correlate nicely with Maths to solve our challenges efficiently, Since we understood the physics behind 5G. This section will explain the maths behind 5G signal processing.

Over the past few years, the need for positioning, and thus the number of positioning services in general, has been in constant growth. This need for positioning has been increasingly focused on constraint environments. To develop such a positioning module, it is of the utmost importance to correctly characterize the mathematical models of the processed 5G signals at each stage of the receiver.

5G systems use Orthogonal Frequency Division Multiplexing (OFDM) signals.. The process to generate an OFDM signal is illustrated in Fig.1. The symbols {d^k0 , … , dk N-1 } are first modulated by applying an inverse Fast Fourier Transform (IFFT*). Then the Cycle Prefix (CP) is added creating an OFDM time symbol. At this point the complex envelope signal model (consisting in one OFDM time symbol) can be expressed as shown in figure

$$s^k[n] = \sum_{p=0}^{N_{FFT}-1} d_p^k e^{\overline{N_{FFT}}} \quad -N_{CP} \leq n \leq N_{FFT} - 1 \qquad (1)$$

Where N_{CP} is the number of Cycle Prefix samples, N_{FFT} is the size of the FFT window, p is the subcarrier, n indicates the n^{th} discrete time epoch, k indicates the k^{th} OFDM symbol, d_p^k is the k^{th} modulated symbol carried by the p^{th} subcarrier.

The OFDM signal is then transmitted through the propagation channel, which CIR mathematical model is usually expressed as $a^k(t)$. The received signal mathematical model can then be expressed by the convolution between the incoming signal and the previously defined CIR propagation channel, where rk(t) expresses the noiseless received signal before the ADC/AGC

$$r^k(t) = s^k(t) * \alpha^k(t)$$

The CP is removed from this received signal, and finally, the signal is demodulated using a Fast Fourier Transform (FFT*).

*Fourier Transform is a **mathematical model which helps to transform the signals between two different domains**, such as transforming signal from frequency domain to time domain or vice versa

VII. CONCLUSION

Building powerful computational infrastructure has many hurdles, whether quantum tunneling, band gap of materials, or providing wide mmWave spectrum access to the globe. Scientists are also trying hard to exploit the materials and to make them ideal for intense signal exchange without loss of electrons. They are also trying to find the right antenna polarization choice for better communication. Once these hurdles are solved, The limit is the sky.

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