History of Electronics

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Abstract

In this paper the history of electronics has been represented in a chronological order along with the discoverer/inventor, who actually is responsible for that. The effects of electronics on the contemporary society are very significant and without the study of the effects the history is incomplete. Thus the effects on the economy, computing and the society as a whole have been studied. In this paper the discovery of the transistor has been considered as the backbone of the development of electronics, but the pre-conditions which lead to the transistor era and the after effects also have been considered in detail.

Introduction

How old is the electronics? Who can say? How can we say that when the electronics started? The answer is very difficult.

As long as the memory goes back we can say that in Greek and Indian mythology the people having extraordinary power were able to send message very quickly. So, what was the basis of that technology? Were they using any kind of wireless devices, whose components are electronic as today's wireless devices. What ever it may be there is no clear idea of those technologies or no proof that whether they were using those things.

In the 21^{st} century we are enjoying well developed electronics. In some form or the other everyday we deal with the electronic devices several times. So why we are interested to look at the past? Because it is required. Like the history of a nation from which its people get inspired (or learn something from their past faults) the history of any science inspires its future generations. Even more than that those who spent their whole life for the inventions/discoveries, they did not do that for themselves rather they did it for the whole society, the whole world. So we should tribute them. This electronic world was not just the effort of some years or decades, rather it is the result of the hard work of great minds since ages. So now it is the time to remember them.

In the coming sections the whole scenario of the development of the electronics in the whole world have been looked at in a chronological order. Also their effects on the contemporary society and economy have been analysed.

Electronics before Twentieth Century

Now let us divide the history of electronics into two broad categories. That can be done on the basis of development of the electronic technology and its use in the in the day to day life. Before the 20^{th} century there was a little or almost no electronics in the day to day life of a common man. So, the time before 20^{th} century can be taken as the pre-developmental era in the growth of electronic technology. So, we should start from the very beginning of electrical engineering, which is regarded as the parent of electronics. The formal beginning of electrical engineering goes back to 18^{th} century when Franklin gave the explanation to the cause of thunder and **lighting**. It was a big mystery at that time. But, the lucid explanation of Franklin gave the first idea of charge flow and its consequence.

Though the concept of charge was there before Coulomb there was no formal mathematical theory to explain the concept. So Coulomb’s theory was regarded as the first mathematical expression that defined the electrical charge in a well defined manner. He also invented the torsion balance and that helped him to calculate the force of interaction between the electrical charges, which is today known as **Coulomb force** after his name.

There after the next big name was Luigi Galvani who discovered the so called bio-electricity from his famous **experiment using the frog leg**. He thought that electricity as one of the sources of life. That created some ideas that electricity is related to life at that time. But, anyway his famous frog leg experiment gave some solid basis to the future researchers to develop the concept of potential difference.

The mystery of the frog-leg experiment was disclosed by Alessandro Volta. He repeated Galvani’s frog leg experiment using various types of electrodes. There after he concluded that the spark in the frog-leg experiment is not due to the frog rather it has a different reason. He told that when the copper and zinc electrodes are kept in the acid there arises some potential difference between the electrodes and the charges flow from one electrode to the there if there is any physical connection between them through some conducting wire. That was the first electric cell mad by Volta. After his name the potential difference is also known as **Voltage**.

The strangest and the most effective thing in the history of electrical engineering is the merging of magnetism with the electricity which gives rise to the one of the most fundamental interactions of nature known as the electromagnetic interaction. But it happened quite late in 1820 when Oersted found that the needle of a compass is deflected when kept near a current carrying conductor. So from that observation he concluded that the magnetism of a compass is affected by current. There after magnetism is considered as an aspect of **electromagnetism**, not as a different entity. Ampere proved the relationship using algebra. Gauss also gave the alternative forms of mathematical equations to explain electricity and magnetism. Those works of Gauss are known as Gauss theorems.

But it was not known why some energy in the form of potential difference is required to make the charges flow from one end to the other. The explanation came from the German scholar George Simon Ohm. He for the first time introduced the concept of **resistance** and conductance. In almost all the conductors there is some resistance that opposes the flow of current through them. That's why the charges cannot flow in the conductors without the presence of any energy source in the form of potential difference. Then it was proved that potential difference is very important to keep the charges moving from one end to the other in a conductor. Potential differences can be created in various ways. At that time the chemical cells were the main sources of electricity.

In the next phase started the real victory of the electrical engineering under the leadership Michel Faraday. He not only gave birth to some interesting theories, but himself invented some fundamental electrical machines like the transformer and electric motors. Faraday was a poor child who had always aims to do something big in the scientific research. He got the opportunity from the then big name Humphrey Davy. After that Faraday had never looked back. He gave many fundamental theories which are like the back bone to the electrical sciences. His concept of **lines of forces** was not accepted by the then scientific community, but was later found to be the fundamental fact of electromagnetism. He first gave the knowledge of electrical power generation and made the first transformer of the world. But it was a bit strange that he himself did not have the idea that his discoveries will some day change the science of the world. **Faraday's laws of electrolysis** were beneficial to both the chemists and physicists of that time. That also was a fundamental tool to prove that the electric charges are quantised. He also gave the concept of inductance, which was also developed by another great of that time, Joseph Henry. Lenz was there to modify faraday's second law of induction. So the electrical engineering was unstoppable and running really fast to be the most attractive science at that time.

Faraday's law was not accepted by many of his contemporaries because the nature of the lines of forces he described did not sound satisfactory to many at that time, but there was another genius to understand and explain it quite lucidly. He supported Faraday and combined all the mathematical equations available at that time to systematise the electrical science. Not only that, he also gave some other stunning theories that changed the science there after. He was none other than Maxwell. **Maxwell's equation** is today fundamental to all theory of electrical machinery and communication sciences. It has used in every field more or less. His theories are one or the best scientific achievements of the world for ever. He unified the optics as a part of the whole electromagnetism. After Maxwell it was just the matter of time to invent the electrical machines and communication devices to deliver the service to the mankind and to take the civilisation in the road of science and technology.

The first achievement after Maxwell's theory was the invention of the electric bulbs by another genius Thomas Edison. The lighted the world by his electric bulbs. He invented numerous electrical devices and contributed the most to the consumer electrics. He was mainly using DC and was the greatest advocate of the use of DC. But one of his contemporaries Nicola Tesla had something different in his mind. He used his brain to make AC popular. He invented the **induction motor** and proved that AC can be used more efficiently than DC. After some years with the help of Westinghouse he took the tender of the Niagara Project and started generating AC. Another big thing had happened at the same time while Edison was trying to light an electric bulb. That was the "**Edison effect**" or the thermoionic effect. Edison found that in a closed environment even without the physical contact of wires there exist a small current through them when they are heated to a sufficiently high temperature.

By the same time there was a great need to reduce the distance of the various parts of the world by means of some communication technology. Alexandra Graham Bell opened the account by inventing the **telephone**. At around the same time the telegraphic communication using the **Morse code** was very popular. That was even used for the transatlantic communications. But the main breakthrough, which mesmerised the communication science, came when the German physicist Henry Hertz discovered the **radio waves** and also gave the methods to transmit and detect them. Then started a new chapter in the communication technology area. Not far than a decade after that the Russian scientist Popov and the Italian electrical engineer Marconi invented the **radio** and used **antennas** for radio communications. The electronics had its identity in the world, but without the presence of its principal components.

Electronics of Early 20th Century

Electronics in the early 20th century started thriving at a greater speed unlike the pre-20th century developments. From the starting itself the electronics got its special recognition. The radio invented by the Italian genius Marconi and the work of Henry Hertz opened the road to further discoveries and inventions. In the first decade the new thing that was welcomed to the technical world was the vacuum tube. The vacuum tubes at that time worked as a miraculous component for the radio devices.

Marconi's radio needs some good detectors for the receiving of the incoming radio waves. For that reason a good rectifier was needed which can convert the AC into DC. There were already many AC generating stations and AC was getting very popular. So, the engineers were planning to change the AC into DC instead of producing the expensive DC. The duo of Tesla and Westinghouse brought many exciting features to the AC at that time. The invention of the induction motor by Tesla was a revolution in the use of AC.

Someone brings the breakthrough when all the great minds are in need. That happened again. The then famous English physicist Fleming found an alternative to the DC production. He invented the first vacuum tube using the principle known as "**Edison Effect**". According to the Edison Effect when there is a small separation in between the two conductors connected to a source of electricity and are heated then there can be a current in the conductor. That means the vacuum in between the conductors becomes a good carrier. That idea was actually in the brain of Sir Ambrose Fleming. So, he tried to do something which can demonstrate the Edison Effect. But when he tested his newly invented device he was happy to find that it can work as a rectifier, means which can change the AC into DC. History was created. This was the real birth of electronics. Here starts a new chapter in the history of human being. At that time Marconi's radio was badly needing some good detectors. This vacuum tube filled that need. It has two electrodes and that's why it was named as **diode**. It was the first diode and the main motivation behind the solid state devices which after some decades take control of the whole world economics. Just after two years of Fleming's diode DeFrost in the US invented another similar device which was named as **triode**, because it had three electrodes. Besides the anode and cathode there was an extra electrode known as grid. The grid was controlling the flow of charges from the anode to the cathode. It was wonderful that triode had the characteristics of an amplifier. So it helped a lot in the growth of the communication at that time. Because the amplifier was an important component in the radio and other communication devices to strengthen the weak radio signals.

A revolution in the whole science came when Einstein proposed his historic theory of relativity. But no one was ready to accept his theory at that time. But the work of J J Thomson and Rutherford opened the secrets of the atoms and its sub-particles. Max Plank and Niels Bohr provide the further explanation to the atomic theory. Einstein himself came with his big version known as the general theory of relativity. He was not bothered about the critics. He himself saved the corpuscular theory of light from death and opened the road to the **quantum theory**. It was not far to bring the quantum theory into light after Einstein's Nobel winning **photo-electric effect**. Louis De Broglie, Heisenberg, Schrödinger and Dirac proved the reality of the quantum theory. So the research in the scientific community got a great speed.

The **computers** were another main attraction at that time. Due to the world wars there was a big need of computers for war related tasks like code breaking. During the first and second world war some computers were made for this purpose. But they were not that efficient as many of them were using decimal systems and all the prime components were made up of vacuum tubes.

The invention of the **television** was a miraculous thing for the mankind. It was revolution in both communication technology and also for the world media. The distances between the continents did not seem to be far enough. People were able to watch the distant things from there home. The entertainment industry got new life. The popular artists through out the world become well known and got a huge recognition. The credit goes to the British engineer John Logie Baird who followed the foot prints of Marconi and tried to send the images in the same way as the speech. After a long experiment he found that a series of static pictures if sent within a small interval of time in between them, seem to be moving. This move was successful after a number of trails.

Then came the Second World War and the scientists were busy in war related research and the attention from the general research was withdrawn. But the war technology also helped a lot in the future.

Discovery of the transistor Effect

The diode valves of the early twentieth century were large enough to be inside the electronic devices and they had many other problems like high power consumption, low reliability and the requirement of good cooling arrangements etc. So the electrical engineers and physicists at that time tried for the development of some alternatives which can fill up the place of troublesome vacuum tube in case of both the detectors and amplifiers. At that time the physics of solids were also on its way to bloom. Many theories like the Fermi-Dirac equations had opened the wide scale research on the solids. In Bell labs the scientists were desperately looking for some alternative to the vacuum diodes and triodes for the communication technology.

After the end of the horrible WW2 the whole world took some rest. But the scientific community who were working in the war forcefully or by the motivation of the country's top leaders did not rest. Rather they started their original intended works at their previous work places. The scenario in the US was also not much different. After the war the economy was weak. So the industrial research was mainly focused on the economic development. Bell labs too took some leading in the development of the communication sciences. The research group in the Bell Labs found that the existing technology and the devices for better communication were not available at that time. So their main concern was to find some alternative for the existing amplifiers. The valve amplifiers were the main obstacle in the road of progress. So, they looked for some solid state devices. The findings of Russell Ohl had confirmed that the pure silicon when doped with some impurities of tri and penta-valent materials can be used as two layers of a **PN junction diode**. They had some foresights that, the junction phenomenon may be used for the building of a new amplifier. The group led by William Shockley was investigating these facts. Other team members were Morgan, Bardeen, Brattain, Gibney, Moore and Pearson.

Fortune favours the brave. The auspicious day came and the science started growing at an exponential rate there after. Thanks to the genius of the three young scientists of the Bell labs. They found a new concept known as "**Transistor effect**". It was for the first time discovered by Bardeen and Brattain. That is known as **point contact transistor**. That was mainly contributed by Brattain and Bardeen, who thought that the effects are mainly due to some surface phenomenon. But Shockley was not dormant. He too was working hard on something different, which is today known as **n-p-n transistor**. He gave the theory that the transistor effect was due to some bulk phenomenon. After that he worked hard on the semiconductor theories and gave a satisfactory explanation to the transistor effect. His book "**Electrons and Holes in Semiconductors**" is a popular book today as well. Despite these two available models of transistor there were some other problems which were barriers in the production of transistors in large scale.

The Endless Journey after Transistor

The real electronics what it is called today was actually started after the discovery of the transistor effect**.** Transistor opened the road for the electronics and there after electronics got its independent identity in electrical engineering. More importantly it opened the road for the computing world. Computers of various types started hitting the market and the research works got a boost.

Some other problems were also there like the assembling of the electronic components on a single mother board. It was worsened when the metallic contacts cross each other and crowded the mother board. Jack Kilby in Texas Instruments found a very nice solution. He suggested to throw away all the wires and tried to connect the resistors, capacitors and transistors on the same piece of wafer internally. Surprisingly his ideas worked and gave birth to the **Integrated Circuit** industries. At around the same time Shockley had left Bell Labs and started his own company in California, whose name was Shockley Semiconductor. Some other brilliant young researchers also joined his company there. Among them who are famous today are Gordon Moore, Robert Noyce and Jean Hoerni. Robert Noyce also did many contributions to the IC technology by joining the Fairchild Company and the Fairchild Semiconductor was born. By the efforts of both Noyce and Kilby the IC industry became very popular and looked forward for its next successor, the microprocessor. Another history was being made in the USSR at the same time. The first artificial satellite **Sputnik** was sent to the space. There was a big demand for the better electronic components for the control and performance of the satellite and other electrical devices like the big motors and generators. Huge demand of transistors and ICs revolutionised the electronics industry at that time. A new type of transistor was invented in early sixties, which is known as **MOSFET**. MOSFET is slower than the junction transistor but it is smaller, chipper and consumes less power.

In 1965 Gordon Moore came out with an awesome paper called "**Cramming more Components onto Integrated Circuits**". In that paper he described that the number of transistors used on a singe chip of silicon will grow exponentially. In 1968 Rob Noyce and Moore left Fairchild to start Intel, both of whom were very popular already in the field of microelectronics. In 1971 their company invented the first **microprocessor** well known as **4004** having 2300 transistors on one silicon chip. The credit mainly goes to the young engineer Ted Hoff. While working on a Japanese project he found some problems with integrated circuits and planned to have even larger integrated circuits which can have the whole computer on a single chip. That microprocessor led the way to the successors like the 8080, 8085, 80486, Pentium series and the most modern processors like the Xeon too.

The Effect on Computing

One of the most important and admirable creation of the 20^{th} century scientists was the invention of computer. That's why many say that 20^{th} century is the century of computers. The needs of computers were at peak during the WWII. In Britain the German-code breaking project was being done by **Colossus**, one of the early computers. At the same time another general purpose programmable computer was being used in Harvard University which was built with help of IBM. The main aim was to break the security codes of the enemy. Keeping this in mind the **ENIAC** was invented in the University of Pennsylvania at Philadelphia. It was a huge computer of 30 tonnes, was fairly fast and having many vacuum diodes and triodes in the operation. It had covered some rooms and many of its parts were mechanical. The discovery of the transistor effect gave birth to new ideas for new computers. They are popularly known as second generation computers. The efforts of Jack Kilby and Rob Noyce gave birth to the third generation computers, which used the ICs and the companies like IBM started the mainframe machines having more storage capacity and faster speed.

After the invention of the first microprocessor 4004 in 1971 in Intel everyone in the microelectronic industries thought that microprocessors can help in the rapid growth of computers. They started many new projects in inventing new microprocessors and the **forth generation of computers** started. The first personal computer built was the **Altair 8800** of MITS which came around 1975. At the same time Apple computer was started and the first Apple machines hit the market in 1976.

Many companies now got ready to provide computers at the household level. Among them the front runners were **IBM and Apple**. In parallel to the development in the hardware the software industry was also blooming. There ware many operating systems and computer languages at the starting of 70s. The most popular languages were FORTRAN, COBOL and PASCAL etc. But the **C language** by Dennis Ritchie found to be very helpful in system programming. Even today C has that dominance. In the early eighties the most popular **OOP** technology was started with the birth of C++. Of course some object oriented features were present in some other languages like Ada, Smalltalk and FORTRAN. At the end of the nineties the new technologies like the Java helped a lot in the development of the web. Then the scenario was stolen by software companies like the **Microsoft** and **Oracle** who made the computing very popular and the computers no more remained a tool of the scientific community.

At the same time there was a huge demand for the time limited tasks, which were nearly impossible by the general computers. So the faster computers or the supercomputers were in the mind of many scientists. Among them the front runner was Seymour Cray, who started the supercomputer industry form his **Cray series**. Unlike the general computers the super computers were using a large number of parallel processors and high speed logics like the **ECL**.

The Effect on Economy

Transistor mesmerised almost everything, including the economy of the 20th century. The economy of the world after the WWII was very weak. Even some rich countries lost a lot in the war. The richest country after the war was Britain followed by Argentina. The GDP of the countries at that time was some billions. The GDP of the whole world at that time was also not that high.

Like the **Moore's law** there is another basic law, which was found from the economy of the chip electronics. It is known as **7/10 cost law**. According to this law the advances in the microelectronic designs has led the prices of the similar chips to be reduced at 30% each year. That means if the price of a chip is 10£ this year it will be 7£ next year, having the same features and functionality. Of course this is possible only due to Moore's law by which the number of transistors per chip is doubling each year.

The economic press had never listened about trillion dollars in the market and it is in doubt that had the transistor effect not been discovered the trillion dollar would have been a dream today too. The electronic industry is worth around $350 billions as far as the hardware markets are concerned. If we will add the consumer electronics then it is of $1.2 trillion. But if we will take all the effects of electronics then everyone will be astonished because almost all the sectors are dependent on electronics. From communication to education, from medical to transportation, from entertainment to adventures and economics everywhere electronics is the main tool behind the development. So simply we can say that electronics is just priceless to the human society today.

Effect on Other Sciences

The effect of electronics is not absent in other branches of sciences. In parallel to the development in electronics they too developed at the same rate. In biology the invention of **electron microscope** was a great break through. Similarly the electronic version of other measuring devices gave a better accuracy and precision. The technologies like the **Optical NMR** gave a new direction to the bio-research. With the development of the sophisticated electronic components the **control systems** of industries, automobiles and big machines were made very robust. The aviation industry, entertainment industry and the manufacturing industries were the front runners and now at their all time best. More or less the world in every sector was changed by electronics.

The Effect on the Whole World

There was a global effect on the population of the whole world and everything seemed to be different after the transistor. The first thing which changed the daily life was communication. With the help of the transistors the distance between the remote places became less. The growth of radios and TVs gave ample entertainment to the public world wide. The electronic press became very dynamic. The list is endless.

Electronics till Date

If we shall consider yesterday as history then there are many things which can be put in history each day. That is due to the rapid growth in the IT industry, its concerned global market and the ultra fast research and development through out the world. Thus while considering the history of electronics we should take some time boundary to consider which is history and which is not. In this case let us take the things of the early nineties as history.

So in this section the most famous inventions of the early nineties and late eighties have been considered. The **domain name system** and **http** were already in use just after their birth, but still the networking of the computers was not that spread. Only some universities of the US and Europe were connected to each other and that was mainly for the research purpose. At that time in CERN many researcher of the whole world were doing some research on the high energy physics. They were using their own system for their own research. So, a lot of varieties of computers were really a problem to share the research data. One of those researchers thought of the interconnection of the computers to form a common network. He tried it using the existing protocols like the http, ftp, and DNS etc. In addition to that he added a new framework which is now popularly known as **WWW** or the World Wide Web. The internet was born. The whole knowledge banks of the world, the whole information regarding anything are just now clicks away. It became possible due to that great person Tim Berners-Lee.

Conclusion

The history of electronics is really a vast area and it is not possible to present the whole details of the systematic history in this limited scope. Anyway electronics which started as philosophy then physics then electrical engineering has now got its own identity and going to be even more diverse in the future. There is no doubt that the modern electronics as we see it today started from the birth of the vacuum diode of Sir Ambrose Fleming. On the centenary year we should remember that great man and both his predecessors and successors. The changes of 20th century are mainly due to electronics, there no doubt about it. All the systems today are almost electronic.

So at last it can be said that the history of electronics is as rich as the electronics itself. Through ages the developments in electronics have started. The future seems to be very bright. The new fields like the quantum communication and bioinformatics are going to be the leading areas of studies in the future which can take the human civilisation to a great high.

The history of electronics is widespread and cannot be described in a paper of limited words. This paper is just one of the bird's eye views on the history of electronics. Here it has been tried to include almost all the great works and the persons behind them. The discovery of the transistor effect has been considered as the development of the modern electronics. But the trail is mainly to find out what led to the discovery of the transistor and what its after effects are. Anyway it is great to remember the great minds on this occasion.

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