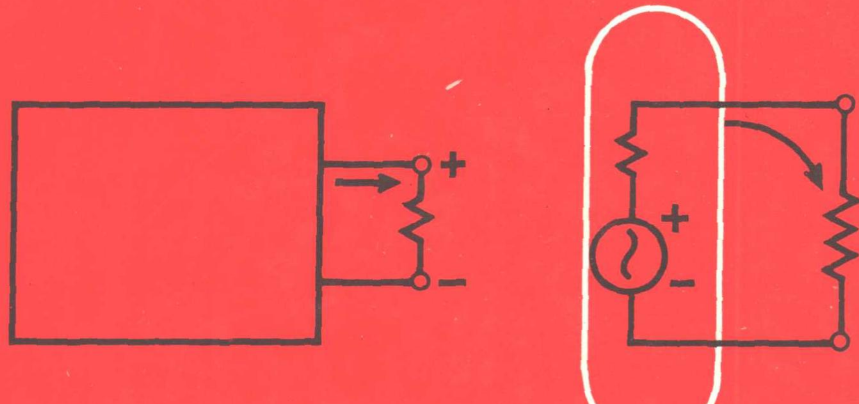
Electrical and Electronics Engineering for Scientists and Engineers



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Electrical and **Electronics Engineering** for Scientists and Engineers

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PREFACE

This book is written for everyone -students, scientists and engineers having an urge to understand the basic principles and applications of Electrical and Electronics Engineering. No prerequisite is required to understand the subject matter of this book. The fundamental concepts are presented in an easily understandable way. The text matter is presented in a simple, progressive and lucid manner.

This text may be separated into two parts, the Eectrical Engineering and the Electronics Engineering. Chapters 1-5 deal exclusively with the basic theory involved in Electrical Engineering and to understand Electronics Engineering which is covered in chapters 6-10. A good understanding of the digital electronics is required to understand the microprocessor and its applications as microprocessor is a Digital Machine. For this reason, therefore, digital electronics have been dealt with, fairly exhaustively.

Chapter 1 covers the history of electrical and electronics engineering, concepts of charge, potential etc, as also the types of resistors and their ratings. Concepts of non-linear and incremental resistance is also introduced.

Chapter 2 explains the current and voltage sources with practical examples. Concepts ;of open circuit and short circuit, ratings of dc machines and batteries are introduced.

Chapter 3 presents the network theorems with a brief introduction of bridges for the measurement of non-electrical quantities.

Chapter 4 introduces the concepts of inductance and capacitance in terms of field theory. Circuit response is also explained.

Chapter 5 details the need for generation, transmission and distribution of ac voltage. The phases are introduced. Resonance circuits as also the maximum power transfer theorem is also considered.

Chapter 6 continues with the material physics, transister model, SCRs and UJTs along with applications.

Chapter 7 covers the aspects about operational amplifiers, their necessity and applications.

Chapter 8 details the number system, Boolean Algebra, concepts of Fan-in and Fan-out, various types of Flip-Flops, application of these for counters and realization of logical functions using commercially available ICs.

Chapter 9 gives an overview of computer concepts wherein the basics of architecture, Hex notation, I/O devices, VDUs, Printers, RAMs, ROMs and mode of connecting them for various purposes is explained.

Chapter 10 introduces to student to the wonder world of microprocessors. A typical microprocessor 8085 is introduced. Architecture, Addressing modes are explained. Instruction set is discussed. Minimal system is presented. Several examples are solved using the method of flow-charting. Use and interfacing of 8155, 8156, 8355 is explained in detail. Concepts of use of stacks, subroutines and interrupts are also introduced.

During the preparation of the text book, many people have helped produce this book. **Mr. M.K. Venkatesha**, Assistant. Professor, Department of Electronics and Communication Engineering Malnad College of Engineering, Hassan, provided a great deal of assistance in the preparation of the manuscript and proof reading of the type set version; and we are pleased to express him our most sincere thanks. **Mr. H.T. Kumar's** skillful typing of the manuscript is highly appreciated.

K.A. KRISHNAMURTHY
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Chapter 1

FUNDAMENTAL CONCEPTS

1.1 A BRIEF HISTORY OF ELECTRICAL ENGINEERING

Although scientific progress and the birth of electrical engineering can be traced back to events occurring in the sixteenth century, one of man's earliest engineering achievements probably occurred around 2600 BC. At about this time lodestone was discovered; devices constructed using this natural ore exploited its magnetic properties. Many investigators were fascinated with lodestone and over the years numerous experiments were conducted with it. However, it was only in 1269 that the first device of practical value viz. the magnetic compass, was constructed.

The discovery of the compass stimulated interest in magnetism and Gilbert who did considerable research in electricity and magnetism published his findings in 1600. Gilbert regarded the earth as a huge magnet and explained the behaviour of the compass on this basis. From his experiments concerning static electrification, Gilbert compiled a long list of materials that could be electrified by friction. He was the first person to use the term electricity but was not the first person to observe frictional electrification. That credit goes to the ancient Greeks and was observed by Thales in 600 BC.

There followed a considerable lapse of time until Otto Von Guericke, in 1660, discovered the first machine to produce electricity derived from friction. With this machine Von Guericke observed many electrostatic phenomenon and also succeeded in transmitting the charge developed by the machine, over a small distance, by using packing thread. In 1729 Gray discovered that some substances were conductors while others were insulators. He may have been the first one to use metallic wires as conductors. In 1745 the Leyden jar was discovered. In its refined version it consisted of a bottle partly filled with water; a metal rod was suspended above water level and held in place at the neck by a cork. The outer sides of the bottle were covered with silver leaf. The jar was capable of storing large quantities of electricity generated by the electrostatic machines of the day and very soon the Leyden jar became a popular research tool.

In 1745 Benjamin Franklin demonstrated the electrical origin of lightning by charging a Leyden jar from the string attached to a kite which was flown during a thunderstorm. From his research experiments he concluded that there is one kind of electricity and that all bodies contain it; when two dissimilar substances are rubbed together one receives an excess of electricity while the other loses an equivalent amount. He even spoke of positive and negative electricity and conducted innovative experiments in which positive and negative electricity neutralized each other. Franklin also designed a rotating device which operated on electrostatic principles.

At about this time, the first inventions took place in the field of measurement. The gold leaf electroscope and the torsion balance were discovered. The latter was used by Coloumb in 1784 to arrive at his law of electric force.

Upto this point all electricity was produced by friction or induction; the observed currents were therefore transient and resulted from the expenditure of stored energy. The discovery of Volta's pile in 1792, however, changed this concept. Soon powerful batteries were invented. It was then thought that there were two kinds of electricity. One was called voltaic and with it were associated heating and chemical effects. The other was called common, i.e., the one derived from electrostatic machines, and with it were associated electrostatic effects such as sparks, etc.

In 1806 Davy proved the chemical nature of the voltaic cell. The great discoveries of Oerstd, Ampere and Biot and Savart followed in 1820. The former two researchers discovered forces exerted on current carrying conductors by magnetic fields. Biot and Savart announced the law of force exerted on a straight current carrying conductor by a magnetic field.

Their work was followed by that of Faraday who demonstrated the principle of electromagnetism, electromagnetic induction and energy conversion. His findings were presented by him in the form of a paper to the Royal Society in 1831. Joseph Henry, Faraday's contemporary, discovered self induction and the principle of the transformer. He also designed and built an electromagnet.

The discoveries of Faraday, Oerstd, and Henry are of great significance because they made possible the design and construction of dc machines.

In the following years many significant developments took place. Measuring and calculating instruments such as the galvanometer, planimeter and the slide rule were invented. The new measuring instruments made possible the verification of old laws and the establishment of new ones. In 1833 the first mechanical computer was designed by Charles Babbage. It had four basic parts which Babbage named as the store, the mill (where calculations were performed), a part which transferred information from the store to the mill and an output. Although Babbage devoted considerable time towards the construction of the device, it was never completed. Babbage also introduced the idea of punched cards for storing information. However he did not follow up on his idea. Meanwhile, the fundamental work of Ampere, Faraday and Henry led to other important inventions. Samuel Morse invented the electric telegraph and demonstrated it in 1837. In 1858 the first direct current generator was constructed and when the incandescent lamp was discovered by Edison in 1880, electric lighting was made possible. In 1875 Alexander Graham Bell invented the telephone.

Considerable progress was also achieved regarding theoretical aspects during this period. In 1839, Gauss and Weber proposed a system of electric and magnetic units. Their fundamental work was followed by those of Heaviside (1882), Lorentz (1894) and Giorgi (1901). In 1845 Kirchoff stated his circuit theory laws and in 1873 Maxwell formulated his equations which introduced the concept of electric and magnetic fields.

The engineers and researchers at this time knew of alternating current and its method of generation. However, they were in favour of direct current as they felt that direct current had many advantages to offer. Besides, the alternating current motor had not been invented yet. The construction of transformers enabled the introduction of alternating current as it was realized that voltages could be stepped up or down easily. The transformer was not a new invention; both Faraday and Henry had used it earlier in their experiments. The first commercial transformer was built in 1886 and was followed by the first large scale ac installation in Buffalo in the same year. Alternating current generators evolved from direct current generators and operated at a frequency of 133 Hz. With the discovery of the induction motor by Tesla in 1888, such high frequencies were found unsuitable and discarded in favour of frequencies of 25, 50 and 60 Hz. In 1895 the first ac installation which converted the energy associated with a head of water into electrical energy in the form of 25 Hz ac was completed in Niagara falls. Soon transmission lines followed. At this time there were no standards. Single, two and three phase systems were in operation at frequencies ranging from 25 to 60 Hz. With the passage of time the use of direct current disappeared, and voltage and frequency standards were adopted.

During the year 1860-1900, other important developments took place. In 1878 Crooke revealed the results of experiments conducted with what is now known as the Crooke's tube. Crooke's fundamental work led to the discovery of the oscilloscope, radio tubes, X-rays etc. In 1880 Hollerith conceived of the idea of using punched cards to expedite and facilitate handling of information. His system was subsequently put into use in the 1890 census. Computer development was aided by the invention of tabulating machines which used punched cards. In 1887 Hertz demonstrated the existence of electromagnetic waves and in 1895, Marconi developed the first wireless telegraph. The origin of television can be traced to some experiments conducted with selenium cells in 1891. In 1898 steel wire was used as a memory device. Telephone messages were recorded along a length of steel wire in the form of magnetization whose variation corresponded to variations in telephone current.

Edison's experiments led to the discovery of the Fleming valve in 1904 and the triode in 1906. These discoveries revolutionized the field of electronics and during the first world war great developments were made but kept secret. After the war the communication industry developed at a fast pace. In 1924 the Western Union Telegraph Company introduced wireless picture services. Modern T.V. had its beginnings during this time with invention of the electronic scanner. Various improvements followed and standards pertaining to television were formulated in 1941.

Meanwhile, on the theoretical side Thomson and Millikan in 1906, found the mass of an electron and the charge associated with it. The period 1900-1940 witnessed tremendous progress in atomic physics. It was in this era that Einstein stated his theory of relativity and the hypothesis governing the interchangeability of matter and energy.

During the second world war the research effort led to the invention of radar. This spurred the development of electronic equipment suitable for use at the higher frequencies. In 1947, microwave communication found its peace time use.

In 1945 the first electronic computer was built at the Massachusetts Institute of Technology. This was the first machine to use the binary system. The magnetic tape recording was first introduced in the thirties and was followed by magnetic cores as a memory device for use in computers in 1950.

The evolution of the Transistor, in the fifties, to a reliable form enabled their use in a host of electronic devices including computers. The transistor in turn led to the development, in the sixties, of integrated circuits in which entire circuits are etched on tiny chips. The development of integrated circuits must be considered as being as revolutionary in its impact on electrical engineering and society as the invention of the Fleming valve in 1904. The design of integrated circuits has given birth to a whole new field of electronics called micro electronics. Integrated circuits have made it possible to reduce the size and cost of electrical systems and devices and at the same time increase their reliability and sophistication. Computer development is progressing rapidly due to advances made in integrated circuit design. In 1971 the microprocessor was introduced which has revolutionized the fields of measurement, data handling and control. Microprocessors are also finding applications in a host of devices ranging from scientific instruments to consumer oriented devices.

1.2 PLAN OF THE BOOK

From the brief historical review we see that Electrical Engineering had its beginning in the discovery of static electrification and electric charge. We will begin the book by considering the electrical nature of matter and the concept of electric charge. In what follows, the student will be introduced to the fundamental laws of electrical engineering and the basic tools necessary for the solution of electric circuits. The concept of alternating current will be introduced next and solution techniques applicable to alternating current circuits will be explained. While the first four chapters deal essentially with circuit theory the next two deal with modern semiconductor devices and their applications. The book ends, like the historical perspective with a consideration of microprocessors and their applications.

1.3 THE CONCEPT OF ELECTRIC CHARGE

Most of us are familiar with the classification of materials under two categories, conductors and insulators. For example, copper and aluminium are good conductors of electricity and are used in the manufacture of electric wires and cables which are insulated with rubber, polyethylene and other good insulators. What is it that is responsible for some materials being good conductors or insulators? The answer may be found by examining the atomic structure of matter. A detailed analysis and explanation is not intended here and is beyond the scope of this text. Rather, a cursory explanation will be afforded.

All matter is known to be composed of atoms whose mass, concentrated at its center, is called the nucleus and is composed of protons and neutrons. The protons and the neutrons are of nearly equal mass, i.e., about 1.67×10^{-27}kg each. The nucleus of diameter $\approx 10^{-14}$m is surrounded by electrons which may be imagined to be moving around the nucleus in elliptic orbits. The electron orbits determine the size of the atom and have diameters which are roughly ten thousand times that of the nucleus. In contrast with the mass of the nucleus, that of the electron is much smaller and is $\approx 9.1 \times 10^{-31}$kg.

The student is no doubt familiar with the laws of mechanics and in particular, Newtons law of gravitation. According to this law the force of attraction between two masses is directly proportional to the product of their masses and inversely proportional to the square of the distance separating them. Thus,

$$F = K \frac{m_1 m_2}{r^2}$$

where K is known as the gravitational constant. Equation 1.1 may be used to calculate the forces between the three particles, the neutron, proton and the electron. If the results of this calculation are compared with experimental findings, it is found that the measured forces are much larger; in some cases the forces are one of repulsion instead of attraction.

Scientists therefore concluded that there was another property associated with the particles. This property is called electric charge. The proton is associated with a positive charge and is equal in magnitude to the negative charge possessed by an electron. The neutrons bear no electric charge. As matter, on the whole, is electrically neutral, the total charge of all the electrons must be equal to that of all protons. The charges exert forces on one another, but unlike the forces of gravitation, the electric forces may be either of repulsion or attraction. Like charges repel whereas unlike charges exert force of attraction on one another.

The electrons, imagined to be in orbital motion around the nucleus are therefore subject to an attractive electric force towards the nucleus in analogous fashion to the forces on the planets directed towards the sun in our solar system. However, rigorous wave mechanical considerations dictate that the electron orbits are not clearly defined. An atomic model of matter, consisting of a nucleus and electrons with well defined orbits is only a rough approximation.

1.4 ENERGY BAND STRUCTURE OF SOLIDS: METALS, SEMICONDUCTORS AND INSULATORS

Let us consider an isolated atom and accept, for simplicity, that the electrons are in motion around the nucleus in well defined orbits. This is in fact the Bohr model. The electrons closer to the nucleus possess lower energies than those farther from it (very much like a mass m possesses greater energy the higher it is above the earth's surface). Thus, each electron is associated with an energy level; between energy levels, gaps exist which electrons are not allowed to occupy. The outermost electrons of each atoms are able to interact with neighbouring atoms and participate in chemical bonds.

What happens when many atoms are brought close together as in a solid? The electrons of an atom are now subject to electric forces of other atoms. This effect is most pronounced in the case of the outermost electrons. Due to these electric forces, the energy levels of all electrons are changed. Some electrons gain energy while others suffer a loss. The energies of the outermost electrons undergo the greatest change. Thus, the energy levels, which were sharply defined in an isolated atom, are now broadened into energy bands. Each band consists of large number of closely packed energy levels. It so happens that, in general, two bands result. One is known as the conduction band and the other the valence band with the former band being associated with higher energy level. These two bands are separated by a region known as the forbidden energy gap. Each material has its own band structure. Differences in the band structure may be used to explain the behaviour of metals, semiconductors and insulators.

Metals : In metals the valence and conduction bands are very close together or may even overlap, i.e., there is no forbidden gap. By receiving a small amount of energy from external thermal or electric sources the electrons readily ascend to higher levels in the conduction band and are available to move through the metal. This movement of electrons is really one of negative electrical charge and constitutes the flow of electric current. In metals the density of electrons in the conduction band is quite high. Consequently metals are good conductors of electricity.

Semiconductors: The two bands are separated by a forbidden gap of sufficient width; at low temperatures no electrons possess sufficient energy to occupy the conduction band and therefore, no movement of charge is possible, i.e., no currents can flow. At modest temperatures, however, it is possible for some electrons to gain sufficient energy and make the transition into the conduction band. At room temperatures the electron density is not as high as in metals and as such, semiconductors can not conduct electric current as readily as metals.

There is another class of semiconductors, containing impurities which are deliberately introduced, known as impurity semiconductors. The impurity atoms account for additional energy levels lying in between the valence and conduction bands and are able to supply electrons into the conduction band by temperature induced motion.

Insulators: In such materials the forbidden gap is very large. As a result, the energies required by the electron to crossover into the conduction band are impractically large. Thus under normal circumstances, such substances can not conduct electric current.

Fig. 1.1 shows schematically the energy band structure associated with metals, semiconductors and insulators.

We have seen that the flow of electric current is associated with the movement of electric charge; in metals it is due to that of electrons. Electrons are not the only carriers of electric current. In chemical cells such as the lead acid cell, current is carried by ions* provided by the solution in the cell.

1.5 UNITS

In mechanics, three basic quantities, length L, mass M and time T are sufficient to develop the units of measurement of other quantities such as force, energy, etc. For example, force is equal to mass times acceleration and has the dimensions MLT^{-2}. A force of 1 kg m/s^2 is required to accelerate a mass of 1 kg at the rate of 1 m/s^2. For convenience this force is called a Newton, so named in honour of Sir Issac Newton. Likewise, energy has the dimensions ML^2T^{-2}. Its units are Force x distance or Newton meter, *N. m.* A Newton meter is also known as a Joule, J.

---

*Consider an atom of a gas from which an electron has been removed by some process which imparts sufficient energy necessary for such an event to occur. The atom is left with a positive charge and is said to be ionized and is known as a positive ion. The removed electron is known as a free electron.

It is possible that, under certain circumstances, a free electron can attach itself to a neutral atom and form a negatively charged particle known as a negative ion.

Likewise, in solutions which, on the whole, are electrically neutral, +ve and −ve ions exist in equal numbers.

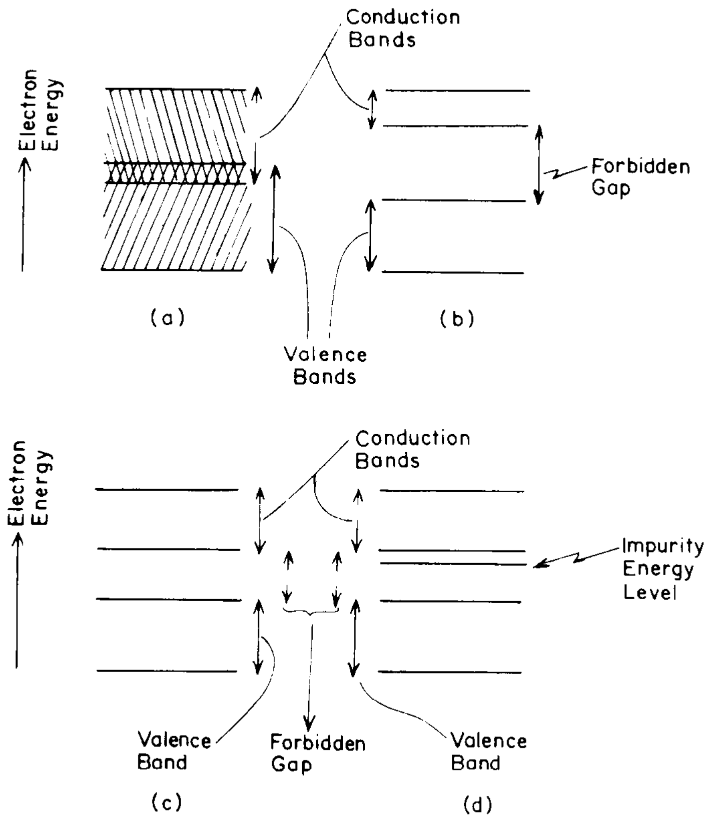

Fig. 1.1 Energy Band Structures in (a) Metals (b) Insulators (c) Semiconductors and (d) Impurity Semiconducrors.

It so turns out that it is impossible to develop a system of units in electrical engineering with the aid of the tree basic mechanical quantities, mass, length and time. A fourth fundamental quantity is needed and this has been chosen to be electric charge denoted by the symbol q. Charge is measured in coloumbs, C, and together with mass, length and time enables one to formulate the laws of electrical engineering in a consistent manner. The unit of charge is named after Coloumb, the discoverer of the law of force between electric charges at rest.

In this book we shall be using the MKS (meter-kilogram-second) system of units. Table 1.1 summarizes the units and dimensions associated with Mechanics. In this table the letters M, L, and T stand for mass, length and time respectively. A table indicating the units and symbols of electrical quantities appears at the end of this chapter.