CHAPTER 1

INTRODUCTION

Vacuum tubes are found as basic or auxiliary elements in numerous technical devices now in use. They are indispensable in communication systems and industrial control. Their development has facilitated advances in the fields of power and transportation. Without the vacuum tube we should be back in the days of the gravity-cell telegraph and the ringer telephone.

In the United States the number of vacuum tubes in use is several times the number of human beings and household pets. The 50,000,000 radio sets manufactured in the United States in the year 1947 alone contained more vacuum tubes than the adult population of the country. Associated with the 25,000,000 telephones and 120,000,000 miles of telephone and telegraph wire in the United States are many more vacuum tubes. Various industrial devices include almost as many more. The United States uses nearly half the world's total of vacuum tubes.

One may conclude that there are many vacuum tubes in use. They must be of some importance. They are.

1.1. Devices Using Vacuum Tubes. This book is more concerned with the properties and functions of vacuum tubes than with the systems utilizing these properties. However, it is well to be reminded of the extent of vacuum-tube applications and the degree to which we are dependent upon them. The following devices are totally dependent upon vacuum tubes.

Radio Receivers. These are too well known to require much description. They range from portable receivers the size of a brick and capable of receiving local broadcast stations to large-size all-wave receivers capable of picking up a signal stronger than the noise level from any point on the globe. Even the smallest receivers use 4 or 5 vacuum tubes. The average home receiver has about 7 tubes. An all-wave receiver may have 20 or more tubes.

Radio Transmitters. Transmitters range from portable walkie-talkie sets to large power-broadcast and short-wave stations. In output power they vary from 0.1 watt to hundreds of kilowatts. In frequency they may range from 100 kc to 60,000 mc. The short-wave transmitters are capable of producing an audible signal at any point on the earth's surface.
Transmitters may use voice or code. They may incorporate static-elimination or secrecy features in their operation. A small transmitter may use only a few vacuum tubes. The largest transmitters may use 50 or more tubes.

Long-distance Wire Telephonesthe connections between telephone stations on the same continent are effected by wire transmission lines rather than by radio. When the distance between telephone stations is large, it is necessary to amplify the speech energy about every 16 miles for cables and every 50 miles for open-wire lines. Each speech amplifier contains several vacuum tubes and amplifies the speech power from about 10 microwatts to about 1 milliwatt, a power amplification of 100. Thus a telephone call from San Francisco to New York passes through 30 or more speech amplifiers.

Television Systems. Television systems achieve the modern miracle of reproducing a visual scene at a point remote from the original. This is done entirely with vacuum tubes and electrical-circuit elements. No mechanical devices are needed. In its present stage of development the reproduced picture as viewed from 6 ft on an 8-in. cathode-ray-tube screen is as good as a motion picture seen from the first row of the balcony. Each television transmitter contains hundreds of vacuum tubes, including a special camera tube. Every television receiver contains 20 or more tubes, including a special viewing tube.

Measurement Devices. Electronic measurement devices are too numerous to mention. Quantities that can be measured, besides all the electrical quantities, are color, weight, light intensity, odor, time interval, and many others. In fact, it can be said that any quantity which can be measured at all can probably be measured by electronic means.

Industrial Control. The number of electronic industrial-control devices is legion. They include counting circuits, sorting systems, illumination-control systems, welding-control devices, and liquid- and gaseous-flow regulators. Typical devices are those which automatically regulate temperature or humidity. All these devices have their primary dependence upon the vacuum tubes in them.

In addition to the above devices, which are totally dependent upon vacuum tubes, there are many others that have acquired a strong dependence upon electronic devices. Thus all commercial flying makes constant use of radio communications to keep posted on the weather and on terminal traffic and to keep ground stations posted on plane positions as well as to guide the planes directly. The invasion of other fields by electronics has already been considerable and is bound to be greater in time to come.

1.2. Functions of Vacuum Tubes. Although the applications of vacuum tubes are almost infinite, the specific functions that vacuum tubes can perform by virtue of their own properties are relatively few. It is these few fundamental functions and their combinations that give rise to the numerous applications.

A list of the functions of vacuum tubes is bound to be an arbitrary one since the tube cannot function by itself without an associated circuit. However, some of the jobs that vacuum tubes can perform are so fundamental that they may be considered properties of the tube itself, independent of the associated circuits.

The principal functions that may be performed by vacuum tubes are listed below.

Rectification. Vacuum tubes are able to convert alternating currents to direct currents. This is known as "rectification." Rectification is an inherent property of vacuum tubes because current can flow in only one direction from a source of electrons.

If a sinusoidal wave of voltage is applied to a vacuum tube of the right type, current will flow in only one direction, giving rise to a succession of half-wave pulses all of the same polarity. It is possible to connect another like tube to insert half-wave pulses of the same polarity between the pulses of the first tube. The average of these pulses constitutes a direct current; the other frequency components are rejected by a filter circuit.

Rectification is important because electronic devices operate best on direct current, while power is usually generated and transmitted in alternating form. It is thus necessary to convert, or rectify, the a-c power to d-c power.

Amplification. The amplification of voltage or power is the outstanding function that vacuum tubes are able to perform. With the exception of the mechanical torque amplifier, no other device can do anything like it. Strictly speaking, the vacuum tube does not amplify power but rather controls the flow of a relatively large amount of power from one source with a small amount of power from another source. The British use the expression "electric valve" for certain types of electron tubes. This term is really better than ours, for it indicates the nature of the amplifying action.

Oscillation. The generation of high-frequency alternating currents, or oscillation, is another remarkable function that vacuum tubes can perform. Oscillation is obtained by causing part of the output of an amplifier to excite the amplifier and thus make the device self-excited and self-sustaining. Tubes can be built that will produce oscillations at frequencies as low as 1 cycle per sec, while other tubes can be built that will oscillate at frequencies as high as 60,000 mc per sec.

Frequency Conversion. Vacuum tubes are able to shift the frequency of a wave. This they are able to do by an electrical "beat" action.
Thus a wave of a given frequency can be mixed with a wave of another frequency in a vacuum tube, and among the products of the interaction is found the difference of the two frequencies. If one of the original waves had certain effects associated with it, these same effects are associated with the difference frequency. The beat action results from the nonlinear characteristics of the vacuum tube.

Modulation. The transmission of intelligence by radio waves or by certain types of wire telephony requires the use of frequencies higher than those audible. It is necessary to superimpose the audible frequencies upon the higher transmitted frequency. This superimposition is known as “modulation.” Modulation is best performed by vacuum tubes.

Basically, modulation takes the form of varying some property of the r-f wave at the audible rate. The commonest form of modulation varies the amplitude of the r-f wave in accordance with the intelligence to be transmitted. This is known as “amplitude modulation.” Frequency modulation is also common.

Detection. Detection is the inverse of modulation and is sometimes known as “demodulation.” It is the process of extracting the intelligence from the modulated wave. In the case of amplitude modulation the detection may be effected by rectifying the r-f wave and then utilizing the average value of the rectified wave, since it follows the amplitude variations in magnitude. Detection of modulated radio signals is best performed by vacuum tubes over most of the range of radio frequencies.

Light-image Production. It is possible for vacuum tubes to convert part of their output energy into visible light. This is done in cathode-ray tubes in which a stream of electrons is caused to hit a fluorescent screen, causing light to be emitted. The cathode-ray tube can be used for viewing wave forms and for doing many other wonderful things, including the reproduction of visual scenes. The fundamental property involved here is the conversion of electrical energy into visual energy.

Photoelectric Action. Vacuum tubes can be made that will convert light energy into electrical energy. This is possible by virtue of the photoelectric effect, which is the emission of electrons from certain surfaces when illuminated with visual energy. The liberated electrons constitute an electric current whose measure is related to the frequency and intensity of the exciting light. Tubes making use of this principle are known as “photoelectric tubes.” The photoelectric tube is one of the tubes most extensively used in industrial-control systems.

The above paragraphs have given a bird’s-eye view of the functions of vacuum tubes. The reader is probably familiar with all the above functions, which are now commonly encountered in everyday life. The rest of the book is devoted to the description and explanation of the characteristics of the vacuum tubes themselves.

CHAPTER 2

BASIC TUBE TYPES

The electronic engineer has about a dozen types of vacuum tube he can call upon for his high-frequency and industrial-control circuits. This is a surprisingly small number of distinct tube types. The small number of types is balanced, however, by the large number of forms in which each type may appear, as determined by the required power capacity and frequency range.

The purpose of this chapter is to list the basic types and their fundamental characteristics as a prelude to a detailed study of their characteristics and the physical laws from which these are derived.

2.1. Vacuum Diode. The vacuum diode is a two-electrode vacuum tube. One electrode acts as an emitter of electrons and is called the “cathode.” The other electrode acts as a collector of electrons and is called the “anode” or “plate.” The emitter may be either directly or indirectly heated. In physical form the vacuum diode may vary from a small metal tube to a large glass rectifier tube.

The current-voltage characteristics of a typical diode are shown in Fig. 2.1. The current follows a three-halfs-power law of voltage over the normal range of operation. At high values of plate voltage or at low values of heater current the plate current tends to be limited by the cathode emission and to increase only very slowly with plate voltage.

The most useful property of the diode is that it passes current only in one direction. This property makes the diode useful as a detector and as a rectifier for d-c power supplies.