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# The effect of quantum physics and superconducting logic on future computers

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**Abstract.** While human progress in the world of electronics, computers and computing is undeniable, new researches show that we can achieve greater speed and lower power consumption based on the principles of quantum physics. Changing from the digital world of today, which is based on CMOS transistors and the electric current, to quantum with no electric current and based on magnetic flux, is now in the middle of its way. Clearly any research in this area or even a comprehensive scientific attention is laudable from the experts' viewpoint. This paper tries to show quantum computers more tangible by describing and analyzing some basic principles and explaining the entrance to this technology. In this article it is explained how the spintronics, superconductivity, and Josephson junction open the ways to the next generation of faster, more compact, and more energy-efficient computers in future; computers that bring about several hundred times the speed and negligible power consumption, along with the revolution of basic principles of electronics. We'll see how the spin transistors transfer data in lower speed and volume, using the electron spin direction to be high or low, or how the superconductivity, which is the key to the future supercomputers, solve the problem of supercomputers power consumption using technologies such as RSFQ.

**Keywords:** Quantum supercomputers, Spin transistors, Superconductivity, Josephson junction

## 1. INTRODUCTION

Quantum computer is a machine that uses the phenomena and laws of quantum mechanics such as superposition (it means: the created final answer, from the effects set of all responses on each other, like the effect of waves on each other), interconnectedness, or tunneling for calculations; which is basically different from the current semiconductor transistor-based computers. The main idea behind these computers is that the properties and laws of quantum physics can be used to store and doing operations on data.

Although quantum computing is at the beginning of its way, few experiments have been done in which quantum computing is implemented on a small number of qubits. Theoretical and empirical research continues in this area and many government and military agencies support research in this area either for civilian purposes or for security ones (e.g. Cryptanalysis). If large-scale quantum computers are built, they can solve special issues faster.

In 1960, "Gordon Moore" stated that the power of computers doubles every two years. A major effort to increase power and speed, along with miniaturization of structures such as transistors has been made, to the extent that there are billions of transistors on a given CPU. After years of passing this roughly correct theory, a question arises that to what extent this miniaturization can be continued? Making small the transistors and integrating them cannot be continued forever, because the quantum effects such as electron tunneling occurs in nanometer scale.

Thus, for the first time in 1982, "Richard Feynman", the Nobelist, suggested that calculations should be entered from the digital world to a new world called the quantum world; which not only eliminates the problems and limitations of the past, but also adds new horizons to this collection.

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## 2. SPIN TRANSISTORS

Transistors that are sensitive to magnetism, which are known as spin transistors, originally released in 1990, and they are currently developing and improving in design. These transistors are built and designed based on the results of electron spin. Electron spin can exist in one of the states of “spin-up” or "spin-down" at any moment.

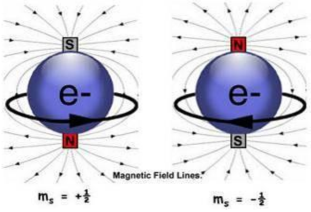

**Figure 1.** Electron Spin.

Unlike the former transistors like CMOS, which worked based on electric current, spin transistors operate at a more fundamental level to electrons and based on the state of the electron spin to store information. One of the characteristics of these transistors is that in addition to recognizing the state of the spin, they can change the direction of spin to up or down without electric current. This feature allows the hardware to detect. This hardware is much smaller, but much more efficient, than today's noisy devices, which requires a lot of time to exchange and store information. Ultimate potential are devices that store more data in less space, consume less power, and are made using less expensive materials and because the electric current is not the transfer factor of information, friction and heat is also dissipated.

The second advantage of this phenomenon is that the spin state of an electron is "semi-permanent and non-volatile"; it means that the spin maintains its previous status without having to spend energy; thus it enables transfer of information from a spin transistor to a given destination, e.g. a memory, and the problem of changing information on the path is removed. This characteristic has been investigated for the development of MRAM memory.

Since the spin transistors have great potential for the future modern computers, a lot of people and institutions, especially in Sweden and England, are studying the basic principles of quantum physics of electrons, spintronic newer materials, constructing equipments in nanometer scale, and integrating ISD instruments with microelectronic current.

Spin transistor is a device consisting of a carbon nano-tube which is connected to two magnetic electrodes and it can control spin orientation of the electrons by the gate. One of the electrodes, known as pinned ferromagnet, creates a constant field and the second electrode, known as free ferromagnet, will be able to determine the direction of electrons spin by creating a field in both directions.

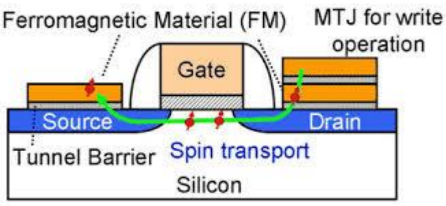

**Figure 2.** The spin transistor.

Polarized electrons are pushed to a device, such as memory, which is sensitive enough to get the spin. In this case the spin-up can be equal to logical one and the spin-down is equivalent to logical zero in the binary system; the result of all is the lack of electrical current and heat, lack of high power consumption, higher speed, and reducing the volume occupied by information. This technology is a window to the ultrafast and low-power computers in future.

## 3. SUPERCONDUCTORS, THE KEY TO THE FUTURE SUPERCOMPUTERS

Semiconductor based transistors dominant from the beginning of computer industry. While up to now the solution of higher speed has been to increase the number of active circuit elements, an unconventional option, that is superconductor, can even lead to decrease the number of transistors while increasing the circuit ability. Superconducting circuits with low resistance wires and very fast switches can do things that silicon-based systems do in more time.

All new designs with superconducting logic is emerging which is not only faster, but is dozens or hundreds of times more efficient than CMOS transistors in energy consumption, and these superconductive processors can provide necessary route for the next generation of computers.

Future computers, which are called Exaflops, can operate ($10^{18}$) in a second, which is about 1000 times faster than existing computers. This could not be imagined before superconductive technology, because recent estimates show that the construction of large-scale supercomputers using CMOS technology consumes about 500 megawatts, which is the output power of a modern nuclear power plant. The lack of electrical resistance and therefore lower power consumption is the success factor of superconducting computers.

“Eric de-Bendix”, from Sandia National Laboratory, says: “What the experts are trying to do is that they can make this fundamental change; a revolution that now is hoped to happen using superconductivity”.

It is a long time that superconducting circuits are an attractive option for very fast processors. At low temperatures, even close to absolute zero, the superconductor can operate in picoseconds less than micro watts. Simple logic superconducting circuits are used to operate at maximum speeds of 770 GHz. (For comparison, the fastest CPUs of Intel company were not more than 4.8 GHZ up to now)

But the speed of making integrated circuits by this technology is low. From 1990s, most of superconducting circuits were made using a scheme called Rapid Single Flux Quantum or RSFQ; which transfers the information bits in the form of voltage pulses, loaded with small vortex of speed flow.

RSFQ is used to build a number of certain devices required for numerical intensive applications with high-performance, such as communication receptors and signal processors (DSP). For it to compete with CMOS chips, still needs high power than superconducting logic ideals.

The high power consumption is due to the current distribution in gates having bias with resistance. To remove the bias resistance we can change the circuit power from DC to AC; it allows the transformers to be replaced by resistors, which reduces power consumption when the circuit is not doing calculations. In this case, the presence or absence of a pulse in certain time periods determines whether the bit is zero or one (depending on the parameters of the Josephson junction, pulses can be 1-10 picoseconds in the range of 2 mv).

You can send a pair of positive and negative peaks by using AC voltage, and the latter is used to adjust and coordinating of the circuit. This leads to the simplification of the Josephson junctions and reduces the number of logic gates. The results of this study are published by Grumman engineers in the Journal of Applied Physics.

Circuits which use new designs of superconductive quantum requires one-three hundredth of the power of advanced CMOS circuits. This estimate includes the power required for cooling the superconducting logic circuits.

New generation's RSFQs have advantages, disadvantages and applications, which in some cases include:

### 3.1. Advantages

- Compatibility with CMOS circuits, microwave and infrared technology
- Very fast operating frequency to several hundred GHz
- Low power consumption of about 100 thousand times less than CMOS
- Existing chip technology can be adapted for RSFQ
- High self-clocking performance in synchronous circuits

### 3.2. Disadvantages

- To achieve superconductivity, they require cryogenic cooling (which cryogenic liquids, such as liquid nitrogen or liquid helium are traditionally used. However, cryogenic refrigerators are designed with a high cost).
- A specific commercial software based on this technology is not yet developed enough.

### 3.3. Applications

- Optical network switching devices, digital processors, even radio signals
- Ultrafast routers
- Fast analog-to-digital converters
- Petaflops supercomputers

Researchers are also working on other projects, such as RQL. In comparison to RSFQ, logic RQL is a new kind of computational superconductors' logic which is designed to solve some of the previous logic problems such as the loss of magnetic scattering.

Thomas Theis, the planning director of IBM Company says: "Superconductor –based computers are a large and aggressive goal, but all revolutions do not occur simultaneously".

## 4. THE PROPERTIES OF TUNNELING AND JOSEPHSON JUNCTION

This characteristic means that if two superconductors are very close together, some of the current leak from one to another. There is no voltage at the end of the tunnel junction. It means that the amount of leakage current does not depend on the voltage, but is very sensitive to even very small amounts of field and magnetic flux. Superconductor performance in this area is somewhat like the semiconductor diode, in which two superconductors with a very thin layer of insulation can be connected instead of connecting two semiconductors of n-type and p-type. Josephson junction is widely used in the technology of manufacturing of measuring devices.

Josephson junction is a very fast switching and switching voltage is almost ten times faster than conventional semiconductor circuits, which is a distinct advantage to be used in computers. Because the computer speed depends on the transmission pulse of the equipment, the high speed of switching increases computer speed and reduces the size of computer.

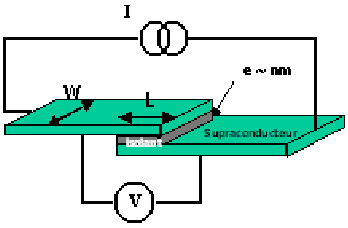

**Figure 3.** Josephson junction

The main use of this instrument as a key piece is in computer circuits. This junction is used as superconductivity transistor in electronic equipment. Switching speed in these transistors is much greater than the former ones and it could even be less than 2 picoseconds.

## 5. CONCLUSION

Faster computers are become a symbol of the struggle for power in countries and each country tries to make more powerful and faster supercomputers. On the other hand, modern quantum computers are nothing more than testing. Researchers can also bring a small number of quantum particles sequentially and these low durability structures can do relatively simple algorithms. But researches show that achieving more complex computers is not far reaching. While we are approaching to the end of CMOS-based electronics and electric current, quantum can be the key to the future supercomputers. In this context, any progress in issues such as high-temperature superconductivity, ultimately will lead to progress in this area. In this article we saw how superconductivity solved the problem of high power consumption without heating. Other approaches showed that if a set of Josephson junctions and inductors are used instead of bias with resistance, we can simply solve losing a lot of energy. The results showed that how the spin transistors multiplied processors speed by removing electric current and appealing to the magnetic flux of the circuit. Researchers are working on new designs and all efforts can be helpful in the structure of low-power, compact and ultrafast superconductive processors. While quantum logic focuses on processors, research on the other processing elements, especially memory, requires more development and more attention.

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