THE SAGA OF THE VACUUM TUBE

by GERALD F. J. TYNE

THE modern vacuum tube may well be regarded as the goal toward which scientists were groping for approximately two hundred and fifty years. The early scientists were seeking an explanation of known electrical phenomena, trying to extend the scientific knowledge of the world, and their contributions to later investigations became of great importance. Actually two centuries of scientific research went into building the foundations of the science of thermionics. Another fifty years elapsed before scientists and technical experts produced the tube which in one generation affected everyday living for people all over the world. Around this tube great industries have been built, great fortunes made and lost. In the short space of fifteen years after its first practical application the tiny glow from this tube lighted up endless paths for study in communication, medicine, and other fields. It shed light on some of the darkest mysteries of nature. The culmination of this two hundred and fifty years of tireless searching, studying, and experimenting was the modern Aladdin's lamp, the vacuum tube.

Born at Binghamton, N. Y., 1899. Attended Canisius College & Rensselaer Polytechnic Institute. Served at latter as instructor, 1921-29. Since then has been engaged in development work in one of largest research and engineering organizations. Was ham 1912-15. Started collecting tubes in 1923 and studying tube history in 1932. Has to call in serviceman when anything except a blown fuse develops in his own home set.

These men of science spent lifetimes spurred on by the conviction that if the electrical phenomena could be understood, this great force in nature might be harnessed and utilized. The solving of the mystery of the combined effects of heat and electricity was one of the greatest challenges science had ever faced. The story of these men who took up the challenge and through sheer heroic persistence mastered the task is a saga as thrilling as any epic of ancient or modern times.

To a great extent we will see that the results attained by scientists and technical experts responsible for the evolution of the vacuum tube reflected the tempo of the ages in which the men lived. In 1672 and the two centuries following, research was geared to a slow pace, partly because of the lack of adequate support for the effort and lack of an efficient system of communication. For what work was done,

Part I of this especially-prepared series of articles giving the complete history and development of the radio vacuum tube.

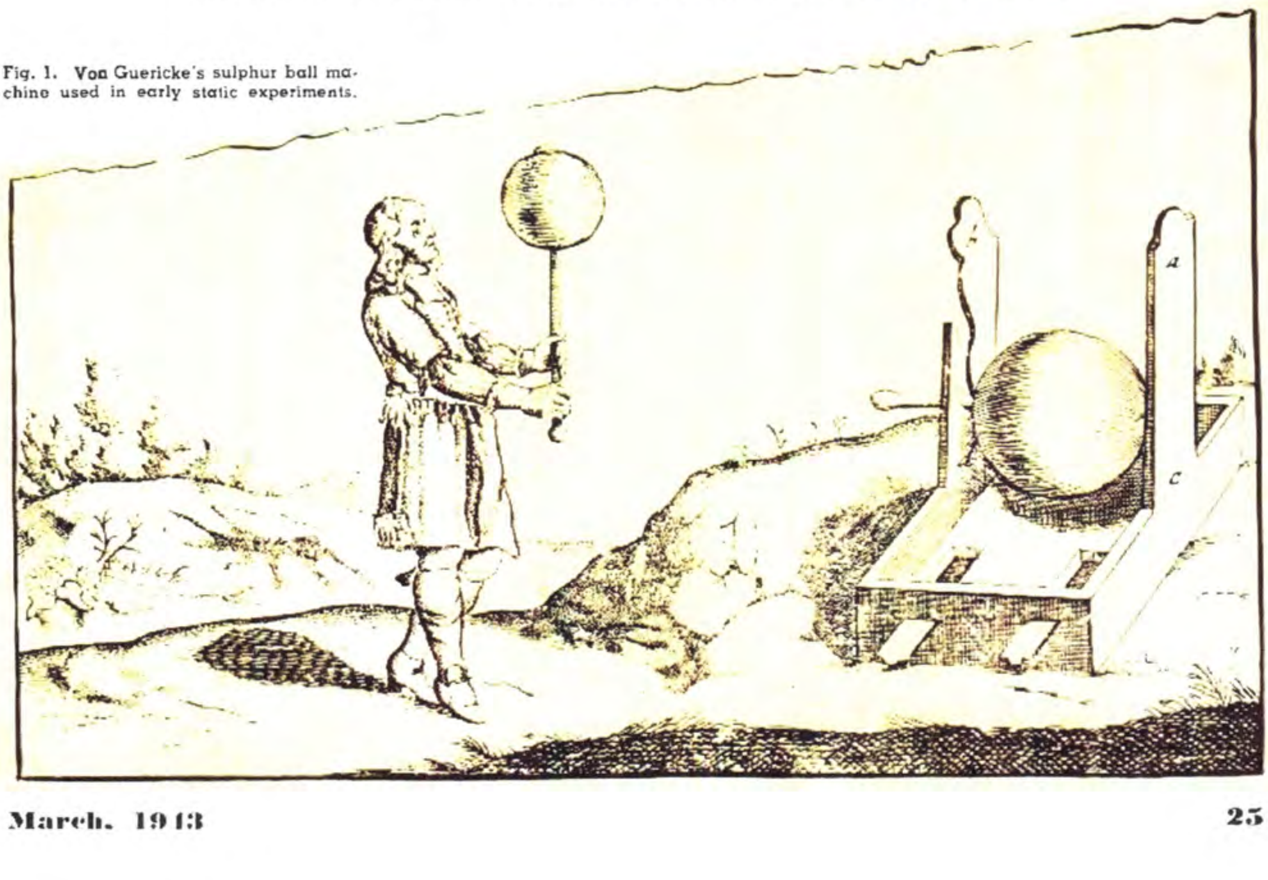


Fig. 1. Von Guericke's sulphur ball machine used in early static experiments.

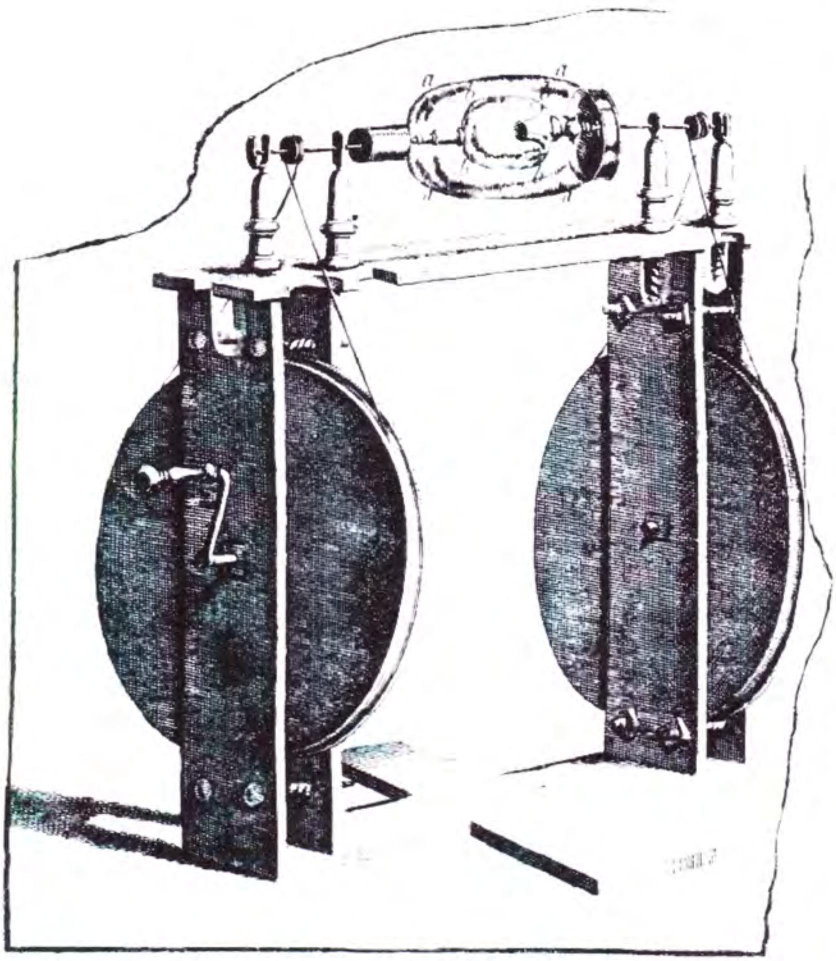
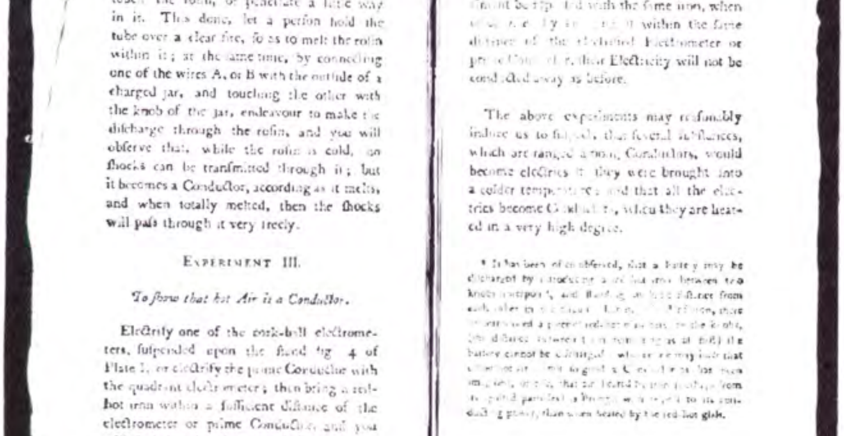


Fig. 2. Cylinder Machine as used by Hauksbee in his early experiments. Note the belt drive to increase speed of rotating elements.

Fig. 4. A reproduction from "Treatise of Electricity in Theory and Practice" (1st edition, London, 1777).



316 A COMPLETE TREATISE

touch the rosin, or penetrate a little way in it. This done, let a person hold the tube over a clear fire, so as to melt the rosin within it; at the same time, by connecting one of the wires A, or B with the outside of a charged jar, and touching the other with the knob of the jar, endeavour to make the discharge through the rosin, and you will observe that, while the rosin is cold, no shocks can be transmitted through it; but it becomes a Conductor, according as it melts, and when totally melted, then the shocks will pass through it very freely.

EXPERIMENT III.

To shew that hot Air is a Conductor.

Electrify one of the cork-ball electrometers, suspended upon the stand fig. 4 of Plate I. or electrify the prime Conductor with the quadrant electrometer; then bring a red-hot iron within a sufficient distance of the electrometer or prime Conductor, and you will find that they soon lose their Electricity, which is certainly conducted by the hot air contiguous to the iron; for if the experiment

OF ELECTRICITY. 317

[illegible] with the same iron, when [illegible] within the same distance of the electrified Electrometer or prime Conductor, their Electricity will not be conducted away as before.

The above experiments may reasonably induce us to suspect, that several substances, which are ranged among Conductors, would become electrics if they were brought into a colder temperature; and that all the electrics become Conductors, when they are heated in a very high degree.

* It has been often observed, that a battery may be discharged by [illegible] between two knobs [illegible] from each other [illegible] [illegible] battery cannot be [illegible] [illegible] from [illegible] conducting power, than when heated by the red-hot glass.

X 2 EXPE-

long periods might elapse before men in Germany or France appreciated what was being done by a scientist in England, though all might be working on the same problem. Better communications no doubt would have accelerated the study of thermionics.

The period from 1850 to 1880 was notable chiefly for the investigations of men who were duplicating, but with better facilities, the work done by their predecessors in the field.

News of the discovery of the "Edison effect" spread rapidly to other countries. This and further development of the incandescent lamp served as an impetus to stimulate scientific investigation. With the improvement of both transportation and communication at this time we find the picture of research and development quite changed. Sir William Preece visited America. Having heard of the work of the great Edison he witnessed demonstrations of the "Edison effect" and took back to England not only his notes on the demonstration but also samples of the magic lamps. Sir John Ambrose Fleming, who was at that time Electrical Adviser to the Edison Electric Light Company of London, studied Preece's work of repeating the experiments he had seen in America and continued investigation in this field, using the same types of lamps.

By 1895 scientists in the United States, England, and on the Continent had carefully studied the phenomena, seeking an explanation.

Five years later men coping with the problems of the wireless telegraph began to investigate the possible use of this device as a detector of electromagnetic waves.

While we will present evidence that Lee de Forest and his co-workers had conceived the idea of using a heated rarefied gas as a sensitive detecting medium in wireless telegraphy, which idea was later developed into the "Audion," it was actually Sir John Ambrose Fleming who obtained the first patent for the application of a thermionic device, as a rectifier, to wireless telegraphy, in 1904.

Even at this stage of the game few saw the possibilities of the device which was the grandfather of the present day detector, amplifier, and oscillator tubes. Several years later, when highly trained physicist-technicians attacked the problem, having at their command all the facilities which only large capital could provide, the full potentialities of this "bottle" began to be realized.

Who really started the ball rolling toward the modern vacuum tube? As we examine the foundations of the science of thermionics we find that the first stones were placed securely in position by such men as von Guericke, Gray, du Fay, Nollet, Winckler, Bose, von Kleist and their successors. To the casual observer these may be no more than a list of names picked out of a physics book, and placed in chronological order. Viewing the evolution of the vacuum tube from present day knowledge, however, we realize the significance and importance of each man's contribution.

Looking closely at these scientists they begin to live again. We see von Guericke poring over his books, working in his laboratory, proclaiming his discoveries to any one who would listen; Gray, experimenting prodigiously, for years jealously guarding the products of his struggles; du Fay "the interloper," performing his so-called "tricks," an expert at coming to the wrong conclusions; Abbé Nollet, the exhibitionist, in his curled wig and black skull cap, with his black gown barely concealing the richly laced coat and rapier beneath, demonstrating the fruits of his genius with one eye on the gallery of the lords and ladies of the French nobility; and Bose, giving superhuman demonstrations, to the awe and wonder of the populace.

They were all real men, the prototypes of men who played a prominent part in the feverish activity surrounding the final forging of the link between the scientific discovery of the "Edison effect" and its practical applications.

Probably no electrical discovery of major importance ever was made but that the honor of discovering it was claimed for more than one person. The origin of the Leyden jar was claimed for von Kleist, van Musschenbroek, and Cunaeus, and there are those who credit de Romas rather than Franklin with the discovery that lightning is an electrical phenomenon. The invention of the electromagnetic telegraph is ascribed to Steinheil by the Germans, to Wheatstone in England, and to Morse in the United States. Reis, Drawbaugh, Gray, Dolbear, and Bell all claimed the invention of the electrical transmission of speech. In the field of the incandescent lamp we have the conflicting claims of Edison, Sawyer, and Mann. In the field of the thermionic tube we have von Lieben, the de Forest-Fleming controversy, and that of Arnold and Langmuir. The scientific forefront from which these advances flowed truly is of international scope.

In the days of the philosophers these disagreements were largely confined to the annals of scientific societies, but in the past half century the commercial interests at stake have been so large that invention disputes have been the subject of long drawn out actions in the civil courts. This is partly the result of the patent system. Whether in the annals of the learned societies or in the courts of the land, these controversies are productive of a wealth of material for the historian. In modern times, when much development work is done in the research laboratories of large commercial organization, such actions bring out and place on record many of the details of interest which would not otherwise become generally known.

In the earlier days of which we shall

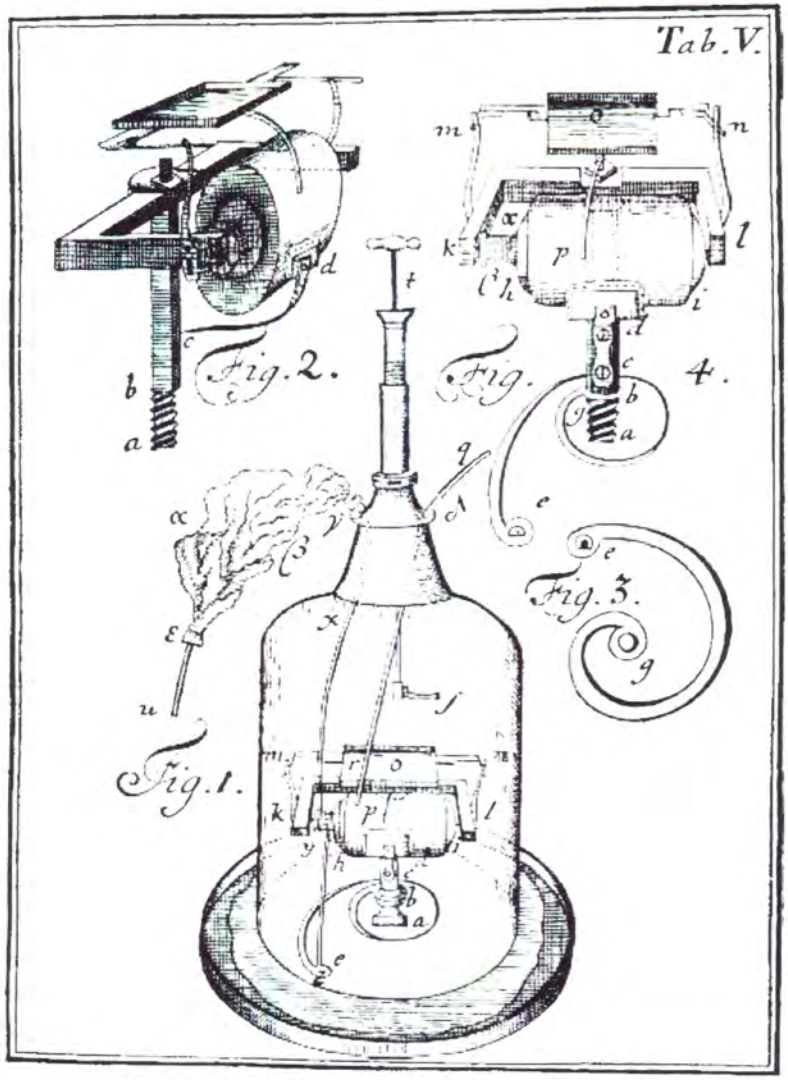


Fig. 3. Details of Winkler's Machine. Fig. 1 shows the machine set up for operation within a vacuum in glass jar.

treat it will be seen that a device produced by a philosopher was improved and adapted by those in other countries, and the use of the improved device brought about still further discoveries or resulted in more fruitful work in still a different country. A barrier to this free interchange of knowledge and ideas is found in the language differences involved. That this was recognized in the early days may be seen from the preface to the second edition of Priestley's famous "History and Present State of Electricity," published in 1769. In this work Priestley says:

"It is certainly to be regretted that philosophers have not one common language but neither the theory of language in general, nor the nature and analogies of things to be expressed by it are sufficiently understood to enable us to contrive a new and philosophical one, which might be easily learnt and would be completely adequate to all the purposes of science;—These circumstances make it the more necessary, that there should be in every country, persons possessed of a competent knowledge of foreign languages, who should be attentive to the progress of science abroad, and communicate to their countrymen all useful discoveries as they are made."

In addition to the language barrier it should be realized that the downfall of feudalism and disintegration of the Holy Roman Empire had resulted in sweeping changes in the social and political system of Europe, which were in progress during this period. Countries were torn by internal strife and external war. While this had its bearing on scientific development and research, consideration of it belongs more to the field of social than electrical science. We need consider only the disastrous effect of these factors upon possible intellectual unity. The rise of nationalism frequently resulted in the negation of honestly attributing the truth where truth was due. The resultant dissen-

(Continued on page 44)

Saga of the Vacuum Tube
(Continued from page 27)

tion in the scientific world, however, gives a multi-faceted picture which, even though it sometimes defies evaluation, gives to the historian much additional factual information.

The story of the development of the vacuum tube may be approached along two different paths, one of which leads us through the study of high voltage-heat phenomena, the other the study of high voltage-vacuum phenomena. Much has been written concerning the evolution which took place along this latter path, hence we shall confine ourselves to travel along the former.

Glazebrook's "Dictionary of Applied Physics" defines the word "thermionics" as the term "applied to the phenomena associated with the discharge of electricity from hot bodies." While we usually think of thermionics only in connection with electron emission in vacuo, the term as defined is much broader than that, and includes phenomena taking place under atmospheric conditions, such as the ionization of air by emission from hot bodies, flames, etc., and it is in this broader sense that we shall use the term.

The early work in thermionics is inextricably bound up with the work done by the philosophers of the seventeenth and eighteenth centuries on static electricity, and usually the experiments were conducted in air at atmospheric pressure. Under these conditions ionization phenomena become observable only where high voltages are available, which was the case during this period, the era of so-called *static* electricity. Knowledge in any field becomes greater as the tools available for use in investigation become perfected; hence it will be seen that as better tools and higher concentrations of energy became available, knowledge of thermionics grew apace. This era of static electricity was the era of high voltage.

Beginning around the turn of the nineteenth century with the work of Galvani and Volta the emphases in electrical research shifted to the field of galvanism and voltaic electricity, which was essentially a technique of low impedances. Hence we find little done in the field of thermionics during this era. Not until the tools of galvanism were developed and perfected, and higher voltages and greater energies were available from low impedance sources, could any great amount of work be done in the high impedance field of thermionics.

Early Investigators

The earliest reference in literature to the beginnings of thermionics is to be found in the work of William Gilbert of Colchester, physician to Queen Elizabeth, as recorded in his famous "De Magnete, Magneticisque Corporibus—." In this book[1], in discussing the effect of heat on amber, he says:

"Moreover the spirit of the amber which is called forth is enfeebled by alien heat—"

and later he makes the statement:

"It is manifest indeed that the effluvia *(charge)* are destroyed by flame and igneous heat; and therefore they attract neither flame nor bodies near a flame."

After Gilbert we find little of importance recorded until Otto von Guericke, Burgomaster of Magdeburg, entered the scene. Von Guericke is one of the few of the early workers to have made contributions to both the paths of research which led to the development of the modern vacuum tube. For, as every high school physics student knows, he was the inventor of the air pump, a device which has proved to be a most useful tool in many branches of research. He also, literally, started the ball rolling, with the invention of the friction type electrostatic generator, the first electrical machine. This machine is shown in Figure 1. It consisted of a globe of sulphur mounted on trunnions and rotated manually. The hand of the operator was used as the friction device. With this machine as a power source von Guericke made many experiments. During the course of his work he observed[2] that a body once attracted by an "excited electric" was repelled by it, and not again attracted until it had been touched by some other object. He also observed that if the repelled (charged) body came near a flame it could again be attracted by the electric without having touched any other body.

While von Guericke was delving so assiduously we know now that over the Alps in Italy similar observations were being made. Some of the members of the Accademia del Cimento, which was founded by the Medici family, and flourished from 1657 to 1667, were making their contributions to the advancement of various branches of human knowledge. We find that they observed[3] that if an electrified amber was presented to a flame it lost its "attractive power," that is, its electric charge.

Over in England Francis Hauksbee published, in 1709, a book[4] of interesting experiments on electricity. He improved on von Guericke's machine by substituting for the heavy sulphur globe a hollow glass globe, with which higher rotational speeds could be attained. A reproduction of an engraving showing Hauksbee's machine, as used in one of his experiments, is given in Figure 2. It will be noted that this machine also uses a pulley and belt drive system to enable the attainment of higher speeds of rotation.

With the work of Hauksbee there came a hiatus in the development of the electrical machine, for what reason we do not know. Many philosophers went back to the use of the glass tube, excited by friction of a piece of cloth, as a source of electricity.

Shortly after Hauksbee's book was published the work of another Englishman, Stephen Gray, began to attract attention. Unfortunately the records of Gray's life and work are hidden in the early annals of the Royal Society. When we first hear of him in 1720, he was about fifty years of age and a pensioner in the Charter House of London. Even then he was described as a crusty and testy old gentleman, to whom life had not been kind. He had no wealthy sponsor in his early years. Truly in his case "Necessity" was the "Mother of Invention." His apparatus was built of materials readily available to the poor. And yet with this crude experimental equipment he determined that the electrical conductivity of bodies depended on the substances composing them, and gave to the world the first practical and useful information on electrical conduction and insulation.

Gray's contribution to thermionics was an indirect one, and consisted of stimulating others. One of these was his co-worker, Mr. Granville Wheeler, who introduced the element of heat into some of his experiments. Another of those influenced by Gray was du Fay, of whom we shall hear more in a short time. Gray's early experimental work was unpublished for some time probably, according to Dr. Desaguliers[5], writing some years after Gray's death, because of his intolerance of opposition and fear of contradiction. In his later years he seems to have changed this attitude, perhaps with the improvement in his economic security which took place. This we deduce from the fact that he contributed a number of papers[6] to the Royal Society, and even while on his deathbed, dictated[7] some of his conclusions to the Secretary of that august body.

Across the Channel in France, Charles François de Cisternay du Fay began, in 1733, his famous work in electricity. At this time he was thirty-five years of age. While it is possible that Gray's temperament prevented philosophers in England from entering the field as competitors, it is evident that neither awe nor fear of this genius crossed the water to frustrate the working of du Fay. As we read of Charles du Fay he becomes a vivid, vital person. To his heritage of culture had been added the gifts of a brilliant mind, keen wit, and charming personality. He used these gifts to win the friendship and co-operation of Gray.

Du Fay's work merited being recorded in the annals of the French Academy. He wrote on every subject considered worthy of public discussion by philosophers. He was the only member of the French Academy who contributed to all six fields into which science was divided by that body. His tastes were catholic and his interests profound.

In the spring of 1733 du Fay learned of the work done by Gray and Wheeler. He immediately set about checking their findings; and determined to continue the experiments along somewhat different lines. During this year and the year following he wrote six Memoires[8] recording his experiences while conducting experiments on electrical phenomena. In one of these Memoires he set forth his theory of electricity, which was known as the two-fluid theory.

It is curious to note that although the electrical machine of von Guericke and Hauksbee must have been known to du Fay and his contemporaries, they did not use it. In all their experimental work they used glass tubes excited by rubbing with silk.

In his Fifth Memoire du Fay describes experiments on the effect of hot air, compressed air, and rarefied air on the electric effect. Another experiment, which was described in his Second Memoire, is especially worthy of note. He observed that the flame of a candle could not be electrified at all, and that it is not attracted by an electrified body. He adds the following:

> "This singularity merits a close examination, in which we will perhaps enter into the question of leakage; but of this we can assure ourselves, for the present, that this (phenomena) is not due to the heat nor to the burning; for a red hot iron and a glowing coal, placed on the glass table, become it (electrified) exceedingly."

Du Fay never examined the effect further, probably because of his interest in other electrical phenomena. He died in 1739 at the age of forty-one and his last Memoire, which was a summary of his concepts of the great phenomenon, was published in 1737.

Du Fay, in December 1733, wrote a brief synopsis of the Memoires which he had published in the annals of the French Academy and sent it to the Duke of Richmond and Lenox for presentation to the Royal Society[9] and to Gray "who works on this subject with so much application and success, and to whom I acknowledge myself indebted for the discoveries I have made, as well as for those I may possibly make hereafter, since it is from his writings that I took the resolution of applying myself to this kind of experiment." This is probably the handsomest recognition of the work of another investigator that has ever been published, and completely won Gray's heart. From that time on Gray and du Fay maintained communication with the greatest of friendliness. It was this which led Fontanelle to remark that he wished that such relations might always typify the intercourse between great nations.

All the experiments of the lonely Gray in England and the spectacular demonstrations of du Fay were soon repeated and publicized by Abbé Jean Antoine Nollet, who might have been as successful in the theater as he was in the field of science.

Nollet, because of his charm and

wit, his talent for simplifying and explaining his theories, entertained the gay French court with his dramatic revelations. The public clamored for the theatricals of the intriguing French philosopher. Contemporary scientists recognized his genius.

Nollet carefully repeated the experiments of du Fay and came to conclusions which contradicted the findings of du Fay, particularly those pertaining to the effect of heat on the electric virtue. Nollet felt[11] that if his friend had lived long enough to study the relationship as exhaustively as he had planned, he would have contradicted himself. Du Fay stated briefly that the application of heat to an electrified tube had little or no effect on the electric virtue. Nollet, after performing many experiments meticulously[11], found that a white hot piece of iron dissipated the virtue very quickly, and that the result was the same when the iron had cooled to a red heat. As the temperature of the iron decreased the dissipation of the virtue was slower. He noted further that when the cooling iron had resumed its brown color, the electricity showed no sign of dissipation.

While Nollet was pursuing his researches in France, scientists in the Germanic states were improving the tools of electrical science.

Johann Heinrick Winckler conceived and brought to execution the idea of using a fixed cushion to provide friction on the electrical machine, instead of the hand of the operator, as originally used by von Guericke and Hauksbee. On March 21, 1745, Winckler communicated to the Royal Society[12] a description of his machine, which is shown in Figure 3. With this device he could obtain much more energy than before. This was later improved by John Canton of England[13], who applied to Winckler's cushion an amalgam of mercury and tin by means of which the excitation was increased.

George Mathias Bose, Professor of Philosophy at Wittemburg, about this time introduced[14] the *prime conductor*, in the form of an iron tube or cylinder, which increased the energy storage capacity of the machine. Figure 3, of Winckler's machine, also shows a prime conductor in the form of a rectangular plate.

About the same time Andreas Gordon, a Scotch Benedictine monk who was Professor of Philosophy at the University of Erfurt, substituted[15] a glass cylinder for the globe used by his predecessors.

With these improved devices much higher voltages could be obtained and greater energies could be stored. By this time the friction type of electrical machine had been developed to nearly its peak, and it seemed as though the time had arrived for some great advance. This came in 1745, when the discovery of the Leyden jar was announced.

The origin of this utilitarian device has been variously attributed to von Kleist, Dean of the Cathedral of Comin in Pomerania; van Musschenbroek, of the University of Leyden; and N. Cunaeus, a burgess of Leyden. It is now established that it was first announced[16] by von Kleist in a letter to Doctor Lieberkuhn, dated November 4, 1745, in which was described an elementary form of the device. His explanation of it was so obscure, however, that it was of little use. Von Kleist felt that the human body contributed part of the force of the jar.

The Leyden Jar, because of the increased energy and storage capacity it provided, was seized upon by the philosophers of all countries as a most versatile and useful tool. Large quantities of energy, with which spectacular experiments could be performed, could be obtained by connecting numbers of these jars together to form what was called a "battery."

The addition of these instrumentalities aided greatly in the progress of research in electrical science.

While this development had been going on, other scientists, such as Delaval, Canton, Watson, and Wilson of England, and Franz Aepinus of Germany were seeking further explanation of the effects of heat on electricity.

While it was customary for the philosophers to repeat experiments made by each other, for the purpose of verification or contradiction, we may attribute the unusual interest in the effect of heat to the fact that in 1756 Franz Aepinus made an important discovery. This celebrated German philosopher reported[17] his results in the study of the tourmaline to the Academy of Sciences and Belles Lettres in Berlin. He found that he could electrify this substance to a high degree by heating it to somewhere between 99½ and 212 degrees Fahrenheit. Up to this time very little was known concerning the necessity of heating the tourmaline to excite electricity.

It is not difficult to understand what followed the publication of his report. Immediately heat was applied by other scientists, not only to the tourmaline, but to all other experiments being conducted. The controversy of the tourmaline stimulated not only the study of this phenomenon but also the exchange of ideas.

Mr. Delaval set forth the results of his studies in this matter in a paper read to the Royal Society on December 17, 1761[18]. Mr. Delaval's explanation of his results was not satisfactory to Mr. Canton, who was similarly interested. Mr. Canton attempted to supply his own explanation of Mr. Delaval's results in a paper which he presented some three months later, on February 4, 1763, to the Royal Society[19].

Mr. Delaval expounded the theory that stones, tourmalines, and similar earthly substances were convertible from electrics to non-electrics by different degrees of heat. Mr. Canton claimed, in his paper, that the substances were conductors when they were cold because they contained moisture (which is the bane of all experiments in static electricity); that when the moisture was evaporated by heat they lost their conductivity; that when they were made very hot, the hot air at or near their surfaces would conduct and the substances only *appeared* to be conductors again. Mr. Canton then proceeded to prove this contention. He says:

"Hot air may easily be proved to be a conductor of electricity by bringing a red-hot iron poker, but for a moment, within three or four inches of a small electrified body; when it would be perceived, that its electric power would be almost, if not entirely destroyed; and by bringing excited amber within an inch of the flame of a candle, when it would lose its electricity before it had acquired any sensible degree of heat."

We mention this particular incident in the history of thermionics for a very important reason.

Abbé Nollet had performed this same experiment using the heated iron to prove that heat dissipated the electric virtue in a glass tube, arriving at the conclusion that, since the virtue was dissipated, the heat was responsible for the dissipation.

Mr. Canton repeated the experiment to prove that hot air was a conductor of electricity. Since the electric virtue was dissipated, he concluded that hot air was a conductor of electricity.

Apparently, what they found depended on what they were looking for, a condition which is not peculiar to the ancients by any means.

But when Mr. Wilson made experiments[20] discharging electrified tubes by means of heated glass, Mr. Canton, who seemed to be always looking over someone else's shoulder, observed that perhaps Mr. Wilson did not discharge the tubes by means of the hot glass, but rather by means of the heated air on the surface of the material.

In 1777 the next important link in our chain was forged by Tiberio Cavallo. In his book,[21] published in that year, we find instructions for performing an experiment. Because of the significance of the explanatory note which he attaches we are here reproducing (see Figure 4) the pages of his book on which it is given. In reading these pages the student should bear in mind that the "battery" of Cavallo's day was a bank of charged Leyden jars as previously described, and not the chemical device which is today termed a battery.

We see that Cavallo contradicted not only Wilson but Canton. Cavallo realized that some element other than heat or hot air was responsible for the discharge. "Perhaps from its ignited particles" is the keynote of the essential difference between his explanation and that of his predecessors.

The term "thermionic emission" was many years in the future.

(*Continued on page 52*)

CATHODE-RAY TUBE CHARACTERISTICS

THE electron beam in a cathode-ray tube may be deflected by either magnetic or electric means, but by far the most common type of deflection is electrodynamic. Magnetodynamic deflection is seldom employed for oscillographic purposes since the impedance offered by the deflection coils varies with frequency, varying the deflecting field and therefore producing indications difficult to interpret, according to Du Mont engineers.

Deflection voltage requirements for electrodynamic deflection systems increase directly with increasing accelerating potential. It is thus necessary to investigate the signal voltage available in conjunction with deflection requirements of the cathode-ray tube to be used. At the same time if an amplifier such as, for example, the deflection amplifier provided in a cathode-ray oscillograph is to be used to amplify the signal for deflection of the cathode-ray tube, care must be taken to insure that the output voltage available is sufficient for full-scale deflection of the tube.

All *Du Mont* instruments, it is pointed out, are designed so that the overload point of their deflection amplifiers is off the screen. This consideration is especially important when it is desired to employ commercial oscillograph amplifiers for deflection of a cathode-ray tube different from that provided with the instrument, since in most cases only sufficient deflecting voltage has been provided for the standard tube supplied with the instrument while operating at potentials available in the instrument. If this precaution is not observed, the overload point of the amplifiers is likely to occur on the screen, thereby seriously distorting the unknown signal.

Electrodynamically deflected cathode-ray tubes are manufactured with either one or two plates of a deflecting-plate pair available for external connection. In the former case one plate of each pair is connected within the cathode-ray tube to the second anode. The free plate of each pair is brought out to a connecting terminal for deflection. Such operation is permissible at low accelerating-potentials but, when it is desired to operate a cathode-ray at high accelerating potentials, the high deflecting voltage required is likely to develop an axial as well as radial acceleration to the beam, which may cause a certain amount of defocusing to appear on the screen edges.

When both plates of a deflecting-plate pair are available for external connection, higher accelerating potentials such as are necessary for satisfactory operation of long-persistence screens and for high brilliance, may be used. –30–

Saga of the Vacuum Tube

(Continued from page 50)

Up to this point we have been concerned with showing a continuity in the study of thermionics. Many scientists not mentioned here were studying the electric phenomena from other angles, and it is true that some considered the factor of heat in some of their experiments. Our purpose has been to show an unbroken chain in the study of the relation of heat and electricity in the early days.

Just as we have traced the foundations of thermionics along the high voltage-heat path, so also we might trace the development along the high voltage-vacuum path, from the work of von Guericke in the development of the air-pump, and the study of the attractive power of electrified bodies in vacuo by Robert Boyle in 1670,[22] and by the Accademia del Cimento.[23]

Following the above, an unbroken chain of experiments with vacuum in connection with electricity may be seen by tracing the observations of Hauksbee,[24] Gray,[25] du Fay,[26] Nollet,[27] Allamand,[28] Ludolph,[29] Hamberger,[30] Waitz,[31] Canton,[32] Watson,[33] Grummert,[34] Wilson,[35] and others.

Up to this time little had been heard from America. Suddenly in the middle of the eighteenth century a voice from this side of the Atlantic was heard.

In 1750 the remarkable discoveries of Benjamin Franklin startled the scientific world. More amazing do the achievements of Franklin appear when we consider his background and contrast it with that of the foreign scientists. Franklin, born in 1709, had very little formal education. At the age of seventeen he arrived in Philadelphia from Boston. He was penniless and had worked for his transportation; at the age of forty he was Philadelphia's leading citizen. Those twenty-three years were spent in work during which time he founded schools and libraries, established a newspaper, organized civic affairs, and founded the Philosophical Society. He always had a desire to study natural sciences but never had the time. Franklin knew nothing of the environment of the European philosopher who spent his time in slow deliberation and contemplation of the causes and effects of the universe.

Yet scarcely five years after he met Doctor Spence and saw his crude electrical experiments in Boston Franklin received world acclaim for his discoveries in electricity. So revolutionary and conclusive were his findings that they almost stunned his contemporaries abroad. His experiments were many, his writings on the subject prolific. At once he was recognized as a genius. He charmed the world with his directness and simplicity, his ability to say "I don't know." With him worked such men as Ebenezer Kinnersley, Thomas Hopkinson, and Philip Sing, all brilliant men.

While they did not contribute directly to the science of thermionics, their work was important enough to make our friends abroad realize that a new era had begun. Their own new date line was "Since the time of Ben Franklin."

The achievements of Ben Franklin are of particular significance today. Thousands of boys in the armed forces are being trained for work in communications. They are required to absorb present day knowledge of radio in the briefest possible time. Many of them have no more technical background than did Franklin. From some of them we may expect inventions and discoveries never thought of by the engineers designing the communications systems. History shows how frequently the men using a device will adapt it to their own needs in ways completely overlooked by the man who, because of his absorption in developing the device, has become a channeled thinker.

REFERENCES

1. *Gilbert, William, of Colchester, "De Magnete, Magneticisque Corporibus——." London.* 1600, *pp.* 53, 59.
2. *Guericke, Otto von: "Experimenta nova Magdeburgica——." Amsterdam,* 1672. *Lib.* 4. *Cap.* 15. *pp.* 147-150.
3. *Maggalotti, Lorenzo: "Saggi di naturali esperienza fatte nell Accademia del Cimento." First edition, Fierenze,* 1667. *Third edition,* 1841. *pp.* 144-145. *See also translation by Richard Waller, "Essays of natural experiments made in the Academy del Cimento." Benj. Alsop,* 1684, *pp.* 128-132.
4. *Hauksbee, Francis: "Physico-mechanical experiments on various subjects——." London,* 1709.
5. *Desaguliers, Dr. J. T.: "Thoughts and experiments concerning electricity." Philosophical Transactions of the Royal Society of London, Vol.* 41, 1739-40, *pp.* 186-193.
6. *Gray, Stephen: Phil. Trans. Roy. Soc. Vol.* 31, 1720-21, *pp.* 104-107. *Vol.* 37, 1731-32, *pp.* 18-44, 227-230, 285-291, 397-407. *Vol.* 39, 1735-36, *pp.* 16, 166, 220, 400.
7. *Grey, Stephen: Phil. Trans. Roy. Soc. Vol.* 39, 1735-36, *p.* 400.
8. *du Fay, Charles Francois de Cisternay: "Memoires de l'Academie Royale des Sciences de Paris."* 1733, *pp.* 31-50, 100-118, 327-357, 617-644. 1734, *pp.* 471-499, 691-723.
9. *du Fay, Charles Francois de Cisternay: "Letter of December* 27, 1733 *to Mortimer." Phil. Trans. Roy. Soc. Vol.* 38, 1734, *p.* 258.
10. *Nollet, Abbe, Jean Antoine: "Recherches sue les causes particulieres des phenomenes electriques." Third edition, Paris,* 1753.
11. *Nollet, Abbe: "Recherches——." Ibid. pp.* 214-215.
12. *Winckler, Johann Heinrick: "Gedanken von der Eigenschaften Wirkungen und Ursachen der Electricitat." Leipzig,* 1744. *See also Phil. Trans. Roy. Soc. Vol.* 43, *pp.* 166-169. *Paper read November* 22, 1744.
13. *Canton, John: "A letter from John Canton to Benj. Franklin." Phil. Trans. Roy. Soc., Vol.* 52, *pp.* 457-461. *Read February* 4, 1762.
14. *Bose, George Mathias: "Tentamina electrica——." Wittenburg,* 1744. *See also "Recherches sur la cause et veritable teorie (sic) de l'electricite." Wittembergue,* 1745.
15. *Gordon, Andreas: "Versuch einer Erklaerung der Electricitat." Second edition. Erfurt,* 1746. *See Plate* 1.
16. *Mottelay, Paul Fleury: "Bibliographical History of Electricity and Magnetism." London,* 1922, *p.* 173.
17. *Aepinus, Franz: "Historie de l'Academie Royale des Sciences et des Belles Lettres de Berlin."* 1756, *pp.* 105-121. *(Memoires de Berlin.) See also "Recueil des differentes memoires sur la tourmaline." Petersburg,* 1762.
18. *Delaval, Edward: "An account of several experiments in electricity." Phil. Trans. Roy. Soc., Vol.* 52, *pp.* 353-356. *Paper read December* 17, 1761.
19. *Canton, John: See reference* 13.
20. *Wilson, Benjamin: "Some electrical experiments." Phil. Trans. Roy. Soc., Vol.* 51, *pp.* 83-88. *Paper read March* 22, 1759.
21. *Cavallo, Tiberio: "A complete treatise of electricity in theory and practice." First edition. London,* 1777.

THE SAGA OF THE VACUUM TUBE

by GERALD F. J. TYNE
Research Engineer, N. Y.

Part 2 of this authoritative series, shows the tremendous amount of preliminary work that led to the discoveries of the radio tube.

UP TO about 1800 the science of electricity was that of static electricity, the electricity which was developed in the electrical machine of that day, and stored in the Leyden jar.

Beginning at that time with the work of Galvani and Volta the emphasis in electrical research shifted to the field of galvanism and voltaic electricity. The technique of this work was essentially a technique of low impedances. We find little done during the next few decades which had any direct bearing on the field of thermionics. Not until the tools of voltaic electricity were developed and perfected, and high voltages and greater energies became available from the low impedance sources could any great amount of work be done in the high impedance field of thermionics.

The names of Galvani and Volta are inseparable in studying the development in this new field. The lives of these men are perfect contrasts in their approach to the study of this branch of science. Each man was a genius. As a result of their conflicting theories, there arose another of the controversies which provide such a wealth of material for the historian.

Luigi Galvani was an amateur in this field in the real sense of the word. He was a physician and anatomist by profession. His studies in the comparative anatomy of animals were responsible for his interest in electricity. A true scientist, his work was done with the utmost care. His powers of observation were so keenly developed that no detail passed unobserved or unrecorded. When he noted certain phenomena of animal electricity, he began to study the effects of electrical currents on animals. As a result of these experiments Galvani soon was convinced that muscular motion depended on electricity in the body.

At this critical time in his study the historical accident, which seemed to substantiate his theory conclusively, occurred. While we find several conflicting reports of exactly what took place, substantially the following occurred.

Galvani's wife, a well educated woman who was deeply interested in her husband's work, spent much time in his laboratory. When she became ill Galvani proceeded to prepare for her a soup of frogs which, according to the custom of the country, was considered a restorative. After he had skinned and cleaned the frogs he placed them on a table near an electrical machine. At that moment he was called away from the laboratory. While the machine was in action an attendant happened to touch, with a scalpel, the crural nerve of one of the frogs that was not far from the prime conductor of the machine. At the touch of the scalpel the frog kicked, and the kick of that dead frog changed the whole face of electrical science. When Galvani returned his wife called his attention to what had happened. It appeared to confirm his hypothesis and he proceeded to investigate the phenomenon at length.*

In the course of these investigations, Galvani attempted to determine what part, if any, atmosphere electricity played in this reaction. Accordingly he prepared some frog's legs, inserted brass hooks in the spinal marrow, and hung them on an iron trellis outdoors. He noted that under these conditions the frog's legs showed occasional convulsions even when the weather was fine, and the atmospheric electricity supposedly quiescent. In the course of his observations he happened to press the hooks against the iron trellis and found that the convulsions were produced whenever these dissimiliar metals were in contact. This was followed by many in-

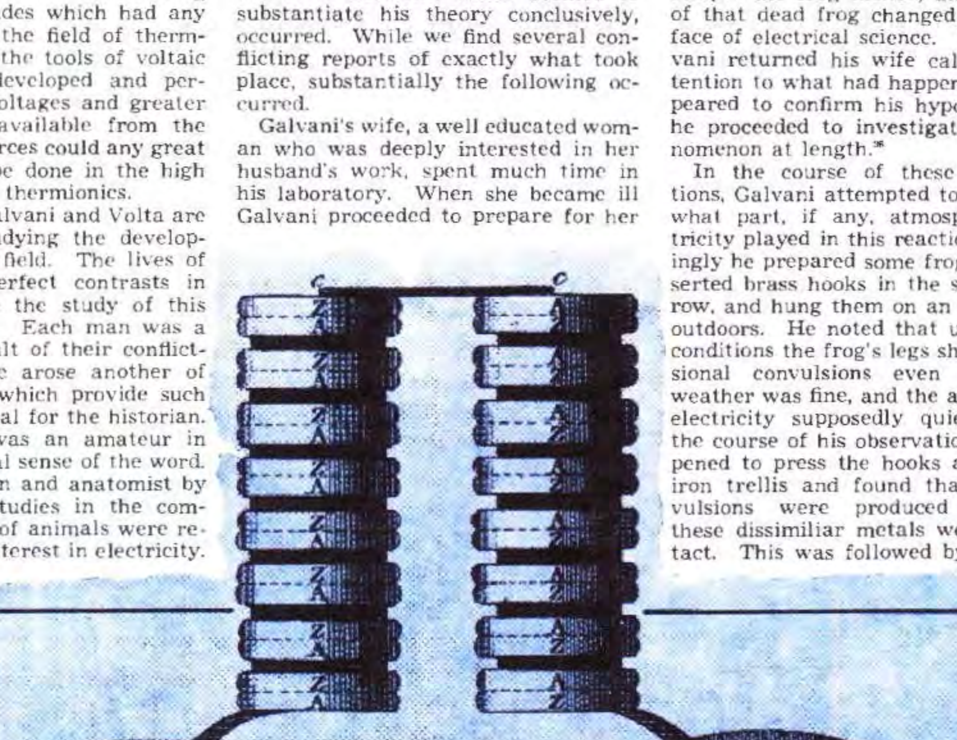


Fig. 5. The famous voltaic pile, made from layers of zinc, silver and water-soaked cards.

genious and clever experiments. His explanation of these results was that the electricity was due to the animal organism.

Similar observations had been made many years before by a Dutch naturalist Jan Swammerdam. In a book[36] published in 1737-8 experiments which he made in 1658 were described. During these experiments he obtained muscular contractions in frog's legs by means of combinations of silver and copper wires connected with the ends of the nerve. Also in a book[37] published in 1767 Johann Georg Sulzer had recorded the "galvanic taste" obtained by putting his tongue between two plates, one of silver and the other of lead, connected together by a wire.

After some years of investigation Galvani published an account of his work. No sooner did it appear than the philosophers in different parts of Europe entered with eagerness into the examination of this action—some to confirm, others to challenge.

theory, and possibly with the experiences of Swammerdam and Sulzer in mind, he finally concluded that the nerve was merely a wet conductor between two pieces of metal, dissimiliar in nature, causing a flow of electricity which produced the reaction that Galvani had observed.

Volta communicated the results of his discoveries to the Royal Society of London, at the end of 1792, in the form of letters to Tiberius Cavallo.[41] He gave an excellent account of Galvani's discovery and added many experiments and observations of his own. In these letters he successfully laid down the basis for the theory of voltaic electricity.

Volta continued to actively investigate these phenomena and perfect his theory. He wisely concluded that, although the effect of one pair of plates or wires was small, it could be multiplied indefinitely by a plurality of such devices. He accordingly obtained a number of silver coins and pieces of

and began to flow smoothly and controllably from pole to pole. A new day had dawned.

No sooner was the discovery of the voltaic pile announced than the English experimentalists began to use it, and almost immediately made some interesting and important observations. William Nicholson and Anthony Carlisle,[43] while conducting some of their experiments, made part of the circuit, connecting the extremities of the pile, of water. They noticed that gas was evolved where the connecting wires came into contact with the liquid. Subsequently the apparatus was arranged so that the gases given off from the two electrodes were kept separate, and it was found that (1) they consisted of oxygen and hydrogen and (2) that they were generated in the proportions that they occur in water.

About this time the relation in which the voltaic pile stood with reference to the Leyden jar and the electrical machine began to be perceived.

Fig. 6. Volta's revised voltaic pile (battery), called the "couronne des tasses."

Among those who did not accept Galvani's explanation was Alessandro Volta, of the University of Padua. In the relations of Galvani and Volta we see another excellent example of the combination of the amateur and the trained scientist—the value of the unchanneled thinker whose observations and discoveries open new doors for the mind of the trained scientist to enter. Volta, being Professor of Natural Philosophy at the University, was such a trained scientist. In fact he was the first of the scientists to confine his activities to that branch of physics dealing with electricity. Of necessity he was interested in allied subjects, but he devoted his life to the specialized field of electricity. Volta knew his theory. For this reason the great French scientist, Arago, said "There is not a single one of the discoveries of Professor Volta which can be said to be the result of chance. Every instrument with which he has enriched science existed in principle in his imagination before an artisan began to put it into material shape."[40]

Volta having read of the work of Galvani, repeated the experiments with his usual precision. Knowing his theory he could not accept Galvani's explanation of the twitching nerves in the frog's legs. He combined his observations with his experience and

zinc of similar dimensions; disposed them in pairs, and placed between adjacent pairs a card soaked in water. Thus came into being the famous *voltaic pile*, the first galvanic battery. See Figure 5. The effect of the combination fully justified his expectations. He found that electric shocks could be obtained from the pile as long as the pasteboard between the metals remained moist. These shocks were of the same kind as those produced by the electric machine.

Volta afterwards constructed another apparatus, or rather arranged the elements of the pile in a different fashion. It consisted of a set of small glasses, placed adjacent, and containing water or some saline solution. A number of metallic loops, with one end of zinc and the other of copper or silver, were inserted in the glasses in a uniform order, each glass having the zinc leg of one loop and the copper or silver leg of another loop, immersed in the liquid. Volta called this arrangement the "couronne des tasses" in his description of it in a letter to the Royal Society.[42] This arrangement is also shown in Figure 6.

Volta seems to have completely overlooked the changes which took place in the solution in the cups.

With the work of Volta electricity ceased to function as a series of jolts,

In the Leyden jar a quantity of electricity under high tension is accumulated on the surface of the glass, and is held there in equilibrium. When communication is established between the two surfaces an almost instantaneous discharge takes place, and equilibrium is soon reestablished. A sudden, instantaneous, and violent effect is produced in whatever bodies are exposed to this electrical discharge in transit. The Leyden jar is a high voltage storer of electricity, quickly discharged. The voltaic pile, by contrast, is a generator of electricity in a continued current. It discharges not suddenly, but with a moderate, continued, controllable action. It is a comparatively low internal resistance device.

The experiments of Nicholson and Carlisle attracted the attention of Sir Humphrey (then Mr.) Davy, who was at that time starting the labors in chemical science which were later to surround his name with so much lustre. He repeated[44] their experiments and found that no decomposition could be obtained when the water was pure, i.e. that conduction depended on the presence of some impurity in the water. He continued his experiments and later demonstrated to the *Royal Society* that other substances than

(*Continued on page* 48)

Saga of the V.T.

(Continued from page 32)

water (such as the fixed alkalis) could be decomposed in the same way, and thus laid the foundations of the science of electrochemistry.

In 1806, Paul Erman of Berlin wrote an elaborate memoir[45] on the conducting power of different bodies, which was awarded the prize of the *French Academy*. In this memoir we find the first mention of the action of flames in connection with the phenomena of voltaic electricity. He divided all bodies into five classes; perfect conductors, perfect non-conductors, imperfect conductors, positive conductors, and negative conductors. The nature of the first three classes requires no explanation; the fourth and fifth classes of bodies act as perfect conductors when applied to either of the two poles separately, but when placed between them, insulate either the positive or negative pole respectively and do not form a communication between them. The flame of a spirit lamp is described as a positive conductor; if it be applied to each pole separately it conducts the electricity; but if placed between the two poles it will not form a communication between them in consequence of its insulating the negative electricity. Although flame is a conductor, it does not conduct as perfectly as the metals. Flame is, however, a very different substance according to the body from which it is procured. The above observation refers to the flame of a hydrocarbon. The flame of sulphur insulates both the poles; that of phosphorus insulates the positive and conducts the negative.

William T. Brande, in 1814, reexamined Erman's work[46] and performed additional experiments with flames. He attempted to explain Erman's results on the basis of Davy's electrochemical theory. He postulated that some chemical bodies were naturally positive and some negative, and that they would be attracted toward the negative and positive poles of the pile respectively. Brande found that the flame of a hydrocarbon was attracted to the negative; and the flame of phosphorus which would contain a quantity of phosphoric acid, was attracted toward the positive. Here the bodies seemed to follow the then known laws of electrochemical attraction.

Meantime experimenters were improving on the voltaic pile and developing other forms of primary batteries. The evolution of this device, from the time of Volta to the present day, would fill volumes, hence we can only touch on it briefly.

In 1803, Hachette and Desormes substituted[47] starch for the liquid in the common voltaic pile, and in 1809 J. De Luc invented[48] the so called "dry pile," consisting of a column of alternate disks of paper gilt on one side, and zinc. This was not in reality *dry*; the paper imbibed and retained moisture enough to activate the pile. These modifications all produced a device which gave a high voltage but which had a high internal resistance.

Mr. John G. Children worked along somewhat different lines. Starting with Volta's "couronne des tasses" he increased the size of the elements, in order (as we now see it) to increase the current or quantity output. He first constructed a battery of twenty cells, with plates four feet by two feet, the cells being filled with a mixture of dilute nitric and sulphuric acids, with which battery he performed numerous experiments. He next made a battery of two hundred pairs of plates, each two inches square. From the experiments he performed with these batteries he deduced[49] that the *intensity* of the electricity is increased with the number of cells and the *quantity* with the extent of the metallic plates. He subsequently built[50] another battery of twenty-one cells, with plates six feet by two feet eight inches in size. This battery was first used in July 1813. Later a battery of two hundred cells, with multiple plates per cell, was installed at the Royal Institution. With the ouput of this battery many substances were fused and the electric arc between charcoal points was publicly demonstrated. This arc, or "arch," was described as follows by one of the historians of that day:[51]

"A singularly beautiful effect was produced by placing pieces of charcoal at the two ends of the wires in the interrupted circuit; when they were brought within the thirtieth or fortieth part of an inch of each other, a bright spark was produced, above half the volume of the charcoal, which was rather more than an inch long, became ignited to whiteness; and by withdrawing the points from each other, a constant discharge took place through the heated air, in a space equal to at least four inches, producing a most brilliant arch of light, this light constituted the sphere of activity of the instrument."

From this demonstration came the subsequent development of the arc lamp as a commercial source of light. Since it was so brilliant later scientists attacked the problem of making the unit smaller, that is, of "subdividing the electric light." This eventually led to the development of the incandescent lamp, and the modern vacuum tube. But this was far in the future, and the development of the tools with which it was finally accomplished went on.

The functioning of these early batteries was none too good, especially those containing acid electrolytes. Investigation by de La Rive showed[52] that this was due in part to "local action" caused by impurities in the electrode material, especially in the zinc electrode. Kemp,[53] followed by Sturgeon,[54] drew attention to the fact that this action could be reduced by amalgamating the zinc plates. In 1836 came the Daniell cell,[55] and in 1839 the Grove.[56] These were the first cells to use depolarizers in a practical way. The principles underlying depolarization had previously been recognized[57] by Becquerel, who also described cells similar to the Daniell, which however were not very much used. The Smee cell appeared in 1840 and the Bunsen cell in 1841.[58] This Bunsen cell was a modification of the Grove. The bichromate type cell usually referred to as the Bunsen cell did not appear until 1875.[59]

We have followed the development of the battery. While our source of electrical energy was growing from the abrupt discharge of the Leyden jar to the steady unidirectional flow of electric current, fortunately for us the age-old question of the relationship of electricity and magnetism still held the attention of some scientists. To these men the voltaic pile and its successors opened a new avenue of investigation. As we look into this phase of electrical research we shall see how their patience was rewarded.

In 1820 Hans Christian Oersted of Denmark, after spending thirteen years seeking some evidence of a physical interaction between magnetism and electricity, was suddenly rewarded for his perseverance. In this year he announced[60] to the world his discovery of the magnetic effect of the electric current. This discovery caused unqualified astonishment throughout Europe; more especially since all previous attempts to connect electricity and magnetism had proved unavailing. As might be expected, the experimental resources of every laboratory were brought to bear on the pursuit of the consequences of this newly-enunciated relation, so long suspected. The inquiry was taken up by Ampere, Arago, Biot, Savary, and Savart in France; Davy, Cummings and Faraday in England; de La Rive, Berbelius, Seebeck, Schweigger, Nobili, and others elsewhere in Europe.

Within less than three months after Oersted's announcement, Andre Marie Ampere communicated[61] the first of a series of Classic memoires on the subject of electromagnetism to the *French Academy*. In these memoires Ampere gave a far more complete exposition of Oersted's discovery than Oersted himself had done. He gave a definite rule concerning the direction in which the magnetic needle deflected when influenced by the passage of the electric current in a nearby wire. This is still known as *Ampere's Rule*. He disclosed the attraction and repulsion of parallel wires carrying electric currents, and proved that the force between them was directly proportional to the product of the currents and inversely proportional to the square of the distance between them. It was Ampere who decided that the direction of the current is the direction in which we imagine the positive electricity to move, and who introduced the term "galvanometer" to describe a current measurer which worked by means of the magnetic effect as it appeared.

While Galvani and Volta supplied the means for this development Oersted pointed out the main road to the application, and Ampere gave this application a fixed form, which is serviceable today. Later Faraday added to it something new and important both in form and matter.

Ampere succeeded because of his analytical mind and fertile imagination. Up to his time even the idea of the electric current was undefined. It was difficult for the philosophers to grasp exactly what happened when the wire was connected to the voltaic pile. We find that Volta used the term "courant electrique"[62] and Gray had previously spoken of the flow of electricity. Ampere decided, in 1820, to call the whole process in the discharge wire an *electric current*, and the direction of the current to be defined as the direction in which we imagine the positive electricity to move. This gave a pattern and terms to the study of electricity. We can understand the importance and significance of this when we note that even Oersted referred to the phenomenon as an "electric conflict" in the title of the book which announced his discovery.

Ampere was the first to make a clear distinction between *electric tension* and *electric current*. He realized that the phenomenon of electric tension existed in the voltaic pile before the circuit was closed, and could be measured by the electrometer, while that of electric current was absent until the circuit was closed. He felt that the current could best be measured by its magnetic effects.

Ampere was also the first to distinguish between *electrostatics* (the science of stationary electricity), and *electrodynamics* (the science of moving electricity). He also named these two branches of the science.

The names of Ampere and Oersted became linked for all time with the study of the mutual effects of electricity and magnetism. Oersted appears to have been the pure scientist. Apparently he gave no thought to the possible practical applications of his discovery. This was in line with his statement before the *University of Copenhagen* in 1814 that "The real laborer in the scientific field chooses knowledge as his highest aim." Oersted appreciated the utilitarian in science, but it took a flash of the genius of Ampere to see the practical application of Oersted's discovery. He thought immediately in terms of an electric telegraph. Ampere was not only a scientist but also an engineer.

Claude Servais Matthias Pouillet, in 1837, developed [63, 64] the sine and tangent galvanometers, which were later improved by Helmholtz. These were all moving magnet type of instruments. The first elementary form of the moving coil type was devised[65] by Sturgeon in 1824, and termed by him an "electrodynamoscope," improved by others until in 1882 it was modified by d'Arsonval to use a mirror and beam of light as a pointer. This instrument has ever since been known by his name.

The development of the tools proceeded. Sources of controllable energy and better instruments and methods of measurement became available. Along with them grew knowledge of the phenomena. Sir Humphrey Davy, as has been previously stated, laid the foundations of electrochemistry. His work was supplemented by that of Guyton-Morveau, Berzelius, and others. This work was rounded out by that of Michael Faraday, of whom we shall speak later.

With the discoveries, clear terminology, and clear cut laws established by Ampere we might think that the next link, Ohm's Law, would be readily seized upon by the scientists. This was far from what actually happened. As Ampere disclosed his findings the philosophers followed him step by step. They found that they could repeat the experiments, but their cold reception of Ohm's Law shortly after showed that, with the exception of Davy, the electrical scientists did not really understand what Ampere was doing. Both Ampere and Davy had conceived the idea of the *resistance* of a conductor. They noted that the strength of the current depended upon the nature of the circuit.

It was Georg Simon Ohm who found the answer to the questions raised concerning the work of Davy and Ampere. Though he had none of the recently developed tools to work with he cleverly improvised apparatus which would give the desired effect. After deep study and repeated experiments he settled forever the question of this distribution of the electromotive force in the circuit and also the strength of the current. So comprehensive was his knowledge of the phenomena that he was able to enunciate,[60] in 1827, the law which bears his name, and which is the keystone of all work in direct current engineering. This was done in a book in which was stated that the current in a circuit was directly proportional to the electromotive force and to the cross-section of the conductor, and inversely proportional to the length of the conductor. His book was ignored. Instead of fame and fortune, it brought its author misery and contempt. Not until 1841 was the importance of this work recognized, when the Royal Society awarded to Ohm the Copley Medal.

Michael Faraday was much more fortunate than Ohm in the matter of prompt recognition for his achievements. His early association with the great Davy placed him in a very advantageous position in announcing his discoveries to the scientific world. The searching mind of this great experimentalist was guided by his motto "It must be tried. Who knows what is possible?" He would spend years delving into the mysteries of science, making excursions into the unknown, with comprehension far beyond that of his contemporaries. And yet when a discovery was made, Faraday's explanation of it would be simple, concrete, and of such a nature as to add something practical to scientific knowledge.

Faraday had followed closely the work of Oersted and Ampere. They had obtained magnetism by means of electricity. He determined to investigate the possibilities of obtaining electricity from magnetism. As a result, mutual inductance, the phenomenon on which all transformer action is based, was discovered.[67] He was also the first to obtain continuous mechanical motion by electromagnetic means, and the first to use the terms "anode" and "cathode."

In 1838 Faraday observed that when an electric discharge is produced in rarefied air the negative electrode is covered with a glowing layer which is separated by a dark space from a glowing column extending from the positive electrode. Later this separation became known as the *Faraday dark space*. Subsequent investigation by Geissler, Plucker, Hittorf, and others, using higher vacua, but with cold electrodes, provided knowledge along the high voltage-vacuum path to the modern radio tube. Since we are confining ourselves to the approach along the high voltage-heat path (as previously stated), these phenomena will not be discussed. The student who wishes information along this line of research is advised to consult the work of Thomson,[68] Townsend,[69] and Loeb,[70] is which this branch of development is discussed at length.

Wilhelm Weber spent a long and industrious life adding to the knowledge of electricity. We have seen the work of brilliant men elsewhere in Europe making great strides in this field. Weber, to whom order was Heaven's first law, began his career by carefully studying what had been done by others. He summarized their work and proceeded to utilize the principles which they had enunciated. He devised more and better measuring instruments, which are the tools of the scientist. Among his achievements may be listed[71] the earth inductor and the electrodynamometer, the latter of which is the fundamental measuring instrument for all low frequency alternating current work. The accuracy of his measurements on newly discovered phenomena was such as to provide in the science of electricity a picture of harmony in which no gap remained. From the exact measurements of Weber stemmed the mathematical development of the electromagnetic theory, first worked out by James Clerk-Maxwell. Weber was also the first to define *unit current* and *unit tension*.

What was being done in America during these years of industrious investigation in Europe? Almost a century after Franklin we find the brilliance of another American star rising in the firmament of this science. Space does not permit us to go into detail concerning the work of the man after whom the unit of inductance was named. Suffice it to say that Joseph Henry constructed[72] the first electric motor embodying an electromagnet and a commutator. He discovered[73] the property of self-induction of an electric circuit, and produced currents in distant circuits by means of an oscillatory discharge.[74] It was from Henry that S. F. B. Morse learned how to make electromagnets for his telegraph. Henry also showed how to properly proportion the coils of a mutual inductance so as to give voltage step-up or step-down, which is to say that he began the work on transformer theory.

With the tools which had thus been developed by workers from all parts of the scientific world, let us see what progress was made in the science of thermionics.

REFERENCES

36. Swammerdam, Jan: "Biblica naturae; sive historia insectum—." Leyden, 1737-8, p. 839.

37. Sulzer, Johann Georg: "Nouvelle theorie des plaisirs—." 1767, p. 155.

38. Alibert, Jean Louis: "Eloges historiques de Galvani." Memoires de la Societe Medicale d'Emulation de Paris." Vol. 4. Paris about 1802.

39. Galvani, Luigi: "De viribus electricitatis in motu musculari, Commentarius." Bologna, 1791.

40. Potamian, Brother, and Walsh, James J.: "Makers of electricity." New York, 1909, p. 175.

41. Volta, Alessandro: "Account of some discoveries made by Mr. Galvani of Bologna, with experiments and observations on them. In two letters from Mr. Alexander Volta, F.R.S., Professor of Natural Philosophy at the University of Pavia, to Mr. Tiberius Cavallo, F.R.S." Philosophical Transactions of the Royal Society of London, 1793, part 1, pp. 10-26 and 27-44. Read on January 31, 1793. Letters are dated September 13, 1792, and October 25, 1792. See also Philosophical Magazine, 1st series, vol. 7, (Sept.) 1800, pp. 289-311.

42. Volta, Alessandro: "On the electricity excited by the mere contact of conducting substances of different kinds. In a letter from Mr. Alexander Volta to the Rt. Hon. Sir Joseph Banks." Phil. Trans. Roy. Soc., 1800, part 2, No. 17, pp. 403-432. Letter dated March 20, 1800.

43. Nicholson, William, and Carlisle, Anthony: "Account of new electrical or galvanic apparatus of Sig. Alex. Volta, and experiments performed with same." Journal of Natural Philosophy, Chemistry and the Arts, (Nicholson's Journal) vol. 4, (July) 1800, pp. 179-187. See also Phil. Mag. 1st series, (Sept.) 1800, pp. 337-3.

44. Davy, Sir Humphrey: "The Collected Works of Sir Humphrey Davy."

45. Erman, Paul: "Ueber die fünffache Verschiedenheit der Korper im Ruksicht auf galvanisches Leitungsvermogen." Annalen der Physik (Gilbert), vol. 22, 1806, pp. 14-50. See also Journal de Physique, vol. 44, p. 121.

46. Brande, William T.: "On some new electrochemical phenomena." Phil. Trans. Roy. Soc., 1814, pp. 51-61.

47. Desormes and Hachette: "Memoire pour servir a l'histoire de cette partie de l'electricite qu'on nomme Galvanisme." Annales de Chimie, vol. 44, 1802, pp. 267-284. See also Biot, Annales de Chimie, vol. 47, pp. 5-45.

48. De Luc, J.: "Analysis of the Galvanic Pile—Part 2." Nicholson's Journal, vol. 26, (August) 1810, pp. 242-272.

49. Children, John George: "An account of some experiments, performed with a view to ascertaining the most advantageous method of constructing a voltaic apparatus, for the purpose of chemical research." Phil. Trans. Roy. Soc., 1809, part 1, pp. 32-38. Paper read November 24, 1808. See also Phil. Mag., vol. 34, pp. 26-30.

50. Children, John George: "An account of some experiments with a large voltaic battery." Phil. Trans. Roy. Soc., 1815, pp. 363-374. See also Phil. Mag., 1815, part 2, vol. 42, pp. 144-145.

51. Bostock, John: "An account of the history and present state of galvanism." London, 1818, p. 98.

52. de La Rive: Memoires de la Societe de Physique (et d'Histoire Naturelle) de Geneve, vol. 3, p. 117.

53. Sturgeon, William: "Voltaic batteries with amalgamated zinc." Annals of Electricity (Sturgeon), vol. 1, (January) 1837,

THE SAGA OF THE VACUUM TUBE

by GERALD F. J. TYNE
Research Engineer, N. Y.

Part 3 of this series covering the Edison era, illustrating many of his outstanding inventions and the problems encountered.

IN 1851 Professor Heinrich Buff, of the University of Geissen, published a paper[75] on the electrical conditions existing in flames. He came to the conclusion that gaseous bodies which have been rendered conductive by strong heating are capable of exciting other conductors, solid as well as gaseous, electrically. At that time the incandescent lamp was far in the future, and the experiments reported were made using two small strips of platinum introduced into a glass tube which was closed at one end. Experiments involving heating the tube even to the softening point of the glass gave a negative result, but when the strips of platinum were exposed to the direct action of the flame of a spirit lamp, a current flowed between the strips, the flow being from the hotter of the two strips toward the colder.

Edward Becquerel, illustrious son of an illustrious father, in 1853 began a study of the electrical conductivity of gases. His method was to apply heat externally to a platinum tube, down the axis of which were stretched two parallel platinum wires, maintained at a difference of potential by a low voltage battery. This procedure was varied in some cases by using the tube as one electrode and a platinum rod placed axially in the tube, and supported at one end, as the other electrode. From his experiments with this apparatus, and the measuring equipment which had been developed by the work of the men of whom we have previously spoken, he came to the following conclusions:[76, 77, 78]

(1) Gases become conductors only at or above the temperature corresponding to red heat, and as the temperature increases so does the conductivity.

(2) At such temperatures they are conductors even when a low voltage is applied.

(3) The relative dimensions of the electrodes have an effect on the conductivity of the gas, the conductivity increasing rapidly with the surface of the negative electrode.

(4) The resistance of the gas varies with the applied voltage, and with the current through it, that is, it does not obey Ohm's law.

(5) Below red heat the pressure of the gas has little effect, there being no conduction at low voltages. Above red heat rarefaction of the gas increases the conductivity.

We know now that these effects noted by Becquerel were due not alone to the fact that the gas was heated, tending to produce ionic conductivity, but also to the fact that the electrodes were heated, whereby thermionic emission was taking place. The results attained by Becquerel do not seem to be widely known, as little credit is given to him in later treatises on the conduction of electricity through gases.

Gustav Wiedemann refused to concede the possibility of gaseous conduction and attempted[79] to explain away Becquerel's results by attributing them to changes in the conductivity of the cement used in sealing the electrodes in place. Blondlot, in 1881, confirmed[80] the results of Becquerel and disproved the contention of Wiedemann.

Fredrick Guthrie, in 1873, repeated Nollet's procedure of more than a century before, of heating iron white hot and testing it for discharging power as it cooled. He found[81] that at white heat an iron ball would retain neither a positive nor a negative charge of electricity, but that at red heat it could retain a negative charge but not a positive one.

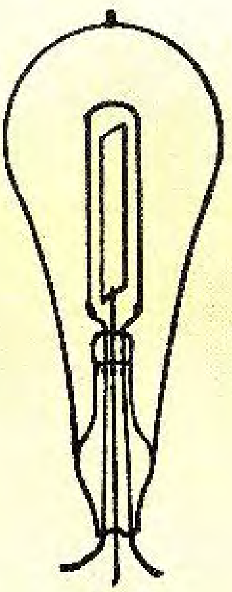


Fig. 7.

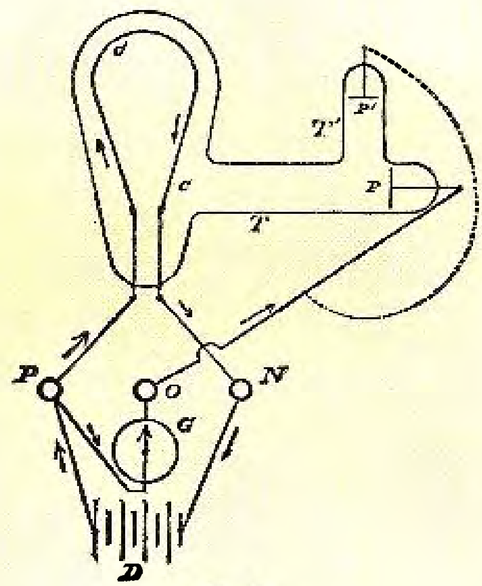


Fig. 8.

The Edison Effect

In 1879 Thomas A. Edison finally succeeded in "subdividing the electric light" when he brought the incandescent lamp to commercial practicability. He was still at work perfecting it

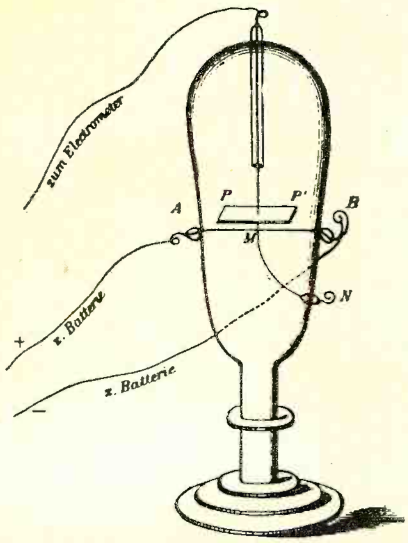


Fig. 9.

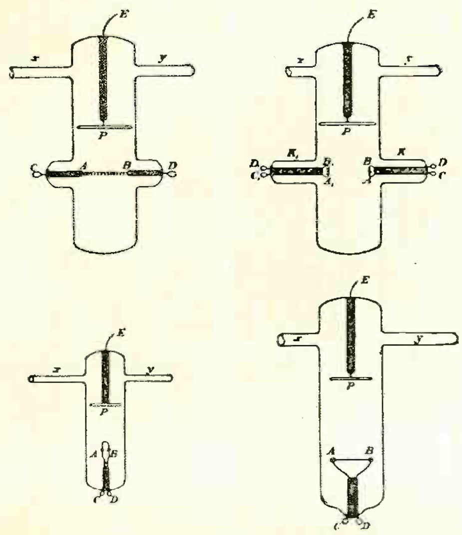


Fig. 10.

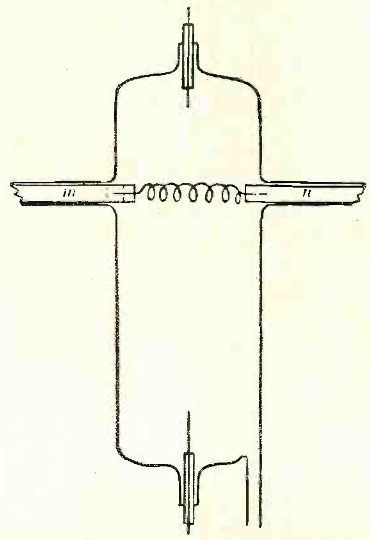


Fig. 11.

some four years later, when he observed and recorded the phenomenon which received the name of the *"Edison effect."*

During his experiments he observed that as the time of operation of his incandescent lamp increased, the light output was reduced by a blackish deposit on the interior of the glass bulb.

In the course of his investigations he noted two other things which were of great importance. The first was that there was frequently to be found on the glass, in the plane of the filament, a line which was not blackened. The second, and this was the more important of the two, was that the leg of the filament which was connected to the positive pole of the circuit was always that which "cast the shadow." It appeared that the opposite side, which was connected to the negative pole, was throwing off minute particles of filament material which traveled outwards and were deposited on the glass everywhere except where the glass was screened by the positive leg of the filament.

In order to study this effect more in detail, Edison had constructed some lamp bulbs containing filaments and, in addition, small metallic shielding plates placed between the legs of the filament. He found [82] that if this plate was connected to the positive end of the filament a current would flow across the vacuous space, but that no current would flow if it were connected to the negative end.

Seemingly the only use which Edison could imagine for this device was as an indicator to show variations of potential on the lighting circuit. In his patent application,[83] filed November 15, 1883, for an "Electrical Indicator," the lamp apparatus used is shown in Figure 7. In this application, however, there is to be found this very significant clause concerning the current across the vacuous space—"This current I have found to be proportional to the degree of incandescence of the conductor or the candle power of the lamp."

Probably because of the work involved in the introduction of the incandescent lighting system, Edison did not have time to carry on further experiments. Even had he done so, and evolved a *"valve"* he would have been at least ten years ahead of his time.

The publication of the *"Edison effect"* aroused interest in many places. In the first paper printed in the first volume of the Transactions of the American Institute of Electrical Engineers, Professor Edwin J. Houston gave "Notes on Phenomena in Incandescent Lamps." In this paper [84] Professor Houston referred to the "peculiar high vacuum phenomena observed by Mr. Edison in some of his incandescent lamps." He then went on. *"The question is, what is the origin of this current? How is it produced? Since we have within the globe nearly a complete vacuum, we cannot conceive the current as flowing across the vacuous space, as this is not in accordance with our preconceived ideas connected with high vacua."*

Professor Houston described another of Mr. Edison's experiments which appeared to throw no little light on the matter. The apparatus used in this experiment is shown in Figure 8 (which is Figure 3 of Houston's paper). Instead of placing the cold electrode between the legs of the filament, as had previously been done, he placed two cold electrodes as shown at "P" and "P1." Edison found that if the galvanometer was connected to the plate "P" as shown by the solid line, a

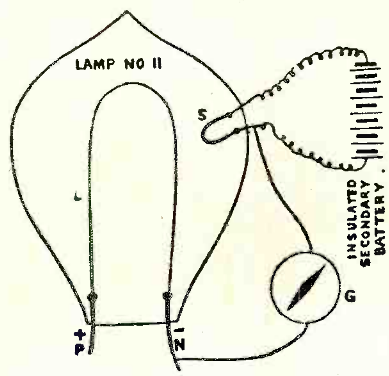


Fig. 12.

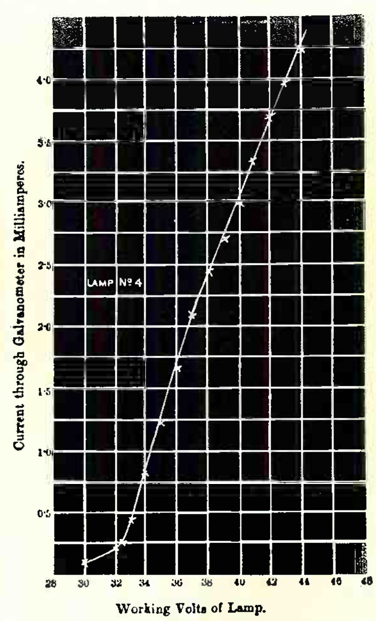


Fig. 13.

current flowed through it, but that this was not the case when it was connected as shown by the dotted line, to "P¹." Apparently the current could not flow around a corner.

Among those present, and taking an active part in the discussion which followed the reading of this paper was Sir William Preece, who was extremely interested in the new phenomena. He announced that he intended to exercise his persuasive eloquence upon Mr. Edison to induce Mr. Edison to give him one of these lamps and said:

"When I go back to England I shall certainly make an illustration before our society there, and then make careful inquiry into it."

How he succeeded and what he did will be seen later.

Let us now return for a while to Germany. Julius Elster and Hans Geitel, beginning about the year 1880, pursued a series of investigations in that country. The results of these researches were reported in a series of articles beginning in 1882. The first four of these articles [85] deal with the characteristics of flames, particularly with reference to their unsymmetrical conductivity, and in part confirm the earlier work done along these lines. The fifth article [86] which appeared in 1887 is entitled "On the Electrification of Gases by Glowing Bodies." In this article experiments were described involving the use of a glass bulb, which could be exhausted or filled with various gases. Across the inside of this bulb was stretched a platinum wire which could be heated electrically. See Figure 9. Opposite this wire, and very close to it, was placed a platinum plate suspended by a leading-out wire. The vacuum used was described as "the best possible—such as Crookes used in his famous experiments." The results of these experiments of Elster and Geitel indicated that *"Electrified Particles"* were thrown off from the glowing wire uniformly in every direction and that the conductivity was unilateral.

The next paper,[87] published in 1889, is entitled "On the Excitation of Electricity when Galvanically Glowing Wires come in Contact with Heated Gases." In this paper various experiments were described involving the use of glowing platinum wires and glowing carbon filaments in exhausted bulbs, with cold electrodes of platinum placed at various distances from the glowing members. Mention is made of the fact that the carbon filament always excites the cold electrode negatively. The bulbs were so constructed that they could be placed within the poles of a magnet of the horse-shoe type, and the effect of the magnet on the apparent conductivity of the vacuous space was noted.

In the latter part of this paper a theory, first enunciated by A. Schuster, is used to explain the unipolar conductivity. This theory is based on the dissociation of the gas molecules by contact with the glowing body. It is interesting to note that in this paper Elster and Geitel acknowledge that their work was made possible by a grant of American funds, provided by the Elizabeth Thompson Science Fund of Boston.

The last paper of this series was published [89] in 1889 and describes further experiments with various other tubes of the forms shown in Figure 10.

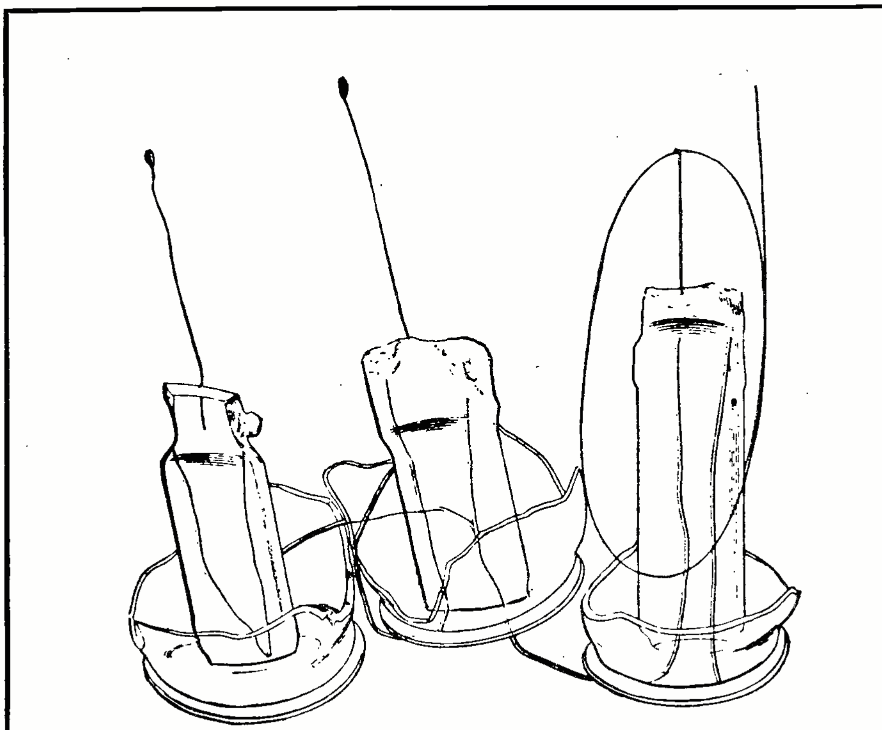


Fig. 14.

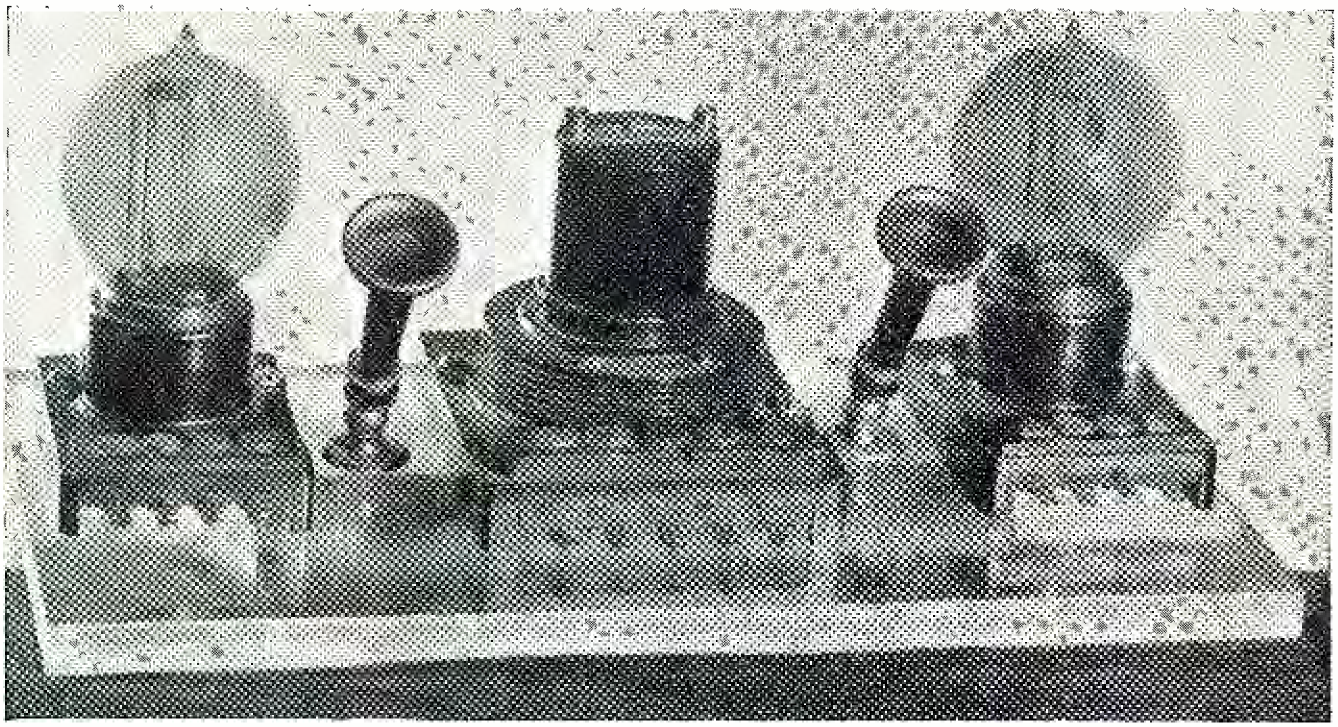
While Elster and Geitel were conducting their investigations another German scientist, William Hittorf, had been for some time working on gaseous conduction. In his work Hittorf made use of high voltages, developed from a large number (2400) Bunsen cells connected in series. This gave about 4000-4500 volts, with which he could observe phenomena of the type seen in the days of static electricity, but which he could reproduce at will, and sustain long enough to permit of taking accurate observations. Hittorf's first paper "On the Conduction of Electricity in Gases" appeared [90] in 1869, his second [91] in 1874, his third [92] in 1879, and his fourth [93] in 1883. In these papers Hittorf describes his work on conduction in rarefied gases, using cold electrodes. It is in his fifth paper, which appeared [94] in 1884, that we first find reference to the use of a cathode which was heated by external means. The apparatus used is shown in Figure 11. He was led to the use of this cathode by the difficulties he experienced with the evolution of gas from the electrodes previously used.

These electrodes became hot, owing to the high energies of the gaseous discharge and the occluded gases which were released impaired the vacuum and affected the discharge. To obviate this difficulty he used a cathode which could be maintained at a high temperature by means which were independent of the discharge. Hittorf's publications are dry, almost repulsive, reading and their value was buried deep in the mass of experimental data which he reported.

The experiments which he performed were essentially those of Becquerel, except that he used higher voltages and better vacua and was able to heat one electrode at a time. He observed that when the spiral platinum cathode was brought to or above a red heat, the conductivity of the gaseous space rose rapidly with the increase of cathode temperature, and that a similar condition was observed if the cathode were made of carbon. He noted [95] (as Becquerel had previously done) that the conductivity increased as the pressure of the gas was lowered.

He also noted that even with the cathode heated by means of an external auxiliary battery it was necessary, in order to maintain the vacuum, to continuously remove, by means of the pump, the gases given off. He observed that the current flowed only when the heated electrode was used as a cathode, at low voltages, that is, that the conductivity of the space was unilateral at those voltages. In this he went a step further than Becquerel, who could not have made such an observation since, due to his experimental arrangement, both his electrodes were heated.

Having thus followed the progress of investigation in Germany up to about 1890, let us now return to England. Early in 1882, after the formation of the Edison Electric Light Com-



A rather odd but interesting desk set made up of Western Electric antique tubes and sockets.

pany of London, John Ambrose Fleming (later Sir John Ambrose Fleming) was appointed electrical adviser to the company. He was thus brought into close touch with the many problems which arose in the use of incandescent lamps. He, like Edison, soon noted that when carbon lamps were blackened in service there sometimes was found on the glass, at a point opposite where the filament had finally burned out, a lighter deposit of the black material than was to be seen elsewhere on the glass.

This he termed a *"Molecular Shadow."* His first mention of it comes in a paper read before the Physical Society of London on May 26, 1883.[96] In this paper he observes that the shadow is found only where there is a copper deposit on the inner surface of the glass bulb, never with the ordinary carbon deposit. This paper was a short one, more or less of a summary, to precede a full discussion. The full discussion, however, did not appear until some two years later, on June 27, 1885,[97] which was some time after the discovery of the Edison effect had been announced. In this latter paper he notes that in some cases where only carbon deposit existed he observed the same molecular shadow as in the case of the copper deposit, wherever both legs of the filament were in the same plane, and the filament had burned out due to the development of a hot spot.

Meantime Sir William Preece had returned from America with the fruits of his "persuasive eloquence" in the form of some of Edison's lamps. With these lamps he proceeded to duplicate the experiments he had observed in America and make quantitative measurements of the Edison effect. The results of these experiments were presented to the Royal Society in 1885.[98]

The paper opens by describing the experiments he had witnessed in America and then goes on to describe his own work using Edison's lamps. It is in this paper that we first find mention of *"blue glow"* or *"blue effect"* (due to the ionization of the residual air) which defied explanation for a long time. This appeared when the lamps were operated somewhat above their rated voltage. In the presence of this *blue glow,* Preece observed that current could be made to flow not only from cold to hot electrode, but also in the reverse direction.

He observed that the current was unaffected by the material of which the cold electrode was composed, but increased rapidly with increasing potential across the lamp. That is, he confirmed Edison's observation that this effect was proportional to the degree of incandescence of the lamp, as stated in his patent which had previously been issued.

On February 14, 1890, Fleming gave a Friday evening discourse before the Royal Institution on "Problems in the Physics of an Electric Lamp."[99] He again discussed *molecular shadows* and the reason for their formation. He also reviewed the work of Preece and repeated his experiments. In addition he showed that a single Clark cell would cause a flow of current across the vacuous space if the positive pole of the cell was connected to the cold electrode, but that if the battery was reversed there was no flow of current. This was in agreement with the results attained by Hittorf in 1884, who showed that even a small voltage was sufficient to send a current across the vacuous space, provided the cathode was a high temperature and the positive pole of the battery was connected to the cold electrode (plate).

Fleming also showed that if the cold electrode is heated to incandescence then the current may be made to flow, by the use of the external battery, in either direction through the vacuous space. Fleming did this by means of the apparatus shown in Figure 12. It should be remembered that this same conclusion was reached by Becquerel, with somewhat poorer vacua, in 1853.

These investigations were carried still further and resulted in another paper before the Physical Society of London on March 27, 1896, and entitled "A Further Examination of the *Edison-Effect* in *Glow Lamps*."[100] In this paper Fleming repeated some of the quantitative experimental work previously done by Preece and gave a curve (See Figure 13) which showed the relation between the potential across the lamps, and the current through the vacuous space. He also announced that even if alternating current was used to heat the filament, that a unidirectional current was obtained in the cold electrode circuit.

The last important work prior to the application of the vacuum tube as a rectifier of high frequency oscillations in wireless telegraphy is recorded in a paper given before the A.I.E.E. in February, 1897, by John W. Howell.[101] This paper was intended as a discussion of the paper by Houston, previously mentioned. It discusses the *Edison-effect* phenomena which occur in lamps when the *"blue glow"* is pronounced, and states that the presence of the blue glow indicates the passage of electric current across the vacuous space. This paper is remarkable in that it is the first to show that currents of more than a few milliamperes may be made to flow across the space

(*Continued on page* 75)

substantial reason for adopting "electronic" as an American all-inclusive term for radio.

Scientists and engineers who have used such care in coining contemporary terms as neutron, magnetron, iconoscope, photo, etc., when they realize the confusion that is now occurring will want to do something about it. Remember, this is the same type of confusion as that between "radio" and "wireless."

We are not in doubt. "Radionics" is descriptive of the scope of this science, and, therefore, RADIO NEWS will use "radionic" in preference to "electronic" wherever it is more descriptive.

There may be exceptions where the term "electronic" is used as a trade name or in a direct quotation from an engineering paper, etc. However, with these possible exceptions, "radionics" will be used in the future by this publication.

RECEIVERS that will see, hear and print were predicted for the post-war era by *James L. Fly,* Chairman of the F. C. C. He said that while such a device may seem to be an impossibility now, present developments appear to make the design of a combination television, facsimile and broadcast receiver entirely feasible. Said Mr. Fly, in explaining the prediction . . . "There will be only one service, and separate television. Standard, F.M., facsimile services and separate receivers will all be washed out. I would conjecture that such an instrument will be based upon the best of the developments we have had to date and those that we get out of the war, and it will be a chain operation carried on by relay. Relay problems are pretty well licked now. We have been in the horse-and-buggy days up to now."

That's quite a strong prediction, but it isn't as fantastic as it may sound!

WHICH reminds us, how are so-called radio servicemen to be classified in the days to come? What with new services and new techniques, it seems that some serious thinking should be done by those keenly interested in making their living in the radio industry from the service standpoint and that they decide now as to which phase or portion of the art will offer the greatest personal appeal.

After this decision is made it would be advisable to obtain as much knowledge of that field as possible. There will be hundreds of new radionic and other gadgets, new television receivers, etc., that must be serviced intelligently by someone. Only by carefully planned study, can the serviceman of tomorrow be recognized!

AS we go to press with this issue, we continue the interesting task of preparing our June issue which we believe will be the most outstanding presentation ever made on the activities of the various branches of Aviation Communications. Among the many specially prepared feature articles will be included factual data by the U.S. Army Air Forces, Navy, Marine Corps, Coast Guard, Civil Aeronautics Administration, and the Civil Air Patrol. In addition, there will be a complete analysis of the part that the radio Industry is playing to supply the aviation services with vital equipment. Never before in our history have we found a closer cooperation between Industry and our Military Branches.

One of the highlights of the June issue will be the appearance of an exact replica of the famous *McElroy* code chart which includes every known code, Arabic, Russian, International Morse, American Morse, Japanese, Spanish, Flag Signals, "Q" Signals, and many others. Printed in color—this chart will be well worth keeping by every reader of this important issue.

73, OR. . . . —30—

Saga of the V.T.

(*Continued from page* 29)

at moderate voltages. Howell states that he had measured vacuous currents in an ordinary carbon incandescent lamp, of more than *25 amperes,* which were sufficient to expand the platinum lead-in wires and shatter the glass.

The effects obtained are shown in Figure 14, which is reproduced from Howell's paper. He also showed that in the presence of the *"blue glow"* the Edison-effect current will flow around corners. In the discussion of this paper, Professor A. E. Kennelly said, "It is interesting to observe that a vacuum tube, in the broadest sense of the word, is capable of supplying . . . continuous currents from alternating currents."

Up to this time, it is to be noted, no one except Edison had shown any technical application of the *Edison-effect.* It is probable that Edison did so primarily for the purpose of obtaining patent protection, although Frank J. Sprague, in a letter to William J. Hammer, dated December 27, 1883,[102] praises the arrangement as an extremely sensitive indicator of small changes in voltage at the operating potential of the lamps.

With these experiments we have reached the end of the pure scientific investigation alone in this field. Inventors, making use of this knowledge, were responsible for the next step in development.

This might naturally be expected with the increase in the pace of living. Man's rapidly increasing demands could not wait for complete knowledge before insisting upon practical applications. Man stated his objective, and electrical experts proceeded to clear the path toward that objective.

INDEX TO FIGURE NUMBERS

Fig. 7. Drawing of Edison effect lamp. Reproduced from U.S. Pat. No. 307031, issued October 21, 1884.

Fig. 8. Edison effect lamp used by Prof. Houston. Reproduced from Trans. A. I. E. E. 1884.

Fig. 9. Tube used by Elster and Geitel in 1887. Reproduced from Annalen der Physik, 1887.

Fig. 10. Tubes used by Elster and Geitel to demonstrate unilateral conductivity. Reproduced from Annalen der Physik, 1889.

Fig. 11. Tube used by Hittorf to demonstrate unilateral conductivity. Reproduced from Annalen der Physik, 1884.

Fig. 12. Tube used by Fleming to demonstrate bi-directional conductivity as unidirectional conductivity. Reproduced from Phil. Mag. 1896.

Fig. 13. Curve showing relation between Edison effect current and lamp voltage. Reproduced from Phil. Mag. 1896.

Fig. 14. Incandescent lamp stems which have been subjected to space currents of 25 amperes. Reproduced from Trans. A. I. E. E. 1897.

REFERENCES

75. *Buff, Heinrich: "Ueber die Electrische Beschaffenheit der Flamme." Justus Leibig's Annalen der Chemie und Pharmacie, vol.* 80, 1851, *pp.* 1-16. *See also National Telegraph Review and Operators Companion, New York, Vol.* 1, *No.* 2, 1853, *p.* 161. *See also Telegraph and Telephone Age, October* 1, 1919, *p.* 484.

76. *Becquerel, Edmond: "Recherches sur la conductibilite electrique des gaz à des temperatures elevees." Comptes Rendus, vol.* 37, 1853, *pp.* 20-24.

77. *Becquerel, Edmond: "Recherches sur la transmission de l'electricite au travers des gaz a des temperatures elevees." Annales de Chimie, vol.* 39, 1853, *pp.* 355-402.

78. *Becquerel, Edmond: "Note sur la passage des courants electriques au travers des gaz incandescentes." Comptes Rendus, vol.* 65, 1867, *pp.* 1097-1099.

79. *Wiedemann, Gustav: "Die Lehre vom Galvanisimus und Electromagnetisimus." Brunswick,* 1861, *pp.* 208-209.

80. *Blondlot, Rene: "Sur la conductibilite voltaique des gaz echauffes." Comptes Rendus, vol.* 92, 1881, *pp.* 870-972.

81. *Guthrie, Fredrick: "On a relation between heat and electricity." Phil. Mag., 4th series, vol.* 46, 1873, *pp.* 257-266. *Abstracted in Proceedings of the Royal Society of London, vol.* 21, 1873, *pp.* 168-169.

82. *Edison, Thomas A.: Engineering, December* 21, 1884, *page* 553.

83. *Edison, Thomas A.: U. S. Patent No.* 307031, *issued October* 21, 1884.

84. *Houston, Professor Edwin J.: "Notes on phenomena in incandescent lamps." Transactions of the American Institute of Electrical Engineers, vol.* 1, 1884, *pp.* 1-7.

85. *Elster, Julius and Geitel, Hans: "Ueber die Electricität der Flamme." Annalen der Physik, und Chemie, N.F., vol.* 16, *No.* 6, 1882, *pp.* 193-222. *"Ueber Electricitätserregung beim Contact von Gasen und glühenden Körpern." Ann. der Phys., N.F., vol.* 19, *no.* 8*A*, 1883, *pp.* 588-624. *"Ueber die Electricität der Flamme." Ann. der Phys., N.F., vol.* 22, *no.* 9, 1884, *pp.* 123-128. *"Ueber die unipolare Leitung erhitzen Gase." Ann. der Phys., N.F., vol.* 26, *No.* 9, 1885, *pp.* 1-9.

86. *Elster, Julius and Geitel, Hans: "Ueber die Electrisirung der Gase durch glühende Körper." Ann. der Phys., N.F., vol.* 31, *no.* 5, 1887, *pp.* 109-126.

87. *Elster, Julius and Geitel, Hans: "Ueber die Electricitätserregung beim Contact verdünnter Gase mit galvanische glühenden Drahten." Ann. der Phys., vol.* 37, 1889, *pp.* 315-329. *This is an abridgement of a paper in Wiener Berichten,* 97, *Abth.* IIa, *October* 1888, *p.* 1175.

88. *Schuster, A.: "Experiments on the discharge of electricity through gases." Proc. Roy Soc. London, vol.* 37, 1884, *pp.* 317-339. *See also Scientific American Supplement, vol.* 18, *no.* 451, *August* 23, 1884, *pp.* 7201-7202.

89. *Elster, Julius and Geitel, Hans: "Einige Demonstrationversuche zum Nachweis einseitiger Electricitätsbewegungen im verdünnten Gasen bei Anwendung gluhender Electroden." Ann. der Phys., vol.* 38, 1889, *pp.* 27-39.

90. *Hittorf, William: "Ueber die Electricitätsleitung der Gase." Ann. der Phys. (Poggendorf), vol.* 136, 1869, *pp.* 1-31, *and* 169 *et seq.*

91. *Hittorf, William: Jubelband,* 1874, *p.* 430.

92. *Hittorf, William: "Ueber die Electricitätsleitung der Gase." Ann. der. Phys., (Wiedemann), vol.* 7, 1879, *pp.* 553-631.

93. *Hittdorf, William: "Ueber die Electricitätsleitung der Gase." Ann. der Phys., (Wiedemann), vol.* 20, 1883, *pp.* 705-755.

94. *Hittdorf, William: "Ueber die Electricitätsleitung der Gase." Ann. der Phys., (Wiedemann), vol.* 21, 1884, *pp.* 90-139. *See also "Physical Memoirs" issued by the Physical Society of London, vol.* 1, *p.* 180.

95. *Hittdorf, William: See reference* 89, *Sections* 90-92, *pp.* 133-136.

96. *Fleming, John Ambrose: "On a phenomena of molecular radiation in incandescent lamps." Phil. Mag., vol.* 16, 1883, *pp.* 48-49.

97. *Fleming, John Ambrose: "On molecular shadows in incandescent lamps." Phil. Mag., vol.* 20, 1885, *pp.* 141-144.

98. *Preece, Sir William: "On a peculiar behaviour of glow lamps when raised to high incandescence." Proc. Roy. Soc. London, vol.* 38, 1885, *pp.* 219-230.

99. *Fleming, John Ambrose: "Problems in the physics of an electric lamp." Proc. of the Royal Institution, February* 14, 1890. *See also Sci. Am. Supp., vol.* 30, *no.* 764, *August* 23, 1890, *pp.* 12204-12206.

100. *Fleming, John Ambrose: "A further examination of the Edison effect in glow lamps." Proc. Physical Society of London, vol.* 14, 1896, *p.* 187. *See also Phil. Mag., vol.* 42, 1896, *pp.* 52-102.

101. *Howell, John W.: "On the conductivity of incandescent carbon filaments and the space surrounding them." Trans. A.I.E.E., vol.* 14, 1897, *pp.* 27-53. *Abstracted in Electrical World, February* 20, 1897, *pp.* 253-254.

102. *Sprague, Frank J.: Letter to W. J. Hammer, dated December* 27, 1883. *Electronics, vol.* 6 *(January),* 1933, *p.* 15.

(To be continued)

Electronic Drive

(Continued from page 12)

similar application is that of synchronizing the speed of conveyors with that of a material in a plastic state as it emerges from an extruding machine, and for maintaining a fixed relationship between two or more conveyors which must handle the same material. Numerous applications of this type may be found in the rubber industry.

Electrical Feed-back Arrangement

Where speed regulation is an essential factor, the electrical feed-back arrangement, utilizing a pilot generator with a suitable circuit, makes it possible to hold the speed of a motor very nearly constant over a wide range of loads.

As in the mechanical arrangement, a full-wave rectifier is used, but a saturable reactor instead of a movable core reactor varies the output of the voltage on the motor.

Full Automatic Control (Thy-mo-trol)

Experience with the type of equipment just described has resulted in the development of the Thy-mo-trol system by General Electric. This control in combination with a suitable motor provides a variable-speed drive with features which are not ordinarily found in other conventional drives.

This electronically controlled motor drive was not developed with the idea that it can or will supplant the various other types of mechanical and electrical drives in use today, where such

THE SAGA OF THE VACUUM TUBE

by GERALD F. J. TYNE
Research Engineer, N. Y.

Part 4 covering the development of communications for wireless telegraph, using thermionic tubes for the first time.

WHILE the work we have been describing was proceeding, the development of the then infant branch of the communications art, the wireless telegraph, was being carried on steadily. Since the earliest utilization of thermionic tubes was in wireless telegraphy, let us see how the two paths of thermionics and communication converged and formed the highway to the modern field of radio. The road thus formed led to the invention of communication systems on which, at the present time, the very security of the American way of life depends. All the knowledge of electromagnetism, heat, and vacua were brought together to solve the problems of converting the high frequency oscillations into sound.

In 1899, John Ambrose Fleming became a technical adviser to Marconi and in 1900 started assisting him in preparations for the experiments which were to lead to the establishment of transatlantic wireless telegraph communication, first in the matter of the transmitting apparatus and later as regards the receiving devices. In those days the only detector of wireless telegraph signals was of the contact type coherers, microphones, and the like. The mechanical delicacy and erratic behavior of such devices led Marconi to develop the Magnetic Detector that proved to be reliable and stable and not to be thrown out of adjustment by the operation of nearby transmitters, but on the score of sensi-

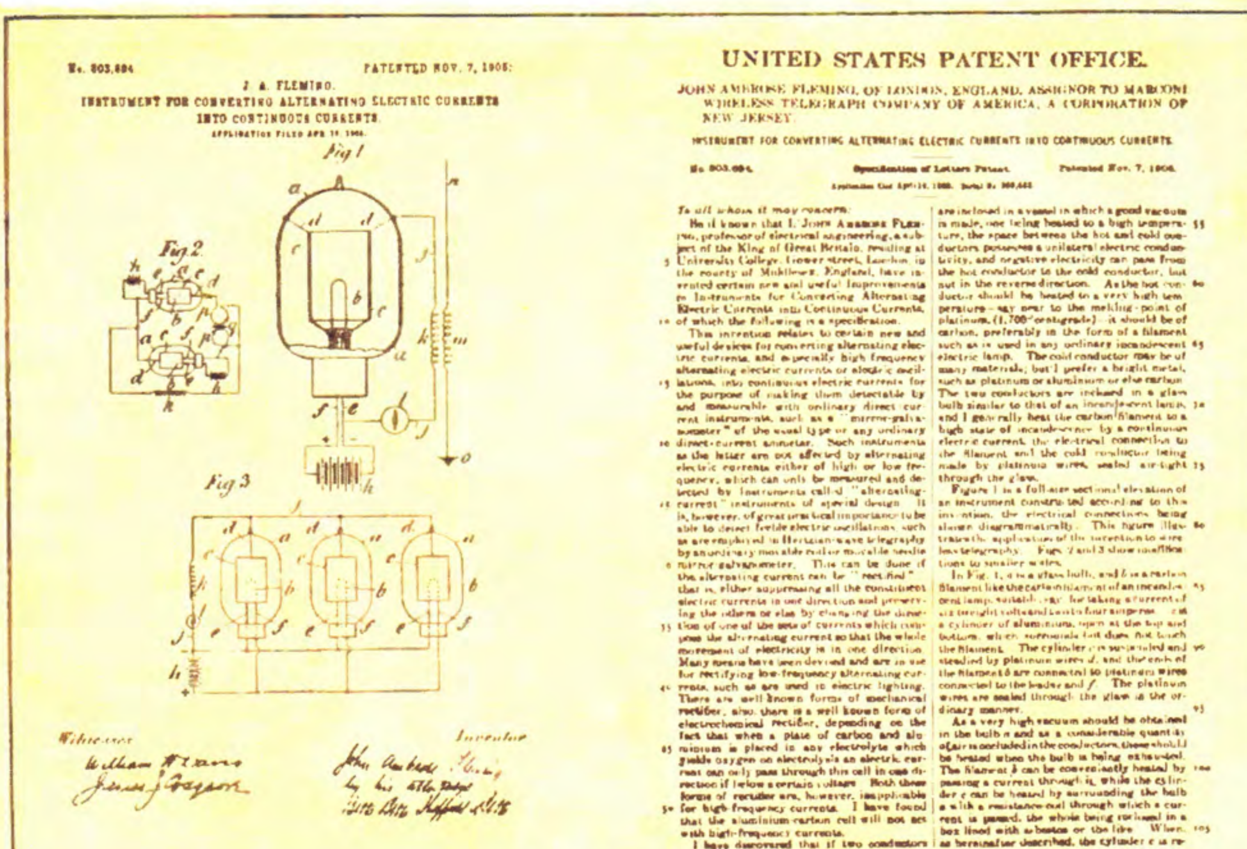


Fig. 15. One of the earliest patents of John Ambrose Fleming.

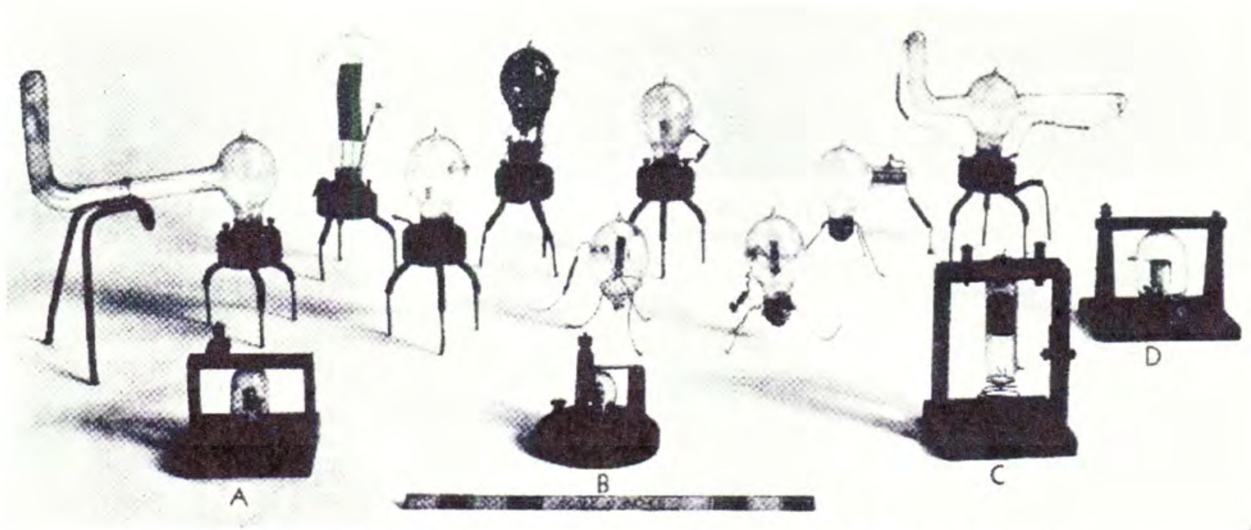


Fig. 16. Group of Fleming valves preserved in the Science Museum at South Kensington, England.

tivity it left much to be desired. In wireless the receiver continued to be a weak element of the system, so that one of the problems which Fleming set himself was that of developing a new type of detecting device. Since he was the victim of a progressive deafness he sought a device which would be capable of operating a recording mechanism, so that the signals might be fixed to be later translated by eye rather than by ear.

The most sensitive current indicating device in use at that time was the d'Arsonval type of mirror galvanometer, which operates only on unidirectional currents. Consequently, Fleming set about finding some means of utilizing this sensitivity, and realized that he needed some device which would act as a rectifier for the incoming high frequency oscillations, in order to have them actuate this type of galvanometer. At that time the available commercial rectifiers were of the electrolytic variety, such as the "Nodon" type. Fleming tried to use these arrangements for the rectification of high frequency oscillations but found them inoperative. This may have been due to the high capacitance of the electrolytic cells, or the fact that their chemical action was too slow. At any rate, he was unsuccessful in their use. Then Fleming did the thing which has so often produced revolutionary developments in many fields. He drew on the knowledge which he had gained by experiment in a totally different field, that of the incandescent lamp. He recalled to mind the work he had done many years before on the Edison effect, and decided to find out by experiment whether the known unidirectional conductivity of the vacuous space for direct current, and its rectifying action at low frequencies, would also exist at the high frequencies of the oscillations used in wireless telegraphy.

Accordingly, in October, 1904—but let us hear his own account of the discovery:[33]

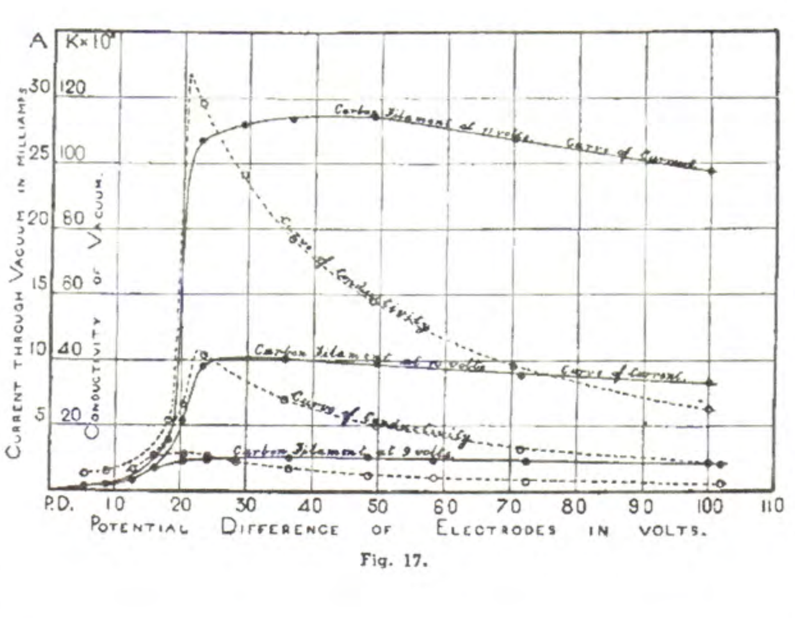


Fig. 17.

Fig. 18.

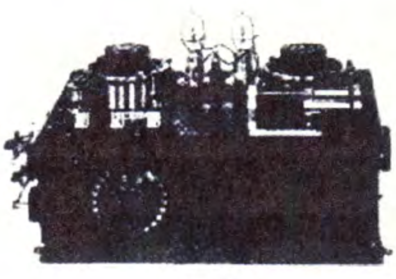


Fig. 19.

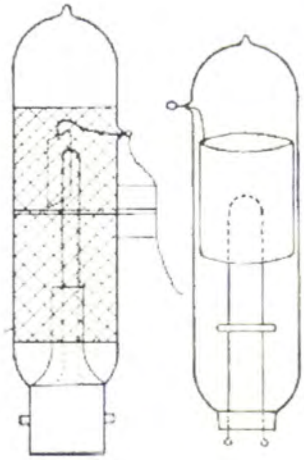


Fig. 20.

Fig. 21.

Fig. 22.

Fig. 23.

Fig. 24.

Fig. 25.

Fig. 26.

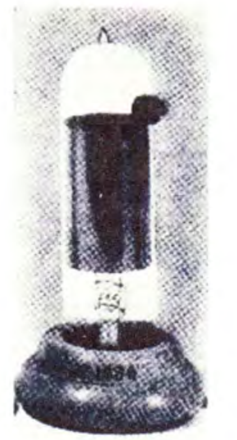


Fig. 27.

"—I was pondering on the difficulties of the problem when my thoughts recurred to my experiments in connection with the Edison effect.

"Why not try the lamps?" I thought. Then and there I determined to see if they would serve the purpose. I went to a cabinet and brought out the same lamps I had used in my previous investigations. My assistant helped me to construct an oscillatory circuit with two Leyden jars, a wired wooden frame, and an induction coil. We then made another circuit, in which we inserted one of the lamps and a galvanometer, afterward tuning it to the same frequency as the first circuit.

It was about five o'clock in the evening when the apparatus was completed. I was, of course, most anxious to try the experiment without further loss of time. We set the two circuits some distance apart in the laboratory and I started the oscillations in the primary circuit.

To my delight I saw the needle of the galvanometer indicate a steady direct current passing through, and found that we had in this peculiar kind of electric lamp a solution of the problem of rectifying high frequency wireless currents. The missing link in wireless was found—and it was an electric lamp."

Fleming gave the name *"oscillation valve"* to the Edison effect lamp as thus utilized, and today in England all types of vacuum tubes are still known as *valves*. In fact, all such electron discharge devices are, in general, considered by the British as lineal descendents of the Fleming valve.

It cannot be emphasized too strongly, however, that Fleming did not invent the device to which he gave the name "oscillation valve." What he did was to apply the Edison effect lamp, a well known device, to the rectification of high frequency oscillations. His patent was not a patent on the device, *per se*, but on the combination of that known device, with minor modifications to suit the application, and a circuit in which it functioned as a rectifier of high frequency oscillations.

Actually Fleming was not the first to use a thermionic device as a rectifier, for just ahead of him was the pure thermionic device with the oxide-coated cathode devised and patented by Wehnelt, as we shall see. Also it is hardly fair today to read the term "valve" as taken from Fleming, on the three element and multi-element tubes used in today's amplifiers, since in this role the device cannot be classed as a rectifier.

In this connection the following passage, from a British text published in 1921, is of interest:[304]

"Fleming, in 1904, utilized the Edison effect, and Elster and Geitel's apparatus in a modified form, to produce a wireless detector, rectification being brought about owing to the unidirectional conduction already mentioned—.

(Continued on page 58)

Saga of Vacuum Tube

(Continued from page 32)

The Fleming valve was purely and simply a rectifier or detector. In no way was it an intensifying device, it did not use a very high vacuum, as is the case in the modern valves of Langmuir and Meissner, and it was not a means of generating oscillations like these later valves.

Whilst Fleming must be credited as being the first to apply thermionic phenomena to wireless detection, the claim that he is alone the originator of the present-day thermionic valve is rather exaggerated, since the intensifying properties of the present-day valve are far more important than its detecting properties—."

Fleming applied for patents on the use of the valve as a detector of oscillations in wireless telegraphy, which patents were granted in Great Britain, Germany, and the United States.[108] Fleming believed that to get complete rectification it was necessary to have the best possible vacuum in the valve. In his United States patent application (See Figure 15) he stated:

"As a very high vacuum should be obtained in the bulb a, and as a considerable quantity of air is occluded in the conductors, these should be heated when the bulb is being exhausted. The filament can be conveniently heated by passing a current through it, while the cylinder c can be heated by surrounding the bulb a with a resistance coil through which a current is passed, the whole being inclosed in a box lined with asbestos or the like."

This insistence by Fleming on the obtaining of the highest vacuum possible, and the use of only one battery, the filament battery (See Figure 15), should be carefully noted by the student, for comparison with the work of de Forest on the Audion.

Figure 16 shows a group of Fleming valves of great historic importance, all of which are preserved in the Science Museum at South Kensington, England.[109] Those marked A, B, C, and D are the later types as actually used in the detection of wireless signals.

Immediately after these first experiments, Fleming had made by the Edison and Swan United Electric Company some new lamps in which the filament was of treated carbon, and of such a size that it would be brought to the operating temperature by a battery of 12 volts. These were of the types marked A, B, C, and D (Figure 16) and had a plate in the form of a sheet metal cylinder, surrounding but not touching the filament. This cylinder was fixed to a platinum wire sealed through the glass. The vacuum was pushed to the highest possible point and during the exhaust the filament and the glass bulb were heated in the manner described in Fleming's patent.

Fleming, on February 8, 1905, read to the Royal Society of London a paper[110] wherein he described experiments to determine the apparent conductivity of the vacuous space. In this paper he describes one of the valves used in this experiment as follows:

"A bulb containing a 12 volt carbon filament rendered brightly incandescent by a current of 2.7 to 3.7 amperes was employed. The filament was surrounded by an aluminum cylinder. The length of the carbon filament was 4.5 cm., its diameter 0.5 mm., and surface 70 sq. mm. The aluminum cylinder had a diameter of 2 cm., a height of 2 cm., and surface of 12.5 sq. cm. The filament was shaped like a horseshoe, the distance between the legs being 5 mm."

In this paper Fleming described the use of a separate insulated battery for sending current across the vacuous space, the negative terminal of the battery being connected to the negative terminal of the filament. In this paper he gives data from which the curves shown in Figure 17 were plotted. He also describes experiments using an a.c. potential on the plate. He further showed how two valves might be used to rectify both halves of the oscillation in order to obtain greater output.

On March 23, 1906, Fleming presented another paper,[128] this time before the Physical Society of London. In this paper he presented a number of experiments using his oscillation valves, and showed that they were usable to make quantitative determinations of high frequency oscillations.

On June 15, 1905, or shortly after presenting the Royal Society paper previously mentioned, Fleming sent to Marconi at Poldhu, Cornwall, five of his oscillation valves for trial in service.[129] Marconi at once began to use these valves, a photograph of one of the earliest types of which is shown in Figure 18. Many more of these valves were supplied in 1905 and 1906. In 1907 the British Marconi Company began to manufacture these valves for themselves. These valves were made for use in combination with a special form of receiving circuit in a complete receiver, known as a "Marconi-Fleming Valve" Receiver. This receiver is shown in Figure 19.

Fleming describes the valves first used commercially as follows:[130]

"The valves first supplied were made with carbon filaments and with sheet nickel cylinders or collecting plates, the filament being of such size that it required about 12 volts to bring it to an incandescence corresponding to 3.0 watts per candle. It was, in fact soon found that for radio telegraphic purposes a small four volt lamp made with a metal cylinder embracing, but not touching, the filament was as effective as a detector as a larger lamp, and required as a heating battery the use of only a couple of portable cells."

Because of the effects of nearby electrically charged bodies on the action of these valves, it was soon found necessary to shield them by means of a covering of copper gauze, which was grounded.

The practical pattern of the Fleming valve which then came into use is described as follows by Fleming:[131]

"The enclosing glass vessel consists of a tube of glass about 1 inch in diameter and 3.5 to 4 inches long. This was equipped at one end with a stem carrying a horseshoe filament of carbon, or later of tungsten wire. The filament was of such a length as to be brightly incandescent at some voltage between 10 and 12 volts. This cylinder is surrounded by a cylinder of copper or nickel sheet attached to a platinum wire sealed through the glass. In a type of valve once used by the Marconi Company, the collecting plate is a single flat plate of copper about 1 cm. square, held near to the carbon or tungsten loop which forms the filament of the valve with the flat surface of the collecting plate parallel to and a few millimeters from the plane of the horseshoe filament loop. The lamp is finished off with the usual bayonet or bottom contact pins so as to work in a standard electric lamp socket.

Figure 20, reproduced from Fleming's book, shows drawings of these valves. This is the first indication of the use of flat plates, or flat anodes, in Fleming valves. Figures 21 and 22 show two commercial valves of the cylindrical anode construction.

Later, in Marconi wireless telegraph receivers, other constructions of Fleming valves, with various types of trapezoidal plates were used. Some of these valves are shown in Figures 23, 24, 25, 26, and 27. Other types using cylindrical anodes were also used, as in Figure 26. Some of those with the trapezoidal plates had spring tension devices to maintain the filaments, which were of inverted "V" shape, type.

CAPTIONS FOR ILLUSTRATIONS

Figure 15. Fleming's United States Patent for the Utilization of the Edison Effect Lamp as a Rectifier of High Frequency Oscillations in Wireless Telegraphy.

Figure 16. Group of Fleming Valves Preserved in the Science Museum at South Kensington, England. Photograph Copyright by *H. M. Stationery Office.*

Figure 17. Characteristic Curves of Fleming Valves. Reproduced from *Proc. Roy. Soc. London.*

Figure 18. Early Type of Fleming Valve Using Cylindrical Plate. Photograph Courtesy *R. McV. Weston.*

Figure 19. Marconi-Fleming Valve Receiver. Two valves are used, with

changeover switch for quick transfer in case of burnout.

Figure 20. Drawings of Early Commercial Forms of Fleming Valve. Note bayonet base for mounting in Ediswan type lamp socket. Reproduced from J. A. Fleming's *The Thermionic Valve and Its Developments.*

Figure 21. Early Commercial Form of Fleming Valve, using Cylindrical Plate. Photograph Courtesy *Radio Corporation of America.*

Figure 22. Later Commercial Form of Fleming Valve, using Cylindrical Plate, and mounted in Ediswan Socket. Photograph Courtesy R. McV. Weston.

Figure 23. Commercial Form of Fleming Valve. Photograph Courtesy *Bell Telephone Laboratories.*

Figure 24. Commercial Form of Fleming Valve. Later development showing improvement in mechanical design. The filament is supported by a tension spring. Commercial product—1913. Photograph Courtesy *Bell Telephone Laboratories.*

Figure 25. Commercial Form of Fleming Valve. This valve has an improved filament support, and the plates are supported by a collar attached to the stem of the bulb. Commercial product—1913. Photo Courtesy *Bell Telephone Laboratories.*

Figure 26. Commercial form of Fleming Valve. Similar in construction to previously made tubes, except that the plate surface is increased and the filament lengthened. Commercial product—1913. Photograph Courtesy *Bell Telephone Laboratories.*

Figure 27. Commercial Form of Fleming Valve. This valve has cylindrical element, and filament is supported by glass arbor inside plate structure. The specimen shown has Ediswan bayonet base, but this valve was also made with Edison medium screw base. Photograph Courtesy *Bell Telephone Laboratories.*

REFERENCES

103. *Fleming, J. A.: "How I put electrons to work in the radio bottle." Popular Radio, Vol. 3, No. 3, March 1923, pp. 175-182.*

104. *Leggett, Bernard: "Wireless telegraphy with special reference to the quenched spark system." London, 1921, p. 160.*

105. *Fleming, J. A.: Patent No. 24,850 of November 16, 1904, in Great Britain. Patent No. 803,684 of April 19, 1905, in the United States. Patent No. 186,084, Klasse 21a, Gruppe 68, of April 12, 1905, in Germany.*

106. *Exhibit No. 20: Catalogue of the Science Museum at South Kensington—Electrical Communication II, 1925, p. 21. The catalogue entry describes these valves and tells the purposes for which they were used in Fleming's work.*

107. *Fleming, J. A.: "On the conversion of electrical oscillations into continuous currents by means of a vacuum valve." Proceedings of the Royal Society of London, Vol. 74, 1905, pp. 476-487.*

108. *Fleming, J. A.: "The construction and use of oscillation valves for rectifying high frequency electrical currents." Proceedings of the Physical Society of London, Vol. 20, 1906, pp. 177-185. See also Philosophical Magazine, 6th series, Vol. 11, No. 65, May 1906, pp. 659-665.*

109. *Fleming, J. A.: Transcript of record of proceedings in the case of Marconi Wireless Telegraph Company of America vs. De Forest Radio Telephone and Telegraph Company. U. S. Circuit Court of Appeals, Second Circuit, Equity No. 12-31. Deposition of J. A. Fleming, p. 128.*

110. *Fleming, J. A.: "The thermionic valve and its developments in radiotelegraphy and telephony." London, 1919, p. 62.*

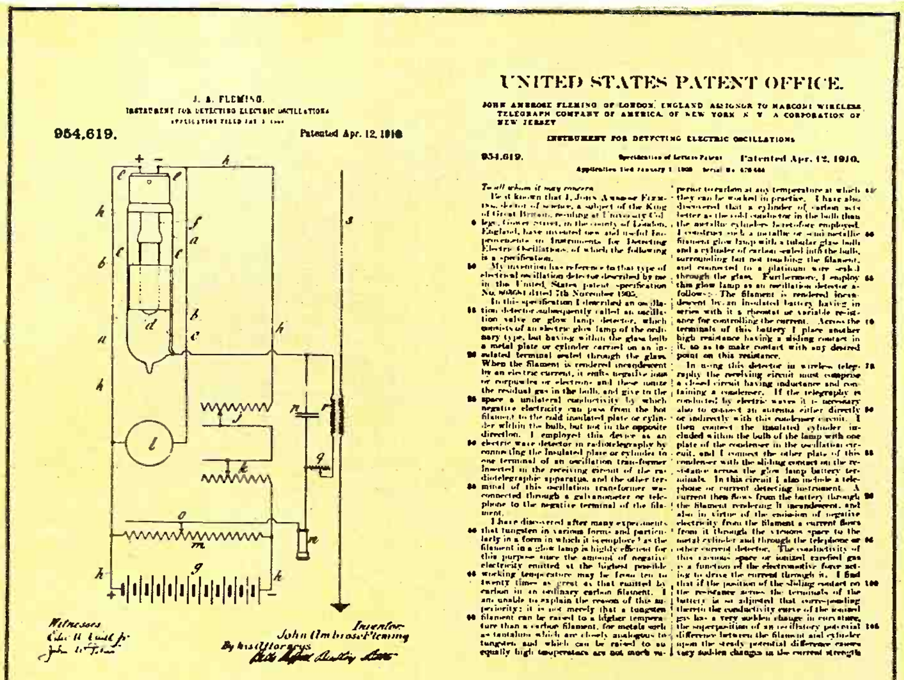
111. *Fleming, J. A.: See reference 110, pp. 65-66.*

—30—

THE SAGA OF THE VACUUM TUBE

by GERALD F. J. TYNE
Research Engineer, N. Y.

Part 5. The era of controversy between patent rights on thermionic tubes designed by de Forest, Fleming, Weagant and others.



UNITED STATES PATENT OFFICE.

JOHN AMBROSE FLEMING, OF LONDON, ENGLAND, ASSIGNOR TO MARCONI WIRELESS TELEGRAPH COMPANY OF AMERICA, OF NEW YORK, N. Y., A CORPORATION OF NEW JERSEY.

INSTRUMENT FOR DETECTING ELECTRIC OSCILLATIONS.

954,619. Specification of Letters Patent. Patented Apr. 12, 1910.

Figure 28.

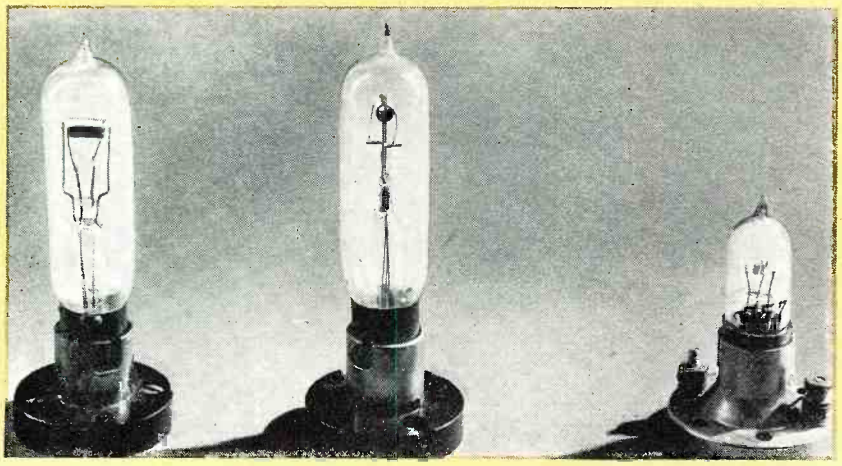


Figure 29.

AFTER the first applications of the valve to the rectification of high frequency oscillations, Fleming began to study their characteristics in detail. Some of the valves had filaments of tungsten. He determined the characteristics of the valves with varying plate potential, this plate potential being supplied by a separate battery which had its negative terminal connected to the negative terminal of the filament. He found that the curves were different with different filaments and different degrees of vacua. Analysis of the curves so obtained suggested to him another means of using the valve as a detector. If the plate potential could be adjusted to cause the valve to operate on the bottom bend of this characteristic, then the superimposed signal oscillation would produce a large change in the mean current through the vacuous space. This would mean an increase in the sensitiveness of the device as a detector.

Fleming applied on June 25, 1908, for a British patent on the use of an oscillation valve with a tungsten filament, and showed such a valve with the filament operated from a high voltage battery, using a large series resistance, and the plate potential adjustable by means of a potentiometer to obtain operation on the bend in the characteristic. The complete specification of this patent was accepted on April 15, 1909 and a corresponding United States patent was obtained in 1910.[112] (See Figure 28.)

This same bend in the characteristic had been shown by Fleming in his February, 1905, paper before the Royal Society, but no application of this phenomena was mentioned until the application for the above-mentioned British patent was filed. It is interesting to note that this application is equivalent to that described in de Forest's paper on the two-electrode Audion published in October, 1906, a year and a half before. The difference between them lay in the fact that de Forest used a separate battery to supply the plate potential, whereas Fleming obtained the corresponding potentials by means of a potentiometer arrangement on the higher voltage filament battery.

Somewhat later, in a paper[113] by Dr. R. S. Willows and Mr. S. E. Hill, there were described experimental Fleming valves in which a Wehnelt oxide-coated cathode was used. Trouble was experienced in these valves with loss of coating from the heating wires. It is not known to the author whether or not any such tubes were ever used commercially.

In the court contest in the United States over the Fleming valve and the de Forest Audion, the attorneys for the Marconi Wireless Telegraph Company of America (the assignees of Fleming's U.S. patents) found it necessary, in order to make the patent stick, to disavow certain of the rectifier claims made in the original specification which were not limited to high frequency applications.

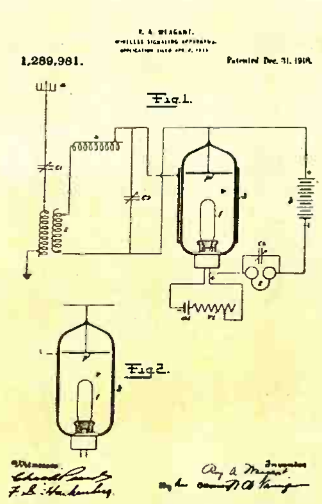
This was necessary because in the use of a thermionic device as a rectifier, the Fleming utilization was anticipated by the Wehnelt valve. Within these limitations the Fleming utilization patent for wireless detection was basic. In a practical sense it contributed little, if anything, to wireless telegraphy of that time. It was less sensitive than other known forms of detector, such as the electrolytic and crystal types, and never came into general use. What usefulness it might have had was soon overshadowed by the development of an electronic device of increased sensitiveness, the de Forest Audion, the first practical three electrode thermionic tube, which will be treated at length subsequently.

The Fleming valve enjoyed a brief revival during the early days of broadcasting in the United States, after the expiration of the Fleming patent. A number of types of diode were put on the market in this country at that time. Examples of these tubes are the "Dietzen Vacuum Tube,"[114] the "Electrad Diode,"[115] and the "Margo Detector,"[116] the latter two of which are shown in Figure 29. They had a rather short vogue, since they could neither regenerate nor amplify.

The development of the de Forest Audion led to a long and bitter controversy between Fleming and de Forest, and finally resulted in the famous Marconi-de Forest patent suit, of which more later.

While this suit was still unsettled the American Marconi Company, probably motivated by a desire to have available an alternative device in case the decision in the suit was unfavorable to them, began the development of a new tube. This work was done under the guidance of the late Roy A. Weagant, who was at that time chief engineer of the Marconi Wireless Telegraph Company of America. Weagant used a Fleming valve type tube and endeavored to obtain control of the electron stream by means of a third electrode which was placed outside of

(*Continued on page 72*)



UNITED STATES PATENT OFFICE.

ROY A. WEAGANT, OF ROSELLE, NEW JERSEY, ASSIGNOR TO MARCONI WIRELESS TELEGRAPH CO. OF AMERICA, OF NEW YORK, N. Y., A CORPORATION OF NEW JERSEY.

WIRELESS SIGNALING APPARATUS.

1,289,981. Specification of Letters Patent. Patented Dec. 31, 1918.

Application filed April 8, 1916. Serial No. 16,064.

To all whom it may concern:

Be it known that I, ROY A. WEAGANT, a citizen of the United States, residing in the town of Roselle, county of Union, State of New Jersey, have made certain new and useful Improvements in Wireless Signaling Apparatus, of which the following is a specification.

This invention relates to apparatus for use in radio communication and its object is to provide an improved means for the detection of electrical impulses or variations.

The invention is an improvement on the well-known Fleming vacuum valve shown and described in U. S. Letters Patent No. 803684, November 7th, 1905. In the improved apparatus shown and described herein there is employed a vacuum chamber, a hot element and a cold element, and outside the chamber an element having extended capacity area in close proximity to the outer surface of the chamber; preferably a metal, as copper, is electro-plated onto the exterior surface of the valve chamber; in any case this outer member is preferably fixed in position, and arranged with its surface area parallel with respect to the path of electrons in the vacuum chamber, moving from the hot element at one end toward the cold element at the other end, the hot and cold elements being fixed at opposite ends of the chamber. The space between said interior elements is extended and the outer element in area is coextensive or a little more extended than the space between the interior elements. The object is to establish an extensive and intimate relation between the path of the electrons and the surface of the outer element. In the form shown the apparatus is adapted for use as a detector of electrical oscillations in association with a local circuit and an indicating device such as a telephone receiver, and in addition the oscillating circuit is electrically connected with the valve and the telephone circuit.

Figure 1 shows the valve and its circuit connections used as a detector; Fig. 2 shows the outer electrode electro-plated on the outer surface of the valve.

The vacuum chamber *e* consists of an evacuated glass vessel, and contains the filament electrode *f* at one end and the plate electrode *p* at the other end. These are fixed some distance apart, so as to leave an open space between them. Outside the vacuum chamber *e*, is a plate of thin metal *k*; it is fixed in position close to the exterior of the chamber and I prefer an electro-plated coating of copper, as shown in Fig. 2; the extent of this outer element is preferably sufficient to span the space separating the two interior electrodes *f* and *p* and includes both said electrodes. The hot filament electrode *f*, is heated by battery *a* the number of cells of battery and the resistance *r*, being varied to graduate the heat. There is a battery *b*, graduated as to its electromotive force by varying the number of cells in series, included in circuit with a telephone or indicating device *t*; a variable condenser *c*³ is in circuit in parallel with telephone *t*; the terminals of this circuit are connected, respectively to the two electrodes *f* and *p* in valve chamber *e*. The antenna wire includes primary coil 1 and variable condenser *c*¹; the secondary circuit is a closed oscillating circuit provided with tuning elements such as inductance 2, inductance 4, which is practically a part of inductance 2, and the variable condenser *c*², one terminal of this circuit is connected to plate electrode *p* and the first described local circuit, the other terminal is connected to the outside element *k*. When the surface of the outside element is disposed parallel to the electron stream between the interior elements as described above, it follows that the field of force of the outside element when charged is at an angle to the electron stream.

The valve so employed as a detector is more stable as regards adjustment and more powerful as regards response to receive impulses. The valve described above operates to amplify feeble oscillating or pulsating currents, and can be used for line telephony, as well as for wireless telephony and telegraphy.

The outside terminal *k* I prefer to designate as an electrostatic control element. I use this designation to define a terminal such as the one shown at *k* disposed outside the chamber, and so connected to the source of oscillations or to the circuit carrying the oscillation current to be detected or amplified that it will operate to vary the flow of electrons within the chamber synchronously with the impulses or oscillations of the current to be amplified or detected.

What I claim is:

1. In combination, an evacuated container comprising an internal source of electrons,

Figure 30.

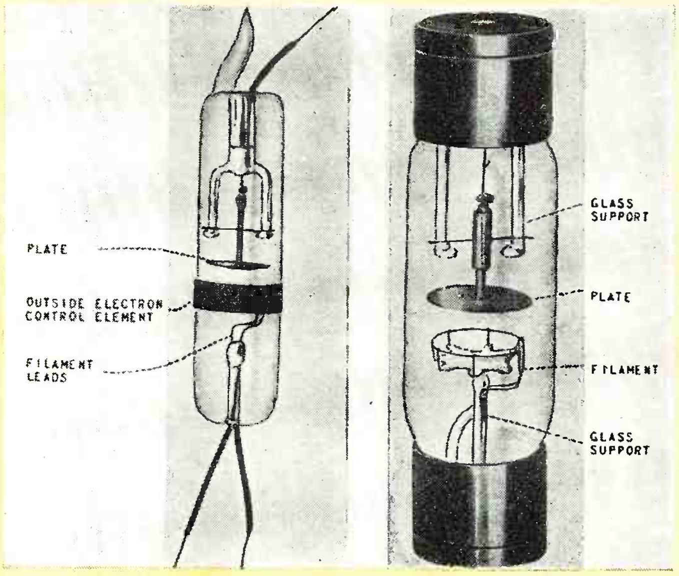


Figure 31.

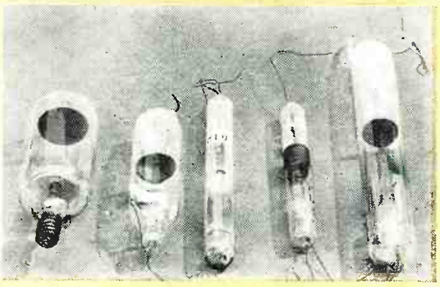


Figure 32.

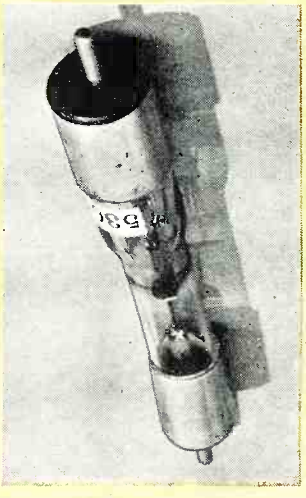


Figure 33.

which separates the leafy portions from the woody stem and crushes the sappy parts, the electric eye being the expert grader. This dehydrator would combine several functions into one operation. It would feed green fodder or other material intended for livestock onto an endless belt, cut the plants into suitable lengths, separate, electronically, the leafy portions from the sappy stems, crush the stalks, pick up the layer of drying material, turn it upside down and deposit it loosely along the traveling conveyor. Soybeans, alfalfa or clover are loaded onto this slowly moving conveyer belt. After passing through crushing rollers which pulverize the sappy stems to a more rapidly drying status, they are then carried through a heating chamber where moisture is expelled. During the process of drying, the temperature is adjusted correctly, thus avoiding scorching or burning the material, a common complaint with some driers. There are a succession of heat zones each supplied with low humidity air, heated to exactly the right temperature, to attain the maximum evaporative effect for each stage of the dehydrating process. The drying is conducted, in part, in an oxygen-free atmosphere and in a chamber wherein all products of combustion are burned completely without smoke.

The units of this community dehydrator consist of a supporting framework; a continuous belt of two flexible steel bands mounted on the framework; a main boxlike structure, extending the length of the conveyer belt and forming an airtight housing for the conveyer screen; another chamber which has a metallic tube and an oil burner for heating the material to be dehydrated; electronic tubes; and other equipment. The interior of the drying chamber has eight cross openings with an air intake opening controlled by a door. This series of hot-air discharge chambers provides an accurate control over the amount of hot gas admitted to chambers.

The above mentioned examples of various applications of radionics to modern farming, serve to show to a certain extent what progress has been made and something of what may be expected in the future. No article of this nature would be complete without mentioning the future possibilities of maintenance and repair in this field. The many radionic devices, which are now available, and those which will be available in the future, will require the services of a great many trained technicians. Men presently engaged in radio servicing, or kindred maintenance, will find this a profitable and timely field to enter. The servicing of the devices should do much to build a splendid post war business for these men, particularly in rural areas.

It is important that the serviceman bring his knowledge up to date on these new devices in order that he can take full advantage of these new opportunities.

Saga of Vacuum Tube

(Continued from page 27)

the tube, and hence might not be considered to be within the scope of the de Forest patents. On December 31, 1918, U.S. Patent No. 1,289,981 was issued to Weagant on a tube of this type.[117] (See Figure 30.) The Weagant Valve, as the device was called, was never applied commercially to any great extent, probably because the decision in the Marconi-de Forest suit was favorable to the Marconi Company. Figures 31, 32, and 33 show various forms of the Weagant Valve, that of Figure 33 being a proposed commercial form of the device. The circuits to be used with this valve were similar to those used with the conventional three-electrode tube, and were published in a magazine article about the time the patent was issued.[118]

With the development of the multi-electrode tubes of the late 1920s and early 1930s communications engineers had available a method of obtaining substantial amplifications at radio frequencies. This resulted in a second revival of the diode for use as a detector. When the signal input to the detector can be made of the proper value, this type of detection presents certain advantages in the way of freedom from distortion. Hence many modern radio receivers use such detectors. A typical detector tube of this sort is the RCA 6H6, which is a double diode detector. Study of Figure 34 will clearly show the changes which differentiate this modern diode from its progenitor, the Fleming valve. These advances are in the nature of engineering refinements, the principle of operation is still the same. The output, however, is utilized not only

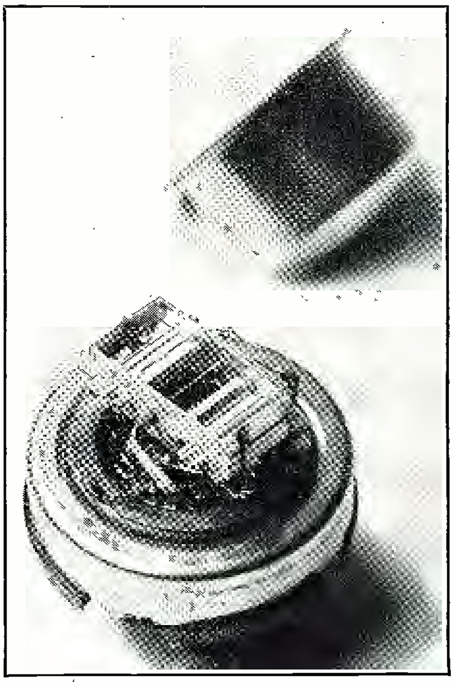


Figure 34.

to provide the audio waveform which was superimposed on the carrier at the transmitter, but also to provide energy for other purposes, such as automatic adjustment of the gain of the preceding radio frequency amplifier. This provides an audio frequency output which is reasonably constant and independent of the variations in the received signal over the operating range of the circuit.

There is still another use of the diode on which we have not yet touched. This is in the field of power frequency rectification. In the early wireless receivers, even well into the broadcast era, dry cells or small storage batteries were used as a source of plate potential. Their use had its disadvantages. The cost was high for the energy which they furnished. The plate potential always existed, even though the set was not in operation, and might be dangerous. If heavy duty batteries were used, in an attempt to reduce the cost per energy unit, the space required for them might be as great as for all the rest of the receiving equipment. These disadvantages became more important with the trend to the higher voltages required for the power output tubes needed for satisfactory loud-speaker operation.

In the case of tube transmitters, the plate potential was at first supplied by generators. High voltage d.c. generators are difficult and expensive to build and, like all rotating machinery, require expert maintenance. A static source of power for the transmitting tubes was much to be preferred, hence the power rectifier was developed.

The first power frequency rectifier of the thermionic type was due to Dr. Arthur Wehnelt of the University of Erlangen, the inventor of the Wehnelt, or oxide-coated, cathode.

In 1903 Wehnelt published a paper [119] describing a method of obtaining "negative ions" in great quantities from incandescent metallic compounds. He used a platinum wire, or platinum strip, coated with calcium or barium oxide, as the cathode in a discharge tube and found that there was a strong emission of negative ions from the

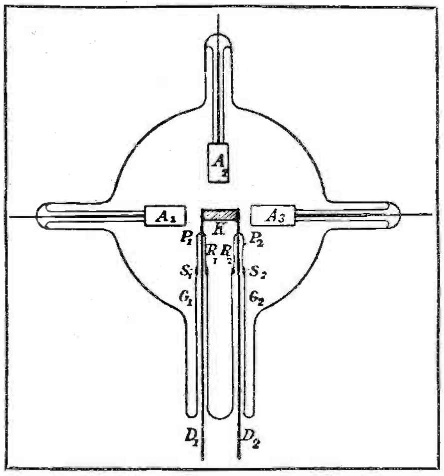


Fig. 35.

cathode when it was made incandescent. He further described experiments which he made on these phenomena in other papers in 1903 [120] and 1904.[121]

On January 15, 1904, he applied for a German patent [122] for the use of such a discharge tube, containing a heated cathode with these metallic oxides, as a rectifier for transforming single phase and polyphase alternating currents into direct currents. No mention was made of any application to high frequency oscillations or wireless telegraph use.

In 1905 he described the use of this device in an article [123] entitled "An Electric Valve Tube" and suggested its use for charging storage batteries, and for supplying potential for the direct operation of Roentgen tubes. This paper was a short summary and was followed by a more complete exposition in 1906.[124] In this last paper he showed that this valve-tube could also be used as a rectifier of high frequency currents. However, it should be noted that this was subsequent to the papers published by Fleming on the use of his valve as a rectifier of high frequency oscillations, and in fact Wehnelt refers to Fleming's work in a footnote in his article. The tube as constructed by Wehnelt is shown in Figure 35.

There appears to have been little

done in this phase of diode development for a number of years thereafter, until the necessity arose for obtaining very high direct current potentials for x-ray work. The initiative in the subsequent development work along this line appears to have been taken by the General Electric Company, whose work will be described in a subsequent article.

References

113. *Willows, Dr. R. S. and Hill, S. E.: "Vacuum Oscillation Detectors." Electrician, Vol.* 48, *No.* 8, *December* 1, 1911, *pp.* 302-303.

114. *Dietzen Vacuum Tube: See advertisement in Radio News, Vol.* 5, *No.* 5, *November* 1923, *p.* 659.

115. *Electrad Diode: See advertisement in Popular Radio, May* 1923, *p.* 22.

116. *Margo Detector: See advertisement in Radio News, Vol.* 5, *No.* 2, *August* 1923, *p.* 206.

117. *Weagant, Roy A.: U. S. Patent No.* 1,289,981, *application date April* 2, 1915, *issued December* 31, 1918.

118. *The Weagant Oscillation Valve: A striking improvement on the original Fleming oscillation valve. Wireless Age, March* 1919, *pp.* 24-25.

119. *Wehnelt, Arthur: Sitzungberichte der Physikalische-Medecin Societat zu Erlangen,* 1903, *pp.* 150-158.

120. *Wehnelt, Arthur: Verhandlungen der Deutsche Physikalische Gesellschaft, Vol.* 5, 1903, *pp.* 150-158 *and* 423-426.

121. *Wehnelt, Arthur: "Uber den Austritt negativer Ionen aus gluhenden Metallverbindungen und damit zusammen hangende Erscheinungen." Annalen der Physik, Vol.* 14, 1904, *pp.* 425-468. *See also Physikalische Zeitschrift, Vol.* 5, *No.* 31, 1904.

122. *Wehnelt, Arthur: German Patent No.* 157,845, *Klasse* 21*g, application filed January* 15, 1904, *issued January* 13, 1905.

123. *Wehnelt, Arthur: Sitzungber. der Physik-Medic. Soc. zu Erlangen, Vol.* 37, 1905, *pp.* 264-269. *This is an abstract of the paper referred to in reference* 124.

124. *Wehnelt, Arthur: "Ein Electrische Ventilrohr." Annalen der Physik, Vol.* 19, 1906, *pp.* 138-156.

Figure Captions

Figure 28. Fleming's Later United States Patent, showing use of biasing potential on plate.

Figure 29. Left and Center, Electrad Diode. Right—Margo Detector.

Figure 30. Weagant Valve Patent.

Figure 31. Left—Weagant Valve with outside electrostatic control element in position. Right—Weagant Valve with control element removed. Photograph Courtesy *Radio Corporation of America.*

Figure 32. Group of experimental Weagant Valves.

Figure 33. Proposed Commercial Form of Weagant Valve.

Figure 34. Modern Diode. RCA 6H6 with cover removed. Photograph Courtesy *Radio Corporation of America.*

Figure 35. Wehnelt Rectifier for Three Phase Operation. Reproduced from *Annalen der Physik—1906.*

—30—

THE SAGA OF THE VACUUM TUBE

by GERALD F. J. TYNE
Research Engineer, N. Y.

Part 6. Covering the period during which Dr. Lee de Forest was at the height of his inventive career. Many of his tube patents are discussed.

IN THE evolution of the vacuum tube the scene shifts back to America, and to Lee de Forest. De Forest had become very much interested in wireless telegraphy while in his senior year at Yale. Some time after leaving Yale he went to work for the Western Electric Company in Chicago, and later for the magazine "Western Electrician." While there he entered into active partnership with E. H. Smythe of the Western Electric Company. Mr. Smythe was a telephone engineer and had several inventions to his credit at that time. The purpose of the partners was to develop a new system of wireless telegraphy. They first devised a new type of detector, which they called a "Responder." In September, 1900, while conducting tests of the new detector, de Forest noted that when the induction coil used in the experiments was in operation, the gas light in the room, which was of the Welsbach burner type, dimmed. When the coil operation ceased, the light returned. Further experiments made it obvious that the variations in the air pressure caused by the sound waves from the spark gap of the induction coil were what caused the dimming of the light. But in the meantime de Forest and Smythe were imbued with an idea that influenced their thoughts ever after.

Smythe made a note of one of their discussions of this phenomenon on September 20, 1900 as follows:

In developing a hypothesis to fit the observed effect of the inductance coil discharge on the Welsbach light it was suggested that the action was due to an electrification and consequent expansion of the gases of the flame.

De Forest suggested an analogy between sun-spots and their accompanying magnetic disturbances and the miniature magnetic storm in the induc-

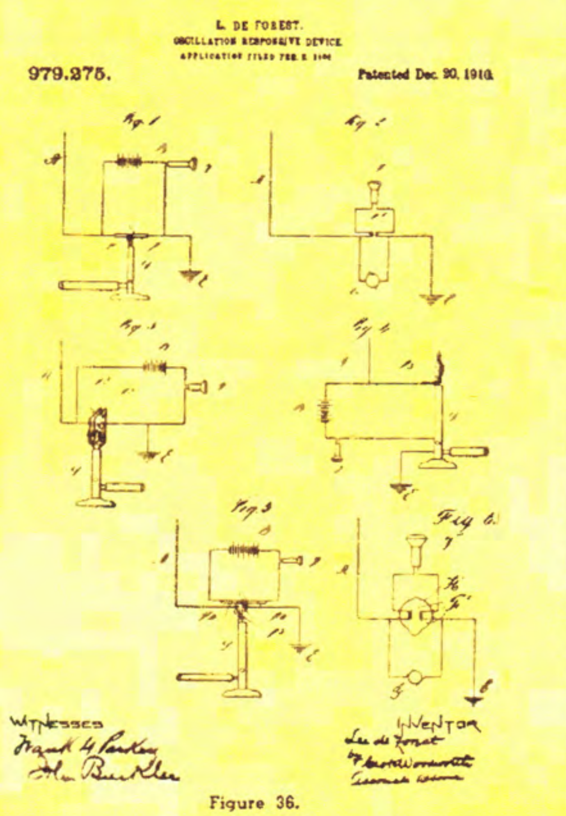


Figure 36.

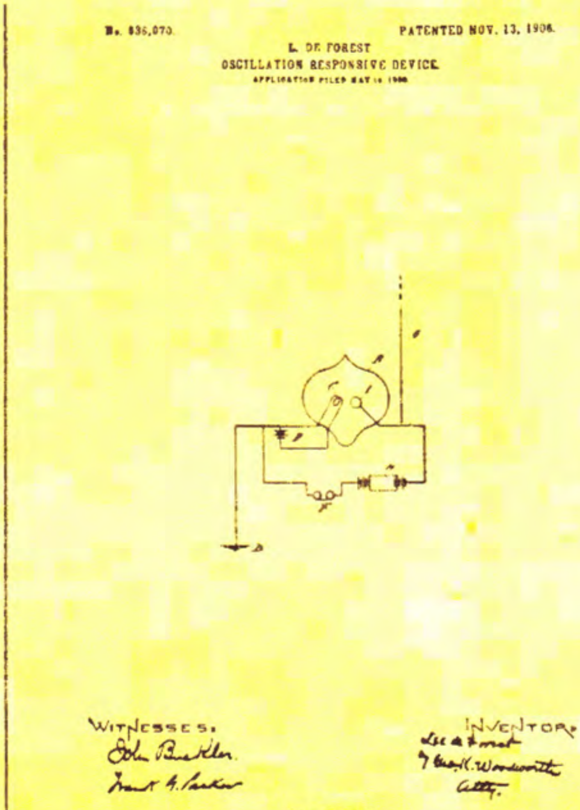


Figure 37.

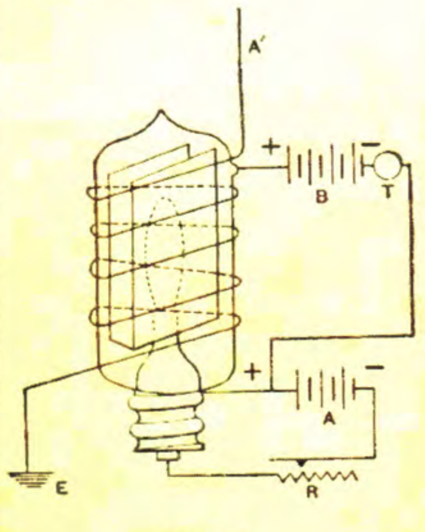


Figure 38.

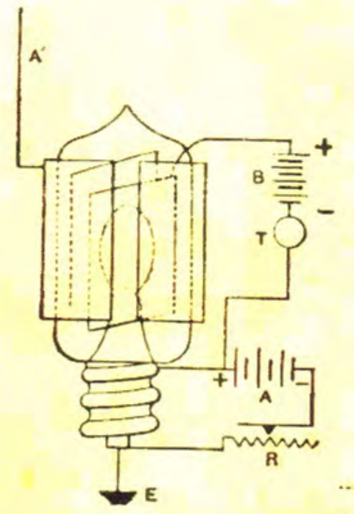


Figure 39.

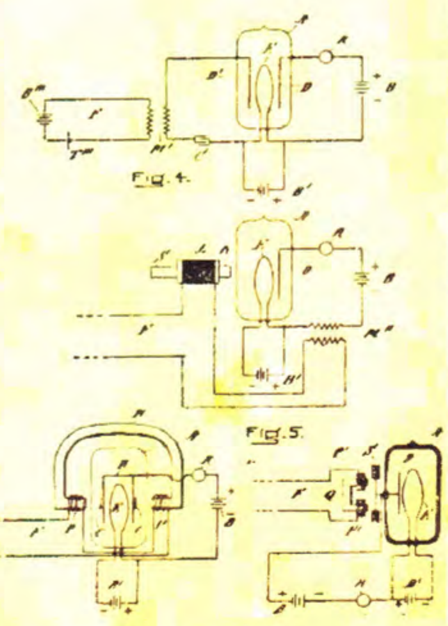


Figure 40.

tance coil and its effect upon the flame. If it should be found true that an electrification of a volume of gas causes expansion, a detector for transmitted impulses might consist of a volume of gas confined and provided with a sensitive instrument adapted to indicating slight changes in pressure. The impulses might be made to affect the gas directly (by confining it in a high upright tube) or indirectly by means of an aerial upright conductor terminating in the receptacle. Possibly the gas could be made more sensitive to the impulses by being rarefied or heated.

While the suggested method of utilization was never realized, the records are of academic interest, and the idea so expressed may well have been the foundation of the later work, by de Forest alone, on the Bunsen burner and rarefied gas tube, both of which were steps in the evolution of the Audion.

A student of the history of the development of wireless during the first decade of this century will find the study of pertinent patent specifications of that period most absorbing. For our purposes at this time we shall examine only those patents forming a definite sequence of steps from the germ of the idea of the heated gas detector to the accomplished fact of the three-electrode grid-type Audion. Some of these devices were found impracticable. The three which are significant are: Patent 979,275 (application date February 2, 1905), which is the parent Bunsen burner patent and is important because it is the first embodiment of the heated gas detector; 836,070 which covers the two-element Audion; and 879,532 (application date January 29, 1907) which covers the three-element grid-type Audion.

We describe briefly twelve patents granted to de Forest, as showing the continuity of development of the Audion. For the convenience of the reader we have starred the significant patents noted above.

About 1903 de Forest, having broken with Smythe, began to search for genuine response to electrical vibrations in the gas flame. He found that the conductivity of the Welsbach burner flame was very small for the range of voltages at which a wireless telegraph detector would be required to operate. Experiments with the flame of the Bunsen burner followed, with the conductivity of the flame increased by the introduction of salts of the alkaline metals. This was actually the first form of Audion. It was not a very practical device, and de Forest thought of it only in connection with wireless telegraphy.

De Forest applied, on February 2, 1905, for a patent ★(U. S. Patent No. 979,275)[125] on such a device and for associated devices shown in Figure 36, among which was one consisting of a bulb filled with a gas (which might be air), in which were two electrodes intended to be heated by a dynamo, although from the diagram given in the patent it would seem difficult of accomplishment. The specification contained numerous claims, and in some cases used such vague phrases as "a self-restoring constantly receptive oscillation responsive device comprising in its construction a sensitive gaseous medium." The various items in this specification were subsequently divided into separate applications which issued as patents as follows: 867,876, issued October 8, 1907; 867,877, issued October 8, 1907; and 867,878, issued February 11, 1908. This last specification claims asymmetric conductivity in the Bunsen burner type detector.

His next patent specification (U. S. Patent No. 823,402),[126] which is for a static valve, discloses another Bunsen burner device, the flame of which is rendered more conductive by the use of salts, and this flame is also described as having asymmetrical conductivity. In this patent he states that positive electricity passes more readily in one direction through the flame than in the other. That is, the Bunsen burner flame acts as a rectifier, and is described as a valve in this specification. This specification also refers to an incandescent lamp type valve which could be used for a similar purpose (as a static valve, and refers to Fleming's paper in the Proceedings of the Royal Society of London[127] for a full description of the physical embodiment of the device.

De Forest's next patent specification (U. S. Patent No. 824,637)[128] was for an oscillation detector "of great simplicity and sensitiveness." This specification covered an invention comprising a receptacle which incloses a gaseous medium put into a condition of molecular activity, so that it is highly sensitive to electrical oscillations when two highly resistant electrodes are heated by an electric current. In the specification, however, it was stated that heating the electrodes was not even necessary, and that the gas might be made responsive to electrical oscillations by heating or by any other suitable means, such as covering the electrodes with a radioactive substance. This specification shows two batteries, one to heat one electrode, the other connected between the electrodes and in series with a telephone receiver.

The original application was subdivided into two others, which issued as patents nos. ★836,070[129] and 836,071[130]. The first of these covers a partially exhausted receptacle into which are sealed two electrodes, one of which may be an ordinary incandescent lamp carbon filament, the other a disc of platinum or other material. Two batteries were shown, as in the original application. The gaseous medium was to be rendered sensitive to electrical oscillations by radiation of heat from the incandescent electrode. (See Figure 37.) *This was the two-element Audion.*

The next specification (U. S. Patent No. 824,638)[131] discloses another type of Bunsen burner detector, in which electrodes of platinum or carbon are placed in the flame. It was claimed that the passage of electrical oscillations through the gaseous medium altered its conductivity.

The next patent specification (U. S. Patent No. 837,901)[132] shows an incandescent lamp detector having a mercury-filled projection on the bulb, which acts as a cold electrode.

This was followed by another specification (U. S. Patent No. 841,386)[133] in which an oscillation detector is described. This consisted of an evacuated vessel having two separated electrodes between which intervened a gaseous medium which formed the sensitive element upon being heated or otherwise rendered highly conducting.

The hybrid name "Audion" was given to this device by C. D. Babcock, one of de Forest's technical aids. The name was derived from the Latin verb *audire* meaning *to hear*, and the Greek derivative *ion*. *Ion* comes from the Greek verb *ienai* meaning *to go*, and the word "ion" had been previously used in connection with electrolytic phenomena to designate an atom carrying a charge and in motion. Hence, "Audion," a device to enable us to hear electricity in motion.

The first public announcement of the invention of the Audion was given by de Forest at the October 26, 1906 meeting of the American Institute of Electrical Engineers in New York, in his paper entitled "The Audion, A New Receiver for Wireless Telegraphy"[134]. This paper was discussed both at this meeting, and at a meeting in Philadelphia which took place two weeks later.

De Forest's paper began by giving an account of the Bunsen burner and electric arc experiments as the foundation of all his work. He described his new invention as a detector for use in wireless telegraphy. It consisted of a partially evacuated glass bulb containing an incandescent lamp filament, the filament being flanked by two platinum "wings" parallel to the plane thereof and about 2 mm. away from it on either side. In the paper de Forest referred to three types of filaments; platinum, tantalum, and carbon.

At the Philadelphia discussion, in response to a question from H. C. Snook, one of the members present, de Forest stated that he was using tantalum filaments entirely, that he had never been able to use the tungsten filament, but that he thought that it (tungsten) might give better results than tantalum. He also said that some work had been done with filaments of the Wehnelt type, coated with alkali salts of potassium and sodium, and that although their life had been short they might yet be produced so as to be better than the tantalum filament.

In his paper de Forest made reference to the work of Elster and Geitel as follows:

"Elster and Geitel, beginning in 1882 a systematic investigation of the ionization produced by incandescent metals, frequently employed an exhausted glass vessel containing an insulated platinum plate, stretched close to which passed a fine metallic filament brought to incandescence by an electric current."

One of Elser and Geitel's earlier papers "Ueber die Electricitat der Flamme" is cited as the foundation of their work, and de Forest then gives a diagram of their later apparatus as described above, taken from a subsequent paper published in 1887.

De Forest also made reference to the work of Fleming with an "Elster and Geitel" tube but stated that the action of the Audion was quite different from that of such a device, and that the Audion acted as a relay rather than as a rectifier. That this was his sincere belief may be adduced from the statements and diagrams of variations in methods of operation, such as the use of an external electrode connected to the antenna (See Figure 38), and the use of what we now know as magnetic control, by passing the high-frequency current through a helix of wire around the Audion bulb (See Figure 39), or through a flat coil brought close to the tube with its axis perpendicular to the tube. These arrangements involved no metallic connections between the oscillatory circuit and the "wings" and hence could not be considered as rectifiers. De Forest attributed the action to the influence of the electrostatic field in the case of the external electrode, and to the electromagnetic field in the case of the coils, on the motion of the ions within the bulb. He also attempted to explain the action of an external permanent magnet on the "flux" (space current) within the bulb.

The discussions which followed the paper showed that the exact principle of operation of the device was not clear, even to de Forest. In response to a question from Percy Thomas at the New York discussion, as to whether the action depended on the ionization of the residual gases or the particles coming from the electrodes themselves, de Forest replied:

"I think that it is due to the ionization of the residual gases; the gases still exist in the lamp, because the vacuum is only that which obtains in all incandescent lamps."

In response to another question from H. C. Snook at the Philadelphia discussion de Forest stated:

"If the exhausting process is carried too far, the Audion loses its sensitiveness. The gas particles rather than the particles of the metal dust are the carriers. I do not believe the dust particles are controlling at all."

Only the day before presenting this

(Continued on page 91)

Figure 41.

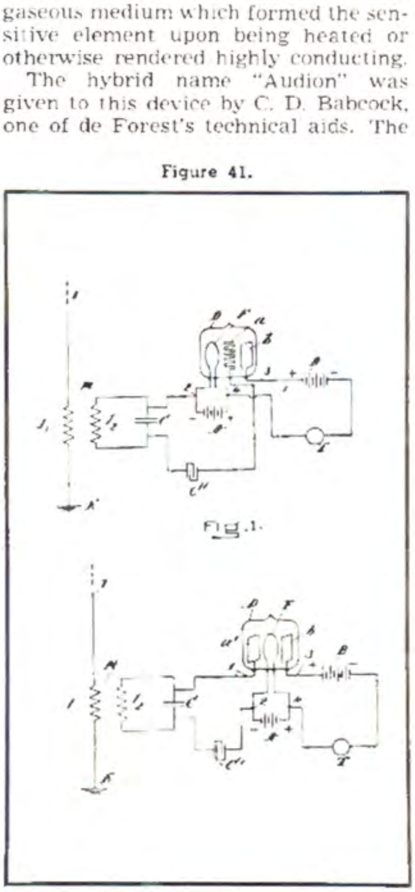


Figure 42.

ESCS Training

(Continued from page 25)

The first installation was bi-dimensional. Its flat surface was unable to provide an impression of depth and perspective. With assistance from the Officers Candidate School drafting and visual aids department, an improvement upon the basic idea has been designed, and is nearing completion. This structure, measuring twelve feet in length, five in height and three in depth was planned and executed by S/Sgt. Ralph A. Vernacchia and T/5 Stanley Elkman upon an original suggestion from Captain Abramowitz.

Its tri-dimensional reproduction of geographical contours, foliage, vehicles, human figures and an airplane offer emphatic visual impact. Simulated blinker lights are set on a hilltop, in the plane itself and in the immediate foreground. It is expected that installation of this display at the new and greatly expanded code and traffic section will mark another significant achievement in the rapid training of Signal Corps Radio Operators by means of dramatic visual facilities.

-30-

Saga of Vacuum Tube

(Continued from page 28)

paper de Forest filed another patent application (U.S. Patent No. 841,387)[135] on an arrangement entitled "Device for Amplifying Feeble Electrical Currents." This application disclosed an incandescent lamp having, in addition to the carbon or metal filament, two metal plates sealed into the bulb. (See Figure 40.) This was not new but the external connections and method of use disclosed were new. The arrangement was said to depend on the electrostatic attraction between the plate connected to the antenna and the filament for its operation. This application contains the first mention of what Fleming later termed a "split cold electrode" and was the first form of the three-electrode Audion.

The next patent application by de Forest was for an "Improvement in Oscillation Detectors" of the type described in U. S. Patents Nos. 824,637 and 836,070. This application, which issued as U. S. Patent No. ★879,532,[136] disclosed a second cold electrode in the form of a grid placed *between* the incandescent electrode (filament) and the other cold electrode (plate). (See Figure 41.) This third electrode had actually been added to the assembly in a laboratory test on December 31, 1906.[137] This was the three-electrode grid type Audion, although de Forest originally applied the term to the two-electrode arrangement.

The first public disclosure of the grid type Audion by de Forest was made at the Brooklyn Institute of Arts and Sciences on March 14, 1907 in connection with a paper on "The Wireless Transmission of Intelligence."

It is perhaps well that no scientist has developed a mechanism whereby we can see into the future. All parents know that the first seven years of a child's life are serious years; years demanding study of this new being, noting its characteristics, guiding it through hazardous days, observing and developing its potentialities. Yet could de Forest have foreseen the turbulent days ahead in the seven years following the first disclosure of his brain-child, the grid type Audion, he might not have taken the trip to Brooklyn on March 14, 1907. De Forest never lacked courage, but the time consumed in tireless efforts to make his contemporaries understand his brain-child, his corporate troubles and desperate attempts to obtain financial backing, the endless litigation into which he was plunged, all were a tragic waste to the man interested primarily in the furtherance of wireless communication. While other men might have cracked under the strain of those years and been lost in the depths of despair, to de Forest had been given the strength and buoyance to lose himself in his work in moments of distress. Trouble produced in him mental stimulation. His brain was most productive when his back was against the wall.

About the time of this first public disclosure of the grid type Audion de Forest was organizing the "De Forest Radio Telephone Company" to develop and market the de Forest wireless telephone system. Funds for this purpose were insufficient and hence a subsidiary company, the "Radio Telephone Company" was formed late in the same year to manufacture and market wireless apparatus on which de Forest owned or controlled patents.

De Forest used the Audion as a detector for both wireless telegraphy and wireless telephony. Only two of the two-element Audions were ever sold, and these to the U. S. Navy for use at the Brooklyn Navy Yard.[138]

Grid type Audions for use as detectors were incorporated in a number of sets of radio-telephone apparatus sold to the U. S. Navy in 1907. When the U. S. Fleet of "Fighting Bob Evans" made its memorable cruise around the world in 1907-1908 over twenty vessels were equipped with such de Forest apparatus. However, radio telephony was so very experimental at the time that a few years thereafter a Naval representative reported, as if with relief, that "all wireless telephone sets thus far supplied, having proved unreliable in action, have been withdrawn from service."

Since from this time on only the grid type Audion was in commercial use, future use of the word Audion, unless otherwise stated, will apply to this type bulb.

The first commercial Audions, a photograph of one of which is shown in Figure 42, were made with a narrow flat plate of platinum or other metal placed near a carbon or metal filament in a more or less cylindrical bulb. Between the plate and filament was fixed a grid or simple zig-zag of wire. The plate and grid were supported on wires sealed through the glass. These were made for de Forest by H. W. McCandless & Company, 67-69 Park Place, New York City, who were manufacturers of Christmas-tree type incandescent lamps.

About 1908 the filament structure was changed to the two-filament type, as shown in Figure 42, the filaments to be used consecutively, in order to increase the useful life of the device. About the same time the bulb shape was changed from cylindrical to spherical.[140] This was done at the suggestion of McCandless, who felt that the spherical bulb would permit of easier assembly. A photograph of one of the earlier spherical types is shown in Figure 43. This tube was made with a candelabra type base which was not changed till some time later.

Figure 43.

References

125. *de Forest, Lee: "Oscillation Responsive Device." U. S. Patent No. 979,275, application date February 2, 1905, issued December 20, 1910.*

126. *de Forest, Lee: "Static Valve for Wireless Telegraph Systems." U. S. Patent No. 823,402, application date December 9, 1905, issued June 12, 1906.*

127. *Fleming, J. A.: See Reference 107.*

128. *de Forest, Lee: "Oscillation Responsive Device." U. S. Patent No. 824,637, application date January 18, 1906, issued June 26, 1906*

129. *de Forest, Lee: "Oscillation Responsive Device." U. S. Patent No. 836,070, original application date January 18, 1906, divided application filed May 19, 1906, issued November 13, 1906.*

130. *de Forest Lee: "Oscillation Responsive Device." U. S. Patent No. 836,071, original application date January 18, 1906, divided application filed May 19, 1906, issued November 13, 1906.*

131. de Forest, Lee, "Oscillation Responsive Device," U. S. Patent No. 824,638, application date January 20, 1906, issued June 26, 1906.

132. de Forest, Lee, "Wireless Telegraphy," U. S. Patent No. [illegible], application date February 14, 1906, issued December 4, 1906.

133. de Forest, Lee, "Wireless Telegraphy," U. S. Patent No. [illegible], application date August 27, 1906, issued January 15, 1907.

134. de Forest, Lee, "The Audion—A New Receiver for Wireless Telegraphy," Proceedings A.I.E.E., Vol. 25, 1906, pp. 735-763. Discussion on pp. 763-[illegible].

135. de Forest, Lee, "Device for Amplifying Feeble Electrical Currents," U. S. Patent No. 841,387, application date October 25, 1906, issued January 15, 1907.

136. de Forest, Lee, "Improvement in Oscillation Detectors," U. S. Patent No. 879,532, application date January 29, 1907, issued February 18, 1908.

137. Archer, G. L., "History of Radio," American Historical Society, 1938, p. 92.

See Also Carneal, Georgette, "The Conqueror of Space," Horace Liveright, 1930, pp. 195-196.

138. [illegible] W. H., "The Life and Work of Lee de Forest, Part VIII," RADIO NEWS, Vol. 6, No. 11, May 1925, p. 208.

139. Robison (Commander) S. S., "Manual of Wireless Telegraphy for Use of Naval Electricians," 2nd edition, [illegible], p. 169.

140. de Forest, Lee, "The History of the Radio Tube, 1900-1916," RADIO NEWS, Vol. 24, No. 6, December 1940, p. 8.

Figure Captions

Figure 36. The Bunsen burner patent. This was the fundamental de Forest heated gas patent.

Figure 37. The two-electrode Audion patent. Note the use of two batteries, one for heating the filament, the other for applying positive potential to the plate.

Figure 38. The Audion with external electrostatic control. An antenna and ground connection is made externally to a wire wrapped around the glass envelope of the tube. Reproduced from *Proceedings A.I.E.E., 1906*.

Figure 39. The Audion with electromagnetic control. Reproduced from *Proceedings A.I.E.E., 1906*.

Figure 40. The first three-electrode Audion patent. Note the external connections.

Figure 41. The grid-type Audion patent. Note the use of the condenser in series with the grid.

Figure 42. Early cylindrical candelabra-base Audion. This specimen was probably made in 1908, since it has a double filament. Photograph courtesy *Radio Corporation of America*.

Figure 43. Early spherical bulb single-grid, single-plate Audion. Both filaments of this Audion are still good, hence the projecting wire has not been connected to the base shell which is of the candelabra type.

(*To be continued*)

R-F Converter

(*Continued from page 29*)

The builder who possesses a broadcast receiver of good quality, will have with the addition of this converter, a short wave combination capable of giving remarkable performance. Most radio parts jobbers are still able to supply most of the items needed. Furthermore, inasmuch as standard parts are used many of them will be found in the average service shop or experimenters, laboratory. The use of an efficient all-wave antenna is highly recommended. No converter can work at its best unless it terminates at a proper receiving system.

Inasmuch as standard tubes are used it is possible to use substitutes simply by changing supply voltages.

THE SAGA OF THE VACUUM TUBE

by GERALD F. J. TYNE
Research Engineer, N. Y.

Part 7 of the series, covering the period during which the first commercial grid-type Audion tube was manufactured for civilian use.

THE first public disclosure of the grid-type Audion was made at the Brooklyn Institute of Arts and Sciences on March 14, 1907 by Dr. Lee de Forest, in connection with a paper on "The Wireless Transmission of Intelligence."

Immediately after this disclosure de Forest organized the "De Forest Telephone Company" and its subsidiary, the "Radio Telephone Co." to manufacture and market wireless apparatus on which he owned or controlled patent rights. Directly thereafter the first grid-type Audion was manufactured for commercial use. It was made with a narrow flat plate mounted near a metal filament. Between these two was fixed a grid wire.

In 1909, in order to increase the conductivity of the tube, and to enable the use of larger energy, the use of two grids and two plates, one set on either side of the filament, was introduced. These were called "double Audions" and were sold at a higher price.[140] A photograph of one of these Audions is shown in Figure 44. Some of these double Audions had separate leads brought out from each grid and plate, as shown in the tube in Figure 45.

The filament structure was changed in 1913 to the so-called "Hudson X" type developed by Dr. Walter Hudson. Dr. Hudson was an independent worker, an avid wireless fan, who had used the tantalum filament type Audion, and found it more emissive than the tungsten type. However, the tungsten filament had a longer life, and Hudson conceived the clever idea of combining both elements, by wrapping a short piece of tantalum wire around the tungsten. He induced McCandless to build up some bulbs of this type, which proved superior to the tungsten filament type, and were in correspondingly greater demand thereafter, even though sold at a higher price. A double grid, double plate Audion employing the Hudson type filament is shown in Figure 46. The tantalum wire wrapping can be seen on the top arc of the filament.

Having briefly outlined the various steps in the evolution of the structure of the earlier Audions, let us now see how they were made available to the purchaser. As far as the author has been able to determine the first Audions offered for sale to the amateur were advertised on page 288 of the September, 1909, issue of "Modern Electrics," in an advertisement by the Radio Telephone Company. This company had been advertising wireless apparatus in that magazine since January, 1909, but the September advertisement was the first to mention "Audion Detectors." A reproduction of this advertisement is shown in Figure 47. The Audions were offered for sale as part of an assembly denoted as the "RJ4 Detector." The designation "RJ," meaning "Radio Junior" was adopted for pieces of equipment that were developed especially for sale to amateurs, and distinguished from the so-called "professional equipment" intended for commercial use.

The bulbs first sold with the RJ4 Detector were spherical and contained a double horseshoe filament, a single grid, and a single "wing" or plate, and were fitted with a candelabra base. The center contact of the base was connected to the common point of the two filaments. The second end of one filament was connected to the threaded shell of the base, and the second end of the other filament was brought out on a wire which came out just above the base, but insulated therefrom by a piece of cotton sleeving. There was a heavy knurled rubber band placed on the base, just below the line where the bulb emerged. The bulb was used until the first filament burned out. Then the projecting wire was wrapped around the base and held in contact therewith by slipping the rubber band over it, thus anchoring it firmly in position. This brought the second filament into use. The life of the average filament was 35-100 hours, despite the higher values claimed in the advertisements.

These detectors were regularly furnished with the regular or so-called "S" grade of Audion bulb which had a tantalum filament. An extra-sensitive or so-called "X" grade bulb could be obtained at an additional cost. After the development of the Hudson type filament, bulbs using this filament could be obtained in both the "S" and "X" grades, but at a higher price than the tantalum filament bulb. A typical advertisement offering the RJ4 and RJ5 Detectors for sale, and listing the various bulbs is shown in Figure 48.

The RJ4 Detector consisted of a ma-

Fig. 44

Fig. 45

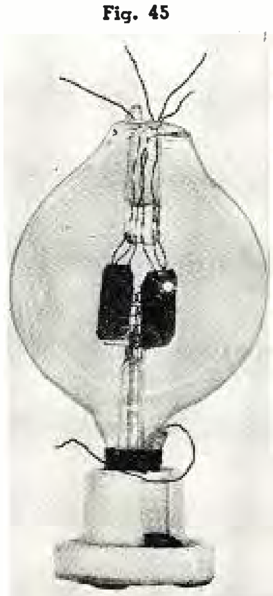
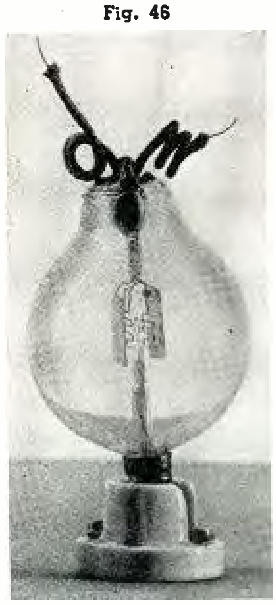


Fig. 46



hogany box, in which were placed the flashlight cells which were used as the "B" battery. On the front of the box were two switches. The one at the left of the "street-light" bracket from which the bulb hung was a tap switch on the "B" battery. The one on the right was the "Off-On" switch for the filament. The filament current was controlled by a porcelain-based rheostat mounted on the right hand end of the box. Binding post connections were provided for the filament battery, the terminals of the input circuit (which was usually the secondary of a "loose-coupler"), and the telephones. The earlier RJ4 Detectors were equipped with a three-point switch for controlling the "B" battery voltage.

For a long time after the Audion was put on sale, it could be obtained from the Radio Telephone Company only by the purchase of a complete detector instrument, such as the RJ4. *(The author understands, however, that audion bulbs were also sold by the H. W. McCandless Company on an over-the-counter basis to customers who came looking for them.)* Owners of such detectors could procure renewal bulbs only on the return of the old bulb at the time the order for the renewal was placed, except as noted below. The price of the RJ4, the cheapest of the RJ series of detectors, was $18, as will be noted from the advertisement shown in Figure 48. This represented a small fortune to many an experimenter. Hence, ways and means were sought to circumvent the necessity of such a purchase.

The only element of this detector which the amateur could not readily acquire was the Audion bulb itself. The rheostat, batteries, switches, etc., were all common articles of commerce. The early Audion bulbs were extremely fragile pieces of apparatus. In fact, they were popularly known as "onion-skins." In order to obviate the necessity of returning broken bulbs, in cases where accidents occurred, a renewal bulb could be obtained if, in lieu of the complete bulb, the grid and plate from the broken bulb were returned. Since the earliest bulbs had only one grid and plate, the return of one grid and plate was sufficient to permit the purchase of such a renewal.

When the double grid, double plate Audion was placed on the market it became a means whereby the less plutocratic amateurs might obtain the coveted Audions. When one of these bulbs passed to its eternal reward the fortunate owner thereof promptly broke it up, returned one set of elements for his renewal, and sold the other set to someone less blessed with this world's goods, who could then return the second set and thus purchase a bulb for himself. This was such a common practice that old-timers will remember advertisements in the "swap" columns of the amateur magazines of that day, offering to buy and sell such elements.

The first popular article on the grid-

(*Continued on page* 78)

De Forest Apparatus

DESIGNED BY EXPERTS

WIRELESS TELEGRAPH AND TELEPHONE

RECEIVING OR TRANSMITTING

HIGH CLASS APPARATUS OF ALL SORTS AT REASONABLE PRICES

Variometers, Loose Couplings, Variable Condensers of all sizes, Helices and Spark Gaps, large and small, Heavy Transmitting Keys, Audion and Radion Detectors, Wavemeters, Telephone Receivers of extreme sensitiveness, Complete Commercial Tuners, etc., etc.

Our R. J. Variometer comprises two instruments in one a Variable Tuning Coil without sliding contacts, and a loose coupling of novel design. Our R. J. Wavemeter comprises THREE instruments in one—it will measure either SENT or RECEIVED wave lengths, is a Tuned Receiving Circuit, or can be used as a Variable Tuning Condenser. We find our Radion the best of mineral-type Detectors.

Technical advice and assistance will be gladly given to all purchasers by our expert engineers.

If you wish a REAL Wireless Station go to those who KNOW HOW! Address

SALES DEPT.

RADIO TELEPHONE CO.

1 Madison Avenue, New York City

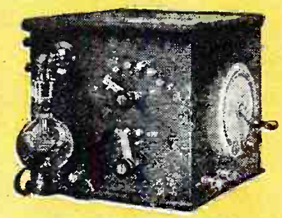
Fig. 47

Fig. 48

DeFOREST AUDION DETECTORS

Incomparably Superior to Any Other Known Type

Type RJ4 Audion Detector



Type RJ5 Audion Detector

If you desire long distance reception of messages, you must have an Audion Detector. Tests of the Bureau of Standards show it to be the most sensitive and reliable detector ever invented. It stays in adjustment even where a transmitting set is used, and can be depended upon, absolutely, at all times.

The above types are regularly furnished with regular, or "S" grade, tantalum filament Audion Bulbs. Fitted with other grade bulbs at the difference of price of bulbs as listed below. A 4-volt storage battery or three dry cells are needed to light the filaments of the detectors, but are not furnished at these prices.

Bulbs are sold only for purposes of renewal, and then only upon return of the old bulb.

Price List, F. O. B. New York

Type RJ4 Audion Detector, with regular "S" grade bulb	$18.00 net
Type RJ5 Audion Detector, with regular "S" grade bulb	25.00 net

***Renewal* Bulbs**

Type "S" Regular Grade Audion Bulb (Tantalum Filament)	$3.50 net
Type "X" Extra Sensitive Audion Bulb (Tantalum Filament)	5.00 net
Type "S" Regular Grade Audion Bulb (Hudson Filament)	5.00 net
Type "X" Extra Sensitive Audion Bulb (Hudson Filament)	7.50 net

Hudson Filament Bulbs have a very long life, between 800 and 1,000 operating hours, which is about three times the life of tantalum filament bulbs

All reliable wireless dealers handle Audion Detectors and renewal Bulbs. If you do not know your local dealer, we will give you his name.

For further information, see your dealer, or write us.

DeForest Radio Telephone & Telegraph Co.

101 PARK AVE. NEW YORK

is the weaker of the two then 190 degrees is the correct direction.

There are several methods employed to give direct readings of the corrected bearings in which the error is already compensated for by mechanical means, the most common types employing a roller and cam arrangement, usually a flat disk has the curve plotted around its circumference and the cam cut out as per the resultant curve which is somewhat elliptical in shape. This, of course, must be calibrated in the usual manner and then the necessary curve drawn and the disk cut as required. As there are many variations of these compensation systems, details of types of course, vary greatly with the different manufacturing concerns.

—30—

Saga of Vacuum Tube

(Continued from page 27)

type Audion which the author has been able to find appeared in the October, 1908 issue of "Modern Electrics."[141] This article was written by John V. L. Hogan, Jr., one of de Forest's early assistants, and now a consulting engineer. In this article the statement was made that there were at that time six distinct varieties of Audion. These were: (1) the flame Audion, (2) the arc Audion, (3) the two-element U-wing type, (4) the external electrostatic control type, (5) the external magnetic control type, and (6) the grid type. In this article the grid type Audion is described in the following: *"The grid audion is usually a 6-volt, low candlepower incandescent lamp with a tantalum filament having a small platinum plate (approximately 10 x 15 millimeters) fastened approximately 3 millimeters from the filament and a grid bent from rather large (say number 22) platinum wire placed nearly midway between the two."*

Despite the fact that the title of the patent on the first three-electrode Audion was "Device for Amplifying Feeble Electrical Currents," the three-element Audion was for many years used only for detection. De Forest and his associates are said to have attempted even at that time to use the grid Audion to obtain audio-frequency amplification, but were unsuccessful. It is probable that attempts to so utilize it were failures because of insufficient knowledge of the characteristics of the device, and the use of high frequency type coupling in an attempt to obtain audio-frequency amplification. Of course, it is probably true that the grid type Audion operated as the sensitive detector that it was, by virtue of its inherent amplifying properties, but it was not used as such by de Forest or by anyone else in the United States as an amplifier *per se* until 1912, about five years after its development.

Many reasons have been advanced to account for the fact that the Audion, throughout the first years of its existence was employed in radio telegraphy only to a limited extent. "Wireless" as a commercial utility suffered damaging setbacks in that period because of sundry stock-jobbing schemes[142] based on earning claims many years in advance of what was likely to be possible. Other reasons sometimes given are: that the majority of users of wireless receivers were boys working as amateur experimenters, to whom the high cost of Audions, previously noted, acted as a deterrent to their use; that the Audion was erratic and little more sensitive than the best of the crystal detectors, which were quite inexpensive devices; and that patent litigation or the threat thereof prevented its use by those who operated ship and shore stations in marine service.

De Forest, following the events of 1912-14, was subjected to no little criticism for having nursed the Audion through infancy and adolescence without discovering the full potentialities of the device. In considering the justification for such criticism the following should be borne in mind. During this period the Audion came into some attention on the part of scientists, engineers, and the more serious wireless experimenters. These men also failed to realize the possibilities inherent in this Aladdin's lamp.

Such a hiatus is not unusual in the development of a new device or system. It will be recalled that a period of seven years elapsed between the announcement by Hertz in 1888 and the achievements of Marconi in 1895.

From 1906 to 1912 the de Forest companies were involved in financial difficulties, and de Forest took a job with the Federal Telegraph Company on the Pacific Coast. There he found the Federal Company using continuous wave arc type transmitters, and attempting to transmit telegraphy at high speed. This development brought with it the problem of getting energy enough to make a record of the high speed signals, for later reproduction and transcription at lower speeds. They were attempting to use the Poulsen telegraphone as a recorder, but the energy of the received signals was insufficient to record satisfactorily. Realizing that what was needed was a device to "boost" the energy of the received signal, deForest took up the Audion anew and attempted to get it to amplify. The problem was one of obtaining amplification at audio frequencies.

In the spring of 1912, de Forest obtained an assistant, H. B. Van Etten. Van Etten was familiar with audio frequency circuits and apparatus, having previously worked for the telephone company in New York. In May and June of 1912, Van Etten, under de Forest's supervision, started experimenting with audio frequency transformers with which to better interconnect a radio detector with receiving head phones.

In July and August, 1912, they succeeded in getting real amplification out of a "double Audion." Later, while still trying to improve the arrangement as an amplifier, they got a howling feedback circuit, and thus was born the Audion oscillator.

De Forest then got in touch with his friend John Stone Stone, also a former telephone company employee, and through him arranged to demonstrate the Audion for use as a telephone repeater. The results of this demonstration, and the process by which the Audion was developed into a practical telephone repeater, will be discussed in a later article. For the present it is sufficient to say that the rights to the Audion for use as a telephone repeater were purchased by the American Telephone and Telegraph Company.

With this transaction the Audion passed out of the realm of the individual inventor into that of the industrial research laboratory. Though de Forest did not know it at the time this was to be the final touch to the years of tribulation he had suffered with his brain-child. He thought his feet were firmly planted on the threshold of success when he saw his child being trained to serve a new master. But when the new master succeeded in developing the child, and had groomed him to perform a specific task, de Forest's paternity was overshadowed by the new developments.

Did de Forest drop his own work on the Audion? Not for long!

Figure Captions

Figure 44. First type of "Double Audion." This specimen has tantalum filament. Photograph courtesy *Radio Corporation of America.*

Figure 45. Double Audion with separate leads from each plate and grid. Photograph courtesy *Bell Telephone Laboratories.*

Figure 46. Double Audion with Hudson type filament. The tantalum wire wrapping can be seen on the top arc of the filament.

Figure 47. Reproduction of the first advertisement offering the Audion for sale to the radio amateur. Reproduced from *Modern Electrics* of September, 1909.

Figure 48. Advertisement showing RJ4 and RJ5 Detectors, and giving prices on various grades and types of Audion bulbs. Reproduced from *Modern Mechanics* of February, 1915.

References

140. *de Forest, Lee: "The History of the Radio Tube,* 1900-1916." RADIO NEWS, *Vol.* 24, *No.* 6, *December* 1940, *p.* 8.

141. *Hogan, John V. L., Jr.: "The Audion: A Third Form of the Gas Detector." Modern Electrics, Vol.* 1, *No.* 7, *October* 1908, *pp.* 232-233. *The diagram given in this article is incorrect, but a correction appears on p.* 275 *of the November* 1908 *issue.*

142. *Fayant, Frank: "The Wireless Telegraph Bubble." Success Magazine, New* 389, 450, 451. *Vol.* 10, *No.* 158, *July* 1907, *York. Vol.* 10, *No.* 157, *June* 1907, *pp.* 387- *pp.* 481-483, 508, 509.

(To be continued)

THE SAGA OF THE VACUUM TUBE

by GERALD F. J. TYNE
Research Engineer, N. Y.

Part 8. Covering the period during which the elements of the triode tube were redesigned to obtain increased performance.

WHILE Fleming was working in England and the de Forest Audion was being put into use in the United States, important work in electronic research was being done in Continental Europe. To go back a little, in 1895 Roentgen announced the discovery of the mysterious penetrating rays which, because their properties were not at that time understood, were called *"X" rays*. As was to be expected, this announcement sent the European savants off into new fields of exploration. One of the earliest finds was that by Becquerel of the radioactivity of uranium, whose rays, like X-rays, produced electric conductivity in air and other gases by ionization.

The earliest of the discoveries in the field of thermionic rectifiers, those of Arthur Wehnelt, have already been discussed and will not be repeated.

At the time Fleming and de Forest were laying the foundations of the great tube art in connection with their work on wireless detectors, von Lieben in Vienna was working on the problem of the telephone relay or amplifier.

Robert von Lieben, the son of wealthy parents, was born in Vienna in 1878. Although he grew up in intellectual surroundings he always disliked formal education, and preferred to educate himself in his own way. Very early in life he showed an aptitude for scientific investigation. At that time electrical engineering was a promising field and it beckoned to von Lieben. He learned the practical phase of this work in the Siemens-Schuckert works in Nuremberg, and then went to the University of Goettingen for physical and chemical research, under the renowned chemist, Nernst.

Returning from Goettingen in 1903 von Lieben set up his own physical laboratory in his parental home. During the years 1905-1910 he developed the *"amplifying relay"* with which his name is associated. With the aid of his father he purchased a telephone factory in Olmutz (Moravia). This concern brought him into association with Eugen Reisz. Von Lieben was much intrigued with the idea of producing a telephone relay. His former professor, Nernst, said of him "No problem impressed him so much as the construction of the telephone relay, or more commonly expressed, a device which is capable of amplifying without distortion small changes in electrical currents".[143]

In his Vienna laboratory in 1905 von Lieben checked Wehnelt's experiments with the oxide-coated cathode, and remembering the cathode-ray beam ar-

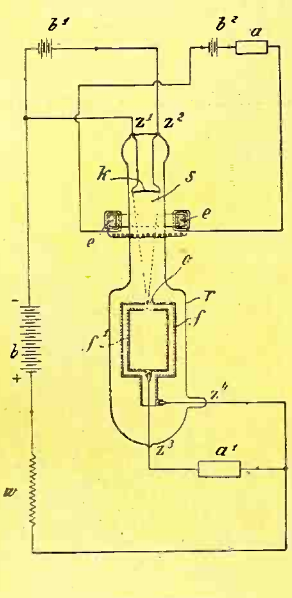


Fig. 49.

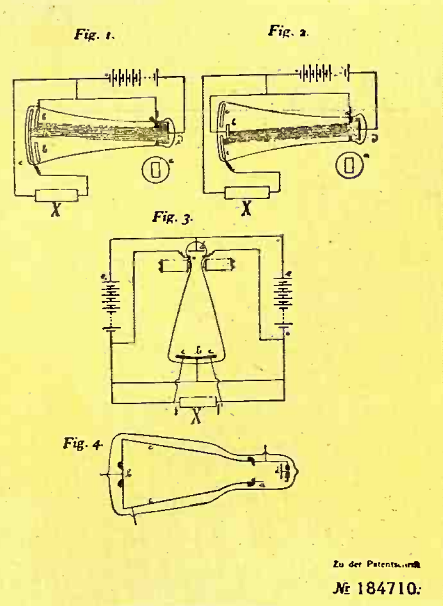


Fig. 50.

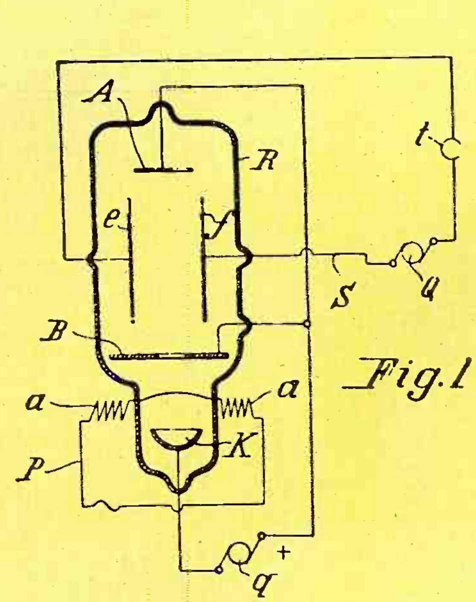


Fig. 51.

rangement used by Braun* in 1897,[144] hit upon the idea of constructing a telephone relay using this combination. He started by controlling the rays magnetically, although electrostatic control of the cathode-ray beam was known at that time. His work soon produced results, and on March 4, 1906 he applied for a German patent[145] on a device which he called a "Cathode Ray Relay." The object of the invention was to enable current variations of small energy at the input terminals to release current variations of greater energy at the output terminals, with frequency and waveform corresponding to that of the input. The patent states that the device is particularly suited to telephone applications such as "relaying of speech to great distance, cable telegraphy, wireless telephony, strengthening of speech, etc."

The diagram given in the patent is shown in Figure 49. It shows magnetic control of the cathode rays, but the patent states that either electromagnetic or electrostatic control may be used.

In this tube, which was described as *"highly evacuated,"* von Lieben used a cathode which was in the form of a hollow mirror, covered with calcium oxide. This cathode was described as being heated by the battery "b¹". The hollow mirror focused the cathode rays on the inner of two concentric cylindrical anodes "f" and "f¹", through the aperture "o". The focus of the rays was altered by the input current flowing in the magnetic field coils "e", which caused more or less of the cathode rays to impinge upon the inner cylinder and thus vary the inner anode current, which also flowed through the load device "a¹". The battery "b" provided the energy in the anode circuit.

Even before this von Lieben patent was published two other men, Max Dieckmann and Gustav Glage of Strasburg, applied on October 10, 1906, for a patent[146] on another type of cathode ray relay which they claimed was capable of giving an output absolutely proportional to the input. In their patent application reference was made to the von Lieben arrangement.

Several possible structures were shown in the diagrams forming a part of the Dieckmann and Glage patent. These diagrams are reproduced in Figure 50. The cathode was a plane and said to be "conveniently treated in order to facilitate the emission of electrons," and the aperture in the diagram "a" was used to obtain a "sharply defined bundle of cathode rays of comparatively large, preferably rectangular cross-section." The axes of the deflecting coils were placed at right angles to the direction of flow of the cathode rays, unlike the von Lieben arrangement in which the magnetic field was parallel to the cathode-ray beam. The magnetic field in the Dieckmann and Glage device

* *This Braun tube was the first embodiment of the cathode-ray oscillograph tube, the development of which will be the subject of a subsequent article.*

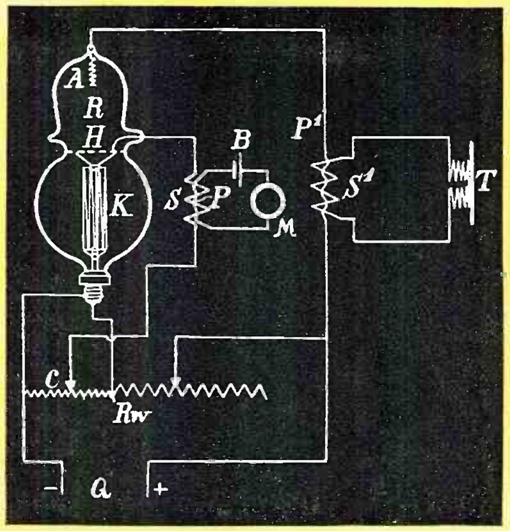


Fig. 52.


Fig. 53.

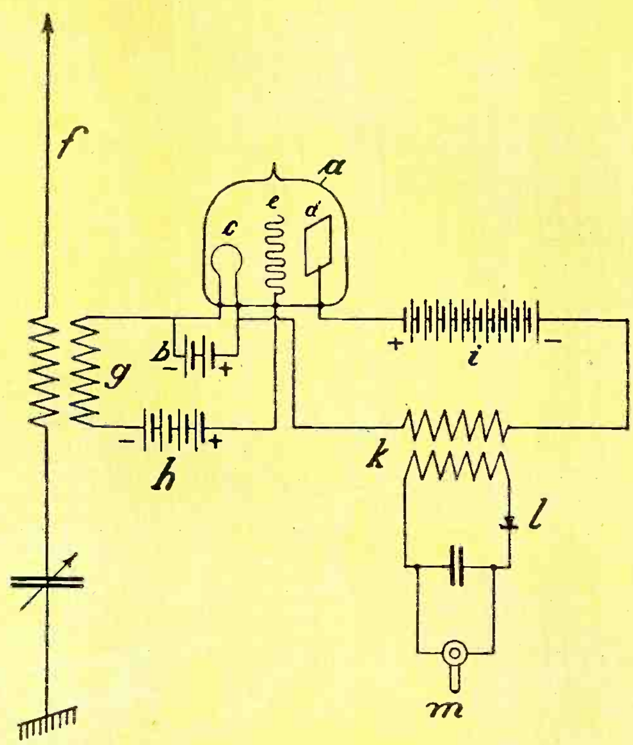


Fig. 54.

acted to deflect the cathode-ray beam from side to side, instead of altering the focus, as von Lieben's did. By means of this deflection more or less of the beam could be caused to fall on the center or side plates, and the currents in the individual anode circuits could thus be modulated.

This relay had the elements of the modern "electron gun" and the configuration shown in the middle figure was even capable of "push-pull" operation, provided the proper auxiliary apparatus was used at "X". The patent also states that the longer the distance from the diaphragm to the screen the greater would be the sensitivity, but that the shorter the distance the lower the operating voltage required. The structure shown in the bottom figure of the patent was given to illustrate how the electrodes might be arranged so as to keep the electron path free from the influence of interfering phenomena. Hence the device may also be said to be self-shielded. Whether the electron emission was obtained by heating the cathode or not is not stated.

About the same time (1908) Otto von Baeyer of the University of Berlin described[147] a three-electrode tube consisting of a central filamentary cathode rendered incandescent by a battery, surrounded by a cylinder of wire gauze, which in turn was surrounded by a cylindrical sheet metal anode. The whole was contained in a cylindrical glass tube which was partially evacuated, to a pressure of about 0.01 mm. mercury. This structure resembled that of some of the triodes which were still years in the future. Von Baeyer used this device to measure the ionization produced by cathode rays emitted from the filament. For this work the inner gauze cylinder was operated at a potential positive to the cathode and the outer cylinder at a potential negative to the cathode, in order to collect on the outer electrode the positive ions produced by the cathode rays in their passage through the space between the gauze electrode and the outer cylinder. Had the potentials been reversed the tube would have been an amplifier.

In the meantime von Lieben continued to strive for a better telephone relay. He was hindered in this work by extensive illness. While serving his year of military duty he had been catapulted from a horse onto a wooden fence, sustaining injuries to his chest. This later resulted in a glandular abscess which eventually brought about his death in 1913, at the early age of 35.

Reisz did most of the later development work on the cathode-ray relay, although several important details of later designs[148] are due to von Lieben, who was very active despite the severe pain due to his physical condition. Later these two were joined by Sigmund Strauss, and subsequent German patents on the cathode-ray relay were issued to all three jointly.

The next development of von Lieben, Reisz, and Strauss is covered by German patent D.R.P. 236716[149], which bears the application date of September 4, 1910. The diagram of this patent is reproduced in Figure 51. It will be noted that the structure bears much resemblance to that disclosed by Dieckmann and Glage in the patent previously discussed. The current to be amplified flows through the coils "a" and the magnetic field thus set up acts on the cathode ray stream. This is described as causing changes in the ionization of the attenuated gas in the open space between the plates "e" and "f". The diaphragm "B" is used to screen the cathode rays in such a way as to prevent their striking the plates "e" and "f". The load device is shown as a telephone in the circuit composed of the generator "Q", telephone "t", plates "e" and "f", and the ionized space between the plates. Note that the hollow mirror type of cathode is still retained. No method of heating the cathode is shown, but the patent specification states that:

> *"The material used and the temperature of the cathode "K", as well as that of the gas in the discharge tube are so chosen that, with comparatively small potential difference, emission of the cathode stream results."*

Note also that the inventors have abandoned the "high vacuum" referred to in the previous patent, and now speak of ionization of the attenuated gas.

"The difficulty of producing the hollow mirror cathode, the non-uniform emission of the cathode rays from the glowing oxide, and particularly the difficulty of maintaining a constant vacuum in the discharge tube were the main reasons" which motivated further development of the 1906 device[148]. From D.R.P. No. 236716 described above it will be seen that the difficulties related to the "high vacuum" were overcome by the utilization of the ionization of a rarefied gas instead of depending on pure thermionic emission.

The next patent issued to these inventors was German patent D.R.P. No. 249142[150]. It bears the application date of December 20, 1910, and is described as a supplement to D.R.P. No. 236716. In this specification, reference is made to the work of de Forest and his use of an "auxiliary cathode" in the form of a sieve or grid. Concerning de Forest's device the statement is made that "the currents to be magnified were led through the cathode and said electrode (grid or sieve)".

This statement would seem to indicate that von Lieben and his associates recognized the Audion structure to be an amplifier, even though de Forest himself had been unable to make it perform this function.

The invention, referred to in this patent, (D.R.P. No. 249142) is described as a modification of the one shown in the previous patent (D.R.P. No. 236716). The modification consisted of the use of electrostatic control by means of an auxiliary electrode to produce the variations in the amplified current, instead of using the variable ionization previously obtained by electromagnetically bending the cathode-ray stream. This auxiliary electrode is described as a "grid, grating, or mesh" so constructed that it "perfectly divides the cathode space from that of the anode". See Figure 52. The effect of this auxiliary electrode is said to be that of modifying the resistance of the space between the cathode and the anode. This results in variations of the anode current corresponding to changes in the resistance of the space.

It will be observed that there is provided, in the potentiometer "c" a means of adjusting the steady state potential of the grid. Concerning this adjustment the patent says:

> *"The adjustable potential thus brought to bear on H, has been found to be of the greatest importance in the successful operation of the relay, because a proportional variation of resistance of the gas discharge tube happens only at a certain definite value of potential difference, and this depends on the gas pressure and temperature of the cathode, etc."*

Figure 53 shows a von Lieben tube of this type, made in 1911.

The diagrams show, in all but one case, a ribbon cathode looped back and forth in the manner of an incandescent lamp filament of that time. This ribbon is oxide-coated, and is heated by a battery. In one suggested form, not shown in Figure 52, the hollow mirror cathode and external magnetic control are retained.

Mention has been made above of the reference in this patent specification to the work of de Forest, and the recognition by von Lieben of the potential

(*Continued on page* 58)

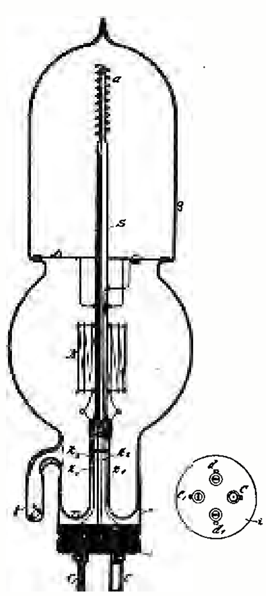


Fig. 55.

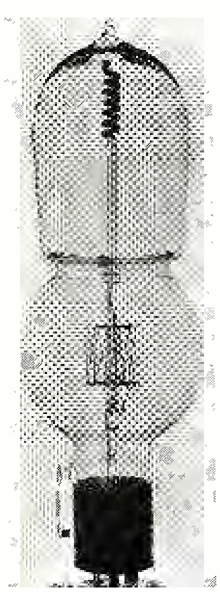


Fig. 56.

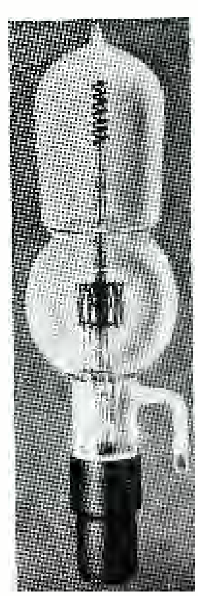


Fig. 57.

anode current 10-15 milliamperes, and the cathode heating current was about 2 amperes. The amplification factor was approximately 33, and a useful life of 1000-3000 hours was claimed.

In the earlier LRS Relays the bulb was about 18 inches high and had a maximum diameter of about 4 inches. Later a smaller bulb about 8 inches high, with corresponding reductions in the other dimensions, was made.[155] There were two types of bases. In one of these all connections were made through bayonet pins which were so arranged that the tube would not be inserted in an incorrect manner into the socket used. Figure 56 shows a specimen of the larger LRS Relay, with a base of this type. Figure 57 shows the same type of tube but with a different base.

The LRS Relay was used for a time as a telephone repeater in Germany, but was never satisfactory. It had several disadvantages. It was, like all ionization devices, undesirably noisy. The filament was subject to bombardment by the positive ions of the mercury vapor, which tended to knock off the oxide coating. Variations in the operating characteristics caused by external influences, such as temperature changes, were excessive. It was very sensitive to extraneous voltages which, if very great, caused paralysis of the tube. Most of these disadvantages are, however, common to all devices which employ mercury vapor. The introduction of this vapor had the effect of reducing the internal impedance of the device, and permitting the use of larger anode currents than had previously been obtained in vacuum tubes. It also simplified the design of the necessary auxiliary apparatus, such as input and output transformers.

When the LRS Relay was in operation the upper portion of the bulb, above the perforated intermediate electrode (grid), was filled with the blue glow of the ionized mercury vapor, except for a dark space just above the grid. This tube was usually operated with a positive potential on the grid, which was adjusted by means of a potentiometer. The most satisfactory functioning was usually obtained when the grid potential was adjusted so that the dark space extended from 1 to 2 cm. above the grid.[156] Some of these tubes had a graduated scale etched on the side of the glass bulb, extending upward from the grid. This was probably used as a guide in adjusting the height of the dark space.

The LRS Relay was made in two sizes, as has been noted before, and also in two types. One type had the electrode construction described above, the other was similar except that the perforated aluminum disc used as a control element was replaced by a fine wire-mesh grid.[157] It is not known to the author whether both types were made in both sizes or not. The tube with the fine mesh grid was intended for use as a "weak current" amplifier, and the other type, although similar, as a "strong current" amplifier.

Some of the difficulties which were experienced in the use of this amplifier in practice were overcome by enclosing the tube in a temperature regulator, as shown in Figure 58. This arrangement was made the subject of a German patent in 1914.[158] It was a makeshift solution, however, which only partially overcame the difficulties.

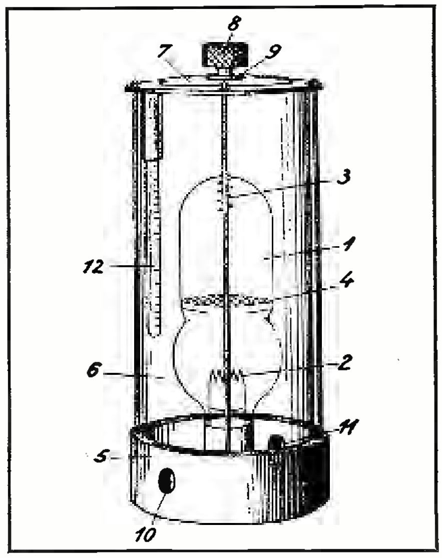


Fig. 58.

A short time later the Telefunken Company abandoned the gaseous tube and brought out a smaller tube with a tungsten filament, and a high vacuum.[159] This and later German high vacuum tubes will be treated in a subsequent article.

It is interesting to note, in passing, that von Lieben and his gaseous ionization tube have been honored by the Austrian Government by being pictured on a postage stamp. The stamp is one of the Charity Series of Commemorative Semi-Postals, issued in 1936. (Scott No. B131)

Concerning the work done in thermionics in other parts of Europe, the author has been able to find record of only two cases of such activity. The first is that of Eric Magnus Tigerstedt of Copenhagen, who, in 1914, obtained a German patent (D.R.P. No. 314085)[160] for a "relay for undulatory currents." A United States Patent covering the same device, and bearing the application date October 19, 1916, was issued

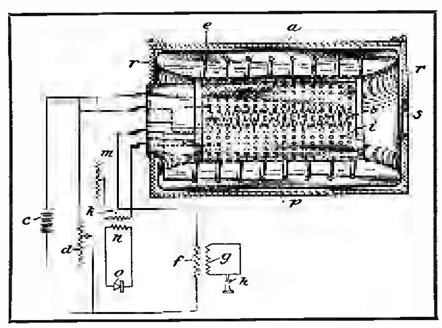


Fig. 59.

to Tigerstedt in 1917.[161] The invention was described as "a relay for undulatory currents comprising an airtight evacuated container, an anode mounted therein, a perforated auxiliary electrode arranged inside said anode, a cathode arranged inside said auxiliary electrode and adapted to be heated by an electric current, and a *mantle* consisting of a magnetically and electrically conducting substance surrounding said container."

Figure 59, which is reproduced from this U. S. Patent, shows the Tigerstedt tube in a circuit arranged for telephone amplification. The spiral wire *"e"* is the anode, the perforated cylinder *"i"* is the grid, and the zig-zag element *"b"* is the cathode. The effect of the external electrostatic and electromagnetic influences was said to be reduced by the concentric element structure, and by the enclosing "mantle." This is the first instance the author has been able to find of the use of a shield on the tube itself.

The other activity was that of Quirino Majorana of Rome, who devised a modification of the de Forest Audion, which he described as an "Electronic Deviator." He obtained a German patent (D.R.P. No. 281014)[162] on this device, which he described in a note to the Accademia dei Lincei in 1912.[163]

The Majorana Electronic Deviator is shown in Figure 60. It is similar in construction and dimensions to the de Forest Audion, except for the grid. The de Forest grid was replaced by two comb-shaped electrodes with their prongs alternating in the same plane. This was the first use of co-planar grids, as far as the author has been able to determine, and we do not find it again for twenty years. Majorana's device was intended for use as a wireless detector, but its possible use as a telephone relay was suggested by Max Ikle.[164]

While we are concerned only with factual material on the evolution of the vacuum tube, at this point an observation might be made, in passing, on the difference between the approach to the work done in America, and the approach to the work done abroad during this period.

The inventors in America, de Forest and his associates, struggling to make and use vacuum tubes, did not actually understand the theory of such devices. They were trying out gadgets to solve their problems with wireless, and by the process of elimination were turning out truly remarkable devices which, when perfected by our applied scientists, opened the door to modern communications.

In contrast to this we have seen how abroad the pure scientists had worked for many years on the mechanism of electrical conduction through gases, and had built up a background of vacuum tube information and technique. Then the inventors stepped into the picture, and by adapting certain laboratory techniques, produced a cathode-ray type of amplifier tube. This line of development eventually produced not only a telephone amplifier, but the cathode-ray tube so essential to the television of today.

We have also seen how confused was the picture, both in Europe and in

America, on the question of gaseous conduction versus pure electron discharge operation. This condition existed until the accumulated scientific knowledge of electronics was brought to bear directly and to the fullest extent on the practical problems of the utilization of these inventive advances.

With the work reported in this and previous articles, evolution of the vacuum tube advanced from the invention stage to that of industrial development. In the succeeding article we shall show how this development progressed in the largest communication laboratory in America, that of the Bell System.

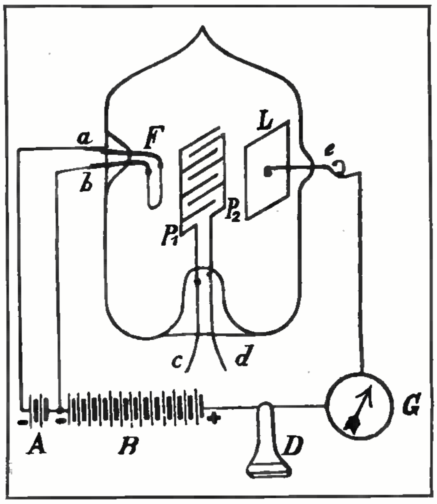


Fig. 60.

References

143. *Nernst, W.: "Zur Erinnung an Robert v. Lieben." Telefunken Zeitung, 6th year, No. 32-33, September 1923, p. 6.*

144. *Braun, Ferdinand: "Cber ein Verfahren zur Demonstration und zum Studium des zeitlichen Verlaufs variabler Strome." Annalen der Physik, Vol. 60, 1897, p. 552.*

145. *von Lieben, Robert: "Cathode Ray Relay." D.R.P. Nr. 179807, Klasse 21g, Gruppe 4, application date March 4, 1906, publication date November 19, 1906.*

146. *Dieckmann, Max and Glage Gustav: "Continuously and quantitatively acting relay, employing the electrical deflecting power of cathode rays." D.R.P. Nr. 184710, Klasse 21g, Gruppe 4, application date October 10, 1906, publication date April 2, 1907.*

147. *von Baeyer, Otto: "Uber langsame Kathodenstrahlen." Verhandlungen der Deutschen Physikalische Gesellschaft, Vol. 10, No. 4, February 29, 1908, pp. 96-114.*
See also Physikalische Zeitschrift Vol. 10, No. 5, pp. 168-176.

148. *Reisz, Eugen: "Neues Verfahren zur Verstarkung electrische Strome." Elektrotechnische Zeitschrift, Vol. 34, November 27, 1913, pp. 1359-1363.*
See also Electrician, Vol. 72, February 6, 1914, pp. 726-729.

149. *von Lieben, R., Reisz, E. and Strauss, S.: "Relay for undulating currents by which an ionizer is influenced by the currents to be intensified." D.R.P. Nr. 236716, Klasse 21g, Gruppe 4, application date September 4, 1910, publication date July 11, 1911.*

150. *von Lieben R., Reisz, E., and Strauss, S.: "Relay for undulating currents." D.R.P. Nr. 249142, Klasse 21g. Gruppe 4, application date December 20, 1910, publication date July 12, 1912.*
See also British Patent No. 1482 of 1911.

151. *Gesellschaft fur drahtlose Telegraphie: "Receiver arrangement for wireless telegraphy." D.R.P. Nr. 271059, Klasse 21a, Gruppe 68, application date September 3, 1911, publication date March 3, 1914.*

152. *Gesellschaft fur drahtlose Telegraphie: "Receiving station for wireless telegraphy and telephony." Brevet d'Invention No. 456,788, application date April 17, 1913, publication date September 4, 1913.*
See also U.S. Patent No. 1,087,892 of July 21, 1914; Austrian Patent 63,593 of February 25, 1914; and British Patent 8821 of 1913.

153. *Gesellschaft fur drahtlose Telegraphie: "Discharge tube with glowing cathode——." D.R.P. Nr. 264554, Klasse 21g. Gruppe 20, application date October 15, 1912, publication date September 26, 1913.*

154. *Scott-Taggart, John: "Thermionic Tubes in Radio Telegraphy and Radio Telephony." Wireless Press, 1921, pp. 62-63.*

155. *Thurn, H.: "Das drahtlose Telegraphieren und Fernsprechen mit Hilfe von Kathodenrohren." 2nd edition, Dietz, Berlin, 1920, p. 7.*

156. *Eichorn. G.: "Tonverstarker" Jahrbuch der drahtlosen Telegraphie und Telephonie, Vol. 8, 1914, pp. 446-458.*

157. *Eichorn, G.: See reference 154, p. 458.*

158. *Gesellschaft fur drahtlose Telegraphie: "Arrangement for cathode ray tube, for operation as amplifying relay." D.R.P. Nr. 293460, Klasse 21g, Gruppe 4, application date August 23, 1914, publication date June 23, 1919.*

159. *von Bronk, Otto: "Die historische Entwicklung der Elektronenrohre in der drahtlose Telegraphie." Telefunken Zeitung, Nr. 32-33, 6th year, September 1923, pp. 7-19.*
See also "Historique des Tubes à Emission électronique employés en t.s.f." Annales des Postes, Telephones et Telegraphes. Vol. 13, 1924, pp. 802-827.

160. *Aktieselkabet "Anod" in Kristiania: "Relay for undulating currents." D.R.P. Nr. 314085, Klasse 21g, Gruppe 4, application date June 27, 1914, publication date October 15 1914.*

161. *Tigerstedt, Eric Magnus: "Relay for undulating currents." U.S. Patent No. 1,212,-163, application date October 19, 1916, issued January 9, 1917.*

162. *Majorana, Quirino: D.R.P. Nr. 281014, Klasse 21a, Gruppe 70, application date October 10, 1912, publication date December 4 1914.*

163. *Majorana, Quirino: "On a new type of indicator of electromagnetic waves based upon electronic emission from incandescent wires." Atti della Reale Accademia dei Lincei, 5th series, Vol. 21, 1912, pp. 274-277.*

164. *Ikle, Max: "Majoranas neuer Wellendetektor." Jahrbuch der drahtlosen Telegraphie und Telephonie, Vol. 7, 1913, pp. 462-468.*

Captions for Illustrations

Figure 49. Von Lieben high vacuum cathode ray relay of 1906, using magnetic field for beam defocussing. Reproduced from *D.R.P.* Nr. 179807.

Figure 50. Dieckmann and Glage cathode ray relay of 1906, using magnetic deflection of cathode rays. Reproduced from *D.R.P.* Nr. 184710.

Figure 51. Von Lieben gaseous cathode ray relay of 1910, using magnetic deflection of cathode rays acting as "ionizer." Reproduced from *D.R.P.* Nr. 236716.

Figure 52. Von Lieben gaseous cathode ray relay of 1910, using electrostatic control of cathode rays. Reproduced from *D.R.P.* Nr. 249142.

Figure 53. Photograph of Von Lieben gaseous cathode ray relay made in 1911. Reproduced from *Archiv fur Geschichte der Mathematik,* 1931.

Figure 54. Von Bronk arrangement for using the de Forest Audion as a high frequency amplifier. Reproduced from *D.R.P.* Nr. 271059.

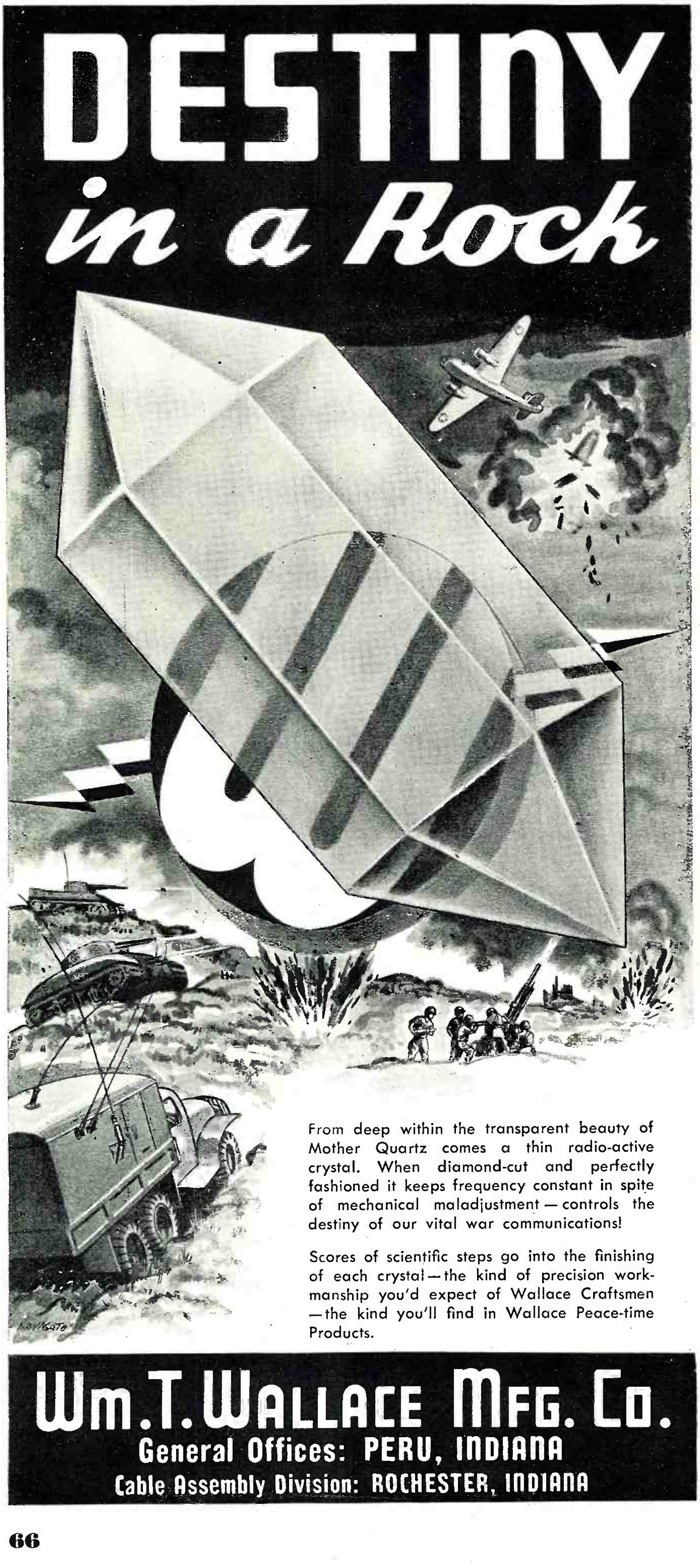


Figure 55. Von Lieben mercury vapor repeater tube in final form. Reproduced from *D.R.P.* Nr. 264554.

Figure 56. Large size LRS Repeater, with perforated sheet aluminum grid and pin type base. Photograph courtesy *Bell Telephone Laboratories.*

Figure 57. LRS Repeater with cylindrical base. Reproduced from *Archiv fur Geschichte der Mathematik,* 1931.

Figure 58. Temperature regulator for LRS Repeater. Reproduced from *D.R.P.* Nr. 293460.

Figure 59. Tigerstedt telephone relay arrangement using magnetically shielded and concentric electrode structure. Reproduced from *U.S.P.* 1,212,163.

Figure 60. Majorana's Electronic Deviator. Reproduced from *Jahrbuch der drahtlosen Telegraphie und Telephonie,* 1913.

—30—

Oscilloscope Applications
(*Continued from page* 41)

In addition to providing hitherto unobtained speed, the oscillographic method of obtaining tube characteristics permits, at the same time, the use of higher electrode voltages than would be possible in taking such data by other means. This is because the various instantaneous values of voltage are maintained for too short a time to produce any injurious effects upon the electrodes. A peak value of plate voltage may thus attain a value which, under conditions of observation, by means of meters, would result in certain damage to the tested tube.

In testing tubes, *any* current characteristic may be plotted on the oscilloscope screen by employing the voltage drop produced by the current flowing through a small resistance. Rectifiers and other diodes may be tested as well as multielectrode types.

Indication of Gas Engine Cylinder Pressure

In investigations of internal-combustion engine operation, cylinder pressures can be measured by means of pressure gages similar to the familiar steam gages. This system possesses numerous limitations. Recent methods make use of electromechanical-pressure kickup devices which are fastened to the outside of cylinder walls and record internal pressure during the various cycles of engine operation. This apparatus is susceptible to great vibrations of the motor and does not possess the required sensitivity for investigating action of anti-knock gasolines.

Engine cylinder pressure is recorded in modern motor laboratories by means of radionic equipment which employs the oscilloscope as an indicator. In this system, virbrational impulses are transmitted from the *inner* wall of the cylinder by a light beam.

THE SAGA OF THE VACUUM TUBE

by GERALD F. J. TYNE
Research Engineer, N. Y.

Part 9. The evolution of the vacuum tube from its original conception to its application as a practical commercial device.

THE evolution of the practical high-vacuum tube from the low-vacuum de Forest Audion provides an interesting example of the painstaking development work required to make of an invention a commercially practicable device. The manifold problems encountered in such development work are almost incapable of solution in any reasonable time by any one individual. It is only in the industrial laboratory, where each problem is attacked by a specialist in the particular field, that the desired result will be attained.

In this and succeeding articles an attempt will be made to follow this evolution as it took place in the Engineering Department of the Western Electric Company and later the Bell Telephone Laboratories. The chief stress will be laid on the mechanical or physical evolution to assist in the identification of the various early types of the tubes that materialized. This is necessary because for many years Western Electric vacuum tubes were designed and manufactured almost exclusively for telephone and Government use, and did not reach the public through the ordinary channels of commerce. Hence, they will not be as familiar to tube collectors as are vacuum tubes made by other manufacturers for general use and for sale to the public, after the advent of broadcast radio had created the demand.

By the year 1912 land-line telephony had made considerable progress in the field of long distance circuits, but there was need of a telephone repeater more suitable than any at that time in use. The useful length of telephone circuits could at that time be extended either by loading or by the use of repeaters, but in general both could not be used on the same circuit at the same time. The characteristics of the mechanical repeaters which had been developed were such that satisfactory operation in tandem was not practicable. It was realized that the solution to the problem must be sought in some form of inertialess repeater, and early in 1911 work was started on the development of a mercury vapor device of the general type covered by the Peter Cooper-Hewitt patents.

This task was undertaken by Dr. Harold D. Arnold, who had studied the infant science of electronics under Dr. R. A. Millikan at the Ryerson Laboratory of the University of Chicago. By the summer of 1912 Dr. Arnold had succeeded in producing an amplifying device which gave promise of becoming a useful telephone repeater. This was known as the "mercury arc" repeater and an experimental form of the device, which was used to a limited extent, is shown in Figure 61. An experimental installation of these repeaters is shown in Figure 62. The development of this device was never carried to the point of commercial practicability because of the appearance on the scene of another device which showed more promise.

In October 1912 John Stone Stone,

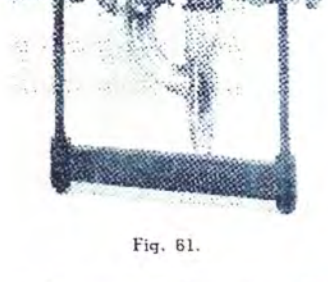


Fig. 61.

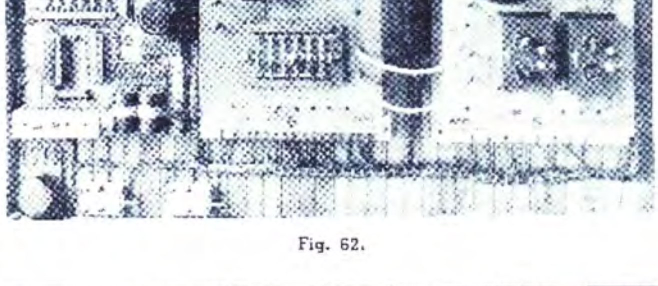


Fig. 62.

acting for Lee de Forest, got in touch with J. J. Carty of the American Telephone and Telegraph Company with a view to demonstrating the de Forest Audion for use as a telephone repeater. A meeting was arranged and on October 30, 1912 de Forest and Stone came to the Engineering Department of the Western Electric Company, ready to demonstrate the device. The demonstration showed that under the conditions of operation employed by de Forest, that is, operation with the grid condenser of its radio detector days, the Audion would function as an audio-frequency amplifier, but only at such low levels as not to build up on the grid a blocking voltage. The demonstration was repeated on the following day with the same results, and de Forest left the apparatus for further tests and experiments by the telephone engineers. There were two forms of Audion used in these demonstrations. One form was that previously shown in Figure 44, the other is shown in Figure 63.

On the next day, November 1, 1912, Dr. Arnold saw the Audion and recognized its possibilities, even though the device and its operating circuit as disclosed by de Forest was incapable of fulfilling the requirements. Arnold recognized the defects and told how they might be remedied. But the accomplishment of the remedies and the development of the comparatively crude Audion into a reliable telephone repeater was a long and arduous process.

A satisfactory telephone repeater must meet many requirements other than the primary one, that of producing amplification. It must be capable of handling the energy levels existing at repeater points on telephone lines, must amplify all frequencies present without discrimination, have long useful life, operate under essentially the same conditions, and produce the same results throughout its useful life. It must be such that it can be manufactured in quantities, and that the individual devices so manufactured be commercially interchangeable.

The device, in general, should be such that, once installed, it will function satisfactorily without any other attention then routine inspection. At the end of its useful life, it must be possible to remove the unit and replace it with another commercially similar unit, and have the circuit ready for operation without changes in the auxiliary apparatus and with only minor readjustments.

The Audion, as demonstrated by de Forest, fell far short of these requirements. It amplified very weak speech currents and amplified them accurately. When the input level was raised to that normally encountered in telephone practice the quality was greatly impaired and the amplification considerably reduced. Under these conditions blue haze sometimes occurred. If the plate battery voltage

(*Continued on page 56*)


Fig. 63.


Fig. 64.


Fig. 65.


Fig. 66.


Fig. 67.


Fig. 68.


Fig. 69.


Fig. 70.


Fig. 71.


Fig. 72.

Saga of Vacuum Tube

(Continued from page 31)

was raised, a condition of permanent blue haze ensued. When blue haze was present not only was the amplification lowered and distortion high, but the device introduced noise.[165] The life of the filament was very short, and frequent readjustment of the filament and plate potentials was required. The structure was flimsy and the bulbs were fragile. Individual bulbs differed greatly in their characteristics.

Yet it would amplify, was remarkably simple in operation, and to one trained in the then science of electronics, gave immediate evidence of real promise. Arnold has testified that when he first saw it he was amazed and realized that he "had overlooked the wonderful possibilities of that third electrode operation, the grid operation in the audion."[168] He recognized that the presence of gas in the bulb, which de Forest had considered essential to its operation, was a liability rather than an asset. He knew that in order to make the operation uniform and reliable the gas should be removed. This would convert the audion from a semi-gaseous thermionic tube into a pure electron discharge device. He also felt that the difficulties presented by the use of the tantalum filament could be overcome by the use of a cathode of the Wehnelt, or oxide-coated, type, a more copious generator of electrons and one which would operate at a comparatively low temperature. This would give an energy-carrying capacity, a stability, and life of operation more in keeping with practical requirements. The mechanical disadvantages could be overcome by a suitable redesign of the element structure.

Arnold, and those in the laboratories who soon joined him in this work, were familiar with the technique of high evacuation. Arnold had been working since he joined the Western Electric Company on the mercury arc repeater, which required careful evacuation even though it operated in the presence of positive ions, and previous to that had been engaged in research work on high vacuum devices at the Ryerson Laboratory under Professor Millikan. Such scientists were also familiar with the literature on the Fleming valve and the Wehnelt cathode.

The first improvement effected was not in the device itself, but in the circuit in which it was used by de Forest. The improvement consisted in removing the series condenser in the grid circuit. This, although necessary for operation of the audion as a wireless detector, was the cause of blocking when the attempt was made to use the audion at telephone operating levels.

The next step was to improve the

mechanical construction of the device. This was done by adding a glass "arbor" to the element assembly to increase its rigidity. Figure 64 shows one of the audions so reinforced. The next change made was to increase the plate area, which was accomplished by the addition of a second grid and plate assembly, thus producing the tube shown in Figure 65.

Up to this point, the changes made were comparatively easy to accomplish. The next steps were not so easy.

Work, meantime, had been begun on a theoretical and experimental investigation of the audion to determine its mode of operation and characteristics. At the same time, the problems involved in obtaining the needed higher vacua and developing a suitable commercial oxide-coated filament or cathode were attacked simultaneously, by Dr. Arnold and his associates. The technique of obtaining high vacua by the use of liquid air and charcoal, which had been developed by Sir James Dewar, could not be used, because there were no facilities available in the vicinity for obtaining the requisite quantities of liquid air and the problems of its transportation had not yet been solved.

Within a month of the time Arnold first saw the Audion, one of his assistants working in accordance with his instructions had succeeded in "cleaning up" or increasing the vacuum by electrical means in one of the audions. This increase in vacuum was sufficiently great so that the tube could be operated as a pure electron discharge device up to a plate potential in excess of 80 volts[16].

In 1912 the Gaede Molecular Pump was placed on the market by a foreign manufacturer. This pump was capable of producing vacua of the order of 0.00001 mm. of mercury, and would remove vapors as well as gases from the space being evacuated. One of these pumps was secured as soon as possible, and by its use tubes were made which could be operated at plate voltages in excess of 200 volts without harmful ionization. That is, they were pure electron-discharge devices.

Development of the oxide-coated filament progressed at such a rate that by the middle of 1913 there had been obtained a preliminary form of such a filament with a laboratory life of 1,000 hours.

In the fall of 1913 the problems of making a satisfactory high vacuum telephone repeater had been solved to such an extent that a field trial of the device could be made. Accordingly, a trial installation was made at Philadelphia on a toll circuit between New York and Washington. The high vacuum tube repeater was actually placed in service on this trial basis on October 18, 1913, and it was probably the first high vacuum tube amplifier to go into service in the annals of electric communications.

The vacuum tubes used in this repeater were known as "Type A" and a photograph of one of them which is still preserved in the Bell System Historical Museum is shown in Figure 66. The type "A" was an unbased spherical tube about $2\frac{3}{8}$ inches in diameter and was double-ended. The stem and press at one end carried the filament, which was Λ shaped, the apex being supported by a wire extending upward from the press. The filament was platinum coated, in the case of this particular tube, with barium nitrate. It was approximately $\frac{7}{8}$ inch high and the lower ends were about $\frac{3}{8}$ inch apart. The plate and grid assemblies were supported from the stem and press at the opposite end of the tube to the filament assembly, and were kept rigid by the use of glass arbors, one for each grid-and-plate. The plates were approximately $1\frac{1}{8}$ inches high and were of nickel. The grids were made by welding hairpin-shaped loops onto a narrow supporting strip. The grid was approximately $\frac{3}{8}$ inch wide by $1\frac{1}{4}$ inches high. Nine hairpin loops were used, hence the grid had eighteen laterals.

After a short period of use the type "A" tube was superseded by the type "B." This tube was an improvement over the type "A" in several ways. The filament was somewhat larger and was of twisted platinum ribbon. The most noticeable difference was in the grid structure. Each grid was made up of eight horizontal wires, evenly spaced in a vertical direction and welded to two upright supports. This construction became known as the "ladder-type" grid, and was extensively used up to a few years ago by the Western Electric Company.

Early in 1914, it became apparent that the use of unbased tubes was unsatisfactory, and steps were taken to provide a suitable base and mounting socket for these tubes. The first based tubes were known as type "M" tubes (M-mounted), and the socket shown in Figure 69 was a heavy cast brass affair, similar to that previously used for the mechanical repeater.

A photograph of a type "M" tube (set in a display mounting) is shown in Figure 70. The base was a heavy machined brass affair, equipped with four studs on the bottom, and a bayonet locking pin on the side. The four studs pressed against corresponding springs in the socket when the tube was inserted, thus completing the electrical connections required. This arrangement made for facility in replacement of the vacuum tube elements.

Vacuum tube repeaters were utilized for very long distances for the first time when the transcontinental telephone line, New York to San Francisco, was opened on January 15, 1915. At that time the type "M" tubes were used. They operated at a filament current of 1.35 to 1.55 amperes at a voltage of approximately 4. The normal plate voltage was 100 volts, plate current 10 to 15 milliamperes, amplification factor 5, and internal plate impedance about 5000 ohms. The useful life of about 400 hours was well in excess of that of the de Forest Audion.

Theoretical studies indicated, however, that this life could be considerably improved by an increase in the electron emitting area of the filament, which would permit operation at a lower filament temperature and still give the required thermionic emission. Hence, a new tube, which came to be known as the type "L," was designed and was first produced on a commercial scale in 1915. The type "M" was still made, for replacement purposes.

A photograph of one of the early type "L" tubes is shown in Figure 71. It will be seen that the filament length has been approximately doubled, resulting in doubled emitting area. Other changes in design have also been made. The grid has been changed from 8 to 9 laterals, and the bracing of the plates is different. This tube had a life of about 4,500 hours, which was eleven times that of its predecessor the type "M," and fifty to 100 times that of the Audions originally submitted to the Telephone Company by de Forest.

The first type "L" tubes carried no patent marking. Late in 1915 patent markings began to be applied. The markings were steel-stamped in 1/16 inch high characters on the base shell.

One of the tubes having this patent marking on the base is shown in Figure 72. There was also a serial number on each bulb, applied with a rubber stamp and "diamond ink."

About the middle of 1916 the use of the letter designations was officially abandoned, and code numbers similar to those assigned to identify other types of telephone apparatus were given to repeater tubes. The type "M" became the "101A" and the type "L" the "101B."

The reader will note that the letter designations were *officially* abandoned. Such official action did not, however, change the mental processes of those who had become familiar with the letter terminology, and today, some thirty years later, we hear even the younger generation of telephone engineers refer to the 101 types as "L tubes."

These tubes were first known as "Telephone Repeater Elements." Later, in 1917, the name was changed to "Repeater Bulb." These names were used rather than "Vacuum Tube" to differentiate the tubes made for telephone repeater use from those made for the U.S. Government and other non-telephonic applications. These latter were officially known as "Vacuum Tubes." This nomenclature was used until about 1922, when the term "Vacuum Tube" was applied to all such devices no matter for what use they were intended.

Captions for Illustrations

Figure 61. Arnold Mercury Arc Telephone Repeater, mounted in swinging bracket. (1914) Photograph

courtesy *Bell Telephone Laboratories.*

Figure 62. Experimental installation of Arnold Mercury Arc Repeaters on transcontinental telephone line. Photograph courtesy *Bell Telephone Laboratories.*

Figure 63. Large single grid single plate Audion submitted to the American Telephone and Telegraph Company by de Forest for consideration as a telephone repeater element. (1912) Photograph courtesy *Bell Telephone Laboratories.*

Figure 64. First modification of the de Forest Audion by Western Electric Company. A glass arbor has been added to promote rigidity of the element structure (1913).

Figure 65. Second modification of de Forest Audion by Western Electric Company. Double grid and plate assemblies, supported by glass arbors. This tube had lower impedance and passed greater plate current than that shown in Figure 64. Photograph courtesy *Bell Telephone Laboratories.*

Figure 66. Philadelphia Audion No. 64. This is a sample of the first high vacuum tube, designated type "A," made by the Western Electric Company. This particular tube was used as a telephone repeater in commercial service at Philadelphia in October 1913. Bell System Historical Museum Exhibit. Photograph courtesy *Bell Telephone Laboratories.*

Figure 67. Double-ended type "B" high vacuum tube. This is the first type to use the "ladder" grid, characteristic of the early Western Electric tubes. Photograph courtesy *Bell Telephone Laboratories.*

Figure 68. Single ended type "B" tube, set in wooden base for display purposes. Later construction than that shown in Figure 67. Photograph courtesy *Bell System Historical Museum.*

Figure 69. Cast brass socket used by the American Telephone and Telegraph Company for the first based repeater tubes (1914).

Figure 70. Western Electric type "M" tube, the first high vacuum based telephone repeater tube (1914). Later designated as "101A Telephone Repeater Element." Photograph courtesy *Bell Telephone Laboratories.*

Figure 71. Western Electric type "L" repeater tube (1915). This was later designated as the "101B Telephone Repeater Element." Note increased length of filament as compared with type "M." Photograph courtesy *Bell Telephone Laboratories.*

Figure 72. Early Western Electric type "L" or 101B Telephone Repeater Element, showing patent markings applied to base (1915).

References

165. *Transcript of Record—General Electric Company vs. De Forest Radio Company. U. S. Circuit Court of Appeals. 3rd District—Nos.* 3799, 3800, 3801—*March term* 1928. *Testimony of E. H. Colpitts, pp.* 497-500.

166. *See reference* 165. *Testimony of H. D. Arnold, p.* 556.

167. *See reference* 165. *Testimony of H. D. Arnold, pp.* 601-604.

(to be continued)


Fig. 73


Fig. 74


Fig. 75

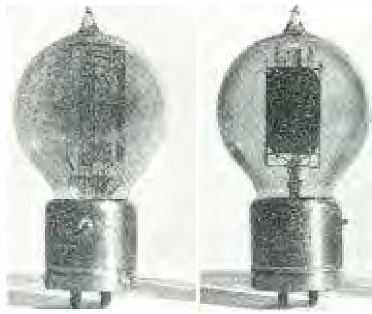


Fig. 76

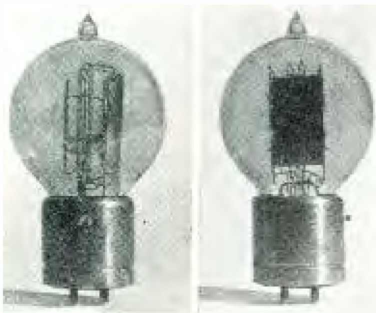


Fig. 77

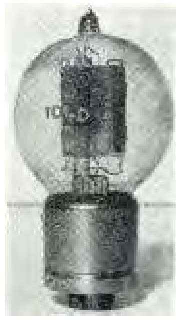


Fig. 78


Fig. 79


Fig. 80

THE SAGA OF THE VACUUM TUBE

by GERALD F. J. TYNE
Research Engineer, N. Y.

Part 9. The early constructional problems of the Western Electric type-101 vacuum tube—covering its multiplicity of shapes and sizes.

NOW we come in our story to the point where we need to know a bit more about this modern Aladdin's lamp; how it looked, how it was constructed, and the multiplicity of forms into which it grew.

To the tube collector, the tube is known by its appearance. So much emphasis in what follows is laid on appearance; on significant changes in construction and markings. The identifying of these changes is a reminder that a great deal of engineering effort goes into developing something which is really serviceable to mankind. Few people have any idea of the multitudinous details of construction and materials involved, or the meticulous measurement work and performance testing.

In this article our consideration will be of the Western Electric 101-type vacuum tube, from the point at which it was left at the end of the preceding article up to the present time, for it is still in use. The early Western Electric tubes merit particular attention for several reasons. They were little known to the public, having been developed for use in the telephone repeater plant, which is largely "behind the scenes." They were by far the best of the early tubes, and they provide a striking example of intensive organized research to produce an article, not for general use or sale in the market place at an attractive price, but for service in a highly specialized application, in a plant where they were treated with care, and in which reliability and long life were the desiderata to be attained.

Late in 1917 the type of base used on Western Electric Vacuum Tubes and Repeater Bulbs was changed. As has been described, up to this time it was a heavy, machined brass, seamless shell. The new base was a formed casing of German silver. Into the bottom of this formed casing was fitted an insulating member on which the contact studs were mounted. (See Fig. 73). The space around the insulating member was filled with a red wax known as "Zinssner's Regular Insulating Wax." This was a mixture of red iron oxide with shellac gums. The wax was poured in to fill the base flush with the bottom of the formed shell and a die applied to form the letters and numerals of the code marking in the center, in raised characters. This type of base was used until about 1925, although later a different filling compound was used. The color of the Zinssner's wax was always red, although the shade varied from lot to lot, sometimes almost to brown. The compound which was later used was black in color.

When the new type of shell was put into use the patent marking read as follows, (see Figure 74):

PAT. IN USA
1-15-07 TWO PATENTS
2-18-08 4-27-15
12-19-16
PAT. APPLIED FOR

The first of the tubes made using this shell bore the code marking only in the wax filling of the shell.

Late in 1918 the markings on the base of the 101B and all other repeater bulbs were changed (as shown in Figure 75) to include the property marking of the A. T. & T. Co. The marking of the 101B thus became:

PROPERTY OF
AMERICAN
TEL. & TEL.
COMPANY
101B

PAT. IN U.S.A.
1-15-07 TWO PATENTS
2-18-08 4-27-15
12-19-16
PAT. APPLIED FOR

The construction of the 101B Repeater Bulb up to this time was that shown in the bulb depicted in Figure 76. The element assembly was supported by a glass arbor which was sealed to the edge of the press, and the plane of the element assembly was at right angles to the plane of the press, both being vertical. Difficulties were experienced with this form of assembly however, the most common source of trouble being breakage of the arbor at the point where it was welded to the press. Many of the tubes still in existence show such breakage.

To overcome these difficulties the element was redesigned and, beginning early in 1919, the arrangement shown in Figure 77 was used. Here the arbor has been made heavier and was welded to the stem somewhat below the press. The positioning of the arbor was such that the element assembly was made parallel to the press instead of at right angles to it. The grid structure was changed from 9 to 11 laterals and the plates were made rectangular with edges turned up at right angles to provide stiffening. The tie wires at the top of the assembly were welded to the turned-up edges instead of the flat surfaces, as had previously been the case.

Late in 1919 the patent marking was changed to read as follows:

(*Continued on page* 54)

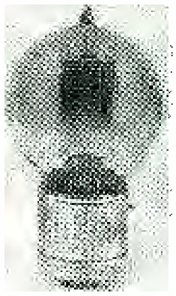


Fig. 81.

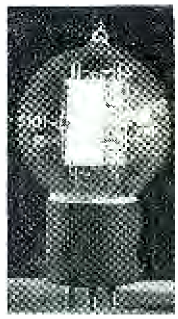


Fig. 82.

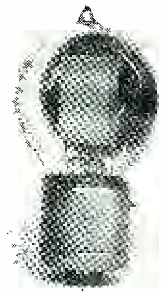


Fig. 83.

Fig. 84.

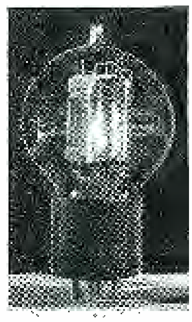


Fig. 85.

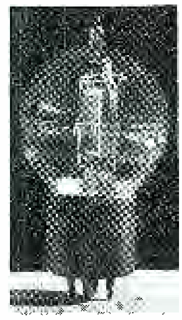


Fig. 86.

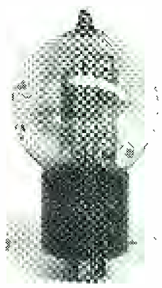


Fig. 87.

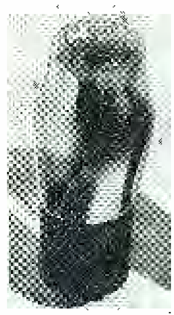


Fig. 88.

Fig. 89.

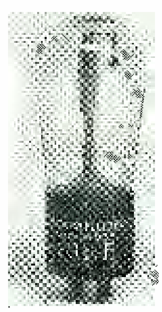


Fig. 90.

Fig. 91.

Saga of Vacuum Tube

(Continued from page 39)

PAT. IN U.S.A.
1-15-07 TWO PATENTS
2-18-08 4-27-15
10-17-16 12-19-16
12-17-18
PATS. APPLIED FOR

Early in 1921 the patent date 10-5-20 was added to this marking.

Meantime, work had been carried on with a view to improving the characteristics of this tube, especially in the matter of power required for the filament. By 1921 theoretical studies and laboratory experience indicated that this could be done without sacrificing the other characteristics, and accordingly, late in 1921 the 101B was replaced by the 101D.

The 101D was the same as the 101B except for the filament; the first of the 101D tubes operated at a filament current of 1.15 amperes as against the 1.30 amperes required for the 101B. The filament of the 101D had a platinum-nickel core instead of the platinum-iridium previously used, and was untwisted. In order to readily distinguish these lower current tubes from their predecessors, the tips were colored green by the application of lacquer. This practice was continued until 1924.

The manufacture of the 101B was discontinued in 1923.

The first of the 101D tubes had the code marking etched on one side of the bulb in letters approximately ¼ inch high, as shown in Figure 78, and had the serial number etched on the opposite side of the bulb. These tubes bore the following patent marking:

PAT. IN U.S.A.
1-15-07 TWO PATENTS
2-18-08 10-17-16
12-19-16 10-5-20
PATS. APPLIED FOR

Early in 1922 this marking was discontinued and the standard type of marking was applied on the base, both on the shell and in the wax. Soon thereafter the patent marking was changed to read as follows:

PAT. IN U.S.A.
1-15-07 12-19-16
2-18-08 12-17-18
10-17-16 1-27-20
PATS. APPLIED FOR

A short time later the patent date 10-5-20 was added. (See Figure 79.)

Early in 1923 the practice of the American Telephone and Telegraph Company was changed and vacuum tubes were sold directly to the Operating Companies instead of being leased to them. Hence the marking of tubes as the "Property of the American Tel. & Tel. Company" was dicontinued and henceforth they were marked "Western Electric—Made in U.S.A." (Figures 80 and 81).

In 1925, in order to effect economies in manufacture, and permit the use of the same shell on all tubes, the markings were removed from the base and applied to the bulb in a single band as shown in the tube depicted in Figure 82.

Later in 1925 the design of the 101D tube was changed to use a molded base, with the code and patent markings being applied to the bulb in a single band as before. The metal bases previously used were difficult to manufacture to the close dimensional limits required; the filling wax tended to flow out under extreme temperature conditions, and the micarta inserts on which the studs were mounted sometimes absorbed moisture.

The first design of molded base, which used soldering tabs on the contact studs, was employed for about a year and was then replaced by a molded base with a type of stud in which the lead-out wire was threaded through a hole in the stud and soldered on the outside. Essentially the same type of contact stud is still used on these tubes. In order to reduce the variations in the resistance of the contact between the stud and the socket spring, all repeater tubes have been equipped, since the early days of the metal shell, with precious metal contact tips on the base prongs.

The practice of magnesium flashing to aid in obtaining high vacuum was introduced just before the change from metal to molded base, and one of the metal-based flashed tubes is shown in Figure 83. Some tubes were still made without this flashing, for use in certain types of carrier systems.

By 1927 studies of filament materials and characteristics had progressed to such a point, and methods of manufacture had been so improved, that satisfactory operation could be obtained with a new type of filament which operated at approximately 0.5 ampere filament current, and approximately the same filament voltage. This represented a great increase of efficiency and consequent lower operating cost, since it halved the power required for filament operation.

Around this new filament was designed a new repeater tube, with approximately the same plate characteristics as the 101D. This new tube was known familiarly as the "half-ampere L tube" and officially as the "101F Vacuum Tube." At the same time the mechanical structure of the element assembly was entirely redesigned. The plate was made of the completely enclosing type, the grid a continuously wound spiral, and the spacing between the elements greatly reduced. One of these tubes is shown in Figure 84. The 101F did not completely replace the 101D, which still continued to be made.

In April 1927 there occurred a revision of the United States Patent Law which provided that the patent marking of any article made under a patent issued after that date should consist of the patent number rather than the date of issue, as heretofore. An article made under patents issued prior to the effective date of the change in the law could be marked with either the date of issue or the patent numbers.

In accordance with the provisions of this law the markings on the bulbs of the 101D and 101F tubes were changed, in 1928, from dates of issue to patent numbers. Photographs of 101D and 101F tubes so marked are shown in Figures 85 and 86.

In 1929 the practice of magnesium flashing the 101D was discontinued and some minor changes in design, such as the relocation of the plate lead and the use of a shielded grid-lead-in wire, were made. About the same time the practice of putting the code marking on the base, in depressed characters, was adopted. (See Figure 87). The patent markings were, at the same time, removed from the bulb and applied to the carton in which the tube was packed.

The construction of the 101D remained practically unchanged from 1929 until 1940, when the tube was completely redesigned and modernized. This redesigned tube, which is in current manufacture, is shown in Figure 88.

The practice of putting the code marking and Western Electric name on the molded base, in depressed characters, was instituted for the 101F at the same time as for the 101D. Figure 89 shows a 101F tube with these markings.

Later the 101F was changed to use a pear-shaped bulb instead of the spherical one, and this tube is shown in Figure 90.

When the 101D was redesigned in 1940 similar changes were made in the 101F, resulting in the tube shown in Figure 91, which is of current manufacture.

Still further studies have since been made which have resulted in the realization of a tube which operates at one-half the filament current of the 101F, and this tube, known as the 101L, is now in production.

The story of the 101-type tube is a most interesting one. The evolutionary steps which they have gone through is an excellent example of what can be accomplished by continued study and long experience in the manufacture and use of a particular type for a definite purpose. The 101 types are, always have been, and probably always will be designed and manufactured for use in telephone repeaters. The conditions under which they operate are exacting, and it is greatly to the credit of the research workers, designers and manufacturer that these conditions have continued to be met satisfactorily. This has been accomplished in spite of the fact that the latest designs require only one-fifth the filament power of the first tubes of this type. And in the process the useful life of the tube has been increased a hundred fold, from the 400 hour life of the 101A to the 40,000 hour life of the 101D.

Truly a remarkable achievement!

CAPTIONS FOR ILLUSTRATIONS

Figure 73. Formed sheet metal base with micarta insert, used on Western Electric Repeater Bulbs and Vacuum Tubes 1917-1925. View before base has been filled with wax.

Figure 74. First type of 101B Repeater Bulb to use formed sheet metal base. The code designation appeared only in the wax filling of the base, and the patent marking was applied in depressed characters to the metal base shell. The markings have been filled white in the illustration, for photographic purposes.

Figure 75. Later manufacture 101B showing code marking and A.T.&T. Co. property marking applied to sheet metal base. The code number was also applied to the wax filling of the base.

Figure 76. Two views of the early 101B Repeater Bulb. This shows the construction in which the arbor supporting the element assembly was attached to the edge of the press. This particular tube was made at the Hawthorne Works of the Western Electric Company, as evidenced by the "H" following the serial number on the glass.

Figure 77. Two views of the improved 101B Repeater Bulb. The glass supporting arbor is heavier, and is welded to the stem below the press. This was a more sturdy construction than that shown in Figure 76.

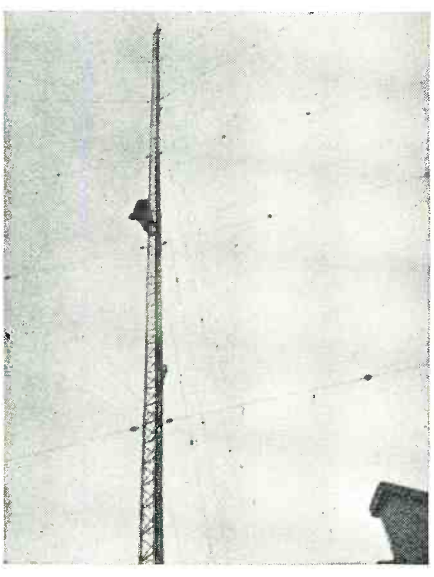
Figure 78. Early type 101D Vacuum Tube. The code marking appeared only on the glass bulb.

Figure 79. Later type 101D, showing code marking, A.T.&T. Co. property marking, and patent marking on base.

Figure 80. Later 101D than that shown in Figure 79. A.T.&T. Co property marking has been replaced by Western Electric marking and patent marking has been revised. Markings are in 1/16 inch high characters.

Figure 81. Same as Figure 80 ex-

Passing the half-way mark up the 200-foot tower of the Maine State Police Department WBNV, Augusta, Me. A ⅞" coaxial gas-fed line leads to a coaxial radial antenna on top of it.



cept that markings are in 3/64 inch high characters.

Figure 82. 101D Vacuum Tube with molded phenol plastic base, code and patent marking on bulb in baked enamel lettering. Patent marking given as dates of issue of relevant patents.

Figure 83. 101D Vacuum Tube with metal base and magnesium flashing.

Figure 84. Early 101F Vacuum Tube—code and patent marking on bulb, patent marking given as dates.

Figure 85. Later 101D Vacuum Tube—markings on bulb—patent numbers have replaced patent dates.

Figure 86. Later 101F Vacuum Tube—markings on bulb—patent numbers have replaced patent dates.

Figure 87. 101D Vacuum Tube with molded base. Code number is in depressed characters on base. Base markings have been filled white for photographic purposes. Patent markings were applied to the carton in which this tube was packed.

Figure 88. 101D Vacuum Tube of latest construction—new element assembly and domed bulb.

Figure 89. 101F Vacuum Tube with markings in depressed characters on phenol plastic base.

Figure 90. 101F Vacuum Tube in pear-shaped bulb.

Figure 91. 101F Vacuum Tube of latest construction.

(*To be continued in March issue*)

Theory of U.H.F.

(*Continued from page* 34)

of the various references given with this article. They contain practically all the published knowledge of the Klystron tube as used with ultra-high frequencies. Those references that have an asterisk contain a mathematical analysis of the Klystron while the others are more or less descriptive.

The operation of another ultra-high-frequency tube will be considered in the next part of this series of articles. The principle of operation will depend upon the instability of moving electrons in a magnetic field. This tube is commercially known as the Magnitron and is also capable of producing ultra-high frequencies in the range of 3000 megacycles.

REFERENCES

1. *W. R. Ferris. Proc. I.R.E. January 1936.*
*2. *Webster, D. L. Journal of Applied Physics 1939, 10, 501.*
*3. *Webster, D. L. Journal of Applied Physics 1939, 10, 864.*
4. *Tombs. D. M. Wireless Eng. 1940, 17, 54.*
*5. *Ramo, S. Proc. I.R.E. 1939. 27, 757.*
6. *Hahn and Metcalf Proc. I.R.E. 1939, 27, 106.*
7. *Haeff and Nergaard Proc. I.R.E. 1940, 28, 126.*
8. *Varian and Varian Journal of Applied Physics 1939, 10, 140, 321.*

(*To be continued in March issue*)

Flying Fortress

(*Continued from page* 23)

The radio man sat back on his parachute pack, loosened his "Mae West," relaxed and listened. Over the intercom came the voices of the crew and observer-commentator as the ship sped towards the continent to bomb the Nazi-held airfield:

Nussbaum: "It's now 8:20. Zero hour is at 8:45. In exactly twenty-five minutes, at zero hour, every plane, every bomber, every fighter on this operational mission. . . ."

Pilot: "Pilot to tail gunner. Check your glasses and see if you can get the number of that aircraft to the right of us."

Tail gunner: "Tail gunner—Roger. Four two eight. . . . . I think it is four two eight. Roger."

Pilot: "Thank you. Roger."

Nussbaum: "As I said, at 8:45, which is in about twenty-five minutes, all the planes on this mission, whether they be bombers or fighters, will be in the air on the way to the target. That is known as zero hour. I can now see the wing ahead of us. It is in perfect formation. They are scheduled to go into the target two minutes ahead of us. We have not as yet made our rendezvous with our fighter escort."

Bombardier: "Altitude 10,000 feet. Put on your oxygen masks. We are at oxygen level."

Tail gunner: "Tail gunner. Roger."

Nussbaum: "As you can hear, we are going on oxygen now. I have just put on my mask, and it may make my

THE SAGA OF THE VACUUM TUBE

By GERALD F. J. TYNE
Research Engineer, N. Y.

Part 10. Covering the evolution of the vacuum tube through the years 1914 to 1918, as a result of the research work done by Western Electric.

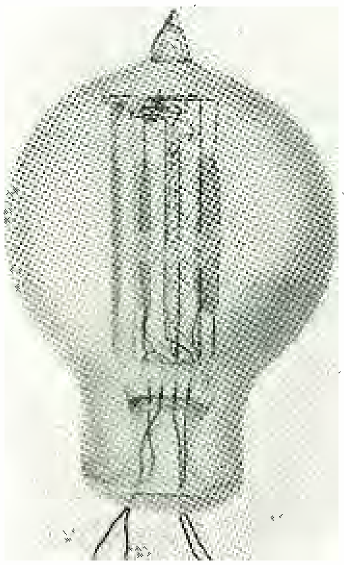


Fig. 92.

THUS far we have considered but one type of Western Electric tube. It has been treated in considerable detail, because of the evolutionary steps through which it passed. These steps show the results which may be attained through painstaking research and careful engineering with but one objective—to produce the most economical and reliable device to fulfill a given function, when operated under expert care and carefully controlled conditions.

Other tubes were evolved in the laboratories and manufacturing plants of the Western Electric Company during the period covered in the preceding articles. Some were for use in the telephone plant, some for the Armed Services of the U. S. Government, and others for divers applications which arose as time went on and wider vistas opened up.

Many of these went through developmental steps paralleling those of the 101 type and will be treated but briefly in what follows. One of the best known of these other tubes is the famous "V" tube. This was probably so called because it was intended for use as a "voltage" amplifier. It was first known as the type "VM"—V for *voltage* and M for *mounted*—but the "M" was soon dropped and it became known as the "V" tube.

The earliest vacuum-tube repeaters, as has been previously stated, used "L" tubes and were single-stage affairs. When the need for higher amplifications than could be obtained in these arrangements arose, two-stage repeaters were developed, and the "V" tube was used in the first stage to provide "voltage" amplification. Its plate-to-filament impedance was too high to permit it to be worked successfully as an output tube, however, and the second stage was an "L" tube with its lower output impedance.

The first experimental "V" tubes

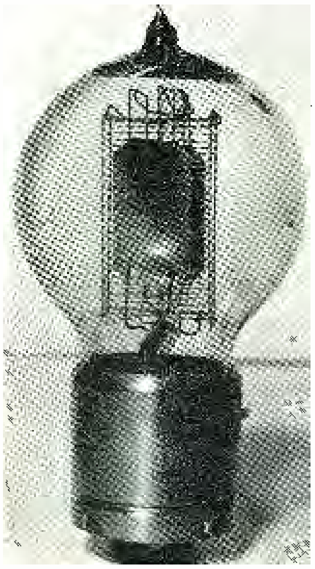


Fig. 93.

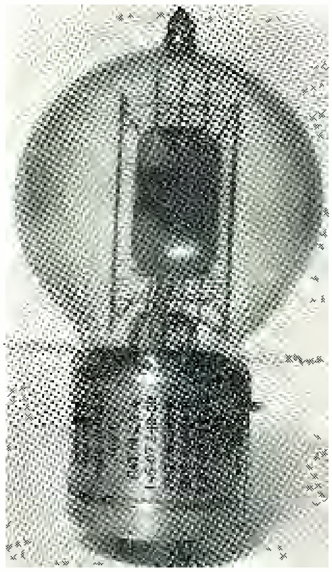


Fig. 94.

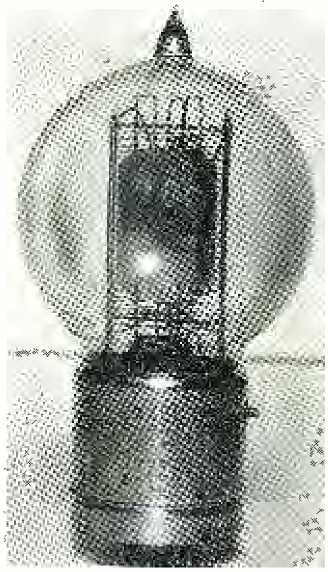


Fig. 95.

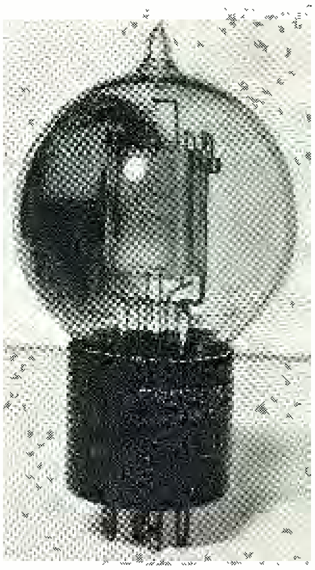


Fig. 96.

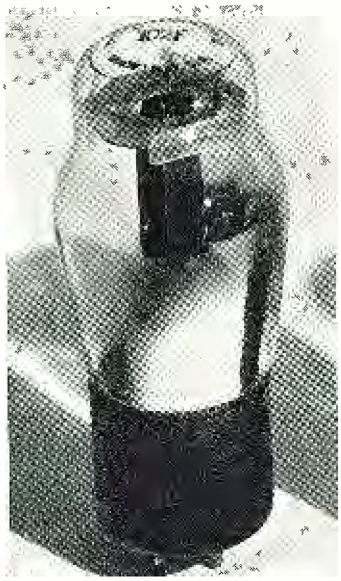


Fig. 97.

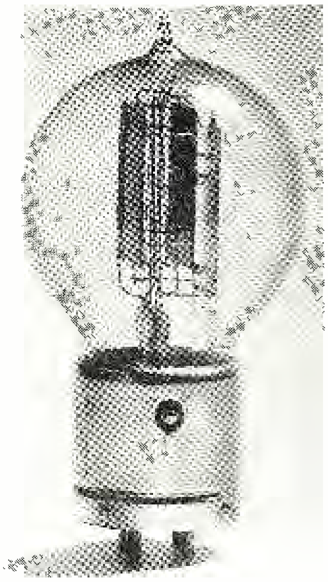


Fig. 98.

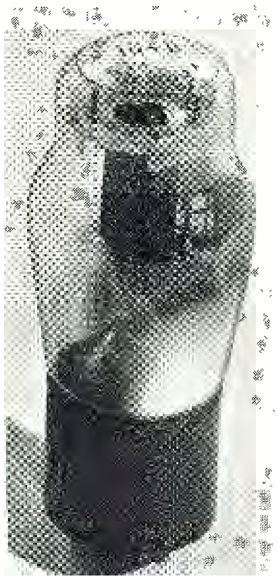


Fig. 99.

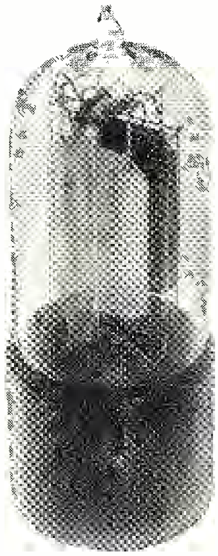


Fig. 100.

were made about the middle of 1914 and the first commercial product appeared early in 1915. Fig. 92 shows one of the earlier tubes before basing.

The "V" tube used the characteristic Western Electric "ladder type" grid and had 31 laterals on each side. The grids were considerably larger in area than the plates, and the filament was Λ shaped. The spacing between grids was about ⅛ inch and between plates about ½ inch. The base used was the same machined brass base used on the "L" tube which has been previously described.

Like the "L" tube, the first of the "V" tubes probably carried no patent markings. Beginning late in 1915 patent markings were applied in a manner similar to that of the "L" tube of that time. In 1916 the code designation "102A Telephone Repeater Element" was assigned to the "V" tube. This was later changed to that of "102A Repeater Bulb."

It is not our purpose to go into further detail concerning the progressive changes made in the "V" tube. However, for the benefit of tube collectors Fig. 93 shows one of the variants of the 102A.

Up to the end of 1918 all of the "V" tubes and some of the other tubes made by the Western Electric Company had been manufactured in the shops of the Engineering Department of the Company in New York. This was done because of the need for close engineering supervision in the early manufacture of a new device. By the end of 1918 progress was considered sufficient to permit their manufacture in the regular factory, and accordingly, production of some of them, among which was the 102A, was begun at the Hawthorne plant of the Company in Chicago.

All of the early Western Electric tubes had a serial number etched or sandblasted on the bulb. In order to distinguish between tubes made in New York and in Hawthorne the tele-

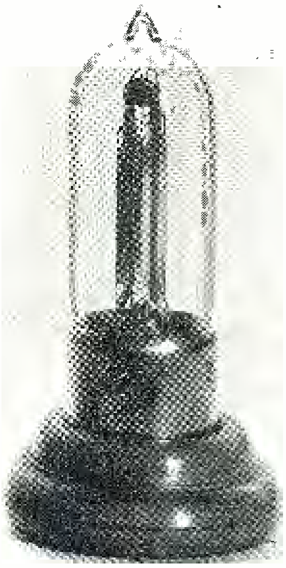


Fig. 101

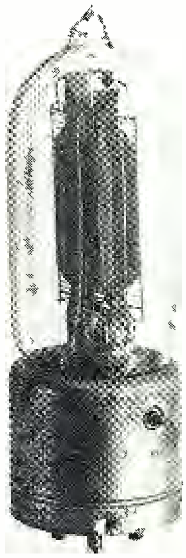


Fig. 102.

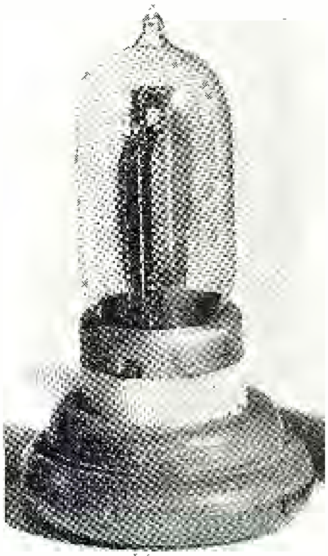


Fig. 103.

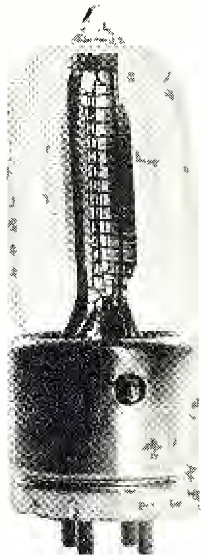


Fig. 104.

phone repeater type tubes made at Hawthorne had the letter "H" appended to the serial number. When production became great enough so that the number of digits in the serial number increased beyond five, the designation letter was changed to "A" and the numbering repeated. The tubes made at New York had no letter included in the serial designation.

There were also some minor details of construction in which tubes made at Hawthorne differed from those made at New York. One of these was in the positioning of the laterals of the grid. In the tubes made at New York the grid laterals were welded to the vertical support wires on the outside of the frame; that is, the side away from the filament. Tubes made at Hawthorne had the laterals on the side of the frame nearer the filament.

The construction of the 102A Repeater Bulb was similar to that of the 101B in that the elements were supported by a glass arbor welded to the edge of the press. Early in 1922 the 102A was replaced by the 102D which had an improved filament, operating at the same filament current as the 101D. The construction was soon changed so that the arbor was attached to the stem below the press, in a manner analagous to that of the later type 101B and the 101D. The single Λ filament was retained since the normal plate current of the 102 types was much lower than that of the 101 types and the electron emission from the smaller surface was adequate.

From this time on the changes in the 102 series, such as location and type of markings, substitution of molded for metal base shells, etc., in general followed those of the 101 series and will not be detailed here. Again for the benefit of the tube collector photographs of some of the variants

(*Continued on page* 90)

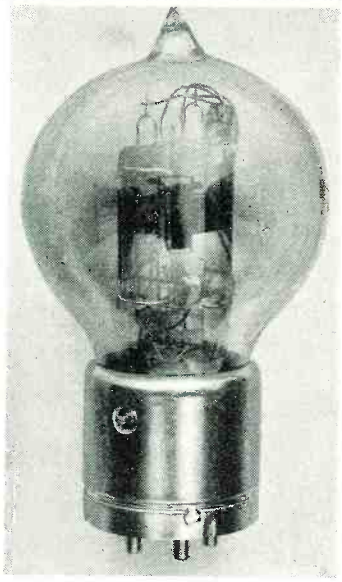


Fig. 105.

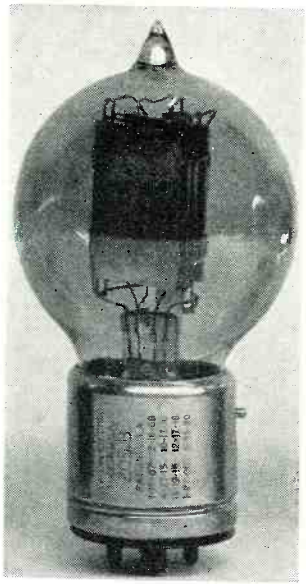


Fig. 106.

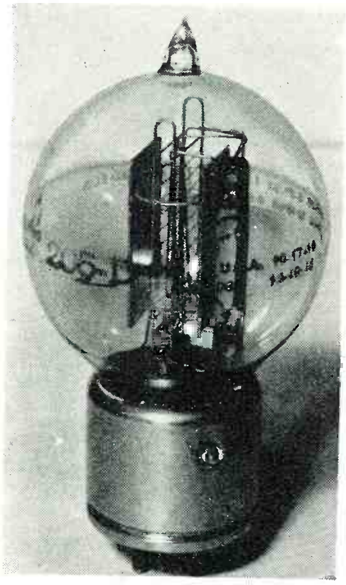


Fig. 107.

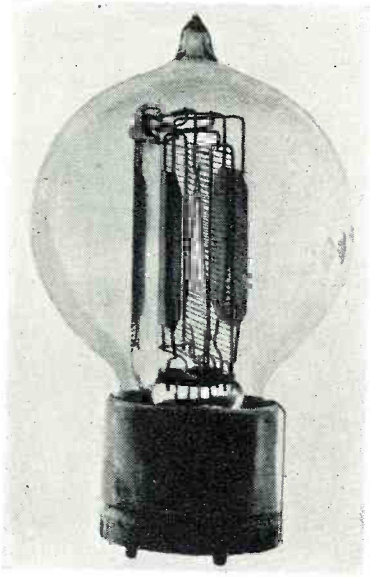


Fig. 108.

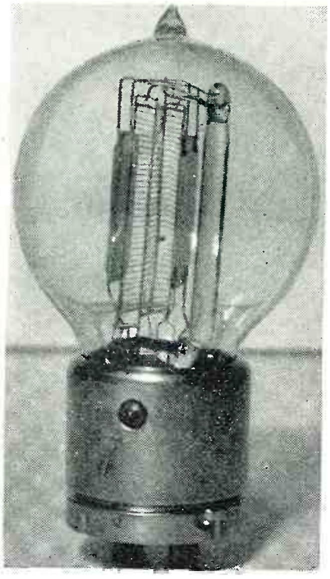


Fig. 109.

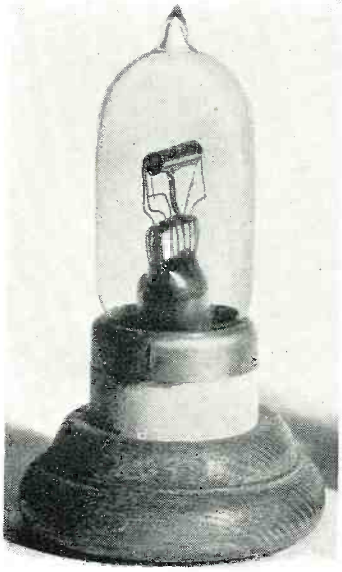


Fig. 110.

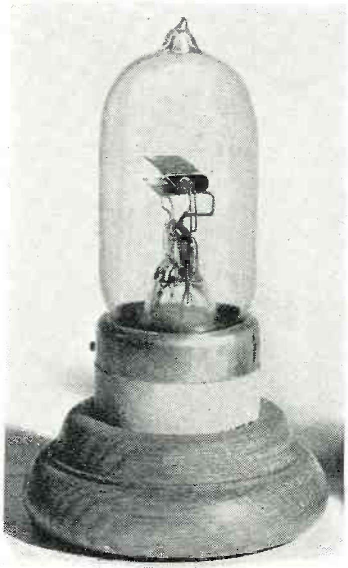


Fig. 111.

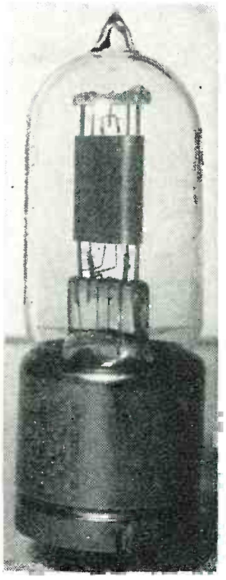


Fig. 112.

It would be highly desirable if the automatic air traffic control equipment for aircraft could be light enough and cheap enough so that all aircraft flying under instrument flight rules would be equipped with these devices. However, it is expected that at least for a long time only the larger aircraft will be so equipped. The most optimistic estimate would place not more than 50% of the aircraft flying in instrument weather by 1950 in the category of those having full automatic air traffic control equipment. This means that the air traffic control system would have to continue to be capable of controlling a substantial amount of air traffic involving aircraft having only the minimum air traffic control equipment such as is required at the present time.

However, the automatic devices for aircraft and the ground aids for air traffic control previously described point to the possibility of obtaining the ultimate objective of permitting the flow of air traffic under instrument weather conditions in the same volume and with the same frequency as is possible under contact weather conditions. This means that at an airport properly designed and adequately served by navigational air traffic control facilities, landings under instrument weather conditions would be possible at extremely short intervals. Thus, future planning seems to indicate that it will be possible for the air traffic control system within the United States to reach the level of safety and efficiency which ultimately will be required by mature air transportation.

-30-

Saga of Vacuum Tube
(*Continued from page* 52)

of the 102 series will be found in Figs. 94 to 97, inclusive.

The 102 type vacuum tube was an extremely long-lived device, because of the conservative engineering behind it and the low plate current required. The writer recently saw a 102A Repeater Bulb which had been removed from service in a laboratory device only two years ago. It had been in daily use for almost 20 years and was still functioning satisfactorily.

Another tube which was used in telephone equipment, but to a lesser extent than the "L" and "V" tubes, was the 104 type, which started life under the appellation of type "O". It was probably so designated because of its original use as an "output" tube. It had a lower plate impedance than either the "L" or "V" types. The "O" tube was first made commercially in the shops of the New York Engineering Department late in 1917. As originally made, it consisted of two plates ¾ inch wide and 1¼ inches high, spaced 5/16 inch apart, and two grids of the ladder type, the same size as the plates and spaced ⅛ inch apart. Each grid had nine laterals. The filament was M shaped. The structural difference between the "L" and "O" tubes was chiefly in the spacing of the elements. The type "O" originally had two glass arbors, one for each plate-grid assembly. Late in 1918 the use of the second arbor was abandoned and the stem thus became similar to that of the type "L". The code designation "104A" was applied to this tube, which was later replaced by the "104D" Figs. 98 and 99 show some of the variants of these types.

All the Western Electric tubes thus far considered were engineered for use under the carefully controlled conditions existing in the telephone plant. But at the time of World War I the engineering skill and manufacturing experience which produced them were invaluable in providing background for the production of tubes for sorely needed military equipment.

Vacuum tubes for military and naval use are a "different breed of cat" from the telephone repeater. They must be capable of giving a reasonable service life under conditions which may vary widely at different times and in different places. In much equipment considerations of weight and space are paramount. Ambient temperatures vary from the cold of the radio cabin in the arctic to the broiling heat of a destroyer engine room in the tropics. Filament and plate voltages may vary widely and rapidly. Mechanical shocks are inevitable.

Nevertheless the Western Electric engineers, at the urgent request of the Armed Services, set about the development of vacuum tubes of stable and rugged construction to meet these new but no less exacting requirements. From their labors emerged a number of reliable tubes, probably the best known of which were the "VT1" and "VT2."

"VT1" was the U. S. Signal Corps designation for the tube, which in its inception was known to Western Electric engineers as the type "J". This same tube was also used by the U. S. Navy under the designation "CW933." The Western Electric code numbers assigned to this type were in the 203 series, the first being the 203A."

The "J" tube was a general purpose tube, being used as detector, amplifier, or low power oscillator. Fig. 100 is a photograph of one of the early "J" tubes. A cylindrical bulb was used instead of the spherical bulb common to the other Western Electric tubes up to that time. The element assembly used the same glass arbor construction as the telephone repeater tubes, and the earliest models had machined brass bases. The grids were of the ladder type and the plates were of flat sheet.

The glass arbor construction proved to be too fragile to withstand the severe vibration conditions imposed on the equipment in which the tube was used. In order to insure permanent alignment of the elements under the severest conditions there was developed a form of element assembly which became known as the "iron-clad" construction, in which the plate formed the support for the grid and filament. This structure was the result of an evolutionary process which can be traced through the steps shown in Figs. 101 to 104 inclusive.

The first change was in the base. The machined brass base was replaced by a lighter sheet metal base similar to that used in the standard telephone repeater tubes. The next construction was that shown in Fig. 101. Here the glass arbor has been eliminated and a new plate structure used. The plates are supported from the stem, and a stiffening rib provided. Ladder type grids with wire laterals are still used. Fig. 102 shows the next modification, which was the substitution of a corrugated plate for the flat plate in the preceding version. Fig. 103 shows a later modification, in which grids of punched sheet metal replaced those of the wire type. The final version, which was manufactured in large numbers as the VT1, is shown in Fig. 104. After the close of World War I many of these VT1s found their way into the general market, via sales of surplus Army equipment, and were used by amateur radio enthusiasts.

The VT1 operated with a filament current of 1.15 amperes at a voltage of 2 to 2.5 volts. The plate voltage used varied from 20 to 100 volts, and the plate current from 0.5 to 2 milliamperes, depending on the purpose for which the tube was used. The amplification factor was about 6 and the internal plate impedance 10,000 to 25,000 ohms.

The other widely known and used tube was the VT2. This was developed as a result of a request from the U. S. Signal Corps in 1917. The request was for a small transmitting tube to operate at a plate voltage of 300 volts. The VT2, which was also used by the U. S. Navy under the designation "CW931," was originally designated by Western Electric Company as the type "E", and later code numbers in the 205 series were assigned.

Fig. 105 shows one of the earlier "E" tubes. The construction was somewhat similar to the type "L" except that the plates had turned-up edges and different bracing wires. This difference in construction was necessitated by the higher plate dissipation of the "E" tube which tended to warp flat plates. The base first used was of the wax-filled type which was standard for use on telephone repeater tubes. This was later found unsatisfactory because of the higher temperature at which the "E" tubes operated, and was replaced by a base using a phenolic insert.

The VT2 operated with a filament current of 1.35 amperes at a voltage of 6 to 7.5 volts. The operating plate voltage was 250 to 350 volts, the plate current 30 to 45 milliamperes, amplification factor approximately 7 and internal plate impedence 3,000 to 4,500 ohms. It was rated at 5 watts continuous output as an oscillator.

Other uses were found for this series of tubes after the war, and the manufacture of the 205B was continued until about 1924, when it was replaced by the 205D. The chief improvement was in the filament. The new filament was better electrically, and differed in appearance in that it was plain instead of being twisted. Since that time the "E" tube has undergone other changes which may be seen in Figs. 106 and 107.

There were, in addition to these tubes, several others made in somewhat smaller quantities for the U. S. Government during World War I. One of these bore the Western Electric code designation "201A," and was known to the Navy as the "CW186." This tube, with its three contact base, is shown in Fig. 108. It was similar to the type "V" except for the grid, which had 37 laterals on each side instead of 31. The 201A, as will be noted from Fig. 108, was made with a base which had three contact studs, the fourth terminal being the metal base shell. This was made in accordance with Navy requirements. This tube in the standard telephone repeater base had been known as the type "D" tube to the Western Electric engineers.

One of the difficulties encountered in the use of this tube by the Navy was microphonic trouble caused by imperfect contact between the metal base shell and its socket. To eliminate this condition the design was changed to use the four contact base, originally used on this type. In this form it was known as the Western Electric 201B, and is shown in Fig. 109. Few were made, however, since it was soon replaced in Navy equipment by the all-purpose "J" tube.

Early in 1918, at the request of the Signal Corps, the work of developing a tube similar to the VT1, except suitable for operation in portable equipment, was undertaken. The chief problem was that of obtaining a filament which would operate with a current of the order of 0.2 to 0.25 ampere from a single storage cell. The tube which fulfilled these requirements was designated "VT3" by the Signal Corps and was known to the Western Electric engineers as the type "P." Figs. 110, 111 and 112 show three of the structures used for this tube, that of Fig. 112 being the final one. The designation "VT-3" was etched on the bulb, in block letters, but the etching is too faint to show in the photograph. Only a few of these tubes were made since the necessity for them was reduced by the cessation of hostilities. The work was not lost, however, since the knowledge gained was used to good advantage in the development of the famous "peanut" tube, which will be discussed in our next article.

CAPTIONS FOR ILLUSTRATIONS

Fig. 92. Western Electric Type "V" Telephone Repeater Element, before basing. 1915. Photograph courtesy Bell Telephone Laboratories.

Fig. 93. Western Electric 102A Repeater Bulb. This is the first variant using the formed sheet metal base.

The code marking appears only in the wax filling of the base. Note colored lacquer—black—applied to tip.

Fig. 94. Western Electric 102D Vacuum Tube, showing Western Electric name, code, and patent marking on base in 1/16 inch characters.

Fig. 95. Western Electric 102D Vacuum Tube, showing Western Electric name, code, and patent marking on base in 3/64 inch characters.

Fig. 96. Western Electric 102F Vacuum Tube with code marking on base in depressed characters.

Fig. 97. Western Electric 102F Vacuum Tube of current construction. New element assembly and domed bulb.

Fig. 98. Western Electric Type "O" or 104A Vacuum Tube — early construction.

Fig. 99. Western Electric 104D Vacuum Tube—current construction. New element assembly and domed bulb.

Fig. 100. Early Western Electric Type "J" or 203A Vacuum Tube with machined brass base and glass arbor construction. Photograph courtesy Bell Telephone Laboratories.

Fig. 101. Western Electric 203A Vacuum Tube—third type—with element assembly supported by collar on stem of tube. Wire ladder type grid and flat plate with stiffening rib. Photograph courtesy Bell Telephone Laboratories.

Fig. 102. Western Electric 203A Vacuum Tube—later type with corrugated plate and wire grid. Photograph courtesy Bell Telephone Laboratories.

Fig. 103. Western Electric VT1 with early type punched grid. Photograph courtesy Bell Telephone Laboratories.

Fig. 104. Western Electric VT1—final version. Photograph courtesy Bell Telephone Laboratories.

Fig. 105. Early Western Electric Type "E" or 205A Vacuum Tube. Sheet metal base, wax filled. Photograph courtesy Bell Telephone Laboratories.

Fig. 106. Western Electric 205B Vacuum Tube—still later type with later patent markings.

Fig. 107. Early Western Electric 205D Vacuum Tube—with metal base and markings on bulb.

Fig. 108. Western Electric Type "D" or 201A Vacuum Tube. This was made for the U. S. Navy under the designation "CW186." Note the three contact base. Photograph courtesy Bell Telephone Laboratories.

Fig. 109. Western Electric 201B Vacuum Tube. Same as 201A shown in Figure 108 except for use of standard four-prong base.

Fig. 110. Western Electric Type "P" Vacuum Tube — first construction. Photograph courtesy Bell Telephone Laboratories.

Fig. 111. Western Electric Type "P" Vacuum Tube — second construction. Photograph courtesy Bell Telephone Laboratories.

Fig. 112. Western Electric VT3 — final form of type "P" vacuum tube. The "VT-3" marking is etched on the bulb in block letters but the etching is too faint to show up in the photograph.

(To be continued)

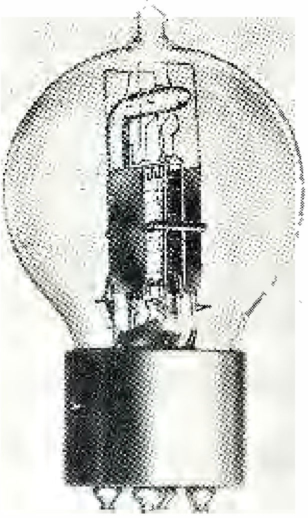


Fig. 113.

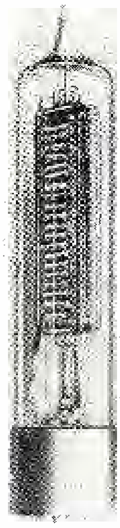


Fig. 114.

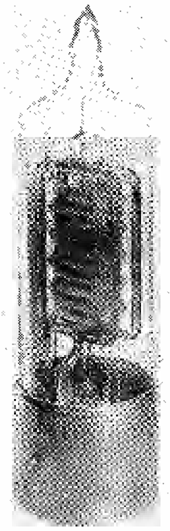


Fig. 115.

Fig. 116.

THE SAGA OF THE VACUUM TUBE

By GERALD F. J. TYNE
Research Engineer, N. Y.

Part II. Covering a number of the unusual earlier constructed tubes that are of particular interest to many old timers.

Fig. 117.

UP TO now we have discussed Western Electric vacuum tubes of the telephone repeater type and a few made for the Army and Navy during World War I. There were a number of other early tubes however, and some of these may fall into the hands of the tube collector. Some will bear few marks of identification but may be recognized from their descriptions and photographs, which follow. First let us consider the power tubes.

The low power output tube for telephone applications, type "O," has already been described as well as the so-called "5-watt" tube, type "E."

The type "E" was preceded by another tube known as the type "K," which is shown in Fig. 113. This was originally intended for application in government equipment as a transmitter tube for aircraft use. It operated at a plate voltage of about 500 volts. This voltage was considered to be a source of serious danger to the operator and the type "K" was abandoned in favor of the type "E" which operated at 300 volts plate. The type "K," to which was assigned the Western Electric code designation "202A" had a machined brass base similar to that used on the early telephone repeater tubes, but of larger size.

Prior to this time the only extensive use of power tubes by the Western Electric Company had been in the famous transatlantic telephone tests conducted in 1915. These were one-way transmissions, the transmitter being at Arlington, Virginia. A bank of some 550 tubes operating in parallel was used in the final amplifier. To fully appreciate such a feat as this and realize the difficulties which had to be overcome by these pioneers, one should hear the stories told by the men who did the job. Problems of division of load, intertube wiring, parasitic oscillations, cooling, and a host of others, which can be fully appreciated only by one who has tried to operate more

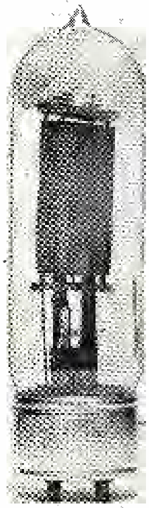


Fig. 118.

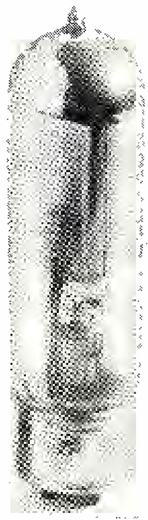


Fig. 119.

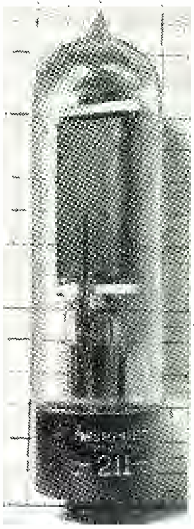


Fig. 120.

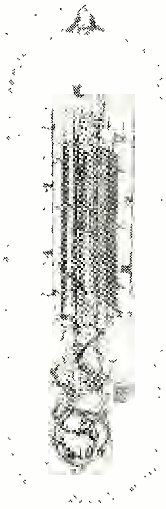


Fig. 121.

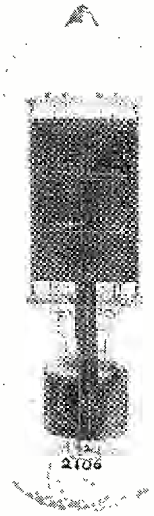


Fig. 122.

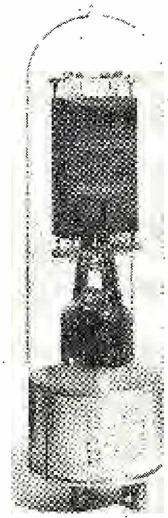


Fig. 123.

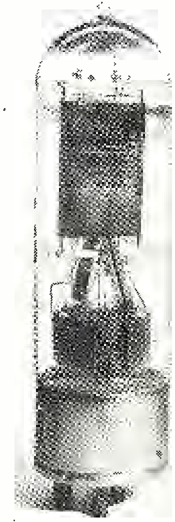


Fig. 124.

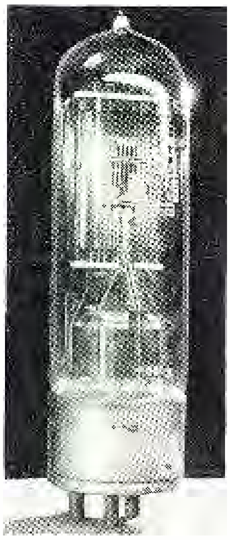


Fig. 125.

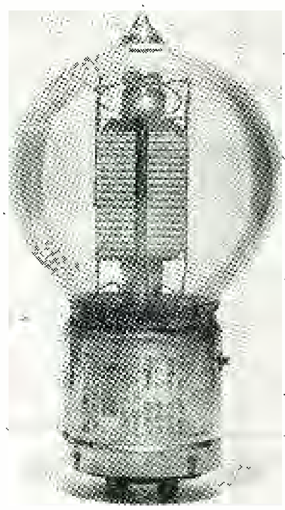


Fig. 126.

than two tubes in parallel, had to be solved. That this was accomplished in a short time is another instance of the results of cooperative effort in an industrial laboratory.

The tubes used in this amplifier were known as type "W" and the official designation was "204B Vacuum Tube." The type "W" operated with a filament current of 4 to 4.5 amperes, plate voltage of 600 volts, and plate current of 150 to 200 milliamperes. Most of the type "W" tubes used at Arlington were unbased although some based tubes, similar to that shown in Fig. 114, were also used.

The most noticeable feature of the type "W" was the plate. Since a solid sheet metal plate of the requisite size would contain much occluded gas which would have been difficult to remove with the evacuation technique of that day, the construction shown in the photograph was adopted. The plate was made from a strip of metal tape bent back and forth as shown. The material used was a high resistance alloy and leads were brought out from both ends of the strip. The tape could thus be heated by the passage of current from an external source, during the evacuation process, and the occluded gases thus expelled.

Another similarly constructed tube, used chiefly as a modulator in the long distance tests preceding the transatlantic tests, was known as the type "S" and had the code designation "204A." This tube is illustrated in Fig. 115. Although this tube was smaller in size, the similarity in construction to the type "W" will be noted. It was the experience and knowledge gained in the development of these tubes which enabled the Western Electric Company to produce the other types of power tubes urgently requested by the U. S. Government for radio communication in World War I.

After the war there grew up a demand for higher powered tubes for radio transmitters and public address systems. This need motivated the development of two series of tubes which are familiar to those acquainted with the early days of broadcasting. One was known during its development as the type "G" and the other as the type "I."

The type "G" was one variety of the size which later became commonly known as the "50-watter" and was the progenitor of the Western Electric 211A and others of the 211 series. As in all such developments, problems were encountered in the process and various structures were tried before one suitable for commercial service was attained. Figs. 116 and 117 show some of the element assemblies tried out during this process. The construction finally adopted, which was given the code designation "211A Vacuum Tube" is shown in Fig. 118.

This tube operated with a filament current of 3.4 amperes at 9 to 10 volts. The plate voltage was usually about 750 and plate current 40 to 80 milliamperes. The amplification factor was about 12 and the internal plate impedance 3000 to 4000 ohms. The operating life was about 300 hours. The base was the same size as that originally brought out by the Western Electric engineers for the type "K" tube, and eventually adopted as standard for all 50-watters, by other manufacturers as well.

The 211 type tubes were intended for operation at a fixed value of filament current, and the value of filament voltage was determined by the filament resistance. They were usually operated, however, from a constant voltage source. Hence, they were classified at the time of manufacture into five groups, and the classification was indicated by a letter etched on the bulb at the end of the serial number. The letters used were A, B, C, D, and E.

Fig. 127.

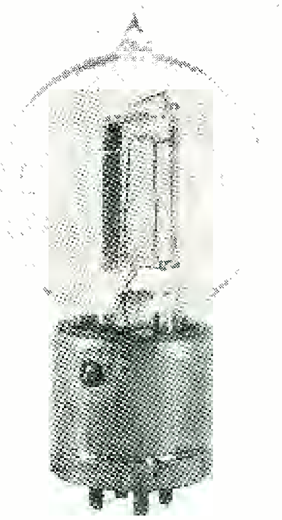


Fig. 128.

This was done so that when two or more were required to operate with their filaments in parallel from the same source, tubes suitable for operation at the same filament voltage could be selected.

The 211A Vacuum Tube was replaced, about the middle of 1924, by the 211D which used a different filament. The characteristics of this new filament were sufficiently controllable so that the classification of tubes in accordance with their filament resistance was no longer necessary to their successful operation in parallel. Hence, no classification letter was needed. A photograph of one of the earlier 211D vacuum tubes is shown in Fig. 119.

In 1926 the 211E was introduced. It differed from the 211D in that it was intended primarily for use as an audio amplifier, and had small spirals incorporated in the grid and plate leads, which may be seen in Fig. 120. The effect of these small radio frequency chokes was to discourage the tendency to set up high-frequency parasitic oscillations in the circuit in which such tubes were operated in parallel.

The code and patent markings were at first placed on the metal base of the 211 types in depressed characters, but later were applied to the bulb by the use of baked enamel lettering. Still later tubes used molded plastic bases. The 211 series of tubes have not been made since 1938, having been replaced by later designs.

The type "I" tube was the forerunner of the 212 series of Western Electric tubes, and was rated at 250 watts. Figs. 121 and 122 show two of the experimental tubes of this type and Fig. 123 shows the early commercial type which carried the code designation "212A." This tube had an over-all height of about 13⅝ inches and a diameter of 3⅝ inches. It was intended for both oscillator and modulator use. The filament current was 6.25 amperes at 12.5 to 14 volts. The nominal plate voltage was 1500 and the plate current 100 to 150 milliamperes. The amplification factor was about 16 and the internal plate impedance about 2000 ohms. The code and patent markings were on the base, as will be seen from the photograph.

Like the 211A, the 212A vacuum tubes bore a letter designation following the serial number, to indicate filament resistance. In addition they bore a ½ inch high numeral (1, 2, 3, or 4) stamped on the bulb a short distance above the base. This numeral was determined by the plate impedance of the particular tube. The classification was such that satisfactory operation in parallel could be obtained with two tubes whose classification numbers did not differ by more than one. That is, a class 1 tube would operate satisfactorily in parallel with another class 1 or a class 2, but not with class 3 or 4. A class 2 tube would operate satisfactorily in parallel with either class 1, 2, or 3, but not with class 4, and so on.

The 212A Vacuum Tube was replaced in 1924 by the 212D, photographs of which are given in Figs. 124 and 125, and somewhat later the 212E was brought out. The 212D tubes were classified in accordance with plate impedance in the same way as the 212A, but because of a new filament did not require classification in accordance with filament resistance.

In addition to the power tubes described, the Western Electric Company also made a number of small tubes during this time for non-telephone applications. Since, for the most part, these were similar in structure to some of the telephone tubes they will be mentioned only briefly.

The 208A and 209A were the same as the 101B and 102A except for the

(*Continued on page* 92)

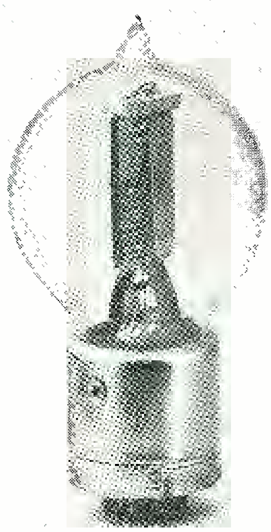


Fig. 129.

Fig. 130.

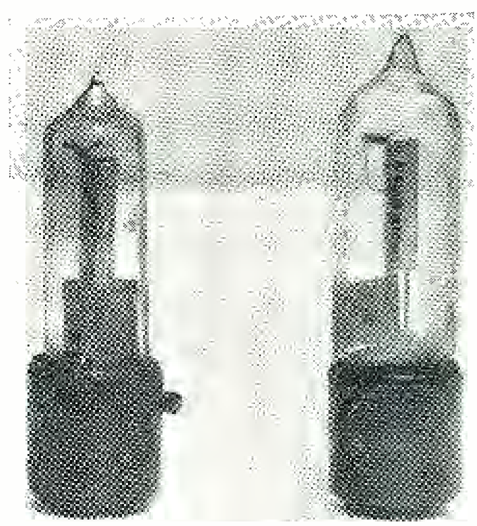
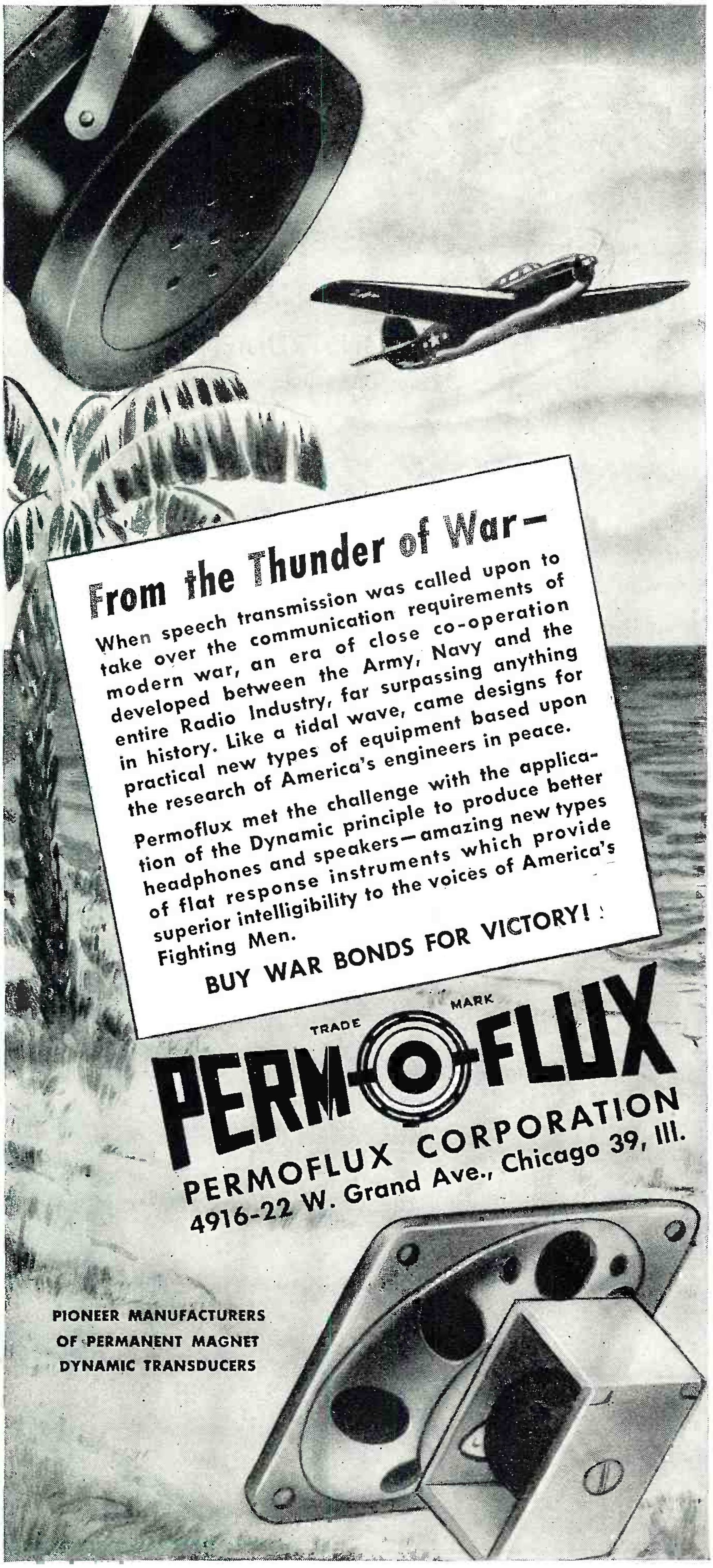


Fig. 131.



Saga of Vacuum Tube

(*Continued from page* 56)

code and property markings. The 210A was similar to the 104A. The marking "Property of the American Tel. & Tel. Company" was omitted and the marking "Western Electric Company" was applied instead. The 223A was similar to the 104D except that a heavier filament was used.

Probably one of the best known of the Western Electric small tubes of this period was the 216A, which was intended for use in the amplifiers of small public address systems and similar low power applications. It was somewhat similar in characteristics to the 101D but with a plate structure resembling that of the VT1. Figs. 126 and 127 show several variants of this tube.

There were also a series of rectifier tubes using the same general construction as the corresponding amplifier tubes. The 214A and 217A shown in Figs. 128 to 130, were similar to the 211A and 216A respectively, with the grid omitted. The 219A and 219D were the rectifier counterparts of the 212A and 212D.

In the low filament power field there were the 230D and 231 D. These were used in the same applications as the well known RCA UV199 and UX199 types. The 221D and 235D were general purpose tubes similar to the RCA UV201A.

The only other early Western Electric tube which the collector is likely to acquire is the 215A, also known as the Signal Corps VT5, and the Navy CW-1344. It was first known as the type "N" vacuum tube. This is the

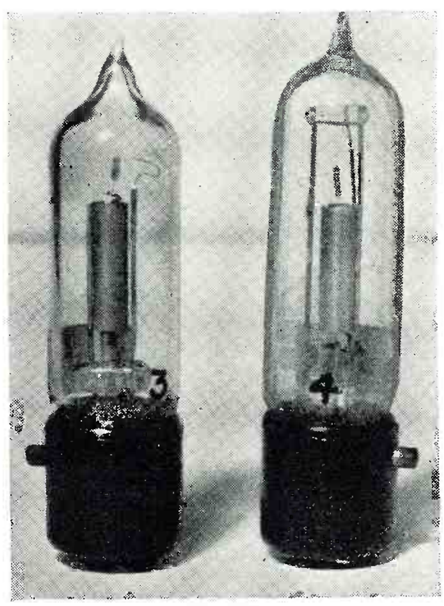


Fig. 132.

original "peanut" tube, so called because of its size. It was the only early Western Electric tube to utilize a concentric element assembly.

The filament was a single strand mounted vertically, the grid a spiral wire, and the plate a cylinder. Fig. 131 shows two of the early variants of this tube, the difference being chiefly in the bulb size. The tube shown at the left in Fig. 132 is the next variant, in which the spirally coiled filament tension spring has been replaced by a single bent wire. These early "N" tubes were very sensitive to mechanical disturbances. This was to some extent overcome by modification of the element structure to include a glass re-enforcing bead as shown in the tube at the right in Fig. 132. All of these earlier "N" tubes had metal bayonet locking pins inserted in the molded plastic base. Subsequently, a new base with a molded bayonet pin was developed and may be seen on the tube whose element structure is shown at the right in Fig. 133. This variant, in which the glass re-enforcing bead has been increased in size, utilized magnesium flashing and was the final development of the 215A.

Somewhat later, for applications which required less sensitivity to microphonic disturbances, and yet low filament power and approximately the same electrical characteristics as the 215A the tube shown in Fig. 134 was developed. This was designated 239A. Earlier tubes of this code had tips but the later ones were of the tipless variety.

With this we bring to a close our consideration of the earlier Western Electric tubes. Very little information has been published concerning the contributions to tube development made by this organization. For this reason these tubes have been treated in as much detail as space will permit. In our next article we shall return to the consideration of this work as carried on by de Forest and his co-workers, with the aid of funds received from the sale of rights to the Audion.

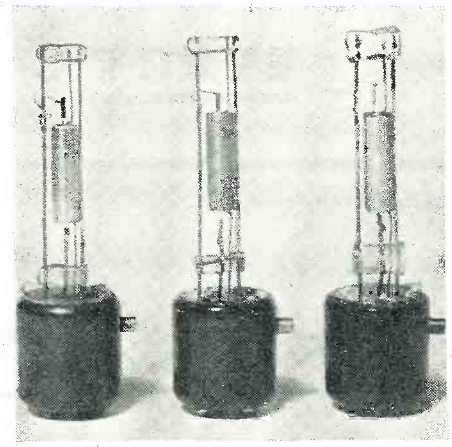


Fig. 133.

CAPTIONS FOR ILLUSTRATIONS

Figure 113. Western Electric Type "K" or 202A Vacuum Tube. The machined brass base is the size of that used by the Western Electric Company, and later by others, for the "50-watt" type tubes. Photograph courtesy Bell Telephone Laboratories.

Figure 114. Western Electric Type "W" or 204B Vacuum Tube. This is a based tube of the type used in the Arlington-Paris tests of 1915. Both based and unbased tubes were used in the transmitter. Photograph courtesy Bell Telephone Laboratories.

Figure 115. Western Electric Type "S" or 204A Vacuum Tube. This is a based tube of the type used as a modulator in the tests which preceded the Arlington-Paris transmissions. Photograph courtesy Bell Telephone Laboratories.

Figure 116. Western Electric Type "G"—second embodiment of the 50-watt type tube. Made in 1919. Photograph courtesy Bell Telephone Laboratories.

Figure 117. Western Electric Type "G"—final version—coded 211A Vacuum Tube—1919. Photograph courtesy Bell Telephone Laboratories.

Figure 118. Western Electric 211A Vacuum Tube—commercial version of the Western Electric Type "G."

Figure 119. Western Electric 211D Vacuum Tube.—Replaced 211A Vacuum Tube. This tube has an improved filament and has the code and patent marking on the bulb in baked enamel lettering. Photograph courtesy Bell Telephone Laboratories.

Figure 120. Western Electric 211E Vacuum Tube—similar to the 211D except for the inclusion of spiral coils in the grid and plate leads.

Figure 121. Western Electric Type "I" Power Tube—first attempt at 250 watt air cooled tube and forerunner of the 212 series of tubes. Made in 1919. Photograph courtesy Bell Telephone Laboratories.

Figure 122. Western Electric Type "I" Power Tube—second version. Made in 1919. Photograph courtesy Bell Telephone Laboratories.

Figure 123. Western Electric 212A Vacuum Tube—sample of the early commercial tubes of this series.

Figure 124. Western Electric 212D Vacuum Tube—improved 250 watt tube which replaced the 212A—front lighted to show construction.

Figure 125. Western Electric 212D Vacuum Tube—same tube as Figure 124 except back lighted.

Figure 126. Western Electric 216A Vacuum Tube—early model. The base has been made from that of the 208A by cancelling the former code marking and those of the patent markings which did not apply to the 216A. The new code number and license notice are carried on a paper band around the neck of the tube.

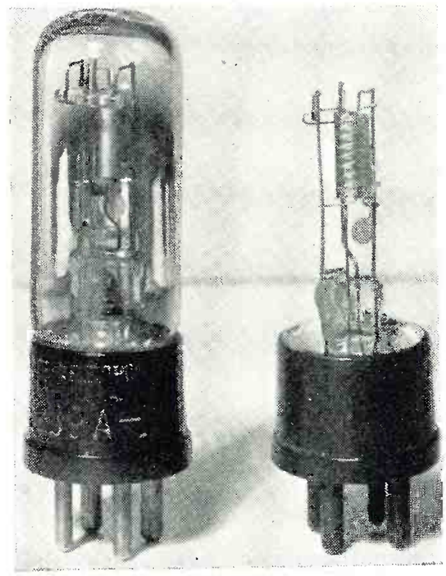


Fig. 134.

Figure 127. Western Electric 216A Vacuum Tube—later version than that shown in Figure 126. The code and correct patent marking are on the base but the license notice is still carried on the paper band around the neck of the tube.

Figure 128. Western Electric 217A Vacuum Tube—early form—rectifier with structure based on that of the 101D. Photograph courtesy Bell Telephone Laboratories.

Figure 129. Western Electric 217A Vacuum Tube—later type—rectifier version of the 216A. Photograph courtesy Bell Telephone Laboratories.

Figure 130. Western Electric 217A Vacuum Tube—still later version in pear shaped bulb. Photograph courtesy Bell Telephone Laboratories.

Figure 131. Left—Early model of Western Electric Type "N" tube. Right—later model using larger bulb diameter.

Figure 132. Left—Western Electric Type "N" Vacuum Tube—redesign showing new filament tension spring.

Right—Later model with small diameter glass beads for stiffening element assembly and reducing response to mechanical shock.

Figure 133. Western Electric 215A Vacuum Tube—commercial production of type "N"—element assemblies. The one at the right with the heavier glass reinforcing beads is the later construction.

Figure 134. Western Electric 239A Vacuum Tube.

Left—Complete tube of late type. Earlier tubes had the code marking on the glass.

Right—Element assembly of this tube with plate opened up to show spiral grid and axial filament.

(To be continued)

Fundamental Optics

(Continued from page 26)

ment automatically. Probably the most widely publicized of these is the Hardy color analyzer. This instrument will accomplish in minutes what formerly took a trained technician hours.

Refraction

As far back as the tenth century the Arab Alhazen demonstrated the true behavior of light as it passes from one medium into another. It remained for Willebrord Snell, over six centuries later, however, to determine the mathematical law relating the angles of incidence and refraction. Snell's law, the law of refraction, states that the sines of the angles of incidence and refraction are in a constant ratio to each other for any given medium. Its proof, based upon the concept of wave fronts, is relatively simple.

Consider, as shown in Fig. 3, the boundary between two materials, one less dense than the other, like air and glass. The plane wave fronts incident upon this surface are brought closer together after entering the denser medium because the velocity of the propagation of light is directly proportional to the density of the material in which it is traveling. If, too, the wave fronts are incident upon this boundary at an angle ABC, as shown, then the wave fronts will suffer a turning action because part of the wave will be slowed down sooner than the remainder. The wave fronts will then leave the boundary at an angle BCD. It can be seen, also, that in the time that point A takes to travel to point C, point B would have traveled to point D. The distances AC and BD, therefore, are proportional to the velocities of the light in the two mediums, or

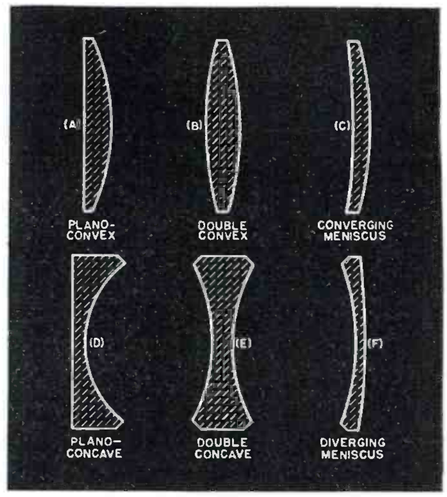


Fig. 11. A number of common lenses having spherical surfaces.

$$\frac{AC}{BD} = \frac{\text{velocity of light in air}}{\text{velocity of light in glass}} = \frac{Va}{Vg}$$

Mathematically, we can divide both numerator and denominator of a fraction by the same quantity without changing that fraction, hence

$$\frac{AC/CB}{BD/CB} = \frac{Va}{Vg}$$

But it is soon evident that

$$AC/CB = \text{sine} \angle ABC$$
$$BD/CB = \text{sine} \angle BCD$$

Fig. 135

Fig. 136

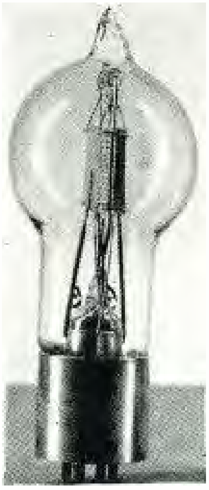


Fig. 137

THE SAGA OF THE VACUUM TUBE

By GERALD F. J. TYNE
Research Engineer, N. Y.

Part 12. The period of increased activity in the wireless industry with Lee de Forest's development of suitable oscillator and detector tubes.

WITH the money received from the sale of the telephone repeater rights on the Audion to the Telephone Company, de Forest went back to his old laboratory in the High Bridge section of New York City and resumed his investigations as of old. Before long, the laboratory was again in operation and things were progressing as before. In the discovery of the ability of the Audion to produce oscillations, little had been learned concerning its operating characteristics as an oscillator, or generator of alternating currents. De Forest, once more free from want, at least temporarily, began work on the problem of making the Audion give high-frequency output in useful quantities.

His peace of mind was not for long, however. One of the by-products of the wireless boom of 1906-1907 and the stock-jobbing schemes previously mentioned was the indictment of de Forest and some of his associates early in 1912. They were charged with using the mails to defraud, in connection with the sale of Radio Telephone Company stock. At the time de Forest demonstrated the Audion before the officials of the Telephone Company, he was free on bail of $10,000 which had been furnished by Beech Thompson, president of the Federal Telegraph Company. De Forest and his associates were brought to trial in late November of 1913. The trial ran for six weeks. So little were the potentialities of the Audion realized at that time that the indictment charged them with using the mails to defraud the public by selling stock "in a company incorporated for $2,000,000, whose only assets were de Forest's patents chiefly directed to a strange device like an incandescent lamp, which he called an Audion, and which device had proven to be worthless." This in 1912!

The Federal District Attorney, Robert Stephenson, in summing up his case said that de Forest had said[168] ". . . in many newspapers and over his signature that it would be possible to transmit the human voice across the Atlantic before many years. Based on these absurd and deliberately misleading statements of de Forest, the misguided public, Your Honor, had been persuaded to purchase stock in his company—" And yet, only two years later this feat was accomplished by the A. T. & T. Company engineers, using improved electronic tubes, based on the Audion which the overzealous District Attorney held up to such ridicule! Truly Mr. Stephenson's face must have been red!

The jury rendered its decision on New Year's Eve, December 31, 1913, seven years to the day after the grid was first inserted in the Audion. De Forest and his friend and patent attorney, Samuel Darby, were acquitted. Two of their associates were found guilty.

De Forest went back to his work. Later in 1914 the Telephone Company purchased additional rights to the use

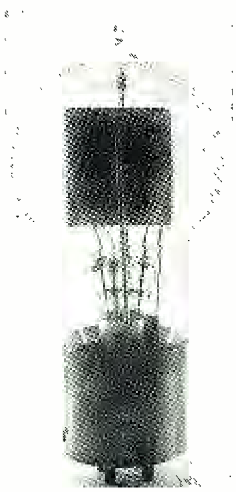


Fig. 138.

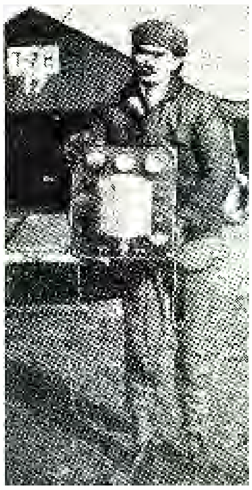


Fig. 139.

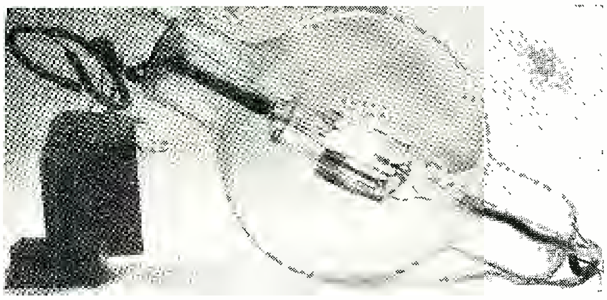


Fig. 140.

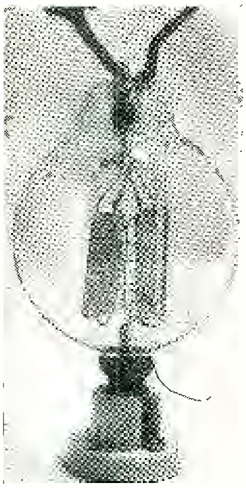


Fig. 141.

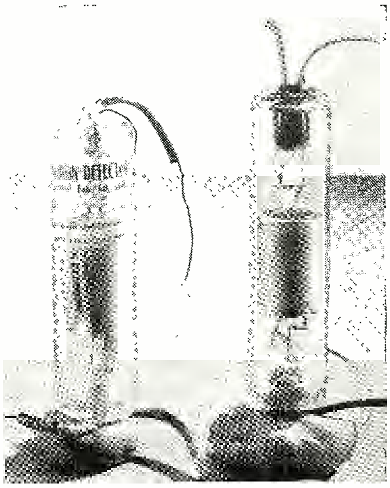


Fig. 142.

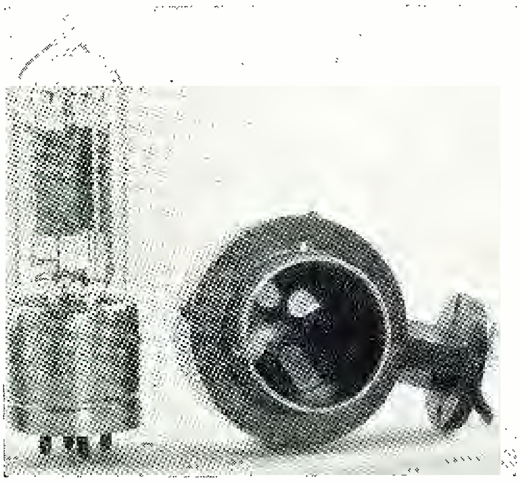


Fig. 143.

of the Audion, this time in the field of radiotelephony, for $90,000. With this additional capital de Forest's work proceeded more rapidly. The High Bridge factory was equipped with newer and better machinery, particularly with the latest and best vacuum pumping equipment. The manufacture of "Oscillions," the name given to Audions intended for use as oscillators, first of the smaller sizes and later of the larger ones, was begun.

One of the smaller types developed was the so-called "Singer" type Audion, which obtained its name from one of its uses—that of producing audio-frequency oscillations, or "singing."

The earliest models of this type had candelabra bases and the grid structure was supported by glass rods. One of the oscillators, denoted as the "Type S Oscillion" incorporating this early model is shown in Fig. 135 and the Oscillion itself is shown in Fig. 136. These Oscillions were used by de Forest in a "musical" instrument, the predecessor of such present-day devices as the Novachord and Solovox.

De Forest demonstrated this musical instrument before the New York Electrical Society in December 1915. While the Proceedings of this Society contain no record of this demonstration, there appeared in one of the popular electrical magazines of that time an article [169] by de Forest on this application of the Audion.

A later variant of the "Singer" type Audion, equipped with the "Shaw Standard" base, and with radically different internal construction is shown in Fig. 137. A rectifier version of this same tube, later used in some of the low-powered de Forest transmitters, appears in Fig. 138.

Other sizes of Oscillions began to come into being. De Forest realized the growing importance of aircraft in

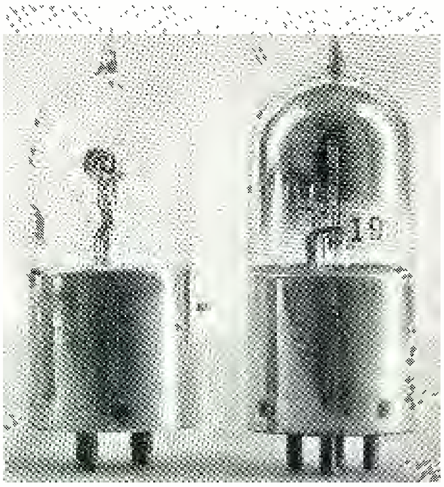


Fig. 144.

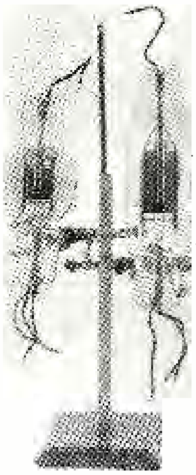


Fig. 145.

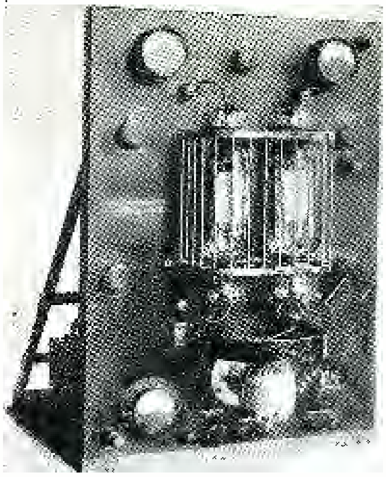


Fig. 146.

the modern way of life and felt that the necessity of plane-to-ground communications would soon become evident. Accordingly, he set about the development of an Oscillion aircraft transmitter. One of the earlier steps in that direction is the transmitter unit held by Dr. de Forest in Fig. 139.

A somewhat similar transmitter, using the same type of tube, but known as the "Type OJ3 Oscillion Telephone," was offered for sale to amateurs in 1917.

Other and higher power output Oscillions followed. This tube (Fig. 140) operated at a plate potential of 1500 volts and had an output of 250 watts. It was this type of tube which was used in the transmitter installed at High Bridge. Through this transmitter the returns of the Presidential election of 1916 were broadcast.

Late in 1915 de Forest engaged Robert F. Gowen as chief engineer. Gowen was not only a trained scientist but an enthusiastic amateur wireless operator of long standing. As a student at Harvard he had aided in organizing a wireless network for intramural communications. This organization was known as the "Weld Phonepterograph Company, Ltd." and was composed of a number of wireless enthusiasts, each of whom operated a wireless station in one of the buildings on the campus.

Under Gowen's supervision High Bridge turned out a number of sizes and types of tubes. In the way of detector tubes there was an improved spherical Audion, which is shown in Fig. 141. This, like the early Western Electric tubes, had a double glass arbor for supporting and stiffening the plate and grid assemblies, but unlike the Western Electric tube had two filaments.

Meantime, competition for the business of the radio amateur began to appear. A cylindrical three-electrode detector tube, known as the "Audio Tron" was put on the market by a West Coast concern. These tubes were good detectors, and what was most important to the amateur—whose ambitions always exceeded his financial resources—could be purchased alone. As will be recalled from a previous article the de Forest Audions could be legitimately obtained only by first buying a complete Detector, after which renewal bulbs could be purchased upon returning the old ones.

Probably to meet such competition the de Forest Company brought out a tubular Audion, designated as the "Type T," which was first offered for sale in April 1916. The "Type T" was a single filament tube, and sold for about the same price as the "Audio Tron," which was a double filament type. A photograph of two of the early "Type T" Audions is given in Fig. 142.

Not long after the appearance of the "Type T" the de Forest Company put on the market the "Type PJ Oscillion Telephone," using an Oscillion of about the same size as the "Type T" but with an internal structure resembling that of the older spherical bulbs.

With the entry of the United States into World War I all amateur activity was stopped, and the de Forest Company began to manufacture tubes for the U. S. Government. One of these, used by the Signal Corps, was designated as the "VT-21." This tube operated at a filament current of 1.1 amperes, and had an amplification factor of 10-12, with plate resistance of 60,000 ohms, at a plate voltage of 20 volts. The bulb shape of the VT-21 varied. De Forest also made tubes for the U. S. Navy, one of these being designated as the "CF-185." This tube was at first supplied to fit the Navy Standard

(*Continued on page* 118)

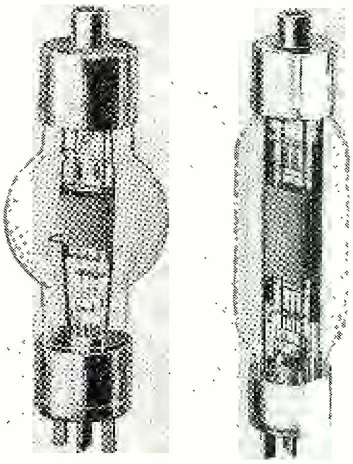


Fig. 147.

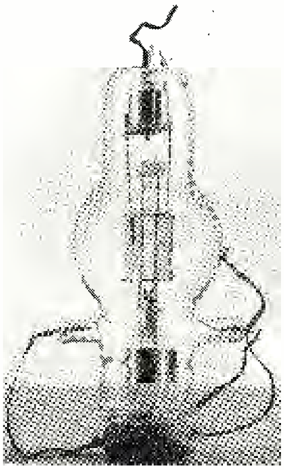


Fig. 148.

the ends of the crossarm. It is effective in providing low angle radiation so desirable in ground to ground communication (as distinguished from ground to airplane communication) at v.h.f. and u.h.f. frequencies.

Horizontal Dipoles and Arrays

Commercial FM and television utilize horizontally polarized waves for most broadcasting functions. Some of the reasons which have been advanced for using this type of polarization are:

1. There is less reflection from buildings in urban areas.
2. There is less interference from man-made noises.
3. Arrays of horizontal dipoles are easier to construct.

A single element horizontal dipole is slightly directive in itself, having maximum radiation in a broadside direction. This directivity may be increased by using a long wave antenna, or a collinear array of dipoles. Parasitic elements tend to concentrate the radiation broadside in one direction.

In addition to directivity in a horizontal plane, maximum vertical radiation at low angle is a most desirable feature for antennas in the v.h.f. and u.h.f. frequency ranges. This effect may be achieved with a broadside array of horizontal dipoles stacked one above one other. In commercial FM and television, uniform radiation in a horizontal direction is often also desirable, so that points in all directions may be served equally well. This uniform horizontal radiation pattern may be produced by crossing two horizontal dipoles perpendicularly at their centers, which combination of dipoles is known as the "turnstile" antenna. A stacked array of "turnstile" antennas will serve two desirable functions, both concentrating the radiation in a horizontal plane and distributing it uniformly in all directions along this plane.

Horizontal dipoles may be mounted directly at right angles to the crossarm. At the lower frequencies, these dipoles, unless made out of rigid tubing, may need auxiliary support in a horizontal plane. Parasite elements may be mounted in a manner similar to the dipoles. Inasmuch as the crossarm may be rotated in any direction, the directivity of such an array may be changed at will. A stacked broadside array may be mounted by using an auxiliary vertical shaft affixed to the crossarm. For "turnstile" arrays, however, as with other special horizontal arrays, it may prove most expedient to dispense with the crossarm and make the mounting an integral part of the array.

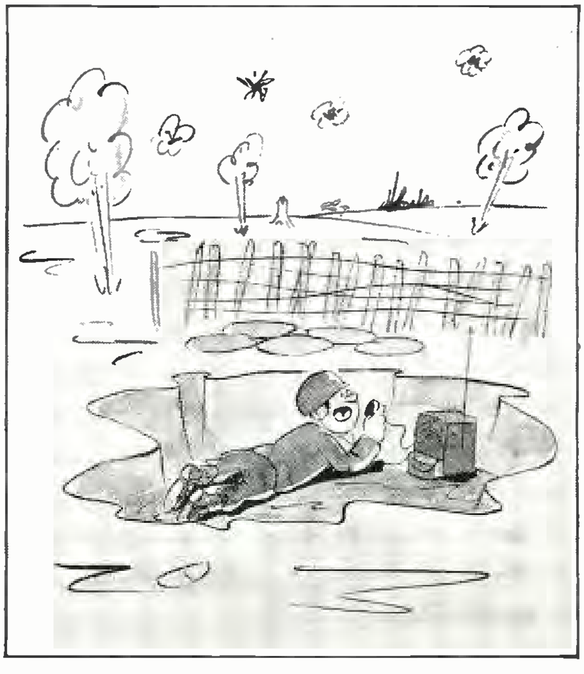
—30—

Saga of the Vacuum Tube

(*Continued from page* 54)

three-contact socket, and had a machined fiber base. The grid was of fine tungsten wire wound on a glass frame. The plates were of sheet tungsten. Subsequently, these tubes were made with the later standard four-point base and one of this variety, using a metal base, is shown in Fig. 143. These tubes were also provided with an adapter which enabled them to be used in the candelbra socket which was characteristic of previously made Audions. The "CF-185" tubes were the first to be made by de Forest using oxide-coated filaments and were claimed to have a life of 5000 hours at a filament current of 0.85 ampere.[170]

It will be remembered that when de Forest sold the rights to the Audion to the A. T. & T. Company he retained a personal, non-transferable right to make and sell Audions for radio use. This he continued to do. In 1914 the Marconi Wireless Telegraph Company of America, owners of the United States Patent on the Fleming Valve, instituted suit against de Forest and the de Forest Radio Telephone and Telegraph Company, claiming that the de Forest Audion was an infringement on the Fleming patent. De Forest promptly filed a countersuit claiming infringement of his patents by the Marconi Company. Before the cases came to trial the Marconi Company confessed judgement as to its infringement of the de Forest patent and were enjoined from further infringement. The case against de Forest, which will be discussed in a later article, was tried and the decision of the Circuit Court was filed on September 20, 1916.[171] This decision was later upheld by the Circuit Court of Appeals.[172]



"Oh hello, is that you, Mert?"

The decision held that the Fleming patent had been infringed and an injunction was issued restraining de Forest from further manufacture and sale of Audions for radio use. This produced a stalemate. De Forest could not make Audions because they infringed the Fleming patent. The Marconi Company could not make Audions because that would infringe the de Forest patent. They could make Fleming Valves, but that was not what they wanted.

During World War I de Forest made Audions for the U. S. Government under guarantee of immunity. After the War the Marconi Company sued the U. S. Government because of the infringements, and this suit was decided only last year. The decision of the United States Supreme Court, handed down on June 21, 1943,[173] held that the Fleming patent had not been infringed, and that the patent itself was void, thus, in effect, reversing the decisions rendered back in 1916 by the Circuit Court and confirmed by the Circuit Court of Appeals.

After the war the injunctions again became operative and the stalemate was restored. It was broken early in May, 1919,[174] when representatives of de Forest and Marconi met with a West Coast manufacturer named O. B. Moorhead. Moorhead had been making and selling "Electron Relays" before the war and was ready to engage in the manufacture of tubes. The conference resulted in de Forest joining forces with Moorhead, in order to permit them to use de Forest's personal license to manufacture Audions, and in the Marconi Company's extending their patent rights to the combination for the manufacture and sale of receiving tubes. The Marconi Company was made the distributing agent for the combination. Two distributing companies were organized. The Pacific Radio Supplies Company had the West Coast territory and the Atlantic Radio Supplies Company covered the eastern part of the United States.

The first tubes put out by this combination were the unbased Moorhead Electron Relay and the Moorhead VT Amplifier.[175] This latter was a high-vacuum tube which had been made by Moorhead during the war and sold to the U. S. Navy under the designation "SE-1444."[176]

The unbased Electron Relay was soon abandoned in favor of a based tube[177] which was also called the "Moorhead Electron Relay." The base was the so-called "Shaw Standard"[178] and was used on the SE-1444 and the Moorhead VT Amplifier as well.

The Marconi Company, in advertising the hard tube, designated it as the "Marconi VT." This tube bore the de Forest and Marconi markings on the brass base, in depressed characters, and the Moorhead markings etched on the glass bulb. The life was claimed as 1500 hours.[179] The glass of some of these tubes had a golden tinge, and the tube was familiarly known as the "Golden VT." It operated with a filament current of 0.7 ampere at about 4 volts.[180]

The tubes made and sold by this organization were the only receiving tubes legally available to the public until the foundation of the Radio Corporation of America.

A short time later the "Electron Relay" was replaced by the "De Forest Type 20" detector. This was at first advertised[181] as a "soft" tube, and is shown at the left in Fig. 144. Later it was apparently made as a hard vacuum tube since the variant at the right in Fig. 144 has a getter.

After World War I de Forest began to develop the higher power Oscillions. This he could do because the injunction applied only to receiving tubes. Two of the postwar Oscillions are shown in Fig. 145. The tube at the left is of 250 watts *input* rating and that at the right is 500 watts *input* rating. Fig. 146 shows a transmitter made by the de Forest Company using two of these "500-watt" tubes. Later models of these tubes are shown in Fig. 147.[182] These later models, as will be seen from the figure, were provided with end fittings to facilitate mounting and connecting into the circuit. They appeared on the market about 1920. In addition to those shown there was also made a 1000-watt *input* tube of similar construction.

With the advent of broadcasting the market for receiving tubes expanded enormously and the demand became huge. The Fleming patent expired in 1922 and its expiration left the de Forest Company free to manufacture Audions for radio use. Some time later the De Forest Radio Telephone and Telegraph Company underwent a reorganization and became the De Forest Radio Company. The new company proceeded to put out a line of vacuum tubes for the broadcast receiving set market.[183] They also made transmitting tubes, one of which, designated as the "Type H" and intended for amateur use, is shown in Fig. 148. This tube was rated at 150 watts *input* and operated at plate voltages from 500 to 3000 volts.[184] There was also a rectifier version of this tube known as the "Type HR."[185]

De Forest's interest in the newly reorganized company was a nominal one, and he began the pursuit of other goals, notably in the sound motion picture field.

The development of the hard vacuum tube occurred almost simultaneously in the laboratories of both the Western Electric Company and the General Electric Company. The work of the Western Electric Company has been covered in previous installments. In our next article we will discuss the evolution of this type of tube in the laboratories of the General Electric Company.

References

168. *Lubell, Samuel—"A Magnificent Failure." Saturday Evening Post, Vol. 214, No. 31, January 31, 1942, page 27.*

169. *de Forest, Dr. Lee—"Audion Bulbs as Producers of Musical Tones." Electrical Experimenter, Vol. 3, No. 8, December 1915, page 394.*

170. *Kahn, Bernard—"Navy Type Audion Detector." QST, Vol. 1, No. 12, November 1916, page 335.*

171. *236 Federal Reporter 942.*

172. *243 Federal Reporter 560.*

173. *Marconi Wireless Telegraph Company of America vs. U. S. Government, No. 369, United States vs. Marconi Wireless Telegraph Company of America, No. 373. Opinions of the U. S. Supreme Court, Vol. 87, No. 18, pages 1296-1337.*

174. *Radio Amateur News, Vol. 1, No. 2, August 1919, page 77.*

175. *Pacific Radio News, Vol. 1, No. 10, May 1920, inside back cover.*

176. *Moorhead, O. B. and Lange, E. C.—"The Specifications and Characteristics of Moorhead Vacuum Valves." Proceedings I. R. E., Vol. 9, No. 2, April 1921, pages 95-129. Paper presented at San Francisco Section on November 19, 1919.*

177. *Pacific Radio Supplies Company advertisement in Pacific Radio News, Vol. 1, No. 11, June 1920, inside back cover.*

178. *U. S. Patent 1,458,153.*

179. *Marconi Wireless Telegraph Company of America advertisement in Radio Amateur News, Vol. 1, No. 2, August 1919, page 52.*

180. *"The Marconi VT." Wireless Age, August 1919, pages 33-34.*

181. *Pacific Radio Supplies Company advertisement in Radio Amateur News, Vol. 1, No. 11, May 1920, page 606.*

182. *Catalog No. 101, Lee de Forest, Inc., San Francisco, Cal.*

183. *Radio Broadcast, September 1923, "Advertiser Section."*

184. *De Forest Radio Company advertisement in QST, Vol. 10, No. 8, August 1926, page 77.*

185. *De Forest Radio Company advertisement in QST, Vol. 10, No. 12, December 1926, page 99.*

CAPTIONS FOR ILLUSTRATIONS

Fig. 135. "Type S Oscillion." Reproduced from page 920 of April, 1917 Electrical Experimenter.

Fig. 136. Early "Singer" type Audion with candelbra base. Tube loaned for this photograph by Robert F. Gowen.

Fig. 137. Later version of "Singer" type Audion.

Fig. 138. Front view of rectifier tube of Singer type.

Fig. 139. Early type of Oscillion Aircraft Transmitter, held by Dr. de Forest. Photograph courtesy of Robert F. Gowen.

Fig. 140. High power Oscillion (250 watts), vintage of 1915.

Fig. 141. Improved form of spherical Audion detector, with glass arbors to promote rigidity of elements.

Fig. 142. "Type T" Audions. Left—with paper label. Right—turned to show "DF" stamped on plate.

Fig. 143. "Type CF-185" with four-point base and socket.

Fig. 144. De Forest "Type 20." Left—early type of soft tube. Right—later tube with magnesium flash.

Fig. 145. 250 watt input and 500 watt input Oscillions—front view.

Fig. 146. Oscillion Transmitter "Type OT-200" using 2500 watt input Oscillions. Photograph courtesy Robert F. Gowen.

Fig. 147. 250 watt input and 500 watt input Oscillions—vintage of 1920—with end fittings. Photograph courtesy Robert F. Gowen.

Fig. 148. De Forest "Type H" short wave transmitting tube—vintage of 1926.

(To be continued)

THE SAGA OF THE VACUUM TUBE

By GERALD F. J. TYNE
Research Engineer, N. Y.

Part 13. Covering the developments by the General Electric Co. of higher power-output alternators for use in the fields of telegraphy and telephony.

THE development of the comparatively crude Audion into a satisfactory high-vacuum telephone repeater element was undertaken and carried through by the engineers of the Western Electric Company because of an urgent need. The problems of wire telephony in general do not involve the use and control of large powers, and the Audion, as submitted for their consideration by de Forest, was limited to low power applications. The General Electric Company, on the other hand, dealt essentially in comparatively high-power devices. Why then did they become interested in the low-power Audion? Paradoxically enough it was because they had need of a high-power device—but one with the type of characteristics exhibited by the Audion at low power levels.

Although in the popular mind the name of the General Electric Company is associated with power equipment in the early 1900's, the engineers of this Company had for some years been engaged in an attempt to develop a radio-frequency alternator for long-distance communication. The work was begun about 1904 at the request of Mr. Reginald A. Fessenden of the National Electric Signalling Company. At that time Fessenden was working at Brant Rock, Massachusetts, trying to develop a method of obtaining a continuous flow of high-frequency energy, and had requested the General Electric Company to undertake the development of an alternator to operate at 100,000 cycles. He was familiar with the work done previously at the General Electric laboratory by Thompson and Steinmetz along this line. Fessenden was using an arc transmitter, the only satisfactory generator of continuous waves of that day. He experienced many difficulties in this work because the arc was tricky to handle and not entirely free from self-modulation. When Fessenden appealed to the General Electric Company to undertake this work, E. F. W. Alexanderson was assigned the job of developing such an alternator. The result of the next few years' work on his part was what became known as the Alexanderson Alternator. The real significance of this development was realized in 1919, when the General Electric Company, after having spent millions of dollars to make such a device practicable, refused to sell to its only customer, the British-controlled Marconi Company, and in so doing helped return the control of transatlantic radiotelegraph stations to the United States.[186] By this act also, the General Electric Company paved the way for the founding of the Radio Corporation of America.

Therefore, it might be said that in the early 1900's the General Electric Company was trying to build a machine—a mechanical device—to do the job of the vacuum-tube transmitter of the present day.

By 1913 Alexanderson had been able to construct satisfactory alternators of several kilowatts output at frequencies up to 200,000 cycles.[187, 188] They were satisfactory, that is, for use

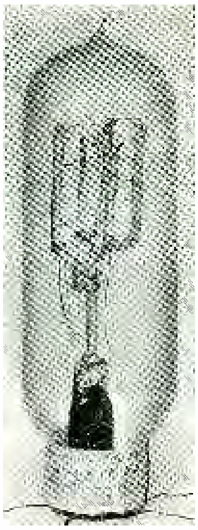


Fig. 149.

Fig. 150.

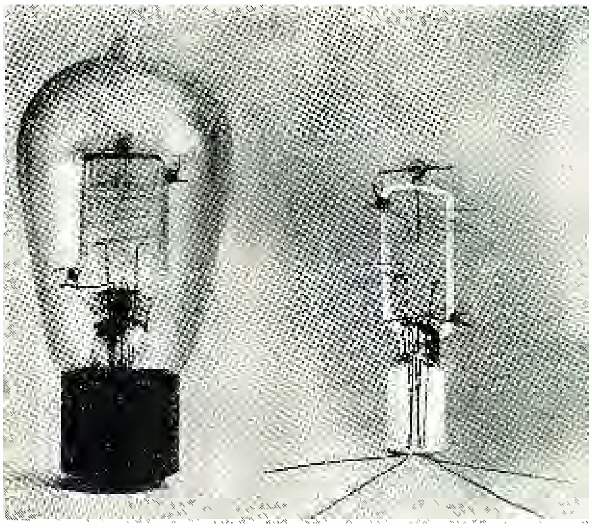


Fig. 151.

in continuous-wave telegraphy, but could not be used for satisfactory radiotelephonic communication since no method of adequate modulation of their output was available. Alexanderson had tried various methods of modulation with varying degrees of success. One method utilized a generator with its field excited by the telephone current. Another involved the use of the so-called "magnetic amplifier" or magnetic modulator.[189] A third was the use of a three-electrode mercury arc tube, in which an attempt was made to control the arc current by the use of the third electrode. None of these methods was completely satisfactory, and Alexanderson continued his search for a better modulator.

In 1912 the General Electric Company sold to John Hays Hammond, Jr., two high-frequency alternators for use in his experimental work on radio-controlled devices. In October of that year Alexanderson discussed with Hammond, at the latter's laboratory in Gloucester, Mass., the problem of obtaining the necessary modulation. While there, Alexanderson was told of some receiving apparatus, designed and constructed by Benjamin F. Miessner, one of Hammond's assistants, in which Audions were used. Alexanderson, who had never seen an Audion, felt from the description of the Audion and its characteristics that it might be promising as a high-frequency relay. He thought that it was in many ways defective but considered that the defects might be overcome. He therefore arranged to obtain a sample of the Audion from Hammond, to see if it might be made into a suitable device for the application he had in mind.

At Schenectady he showed the Audion to Drs. W. D. Coolidge and Irving Langmuir, with whom he often discussed problems. The discussion with Langmuir was fruitful. Langmuir said that he could develop a high-vacuum device of the three-electrode type which would function satisfactorily as a high-frequency relay. Alexanderson felt that such a device as Langmuir described could be used not only for modulation of the transmitted wave from his alternator, but also could be used in a new system of reception on which he was working. Accordingly, Langmuir set about the development.

Irving Langmuir had been in the employ of the General Electric Company since 1909. He was graduated from Columbia University in 1903, and had done postgraduate work at the University of Göttingen under Nernst, receiving his Ph.D. in 1906. When he entered the employ of the General Electric Company he attacked some of the problems still to be solved in connection with the tungsten filament incandescent lamp. The Coolidge process of making drawn tungsten wire had recently been introduced into commercial manufacture and had given rise to a number of problems, as does any new process.

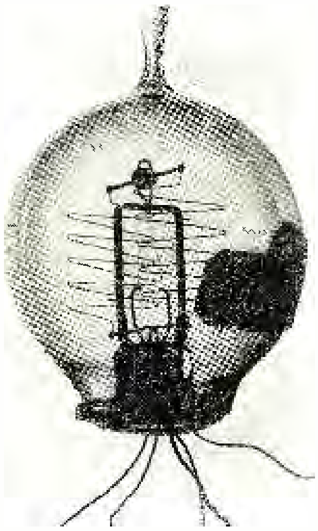


Fig. 152.

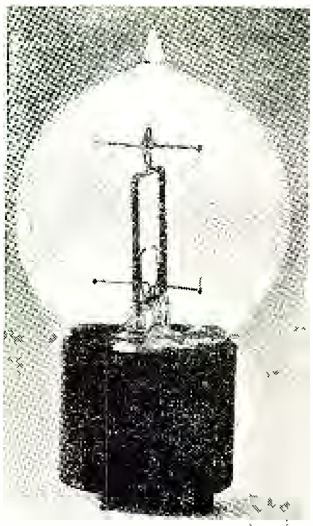


Fig. 153.

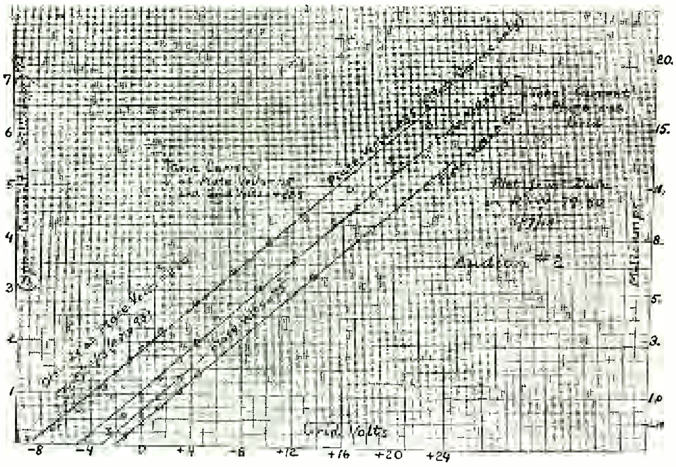


Fig. 154.

One of the problems which Langmuir studied in connection with tungsten filament lamps was the blackening of the bulbs in service. This same problem in connection with carbon filament lamps, it will be remembered, led to the discovery by Edison of the "Edison Effect." It was the common idea in the General Electric laboratory that this blackening, in the case of the tungsten filament lamp, was due to secondary causes, among them electric discharges. It had been observed that the "blue glow," characteristic of insufficiently exhausted lamps, caused very rapid blackening. Also the presence of water vapor in the lamp bulb accelerated the blackening. From this it would seem that better vacuums were desirable.

Others had attempted to solve the problem by increasing the vacuum. Langmuir adopted a different approach. He attempted to determine the cause of the blackening by increasing the amount of the impurities introduced into the bulb. Particularly he studied the effect on the filament of gases introduced. Some of these, such as hydrogen, would disappear if introduced in limited amounts. Others, such as nitrogen, would react with the tungsten vapor given off by the hot filament.

In this work Langmuir had to differentiate between the effects due to evaporation of the filament—because of its high operating temperature—and the effects due to electric discharges within the bulb. To accomplish this he used low-voltage filaments to study the evaporation phenomena, and high-voltage (50-250 volt) filaments to study the effect of discharges. From all this he began to get a picture of what would happen in a perfect vacuum. He concluded that the blackening of the bulb was due to normal evaporation of the filament, not to electric discharges. He found the reason why the presence of water vapor accelerated the blackening. He found that even if the vacuum were perfect the blackening still would occur.

From his studies he concluded that

(*Continued on page* 94)

Saga of the Vacuum Tube

(*Continued from page 47*)

the presence of pure gases was not harmful, and from this work came the high-efficiency, gas-filled incandescent lamp.

During the period just before Alexanderson brought the Audion to his attention, Langmuir had been studying the properties of filaments as a function of their length. It was thought at the time that with long filaments, requiring a comparatively high voltage for their operation, there might be a considerable amount of current flowing through the vacuous space and hence, for the same total current into the lamp, the actual filament current might be less and the lamp less efficient. Langmuir looked for this effect but could not find it. That is, in well-exhausted lamps there was a negligible space current, regardless of the length of the filament. Others had worked along this same line and were of the opinion that in a perfect vacuum there would be no space current.

One of these others was Dr. Coolidge, who was working on X-ray tubes. In the old-fashioned X-ray tube of high power most of the electrical energy supplied to the tube appeared at the anode, which would operate sometimes at white heat. Coolidge used tungsten for the anode and in some cases tried tubes with tungsten cathodes as well. In the case of the tungsten cathodes he found that after the tube had been in operation for some time the cathode also became white hot, and shortly thereafter the tube ceased to pass current and became inoperative. Coolidge was aware of the "clean-up" effect of white-hot tungsten and believed that the stoppage of the tube was caused by its becoming too "hard," that is, the vacuum had become too high to permit the passage of current. Langmuir's own experimental work indicated that these currents would become very small when the highest vacuums, obtained by thoroughly baking the lamps to free them from occluded gases, were attained.

On the other hand, Langmuir was familiar with the work of O. W. Richardson on thermionic emission, which showed that thermionic emission increased with temperature.[190] Calculations based on Richardson's equations indicated that at the temperature at which Langmuir was operating his tungsten filaments the thermionic currents should have been hundreds of amperes per square centimeter of filament surface. He checked the discharge from a hot filament to a cold anode in the presence of mercury vapor and found that the space current followed Richardson's law up to very high filament temperatures. Hence, he concluded that there was nothing abnormal about tungsten and that the filaments actually were emitting electrons in accordance with Richardson's law.

The ordinary tungsten lamp of that time had a long zigzag filament of six loops, with two leads brought out and connected to a base for use in a standard screw type socket. Langmuir had made some experimental lamps in which two additional leads, connected to intermediate points on the filament, were brought out. These leads were placed so that between any two consecutive leads there were two loops of filament. These lamps were exhausted by the ordinary procedure, but Langmuir then proceeded to raise the middle two loops of the filament to a very high temperature and vaporize the tungsten, so as to "clean-up" the vacuum. The act of vaporizing the tungsten assists in the removal of some of the residual gases. The tungsten vapors will combine with nitrogen, oxygen, carbon monoxide, and carbon dioxide, and these are the gases which are likely to be present in the bulbs. When this was done, and the middle portion of the filament burnt out, there were left two sections of filament electrically separated from each other, between which a voltage could be applied.

Langmuir then heated one filament by passing a current through it, and applied a voltage between that filament and the other which was cold. He measured the space current as a function of temperature for various filament temperatures and compared the results obtained with values calculated according to Richardson's law. He found that at first the space current followed the law, but as the temperature increased the space current tended toward a constant value. This always occurred, although the limiting value was different for different voltages between the hot and cold electrodes. He found that this limiting current was approximately proportional to the voltage difference between the hot and cold electrodes, and to the area of the anode.

He discovered also that a potential applied to the bulb externally affected the space current. If, for example, he placed one hand on the bulb and with the other hand touched the terminals of the d.c. power circuit in the laboratory, the space current increased or decreased.

By November 22, 1912, Langmuir had accumulated enough data to enable him to formulate a qualitative theory concerning the space current. This theory, as entered in one of his notebooks under that date, was as follows:

"New Theory of Edison Current. The velocity of electrons in a conductor corresponds to that produced by a fall through a potential diff. (sic) *of only a few tenths of a volt. Electrons leaving a filament will leave irrespective of the presence of a field, but they will only travel a very short distance if there is an electric field of only 0.1 volt per centimeter against them. Hence, around filament there is an atmosphere of electrons in equilibrium with the filament. Below a certain temperature the potential is determined by wires* (i.e. electrodes) *only.*

"Above a certain temperature the concentration of electrons becomes so great that they determine the field. Hence, two laws: Richardson's at low and some other at high temperature.

"Cooling bulb has no effect when no gas molecules present, but if gas is there the molecules collide with electrons (which have the same velocities as those of the filament) and slow them up and make them more readily absorbed by the anode wires."

This last paragraph was an attempt to explain the fact that the presence of gas caused an increase in the space current. This, we know now, was not the correct theory. The increase in current when the gas is present at high voltage is due to the fact that the positive ions formed, neutralize the space charge and allow the space current to rise toward the temperature saturation value.

These experiments threw an entirely new light on the theory of discharges from hot electrodes in very-high vacuums. It showed why, in the past, such small space currents were found under conditions where large currents were indicated by Richardson's equation.

Langmuir attached great importance to this explanation and theory, and proceeded to make a detailed study of the laws governing the phenomenon under high-vacuum conditions. His first step was to have constructed another lamp in which were placed two independent filaments, both of which could be heated during the process of exhausting the bulb. The bulb of this lamp was baked at high temperature during exhaust and a liquid air trap was used to remove traces of water vapor and carbon dioxide. Thus Langmuir removed as much of the occluded gases as possible, and pushed the vacuum to the limit attainable with the available equipment.

Tests run on this new bulb were made using anode voltages up to 250 volts d.c. and about 500 volts a.c. When the test data was plotted in a curve, the shape of the curve indicated that the space current varied as the 1.5 power of the voltage.

This, then, was the background of knowledge born of experience that enabled Langmuir to tell Alexanderson, in January of 1913, that he could improve the gadget which Alexanderson had obtained from Hammond, and make of it a device which would enable Alexanderson to do what he wanted. In order to do so Langmuir needed another assistant, and William C. White was assigned to this work. White studied the characteristics of the Audion and discussed the results of his tests with Langmuir.

While White was studying the

Audion, Langmuir had made up a tube similar to the Audion but with leads widely separated in order to enable him to apply high voltages during the exhausting process, and thus heat the electrodes by bombardment and free them from occluded gases. The results obtained were unsatisfactory and Langmuir decided to alter the construction of the tube in such a way as to facilitate the evacuation.

In order to accomplish this he abandoned the conventional Audion construction and made a three-electrode tube in which all three of the electrodes (filament, grid, and anode) were made of wire. The filament was made of 2.7 mil tungsten wire and was about 5½ inches in length. The grid was of 1.5 mil wire, hand wound on a glass frame. The anode was a zigzag wire 5 mils in diameter. The filament operated at about 2.5 amperes. This tube was known as "Tungsten Wire Audion No. 2" and is shown in Fig. 149.

This type of construction was adopted so that the electrodes could be heated by current from an external source during exhaust, in order to expel the occluded gases. This form of construction was used from March, 1913 until well into 1914 for all small tubes for operation at or below 250 volts, and somewhat longer for special tubes. Samples of tubes using this construction are shown in Figs. 150, 151, 152, and 153.

After this tube had been exhausted and sealed off the pump at a pressure of 0.05 micron it was subjected to numerous tests. In one case the anode voltage was held constant at 250 volts and the anode current measured as a function of grid voltage. Curves plotted of total space current showed that the space current obeyed the 3/2 power law. These curves are reproduced in Fig. 154.

This tube was also tested and functioned satisfactorily as a detector of wireless signals. Others made up shortly thereafter were also operated successfully when tested, in May of 1913, by Alexanderson for use as radio-frequency amplifiers.

While these experiments were under way, Coolidge was continuing his work on X-ray tubes. In December, 1912, Langmuir had discussed with Coolidge the results of his experiments and suggested that Coolidge try a tungsten cathode which could be heated by electric current from an external source, for the purpose of getting electrons in his X-ray tube. He told Coolidge that electrons were emitted from such filaments even in the highest vacuum, and that controlling the heating current would control the electron emission and the space current, independently of the applied voltage. Coolidge immediately proceeded to build an X-ray tube using an independently heated tungsten cathode of the type suggested. He used a tungsten anode, which he degassed by electron bombardment while the tube was still on the pump. He found it necessary to add a focussing shield around the cathode, and with this addition obtained a tube which was steady in operation, with none of the crankiness of the old type of cold-cathode tube, and one with which he could obtain reproducible results. By December, 1913, Coolidge had developed this tube to the point of commercial use, and described it in a paper before the American Physical Society.[191]

References

186. *Report of the Federal Trade Commission on the Radio Industry. Government Printing Office*—1924, *pp.* 14-16.

187. *Alexanderson, E. F. W.—"Alternator for* 100,000 *Cycles." Trans. A.I.E.E., Vol.* 28, *Part* 2, 1909, *pp.* 399-415.

188. *Alexanderson, E. F. W.—"Magnetic Properties of Iron at Frequencies Up To* 200,000 *Cycles." Trans. A.I.E.E., Vol.* 30, *Part* 3, 1911, *pp.* 2433-2454.

189. *Alexanderson, E. F. W. and Nixhoff, S. P.—"A Magnetic Amplifier for Radio Telephone." Proc. I.R.E., Vol.* 4, 1916, *pp.* 101-129.

190. *Richardson, Owen Willans — See Proceedings of Cambridge Philosophical Society, Vol.* 11, *page* 296 *for preliminary note on this work.*

Richardson, Owen Willans—"The Electrical Conductivity Imparted to a Vacuum by Hot Conductors." Philosophical Transactions of Royal Society of London. A, Vol. 201, 1903, *pp.* 497-549. *An abstract of this paper will be found in Proc. Roy. Soc. London, Vol.* 71, 1903, *pp.* 415-418.

Richardson, O. W. and Brown, F. C.—"The Kinetic Energy of the Negative Electrons Emitted by Hot Bodies." Philosophical Magazine, 6*th Series, Vol.* 16, *No.* 93, *September* 1908, *pp.* 353-376.

Richardson, Owen Willans—"Thermionics Phil. Mag., 6*th Series, Vol.* 17, *No.* 102, 1909, *pp.* 813-833.

191. *Coolidge, W. D.—"A Powerful Roentgen Ray Tube with a Pure Electron Discharge." Physical Review,* 2*nd Series, Vol.* 2, *No.* 6, *December* 1913, *pp.* 409-430.

CAPTIONS FOR ILLUSTRATIONS

Fig. 149. Langmuir's "Tungsten Wire Audion No. 2". Reproduced from Interference Record, Interference No. 40,380.

Fig. 150. Early type of wire element Pliotron, now in Science Museum, South Kensington, England. Photograph copyright by H. M. Stationery Office.

Fig. 151. Left—early Langmuir Pliotron complete. Right—element assembly on stem. Photograph courtesy General Electric Company.

Fig. 152. Early Langmuir Pliotron, before exhaust. This Pliotrom has a grid of tungsten wire 0.4 mil in diameter, wound on a metal frame, with a pitch of 120 turns per inch. The anode is of 7 mil tungsten wire. Note the 5 leads, two filament, one grid, and both ends of wire anode. Exact date uncertain, but prior to 1917.

Fig. 153. Completed, based Pliotron, Type CA. Vintage of 1917. This is a high-mu triode. The filament takes 1.0 ampere at 3.5 volts. The usual plate voltage was 180 volts. Photograph courtesy General Electric Company.

Fig. 154. Characteristic curve of Langmuir "Tungsten Wire Audion No. 2". Reproduced from Transcript of Record, General Electric Company vs. De Forest Radio Company, U.S.C.C. of A., Nos. 3799, 3800, 3801, March Term, 1928.

(To be continued)

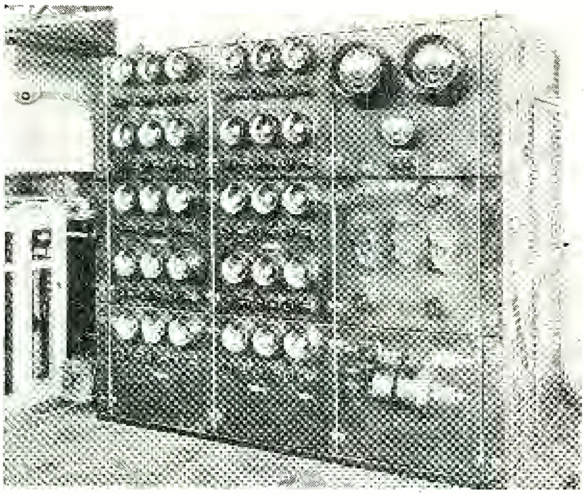


Fig. 155.

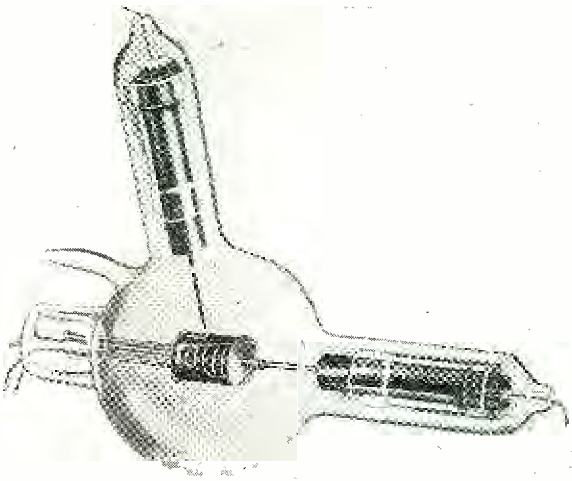


Fig. 156.

THE SAGA OF THE VACUUM TUBE

By GERALD F. J. TYNE

Research Engineer, N. Y.

Part 14. Covering the development of the "Kenotron," "Pliotron," "Dynatron," and "Magnetron" by Drs. Langmuir, Dushman, and Hull of the General Electric Laboratories, during the years 1913 to 1921.

IN APRIL of 1913 Langmuir and Dr. Saul Dushman of the General Electric laboratory attended a series of lectures delivered by Professor Wilhelm Wien at Columbia University. During their return trip to Schenectady they discussed the work which Langmuir and White had been doing and it was agreed that Dushman would take over that portion of the work on the new device which had to do with its use as a high-voltage hot-cathode rectifier and relay, and that White would continue to work on tubes for wireless and similar low-power applications.

By June of 1913 Dushman had a three-electrode tube which was capable of operation, while still on the pump, at 20,000 to 40,000 volts on the anode and with a space current of 100 milliamperes. This tube had been exhausted to a high vacuum by means of a Gaede molecular pump. It was a bulb about 6 or 7 inches in diameter with side arms which contained the leads to the electrode terminals. The anodes were plates of sheet tungsten and the grid a spiral of 1.5 mil tungsten wire wound on glass supports. It was at first operated while still connected to the pump, but was then sealed off and became, in effect, a large power tube. After sealing off, it could be operated without blue glow at 10,000 volts on the anode and space current of 100 milliamperes. It was, on May 14, 1913, used to successfully accomplish what Alexanderson had in mind when he first brought the Audion to the laboratory; that is, to control the output of one of his high-frequency alternators. Still later it was used as a modulator in actual wireless tests.

This single tube was later replaced by a bank of tubes, and in 1919 the 200 kw. Alexanderson alternator, installed at New Brunswick, was modulated through a magnetic amplifier by a bank of thirty Type "P" Pliotrons operated in parallel. Fig. 155 shows the amplifier used in this work. The anode voltage used was about 2300 volts and the anode current varied over the range 0 to 4 amperes. This represented a variation in modulating energy of about 4 kw.

It was in November, 1913 that the need was felt for characteristic names for these new devices, and the term "Kenotron" was chosen for the pure electron discharge tube, and "Pliotron" for the pure electron discharge relay. The word "Kenotron" was derived from the Greek *"kenos,"* signifying *empty space* (vacuum) and the ending *"-tron"* used by the Greeks to denote an instrument. Similarly "Pliotron" is derived from the Greek *"pleion"* signifying *more*. A Pliotron is thus an instrument for giving more, or an amplifier. It was the coining of these and other like words to describe later devices that provoked de Forest into dubbing them "Graeco-Schenectady."

The first publication dealing with Langmuir's work came in October, 1913 when Langmuir read a paper in which he disclosed the method which he had used to prepare the electrodes and exhaust the tubes in such a way as to obtain a pure electron discharge. The paper was read at Columbia University and subsequently published.[192] During the discussion which followed the presentation of this paper, Dr. H. D. Arnold brought out the fact that

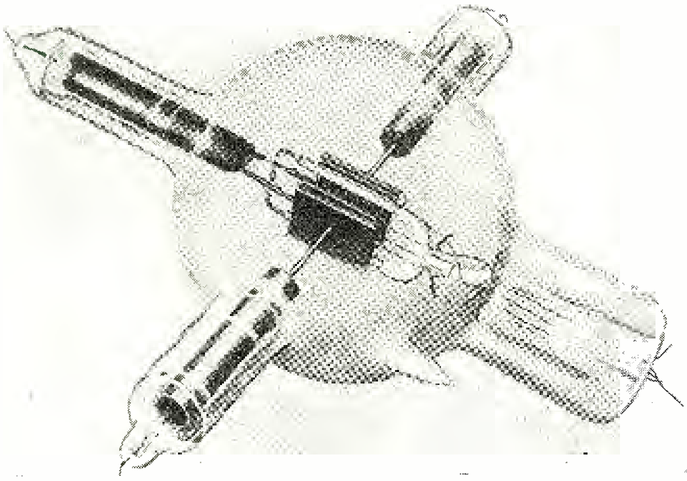


Fig. 157.

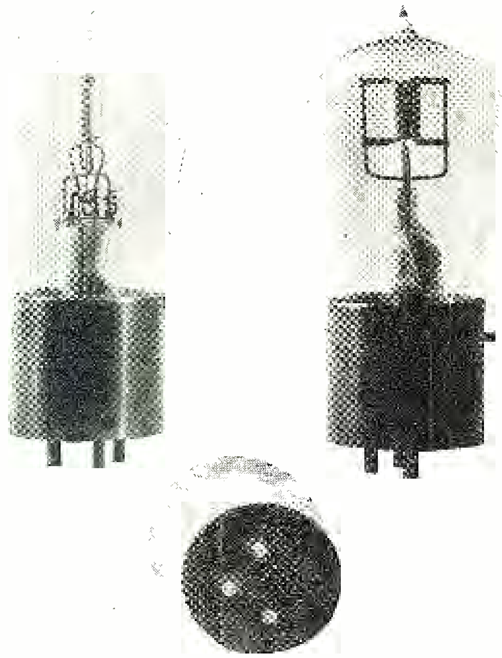


Fig. 158.

the 3/2 power law for the case of parallel plane electrodes had been published by O. D. Child in 1911,[193] and that Lilienfeld had previously obtained the 3/2 power law experimentally and had published his results in 1910.[194]

Later Langmuir published two other papers in German publications. These later papers covered the same ground as his Columbia paper but went into somewhat greater detail. [195, 196]

The next publication was by Dushman in the General Electric Review and dealt with high-power rectifiers.[197] The tubes described were high-voltage rectifiers (Kenotrons) exhausted to a pressure of 5×10^{-7} mm. mercury (0.0005 micron). Tubes which operated at voltages up to 100,000 volts and with space currents up to 100 milliamperes were described.

Then in April, 1915 Langmuir presented to the I.R.E. his famous paper on "The Pure Electron Discharge and Its Applications in Radio Telegraphy and Telephony."[198] In this paper he gave the theoretical equations for the maximum space current between parallel plates, and for cylindrical structures. This equation came to be known, albeit somewhat incorrectly, as "Langmuir's 3/2 power law." He gave diagrams of the structures used in two of the types discussed, both of which had wire elements. He also disclosed that Dushman had succeeded in making Kenotrons for a voltage of 180,000 volts at a current of 250 milliamperes.

Meantime Dr. Albert W. Hull of the General Electric laboratory also had been engaged in work on pure electron discharge devices. This first came to light when he presented a paper, on October 30, 1915, before the American Physical Society in New York.[199] His work was somewhat unorthodox. The title of his paper was "Negative Resistance." He had succeeded in obtaining a negative resistance characteristic in the anode circuit of a three-electrode discharge tube by operating

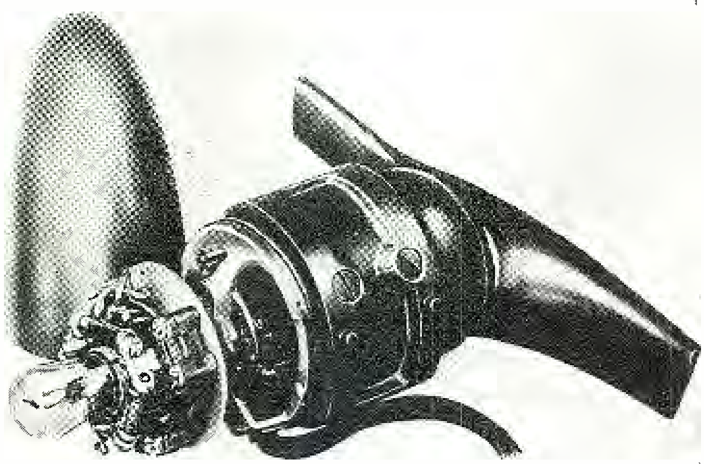


Fig. 159.

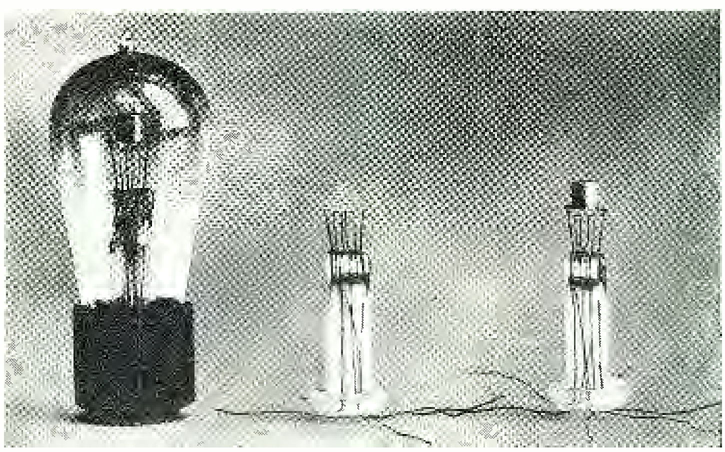


Fig. 160.

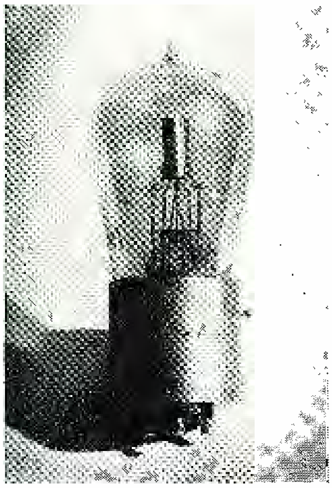


Fig. 161.

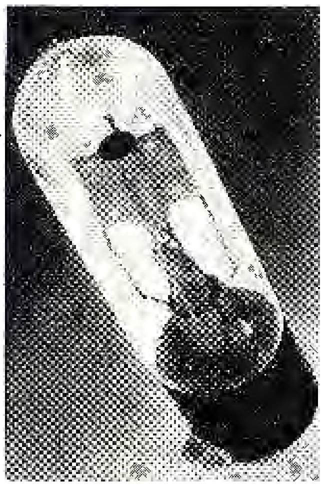


Fig. 162.

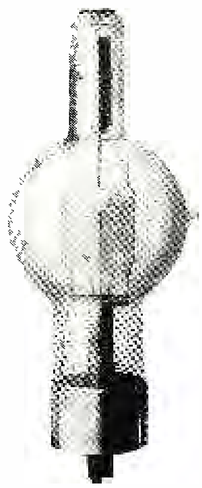


Fig. 163.

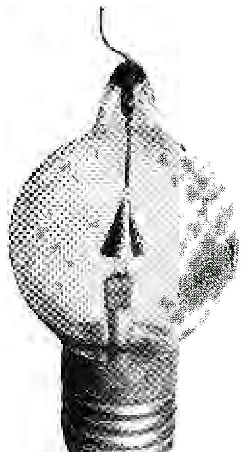


Fig. 164.

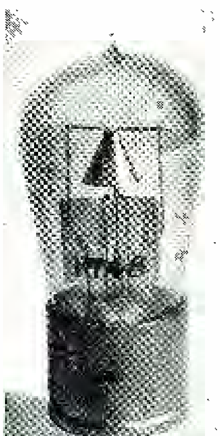


Fig. 165.

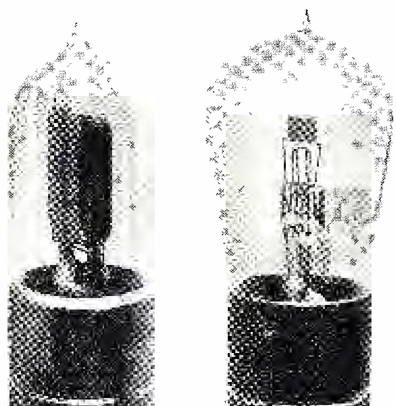


Fig. 166.

it with a positive voltage, higher than the anode voltage, on the grid. That is to say, he found a region of operation where an increase of anode voltage caused a decrease rather than an increase in the anode current. This device was dubbed the "Dynatron" and was described by Dr. Hull in a paper sent to the I.R.E. in January of 1917.[200] This paper is probably the first to describe a four-electrode tube. One of these tubes, called a "Pliodynatron," is described and pictured in Hull's paper. Figs. 156 and 157, reproduced from this paper, show the "Dynatron" and "Pliodynatron" respectively.

Dr. Hull continued his experimental work and some time later published a paper on the "Magnetron," the Graeco-Schenectady name for a vacuum-electric device which was controlled by a magnetic field. Electrically it was a valve operated by a magnetic field. It was really a relay with no moving parts or inertia, the only limitation in speed of operation being the time necessary to build up the magnetic field.

The Magnetron consisted of an evacuated tube of cylindrical shape with an axial filament and a cylindrical anode. The magnetic field was set up by an external coil surrounding the tube in such a way that the lines of force were parallel to the axis of the tube. The characteristics of this device were such that with constant voltage between anode and cathode, the current flow in the filament was not affected by a magnetic field weaker than a certain critical value, but fell to zero if the field was increased beyond this value. This was an extremely sensitive method of control. In fact, with proper adjustment the simple reversal of position of such a tube and coil in the earth's magnetic field is sufficient to completely cut off the space current.

Dr. Hull gave the theory of this tube in a paper published in the Physical Review in 1921,[201] and later in the same year described the tube and its possible applications before the A.I.E.E.[202]

During World War I a very large amount of development work was done in the field of radio transmission. Apparatus developed prior to the war rapidly became obsolete. It was appreciated by those in charge of development of apparatus for the Armed Forces of the United States that vacuum tubes played an important part in the equipment which must be provided. For such uses large quantities of these tubes were required, and a uniform interchangeable product was an absolute necessity. We have seen already that over half a million of these tubes were supplied by the Western Electric Company, some by the de Forest Company, and some by the Moorhead Laboratories. The General Electric Company also was called upon to produce such tubes and because of the research work of Langmuir and his associates, and because of their long experience in incandescent lamp manufacture, they were in an excellent position to do so. In fact, the General Electric Company supplied over 200,000 tubes to the Armed Forces, the great majority of which were manufactured and delivered in the year 1918. These tubes were, for the most part, manufactured at the Nela Park plant of the National Lamp Works of the Company at Cleveland, Ohio.

The bulk of the General Electric tubes supplied to the Armed Forces during World War I can be divided into five types. The first of these is the Kenotron which was designated by the U. S. Signal Corps as the "TB-1," of which approximately 4500 were supplied to the Signal Corps.

This Kenotron was used in large numbers for regulation of the output voltage of the wind-driven generators used with airplane radio equipment. Because of the vibration to which they were subjected while in use, they had to be of extremely rugged construction. Fig. 158 shows three views of one of these tubes which, it will be seen, had a base of the three-contact type, and Fig. 159 shows a generator with the tube in place. The bulb was about 1¾ inches maximum diameter and extended upward from the base about 2½ inches. The base was of the "Shaw Standard" type. The filament was made of tungsten wire, 3.15 mils in diameter. It had a total length of about 2½ inches and was helical in form. The inside diameter of the helix was .145 inch and the pitch of the winding was 14 turns per inch. The anode was a molybdenum cylinder, 5 mils thick, 9/32 inch in diameter, and ⅝ inch long. The anode voltage varied under normal operating conditions but had a maximum value of about 250 volts. The maximum anode current was about 125 milliamperes. The filament operated at 1.45 amperes and the maximum filament voltage was 10.75 volts.

The "Type G" Pliotron was used by both the U. S. Navy and the U. S. Signal Corps as a detector, amplifier, and oscillator for heterodyne reception. It was originally made for the Navy under the designation "CG-886." As so made, it had a Navy standard three-point base of composition material. Somewhat later, at the request of the Signal Corps, this same tube was equipped with a four-point base and designated as the Signal Corps "VT-11." The Navy soon adopted the four-point base tube and assigned to it the designation "CG-890." This tube, which is shown in Fig. 160, had a tungsten filament, 3.25 mils in diameter and was approximately 1 inch long, wound as a helix with inside diameter of .065 inch, and a pitch of 22 turns per inch. The grid also was helical, being of 3.9 mil tungsten wire, .120 inch inside diameter, with a pitch of 20 turns per inch. The length of the grid helix was about ¼ inch. The anode was cup-shaped, of 5 mil nickel, about ¼ inch in diameter and 9/32 inch high. The filament operated normally at 1.1 amperes with a voltage of 3.3 to 3.9

(*Continued on page* 124)

Saga of the Vacuum Tube
(Continued from page 60)

volts. The anode voltage used ranged from 18 to 44 volts and the anode current from a few tenths to 1 milliampere. The filament voltage was chosen so that the filaments could be heated by a two-cell lead storage battery without a rheostat. About 111,000 of these tubes were delivered to the Signal Corps in the early part of 1918.

The construction of this tube was later changed to use a cylindrical anode instead of the cup-shaped one, and this also resulted in an improvement in the operating characteristics. This improved tube was assigned the designation "VT-13" by the Signal Corps, while the Navy continued to use the former designation "CG-890." The VT-13 had a 3.25 mil tungsten filament approximately 1 inch long, mounted in the form of a V. The grid was of 7 mil tungsten wire wound as a helix, about .55 inch long, on a mandrel .155 inch in diameter, with a pitch of 20 turns per inch. The anode was of 5 mil sheet nickel, about ¼ inch in diameter and ½ inch long. About 3500 CG-890 tubes of both types were supplied to the Navy. A total of about 1100 of the VT-13 type was supplied to either the Army or the Navy.

The "Type T" Pliotron was used as a low-power oscillator for small radiotelegraph and telephone sets, chiefly by the Navy on submarine chasers and in aircraft transmitters. The Type T was first designated by the Signal Corps as the "VT-12," and this tube is shown in Fig. 161. This designation was used but a short time when changes were made in the filament design to increase the life of the tube. The revised design was assigned the designation "VT-14" by the Signal Corps and "CG-1162" by the Navy. The bulb was similar to that used for the TB-1. The filament was a helix of 4.05 mil tungsten wire, with a total length of about 2 inches. It was supported by a molybdenum wire extending upward from the press. Concentric with the filament was a helical grid of 7 mil tungsten wire wound with an inside diameter of .130 inch and a pitch of 10 turns per inch. The length of the grid wire was about 3⅜ inches, making a helix about 11/32 inch long. The anode was a cylinder of molybdenum 5 mils thick, with an inside diameter of 9/32 inch and a length of ⅝ inch. The filament normally consumed about 7.5 volts at a current of 1.75 amperes. The normal anode voltage was about 350 volts, and the anode current about 40 milliamperes. The power output when the tube was used as an oscillator was about 5 watts. It is interesting to note that many of these tubes were used by amateurs as Barkhausen oscillators in the earlier days of amateur activity at ultra-high frequencies, after they had appeared on the salvage market.

The "Type U" Pliotron was the first of the General Electric "50-watters," and the prototype of the RCA UV-203. It was designated "CG-1144" by the Navy, and "VT-18" by the Signal Corps, and is shown in Fig. 162. It had a cylindrical bulb about 2 inches in diameter and 6 inches long. The filament consisted of a tungsten wire, 10.1 mils in diameter and having a total length of 3⅞ inches. It was helical in shape, ⅛ inch inside diameter, with a pitch of 20 turns per inch. The filament was placed inside a grid helix and supported by a molybdenum rod passing up the axis of the helix. The grid was of 5 mil molybdenum wire helically wound on a .200 inch mandrel with a pitch of 20 turns per inch and a length of ⅞ inch. The grid was supported by two molybdenum wires electrically welded along the sides of the helix. The anode was of 5 mil sheet molybdenum bent in such a way as to form a cylinder ½ inch in diameter and 1⅛ inches long, having four fins extending ⅜ inch out from it. These fins were intended to increase the radiating surface of the anode, thereby increasing the permissible anode dissipation. This tube operated with a filament current of 6.5 amperes at 10 volts. The normal anode voltage was 750-1000 and anode current 150-200 milliamperes. As a high-frequency oscillator this tube would put out about 50 watts.

This tube was a later development than the other Pliotrons, but was used to a considerable extent by the Navy in seaplane transmitters. About 1200 were supplied to the Navy and 200 to the Army.

The largest of the early Pliotrons was the "Type P," shown in Fig. 163. This was known to the Navy as the "CG-916" and to the Signal Corps as the "VT-10," and was the forerunner of the RCA UV-205. The bulb was about 5 inches in diameter. The filament was W-shaped, of 7 mil tungsten wire, with a total length of 6¼ inches. It operated with 3.6 amperes at a voltage of 13-19 volts. Surrounding the filament was a grid of 3 mil tungsten wirewound on a rectangular form of tungsten or molybdenum. The pitch of the grid was 30 turns per inch, and it was spaced .090 inch from the filament. The anode consisted of two rectangular plates of 25 mil thick tungsten. These were 2 by 2⅜ inches in size, set parallel and ½ inch apart. The anode voltage was normally 1500-2000 volts and the anode current 150-

200 milliamperes. As an oscillator it delivered about 250 watts, and was used by the Navy in seaplanes and flying boats.

There were other tubes made in limited quantities during this period. One of these was the VT-16, which was being worked on at the time of the Armistice in 1918, and which differed only in minor details from the VT-14. Two other interesting tubes made by General Electric are shown in Figs. 164 and 165. That shown in Fig. 164 is a small Kenotron made in the General Electric Research Laboratory in 1916 or 1917. The cone-shaped anode, which is of molybdenum, fits closely around the filament in order to minimize the voltage drop in the tube. This tube was used to furnish high-voltage d.c. for some of the early experiments which led to broadcast transmitters.

The Pliotron shown in Fig. 165 might almost be considered the first "variable mu" tube. The filament and grid were coaxial helices. The anode was conical, hence the ratio of grid-filament distance to plate-filament distance varied at different points along their common axis. This tube was made about 1919, but only on an experimental basis.

To tube collectors who wish to identify the place of manufacture of specimens of these tubes, the following may be of interest. Many of these earlier General Electric tubes have hand written markings on the press, such as "H-6," "G-25," and the like. Those with the letter "H" were made at the Harrison Lamp Works and those marked "G" were made at Nela Park. The numbers following the letter designation are lot numbers.

When the vacuum tubes made for the Armed Forces by the General Electric Company are compared with those made by the Western Electric Company one fact stands out in a startling manner. Tubes made by these two companies for identical purposes were totally different in appearance, materials, and structure, *yet were interchangeable in use*. As an illustration, let the reader compare the VT-11 described above with the VT-1 made by the Western Electric Company and described in a previous article. Both are shown in Fig. 166. No more forcible illustration could be made to bring out the point that each company brought to the field of development of this new device its own peculiar background of experience, gained through trying to solve its own problems in other fields.

The scientists of these two companies, seeking answers to the same questions had, because of experience, taken different paths but arrived at a common designation.

References

192. *Langmuir, Irving—"The Effect of Space Charge and Residual Gases on Thermionic Currents in High Vacuum." Physical Review, 2nd Series, Vol. 2,* 1913, *pp.* 450-486. *See also Science Abstracts, A, No.* 725, 1914.

193. *Child, C. D.—"Discharge from Hot Calcium Oxide." Physical Review, Vol.* 32, *No.* 5, *May*, 1911, *pp.* 492-511.

194. *Lilienfeld, J. E.—"Die Elektrizitätsleitung im extremen Vakuum." Annalen der Physik, 4th Series, Vol. 32, No. 9.* 1910, *pp.* 673-738.

195. *Langmuir, Irving — "Thermionenströme in hohen Vakuum. I. Wirkung der Raumladung." Physikalische Zeitschrift. Vol.* 15, *No.* 7, *April*, 1914, *pp.* 348-353.

196. *Langmuir, Irving — "Thermionenströme in hohen Vakuum. II. Die Elektronenemission seitens des Wolframs und die Wirkung von Gasresten." Phys. Zeit., Vol.* 15, *No.* 10, *May* 15, 1914, *pp.* 516-526.

197. *Dushman, Saul—"A New Device for Rectifying High Tension Alternating Currents—The Kenotron." General Electric Review, Vol.* 18, *No.* 3, *March*, 1915, *pp.* 156-165. See also *Physical Review, Vol. 5, April*, 1915, *p.* 339.

198. *Langmuir, Irving—"The Pure Electron Discharge and Its Applications in Radio Telegraphy and Telephony." Proc. I. R. E., Vol.* 3, 1915, *pp.* 261-293.

199. *Hull, Albert W.—"Negative Resistance." Physical Review, 2nd Series, Vol.* 7, *No.* 1, *January*, 1916, *pp.* 141-143. *Abstract of paper presented at a meeting of American Physical Society in New York, October* 30, 1915.

200. *Hull, Albert W.—"The Dynatron—A Vacuum Tube Possessing Negative Resistance." Proc. I. R. E., Vol.* 6, *No.* 1, *February*, 1918, *pp.* 5-35.

201. *Hull, Albert W.—"The Effect of Uniform Magnetic Field on the Motion of Electrons between Coaxial Cylinders." Physical Review, 2nd Series, Vol.* 18, *No.* 1, *July*, 1921, *pp.* 31-57.

202. *Hull, Albert W.—"The Magnetron." Journal A. I. E. E., Vol.* 40, *September*, 1921, *pp.* 715-723.

CAPTIONS FOR ILLUSTRATIONS

Fig. 155. Pliotron Amplifier, using 30 "Type P" Pliotrons, used to modulate the 200 kw. Alexanderson alternator at New Brunswick in 1919. Photograph courtesy General Electric Company.

Fig. 156. Hull's Dynatron. Reproduced from Proc. I.R.E., 1918.

Fig. 157. Hull's Pliodynatron. Reproduced from Proc. I.R.E., 1918.

Fig. 158. Kenotron TB-1. Photograph courtesy Bell Telephone Laboratories.

Fig. 159. Wind-driven generator, showing TB-1 tube in mounting. Photograph courtesy Bell Telephone Laboratories.

Fig. 160. General Electric "Type G" Pliotron (VT-11, early CG-890). Left—completed tube. Center—filament and grid assembly. Right—complete assembly on stem. Photograph courtesy General Electric Company.

Fig. 161. General Electric "Type T" Pliotron, VT-12.

Fig. 162. General Electric "Type U" Pliotron (CG-1144, VT-18). Photograph courtesy Bell Telephone Laboratories.

Fig. 163. General Electric "Type P" Pliotron (CG-916 or VT-10). Photograph courtesy Bell Telephone Laboratories.

Fig. 164. Small Kenotron with Edison medium screw base and conical anode. Used about 1917.

Fig. 165. Small receiving type Pliotron with helical grid and filament and conical anode. Made about 1919.

Fig. 166. Left—Western Electric VT-1. Right—General Electric VT-11. These tubes were interchangeable in use. Photograph courtesy Bell Telephone Laboratories.

(To be con't in January Issue)

THE SAGA OF THE VACUUM TUBE

By GERALD F. J. TYNE

Research Engineer, N. Y.

Part 15. The early growth of the amateur fraternity, with the development and manufacture for public use of the Audion and crystal detector.

The Audio TRON Bulb

Price $7.50

The cost of a complete Audion" type receiving set has prevented many experimenters from enjoying the advantages of this improved detector.

This Is Your Opportunity

to purchase the latest and most sensitive type bulb only and thereby greatly increase your receiving radius.

Special Offer

All orders mailed prior to November 30, 1915, will be shipped postpaid and insured at the Special Introductory Price,

$6.50 each

including full set of wiring diagrams and directions.

You are protected by an unusually strong guaranty—such is our confidence in the efficiency and reliability of the Audio Tron Detector.

Guaranty:—All Audio Tron bulbs are alike and all extra sensitive. Every bulb is carefully tested and all non-sensitive bulbs discarded. This "one type" Audio Tron is used as a detector, amplifier or ultra-audibility detector. So great is its sensitiveness that a two-step Audio Tron amplifier has a greater efficiency than any other three-step amplifier. Every Audio Tron is guaranteed to have a life of 1,000 hours and to arrive in perfect condition.

DEALERS: A splendid opportunity to increase your sales. Write for trade propositions

Audio TRON Sales Co., 315 Lick Building, SAN FRANCISCO

Fig. 167

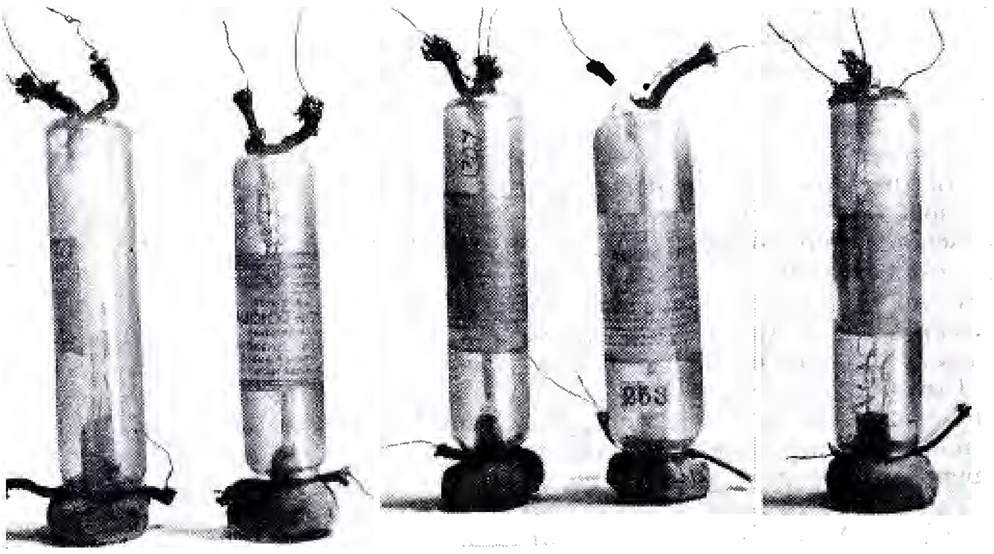


Fig. 168

THE amateur fraternity was small during the first decade of the twentieth century. Equipment was crude; progress was slow and beset with difficulties. Little factory-made equipment was available and reliable construction information was difficult to obtain. This situation was partly alleviated by the International Electrical Congress held at St. Louis in 1904, which became a clearing house for information along wireless lines as well as other branches of the electrical art. At this Congress papers describing recent advances in theory and practice of wireless were presented by John Stone Stone, Lee de Forest, J. A. Fleming, and others.

The de Forest Audion and the crystal detector both appeared in 1906-7. The crystal detector was adopted instantly by the amateur. It was simple, cheap, and sensitive, and in time came into almost universal use. It made the amateur receiver really usable. The Audion was expensive and short-lived, and required expensive auxiliary equipment. A dry-cell anode battery and a filament storage battery were needed. Small dry cells were short-lived and the problem of charging and otherwise maintaining a storage battery was not to be taken lightly. The Audions varied greatly in their characteristics, not only initially but with use. Hence they were not widely used.

In the early part of the second decade a number of factors tended to promote the use of the Audion. The ranks of the amateur fraternity were swelled by many hundreds of 'teen age boys (and older ones as well) whose interest in this fascinating avocation had been aroused by newspaper tales about rescues at sea. Stories of the rescue of survivors of the ill-fated *S.S. Republic* and *S.S. Titanic,* and the part played by wireless in the rescue work, all aroused widespread interest in this newest branch of the communications art.

Once the desire was aroused, the ingenuity of Young America was called upon to provide the necessary equipment for the home station. The family rolling-pin disappeared from the kitchen only to reappear later, disguised by the application of a layer of wire, as a tuning coil. Bits of wire, scraps of metal, odd chunks of wood, all provided grist for the mill which turned out the wireless set of the eager constructor. Practically everything except the headset could be made in the cellar workshop, and it usually was. It was the era of "haywire" and home-brewed apparatus, even for elaborate stations.

By 1915 the Audion was much better known, particularly on the West Coast. The opening of the transcontinental telephone line and the publicity attendant thereon, the Panama-Pacific Exposition with its displays of wireless equipment—both tended to promote knowledge of this device. It became the ambition of almost every embryonic Marconi to possess an Audion.

The problems of obtaining and main-

Fig. 169

Fig. 170

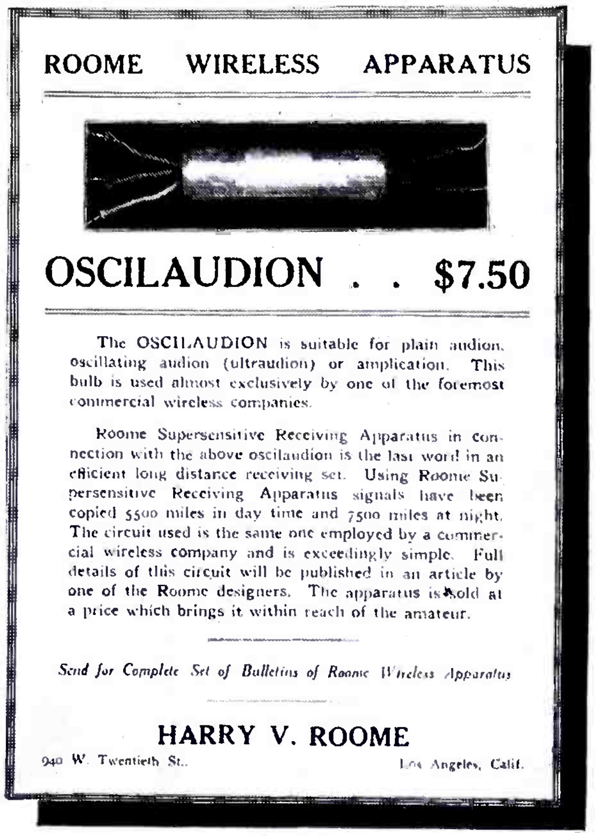


Fig. 171

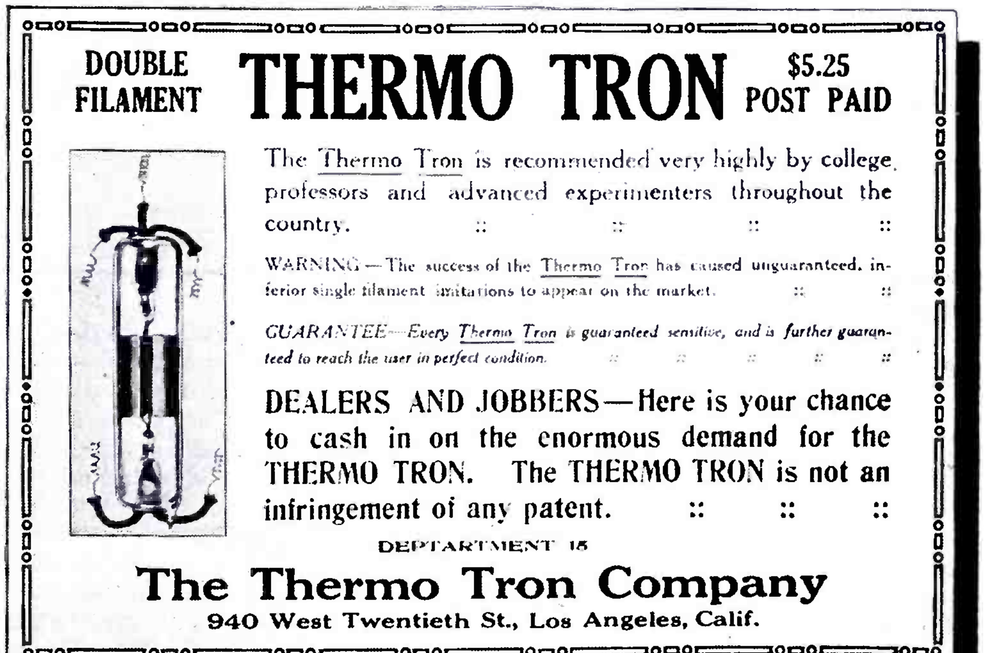


Fig. 172

taining the requisite storage battery in the meantime had been lightened by the development and use of electric starting and lighting systems for automobiles. Better and cheaper batteries and charging equipment were available. In most cases, consequently, the chief problem confronting the amateur was that of obtaining the Audion itself, and here the ambition still outran the exchequer. The policy of the only legitimate source of supply, the de Forest Company, was to sell not "Audions" but "Audion Detectors" at a minimum of $18 each. The difference in name was not great, but the difference in effect on the amateur's pocketbook was fatal. True, Audions could be purchased for replacement purposes in Audion Detectors, but the initial outlay to obtain the latter would have been a crushing blow to solvency. A few fortunate amateurs in the vicinity of New York City were able to obtain Audions on an over-the-counter basis in New York, but such sales were in the minority.

This policy on the part of the de Forest Company had the effect that does sumptuary legislation. Other sources provided a supply of the article in demand, and the making of vacuum-tube detectors by "independent" manufacturers came into being. Some of these made an attempt to get around the de Forest "grid patent" by using a control electrode on the outside of the tube; others frankly infringed.

As readily may be appreciated, authoritative information on these early independent tubes is difficult to obtain. Manufacture and sale in many cases was carried on sub rosa, and practically the only method of tracing their evolution is through the advertisements which offered them for sale. As will be seen, these advertisements almost always made extravagant claims, probably because the manufacturer felt sure that there would be

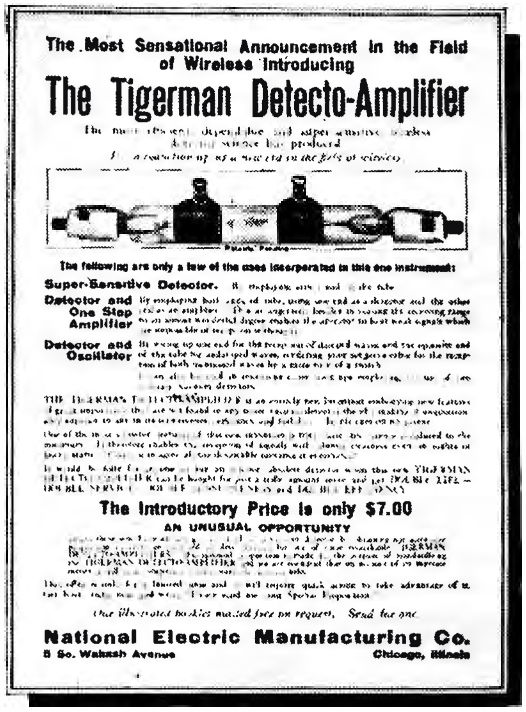


Fig. 173

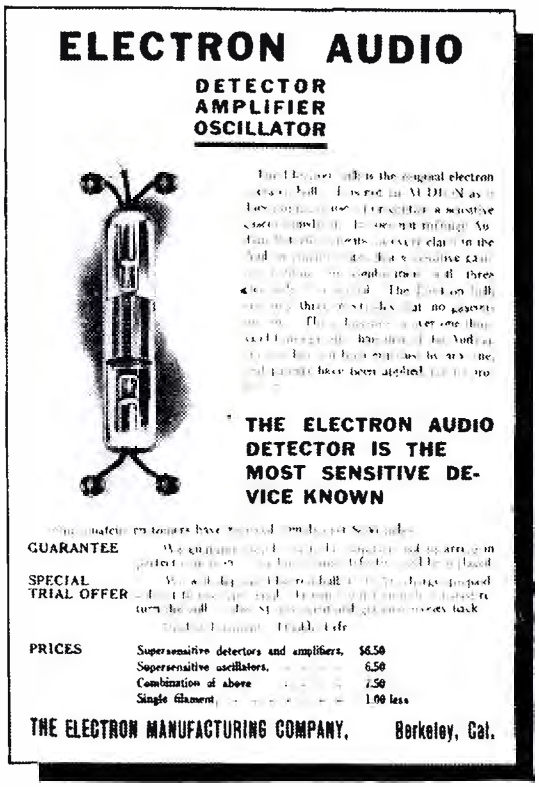


Fig. 174

Fig. 175

little comeback on the part of the purchaser. Hence, little reliable information on the characteristics of these tubes is available.

The first of these independent tubes to appear was also the last to disappear, and the most widely sold and used of all the early independent tubes. It was known as the "Audio Tron." This tube was the brain-child of Elmer T. Cunningham of Los Angeles. It was made at Oakland, California, and was first sold in August of 1915. It was first advertised for sale in November, 1915,[203] the advertisement being that reproduced as Fig. 167.

The original Audio Tron was a double-ended, cylindrical, unbased tube about ¾ inch in diameter and 4 to 5 inches long. It comprised a double tungsten filament, a coarse spiral grid of copper wire, and a cylindrical aluminum anode. The anode fitted rather closely the inside diameter of the glass, as will be seen from Fig. 168, which shows a group of these tubes. The Audio Tron sprang into instant popularity, particularly among those who could not afford the luxury of "all de Forest" equipment.

Steps were soon taken by de Forest to prosecute the "Audio Tron Sales Company" for infringement. In February, 1916 the de Forest Company filed suit against the Audio Tron Sales Company and others. The Audio Tron Sales Company filed bond on August 14, 1916 and continued the manufacture and sales of its product.[204] The suit was later settled out of court.

The de Forest Company, to meet this competition, brought out, in April, 1916, the "Type T" Audion,[205] similar in appearance to the Audio Tron but with a single filament, which could be purchased without the necessity of buying a complete expensive detector unit. The "Type T" was announced for sale at $5.50 and Cunningham promptly cut the price of the Audio Tron to $5.25 to meet this challenge.[206] See Fig. 169.

The advertisement of the Audio Tron in at least one publication was discontinued after the filing of the infringement suit,[207] but for a short time another tube, of the two element type, called the "Amplitron" was advertised in its place. See Fig. 170. This continued for only two or three months and subsequent advertisements of the Audio Tron Sales Company confined themselves to the suggestion that the readers write for information on their apparatus.

The war proclamation which ordered the dismantling and sealing of amateur apparatus was issued by President Wilson on April 6, 1917, hence the market for this apparatus disappeared.

After the war, however, we find advertisements for the Audio Tron reappearing, first in June, 1919, in one magazine,[208] and later in others.[209] These advertisements described the Audio Tron as having a thoriated tungsten filament, with a life of 2000 hours, and further stated that it was licensed under the de Forest patents for use as an amplifier in radio communication. It was described as "The Original Vacuum-Tube Amplifier" and priced at $6. Almost simultaneously there appeared for sale the "Marconi VT," made by Moorehead, and warning that the Audio Tron was not licensed under the Fleming patents.[210] These advertisements continued to appear for some time.

Meantime the Radio Corporation of America instituted suit against Cunningham in the U. S. District Court of the Northern District of California for infringement of the Fleming patents. Apparently Cunningham was capable of presenting a rather strong defense in this suit because it was settled by agreement out of court. This agreement,[211] dated June 15, 1920, gave to Cunningham a personal, non-transferable license under the Fleming and de Forest patents for a period of ninety days, to manufacture and sell tubes of not more than 5-watts output, and not more than 5000 tubes in all. These tubes were to be marked "For amateur and experimental use only" and to be made by Cunningham doing business under the name and style of "Audiotron Manufacturing Company." The tube at the extreme right in Fig. 168 is one so marked, the markings being etched on the glass.

(*Continued on page* 92)

the more important "image" and other forms of interferences increase when such low values of i.f. are employed, they are no longer widely employed in broadcast receivers and, so harmonic-of-i.f. interference is now possible in some localities.

Realignment of the i.f. stages of any existing receiver thus affected, is the usual field cure for trouble of this sort. It should be carefully noted and checked as to whether the signal operating at the second harmonic of the i.f. is being picked up on the under-chassis wiring of the receiver, in addition to the antenna. In this case the whistle produced will be aggravated. In extreme cases, it is possible to eliminate the whistle by providing a wave trap tuned to the second harmonic of the signal and placed in the circuit feeding the mixer stage.

(To be Continued)

Saga of the Vacuum Tube

(Continued from page 56)

A second agreement,[212] under the same date, between the Radio Corporation of America and Cunningham provided that when the ninety day license had expired the Audiotron Company would discontinue the manufacture and sale of vacuum tubes, and would sell Radio Corporation tubes, until the expiration of the de Forest patent No. 879,532 on February 18, 1925. These tubes were to be marked as Cunningham desired, and no Radio Corporation markings were to appear. The agreement gave to Cunningham not less than 25,000 tubes per month and not more than 280,000 tubes total during the period which the agreement covered. These tubes were to be sold to Cunningham at a discount of 20% below the lowest net price quoted to anyone else. Deliveries were to begin September 15, 1920, or as soon thereafter as possible.

As a result of the first agreement noted above, subsequent advertisements[213] of the Audiotron Manufacturing Company, successor to the Audio Tron Sales Company, stated that the Audiotron was now free from all restrictions. The first agreement was modified, on September 13, 1920, and the license period extended to October 15, 1920. The advertisements continued up to November, 1920.

With the December, 1920 advertisement,[214] however, the effects of the second agreement begin to appear. This advertisement announced the "Audiotron Detector Type C-300" with four-point base at $5 and the "Type C-301 High Vacuum Navy Type Amplifier" at $6.50. The tubes were "Guaranteed by E. T. Cunningham, trading as the Audiotron Manufacturing Company."

The next advertisement, in January, 1921,[215] refers to "Cunningham Audiotron Tubes" in the heading, but "Cunningham Tubes" in the body of the advertisement.

The following month reference is made[216] to the "Cunningham Detector Tube Type C-300" and the word Audiotron has completely disappeared except for the retention of the firm name of "Audiotron Manufacturing Company."

The next advertisement[217] offers for sale the "Cunningham Power Tubes C-302, C-303, and C-304" and admits that these tubes are the product of General Electric Company research.

From then on the prominence given to the name of the company grows less, until in December, 1922 the word "Audiotron" completely disappears, and the concern is renamed "E. T. Cunningham, Inc."[218]

The success of the Audio Tron appears to have served as encouragement to other manufacturers. Shortly after its rise there appeared another tube, enough like the Audio Tron to have been cast in the same mold. This was the Roome "Oscilaudion," first advertised[219] in January, 1916 (see Fig. 171) by Harry V. Roome of Los Angeles. Roome had been advertising wireless apparatus for some time, but this was the first mention of vacuum tubes. Two months later, in March, 1916, the advertisement reappeared,[220] this time for the "Oscilaudion Bulb and Cabinet." No further advertisements appeared until July, 1916, when the "Thermo Tron" was advertised by "The Thermo Tron Company" from the same address as Harry V. Roome. This advertisement,[221] reproduced in Fig. 172, is very ambiguously worded, making no mention of any restrictions as to use. Since it appeared in a wireless magazine, however, the reader might be pardoned for assuming that it was intended for wireless use. However, when the purchaser received the device, orderd by mail from the advertisement, he received with it a descriptive leaflet which contained no ambiguous statements whatever, but described it as an "experimental hot-cathode apparatus designed for the study of the Edison effect, thermionic currents, pure electron discharge, passage of electricity through electrons (sic), and other scientific phenomena." It also carried the following warning:

"It is distinctly understood by the purchaser that the Thermo Tron is sold for the purpose of scientific study to be used with the circuits shown in this bulletin. If the Thermo Tron is used for commercial work in wireless telegraphy as a detector, amplifier, or oscillator, or if the Thermo Tron is used for commercial work in an Armstrong circuit, or if the Thermo Tron is used in any way as an infringement of any patent, the Thermo Tron Company assumes no liability whatever."

It might be suspected that the change from the "Oscilaudion," which was frankly sold as a wireless detector, to the "Thermo Tron," a pure scientific device, was perhaps motivated by the legal action initiated by de Forest against the Audio Tron at about the time this advertisement was being prepared. The success of the Audio Tron Sales Company in staving

VOICE-COIL IMPEDANCE MATCHING TABLE

As many radio servicemen have some output transformers around their shops and do not know the type of tubes and voice coils with which they can be used successfully, Mr. Ralph W. Wilson of Falmouth, Kentucky, has sent us the following chart, which he has found very useful.

Mr. Wilson said that this chart is simple to use, all that is required being a low-range a.c. voltmeter and a 115-volt a.c. source. Connect the primary or plate winding to the 115-volt a.c. source and the voltmeter to the secondary or voice-coil winding. The reading of the meter may be found on the chart under several voice-coil impedances or very near them. For instance, a reading of 2.9 volts could be used from 3000 ohms to 2 ohms or from 6000 ohms to 4 ohms; also from 10,000 ohms to 6 ohms or 12,000 ohms to 8 ohms. This, of course, gives the proper turns ratio. Of course the transformer should be properly designed and large enough so that it will not reach magnetic saturation.

The chart is figured for 2, 4, 6, and 8-ohm voice coils. For other impedance combinations the following equation can be substituted:

$$E = \frac{\sqrt{Z_s}}{\sqrt{Z_p}} \cdot E_L$$

in which E = Meter reading on secondary; Zs = Impedance of voice-coil winding; Zp = Impedance of plate winding; and E_L = line voltage applied to primary.

Primary Impedance	Voice-Coil Impedances 2 ohm	4 ohm	6 ohm	8 ohm
25,000	1.02 v.	1.45 v.	1.77 v.	2.04 v.
15,000	1.33 v.	1.87 v.	2.30 v.	2.66 v.
12,000	1.48 v.	2.09 v.	2.56 v.	2.96 v.
10,000	1.63 v.	2.30 v.	2.82 v.	3.26 v.
8,000	1.82 v.	2.57 v.	3.15 v.	3.64 v.
7,000	1.94 v.	2.74 v.	3.36 v.	3.88 v.
6,000	2.10 v.	2.97 v.	3.64 v.	4.20 v.
5,000	2.30 v.	3.25 v.	3.99 v.	4.60 v.
4,000	2.57 v.	3.63 v.	4.45 v.	5.14 v.
3,000	2.97 v.	4.20 v.	5.14 v.	5.93 v.
2,000	3.64 v.	5.15 v.	6.30 v.	7.28 v.
1,000	5.14 v.	7.25 v.	8.89 v.	10.28 v.
500	7.27 v.	10.28 v.	12.60 v.	14.54 v.

off an injunction and continuing business as usual is perhaps reflected by the next advertisement,[222] appearing the next month, in which the name of Roome again appears, and the "Super-Sensitive Oscilaudion" is boldly advertised for use as detector, amplifier, or oscillator.

With the Oscilaudion the purchaser received a leaflet, of the same size and typography as that supplied with the Thermo Tron, and using the same cut for an illustration, but setting forth the virtues of the Oscilaudion as a wireless device.

This was the last time this tube was advertised, as far as the author has been able to determine, and it is probable that the source of supply disappeared. The author understands that Harry V. Roome was at that time a high school boy in Los Angeles, and that he obtained the tubes he sold from a San Francisco manufacturer, who would supply him with only a limited number, and who eventually refused to sell to him at all.

There were a few other prewar independent tubes on which little information is available. One of these was the "Tigerman Detecto-Amplifier," advertised [223] in 1917 by the National Electrical Manufacturing Company of Chicago. Fig. 173 is a reproduction of the advertisement which announced this tube. It was a double-ended tube with two sets of filament-anode electrodes, one at each end. The control electrodes were applied on the outside of the glass and were simple metallic bands clamped around the tube, which was about 5 inches long and had a candelabra base on each end. Apparently it was not sold to any great extent, since an advertisement in April, 1917 [224] offered them for sale "while they last" at $5 each.

The "Electron Audio," another tube similar in construction to the Audio Tron, was made by the Electron Manufacturing Company, and was first advertised in July, 1916.[225] The initial advertisement claimed that it was "formerly the Audio Tron," and the next advertisement,[226] reproduced in Fig. 174, showed a tube of the same construction as the Audio Tron. The "Electron Audio," however, could be obtained with either a single or a double filament. It quickly lapsed into obscurity, and probably had a limited sale, although it was regularly supplied by at least one manufacturer as a part of a radio receiver. In this receiver the tube was inserted into an "autotransformer," which was claimed to be of "remarkable importance to our undamped wave apparatus since its magnetic field oscillations are absolutely in synchronism and consequently stimulate the periodical electron discharge from the filament and the ionization of the gas within the bulb by the heat of the filament"! [227]

Two others of the same type were advertised by the Radio Apparatus Company of Pottstown, Pennsylvania. One was the "Type 36 Electron Detector" [228] and the other was the "Liberty Valve." [229] The Liberty Valve is shown in Fig. 175. Since this company also advertised the Audio Tron at the same time,[230] it may well be that the Liberty Valve was the Audio Tron with a different label.

Still another tube called the "Oscillotron" was advertised [231] briefly just after amateur activity was resumed following the end of World War I. This was advertised by the G & M Specialty Company of Cleveland, Ohio, but no information is available on it.

There were also two other tubes on which the author has been unable to obtain information. One of these was the "Bartley" tube, which was sold about 1919,[232] and the other was the "Corcoran" tube which is alleged to have been made at Lynn, Massachusetts, about 1914 or 1915.

The only other early independent tubes of which the author has knowledge were those marketed by O. B. Moorhead, which will be covered in a subsequent article.

CAPTIONS FOR ILLUSTRATIONS

Fig. 167. First announcement of the Audio Tron. Reproduced from Popular Science Monthly and The World's Advance.

Fig. 168. Audiotrons. The second from the left has label printed in black ink. Third and fourth from left have labels printed in red ink. Tube at right has markings etched on glass.

Fig. 169. Advertisement giving price

reduction on Audio Tron to meet de Forest competition. Reproduced from Electrical Experimenter.

Fig. 170. Advertisement for Amplitron. Reproduced from Electrical Experimenter.

Fig. 171. Announcement of Roome "Oscilaudion." Reproduced from Wireless Age.

Fig. 172. Advertisement for Thermo Tron. Reproduced from Electrical Experimenter.

Fig. 173. Announcement of Tigermann Detecto-Amplifier. Reproduced from Electrical Experimenter.

Fig. 174. Announcement of "Electron Audio." Reproduced from Wireless Age.

Fig. 175. Liberty Valve. Photograph courtesy Bell Telephone Laboratories.

References

203. *See advertisement in Popular Science Monthly and the World's Advance, Vol. 87, No. 5, November,* 1915, *p.* 120.

204. *"The Vacuum Detector Patent Situation," Pacific Radio News, Vol.* 1, *No.* 5, *May,* 1917, *pp.* 203-206.

205. *See advertisement in Electrical Experimenter, Vol.* 3, *No.* 12, *April,* 1916, *p.* 726.

206. *See advertisement in Wireless Age, Vol.* 3, *No.* 10, *July,* 1916, *page I; and Electrical Experimenter, Vol.* 4, *No.* 4, *August,* 1916, *p.* 282.

207. *Gernsback, Hugo—"De Forest vs. Electrical Experimenter," Electrical Experimenter, Vol.* 4. *No.* 11, *March,* 1917, *pp.* 808-809.

208. *See advertisement in QST, Vol.* 2, *No.* 11, *June,* 1919, *p.* 29.

209. *See advertisement in Radio Amateur News, Vol.* 1, *No.* 8, *February,* 1920, *p.* 441; *also QST, Vol.* 3, *No.* 9, *April,* 1920, *p.* 81.

210. *See advertisement in Radio Amateur News, Vol.* 1. *No.* 8, *February,* 1920, *p.* 396; *also Pacific Radio News, Vol.* 1, *No.* 7, *February,* 1920, *inside back cover; also QST, Vol.* 3, *No.* 8, *March,* 1920, *p.* 78.

211. *See Exhibit Z-1, Report of the Federal Trade Commission on the Radio Industry—Government Printing Office*—1924.

212. *See Exhibit Z-2, Report of the Federal Trade Commission on the Radio Industry—Government Printing Office*—1924.

213. See RADIO NEWS, *Vol.* 2, *No.* 1, *July,* 1920, *inside front cover; also QST, Vol.* 4, *No.* 2, *September,* 1920, *p.* 61.

214. *See* RADIO NEWS, *Vol.* 2, *No.* 6. *December,* 1920, inside front cover; also QST, *Vol.* 4, *No.* 5, *December,* 1920, *p.* 101.

215. *See* RADIO NEWS, *Vol.* 2, *No.* 7, *January,* 1921, *inside front cover; also QST, Vol.* 4, *No.* 6, *January,* 1921, *p.* 93.

216. *See* RADIO NEWS, *Vol.* 2, *No.* 8. *February,* 1921, *inside front cover.*

217. *See* RADIO NEWS, *Vol.* 2, *No.* 9, *March,* 1921, *inside front cover.*

218. *See* RADIO NEWS, *Vol.* 4, *No.* 6, *December,* 1922, *inside front cover.*

219. *See Wireless Age, Vol.* 3, *No.* 4. *January,* 1916, *page I.*

220. *See Wireless Age, Vol.* 3, *No.* 6, *March,* 1916, *page I.*

221. *See Wireless Age, Vol.* 3, *No.* 10, *July,* 1916, *page III; also QST, Vol.* 1, *No.* 8, *July,* 1916, *p.* 188; *also Electrical Experimenter, Vol.* 4, *No.* 4, *July,* 1916, *p.* 193.

222. *See QST, Vol.* 1, *No.* 9, *August,* 1916, *advertising section; also Electrical Experimenter, Vol.* 4, *No.* 4, *August,* 1916, *p.* 283.

223. *See Electrical Experimenter, Vol.* 4, *No.* 8, *December.* 1916, *p.* 602.

224. *See Pacific Radio News, Vol.* 1, *No.* 4, *April,* 1917, *p.* 182.

225. *See Wireless Age, Vol.* 3, *No.* 9, *June,* 1916, *page* III.

226. *See Wireless Age, Vol.* 3, *No.* 10, *July,* 1916, *page* II.

227. *"Mignon Undamped Wave System," Pacific Radio News, Vol.* 1, *No.* 2, *February,* 1917, *p.* 79.

228. *See QST, Vol.* 2, *No.* 5, *April,* 1917, p. 83.

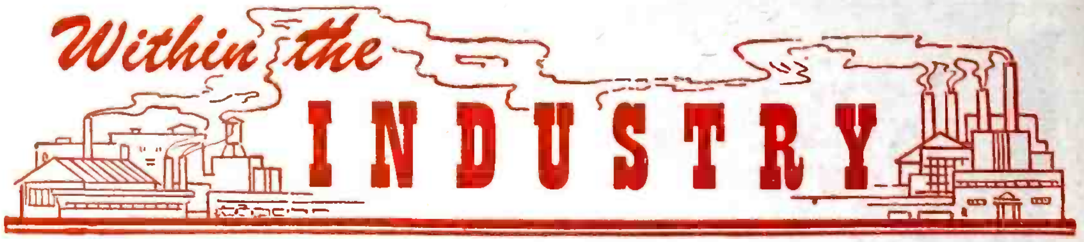
229. *See QST, Vol.* 3, *No.* 6, *January,* 1920, *p.* 48.

230. *See Wireless Age, Vol.* 6, *No.* 10, *July,* 1919, *p.* 45.

231. *See QST, Vol.* 3, *No.* 5, *December,* 1919, *p.* 64.

232. *"Fleming's Valve and Up," Radio Craft, Vol.* 9, *No.* 9, *March,* 1938, *p.* 582.

(Continued in March Issue)



ADMIRAL CORPORATION of Chicago has announced several organizational appointments through its president, Ross D. Siragusa.

Wallace C. Johnson has been named Midwest Regional Manager for both radios and appliances. His headquarters will be at 444 Lake Shore Drive, Chicago.

United Distributors, Inc., will serve as distributors of Admiral radios, refrigerators, electric ranges and home freezers in the Boston area and part of Vermont, while Appliance Merchandisers Company of Peoria will handle the company products for central Illinois.

The Bimel Company of Cincinnati will handle the appliances in the Cincinnati area and Griffith Distributing Corporation will take care of the company's business in Indianapolis.

* * *

Z. V. THOMPSON, who has been serving as a Major in the U. S. Army Air Corps, is returning to civilian status as a sales representative for Tung-Sol's Indiana territory. Mr. Thompson, who held a reserve commission as Second Lieutenant upon his graduation from Clemson College in 1928, returned to active duty with the rank of Captain in August, 1941. His promotion to Major was effected February, 1942.

* * *

RAYTHEON MFG. COMPANY has launched the coast-to-coast sponsorship of the "Meet Your Navy" program which is heard on Saturday evenings, features Navy personnel broadcasting from the Great Lakes Naval Training Station.

Rear Admiral Arthur S. Carpender, Commandant of the Ninth Naval District, and Mr. L. K. Marshall, president of Raytheon, were special guests at the first performance under Raytheon's sponsorship. Lt. Clint Stanley is the producer of the Navy show.

* * *

FARNSWORTH TELEVISION AND RADIO CORPORATION has outlined postwar plans for its dealers through General Sales Manager, Mr. E. H. McCarthy. The distribution structure will be a strong distributor-dealer operation, with the distributors to be selected after exhaustive survey of potential sales outlets in each area.

Fifty distribution agencies already have been appointed under the new plan and new appointments will be announced from time to time.

* * *

SAM PONCHER of the Newark Electric Company of Chicago was elected president of the Chicago chapter of the National Electronic Distributors Association at a meeting of that organization held in Chicago. Various trade problems were discussed and an election of officers took place, resulting in the election of Mr. Poncher, and Ralph E. Walker of Walker-Jimieson, Inc., to the post of Secretary-Treasurer.

* * *

THE HALLICRAFTERS COMPANY, makers of the SCR-299 mobile radio communications unit, dedicated a radio ham "shack" to the achievements of the nation's amateur radio operators. The "shack" is located at 643 N. Michigan Avenue, Chicago, and is stocked with a display of the company's products. There are an estimated 25,000 "hams" in the military services at the present time and the dedicatory program is centered about their work.

A service flag, commemorating the "ham's" military service was presented by Chet Horton, member of the Hamfesters Radio Club of the Chicago area, to the A.R.R.L. Carol K. Witte, acting communications manager of the A.R.R.L., accepted the service flag for the League. More than 50 members of the Hamfesters Club were present at the ceremony.

* * *

H. V. MYSING is the new manager of sales and engineering service for RCA's Auto Radio Department, according to the announcement made recently by Thomas F. Joyce, General Manager of RCA's Victor Radio, Phonograph and Television Department. Since the outbreak of the war Mr. Mysing has been serving with a group of RCA engineers working with the U. S. Army Signal Corps on an engineering development contract in connection with combat radio communications problems. His headquarters will be in Detroit.

* * *

STEWART-WARNER CORPORATION has appointed George Johnson to handle sales promotional work pertaining to civilian postwar radios. His duties will also include radio distributor relations.

Mr. Johnson comes to the company

THE SAGA OF THE VACUUM TUBE

By GERALD F. J. TYNE
Research Engineer, N. Y.

Part 16. The early manufacture and sale of the "Electron Relay" and other amateur tubes by Otis B. Moorhead.

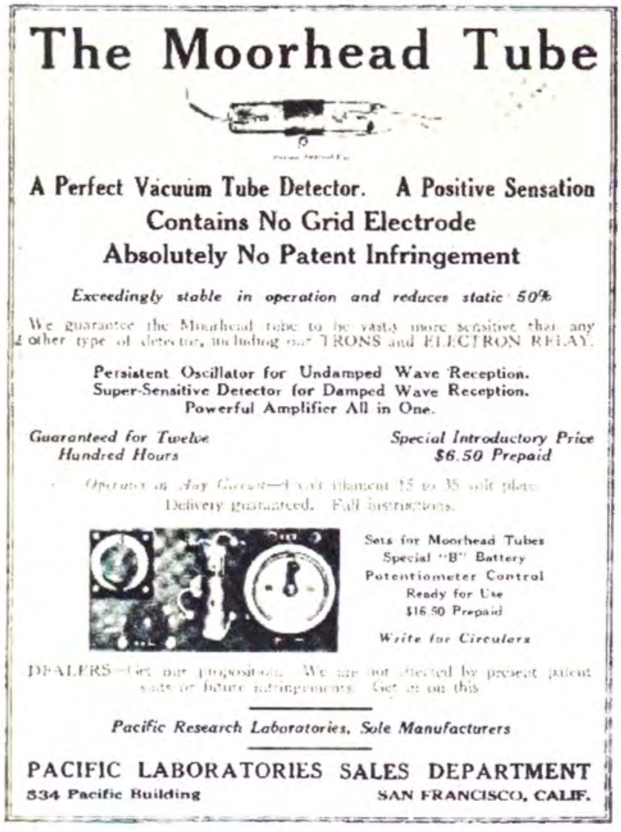


Fig. 176.

Fig. 177.

IN THE preceding installment of this series there was discussed a number of the so-called "independent" tubes, made prior to the advent of broadcasting and intended primarily for the amateur trade. One of these was the "Audio Tron," made by Elmer T. Cunningham, and which was later manufactured under license. The only other early independent manufacturer to follow a similar procedure, so far as the author has been able to ascertain, was Otis B. Moorhead, of San Francisco.

The first of the Moorhead tubes was known as the "Electron Relay," and this same name was applied to many of the later tubes which he made. It was the work of Moorhead and Ralph Hyde, and it first appeared in April, 1915. Moorhead, who had for some time been an ardent radio fan, had worked in the de Forest booth at the Panama-Pacific Exposition early in the year, selling Audions. They sold so well that he was impressed with the possibilities of reaping a financial harvest by their manufacture. Hyde, who was an expert glass blower, had formerly been Superintendent of the Oakland Mazda Lamp Works of the General Electric Company, and had

Fig. 178.

Fig. 179.

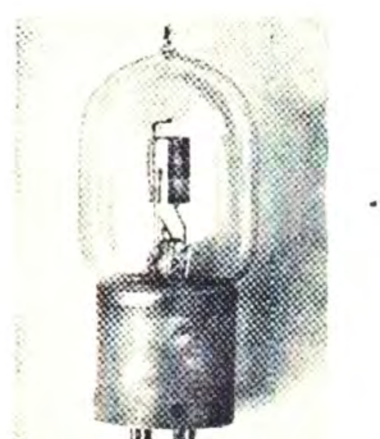


Fig. 180.

been repairing Audions as a side-line.[244] He left the employ of the General Electric Company on March 1, 1913, and later worked with E. T. Cunningham in the manufacture of the "Audio Tron." Hyde joined forces with Moorhead in 1915 to produce the Electron Relay, but this combination later split up and Hyde went back to making bulbs for Cunningham.

The first advertisement announcing the "Electron Relay" for sale appeared in July, 1916,[245] and announced that "the former manufacturers of the Audio Tron are now making a newer and better tube." The Electron Relay was advertised for use as an amplifier, detector, or oscillator, and could be obtained with either single or double filament. The "guaranteed" life was 400 hours per filament, and the price of the double filament type was quoted as $5.50. The advertisement was signed by "Pacific Research Laboratories O. B. Moorhead, Manager."

The Electron Relay so advertised was similar in appearance to the Audio Tron, having a straight axial filament of tungsten, a coarse spiral grid of heavy (about No. 18 B. & S.) copper wire, and an anode of aluminum sheet bent into the form of an almost-closed cylinder. It was claimed that these materials were chosen because of their relative positions in the electrochemical series "and also because we could procure these metals with ease on the Pacific Coast."[246] It can scarcely be doubted that the latter of the two reasons was the controlling one. It was claimed that the Electron Relay was a "high-vacuum" device, being exhausted to a vacuum better than .04 mm. mercury.

The avowed purpose of the production of this new device was to "bring the sacred Audion to terms." What it first succeeded in doing was having the makers prosecuted for infringement of the Audion patents. With the Audio Tron, however, it furnished a source of tubes for the lean-pursed amateur and resulted, as has been previously told, in de Forest's putting on the market a similar tube, sold without the necessity of purchasing the $18 "little red box."

Although the author has been unable to find any advertisement prior to July, 1916 offering the Electron Relay for sale, it apparently had been sold to a considerable extent in 1915, since on February 15, 1916 the de Forest Radio Telephone and Telegraph Company filed complaint against Moorhead and Hyde, alleging infringement of seven of the de Forest patents. Several Pacific Coast radio "experts" submitted affidavits in reply to the complaint and in support of Moorhead and Hyde. This action was brought at the same time as that against Cunningham.

The action was begun by requesting an injunction against Moorhead, Cunningham, Hyde, and others. The Justice before whom the preliminary action was brought ruled[247] that since the validity of the de Forest patents had not yet been passed on, an injunction would not be granted, but that an indemnity bond would be required from the defendants until the question of validity had been settled. Apparently Moorhead posted the required bond since in July of 1916, the advantage of operating sub rosa having been eliminated by the court proceeding, the above-mentioned advertisement appeared.

The next advertisement, which appeared the following month (August, 1916)[248] announced that there had been a "25% improvement" in the Electron Relay during the preceding month, claimed that the new tube was the "Most Sensitive Wave Responsive Device Known," and was signed by the "Pacific Laboratories Sales Department," Moorhead's name not being mentioned.

Apparently Moorhead did not feel too secure in the matter of patent infringement since the next advertisement[249] was for a totally different tube, the "Moorhead Tube," with a single filament, but guaranteed for 1200 hours operation, and claiming a much superior performance. This advertisement is reproduced in Fig. 176. A photograph of this tube, given in Fig. 177, shows the radical change in construction. The anode had been changed from aluminum cylinder to aluminum disc, the filament from straight to hairpin-shaped, the grid removed from the tube and replaced by an external control electrode in the form of a perforated band of brass, clamped around the outside of the tube opposite the filament-anode space. The filament of this tube was intended for operation at 4 volts, and the anode voltage was stated to be 10 to 35 volts.

The manufacturer of the tube was indicated by the marking "Moorhead —Patent Pending" in raised letters on the circular disc anode. It is worthy of note that this was the first of the independent tubes to bear the name of the maker indelibly impressed thereon, and to carry information as to operating conditions. This tube with the external control electrode continued to be advertised for the remainder of that year.

Apparently this new construction was not as great an advance over the former one as was claimed, since with the advertisements in January, 1917[250] the external control electrode tube was given less attention and the Electron Relay came again to the fore. The Electron Relay which was advertised had again undergone improvement "within the last thirty days" and the "improved tube" could be identified by the letters "ER" stamped on the cylindrical anode. This tube is shown in Fig. 178. It may well be that the decision handed down in an Eastern court, holding the de Forest Audion patent to be subservient to the Fleming diode patent, had something to do with the reappearance of the Electron Relay.

In February, 1917 the "Pacific Research Laboratories" was taken over by "Moorhead Laboratories, Inc."[251] but the advertisements for the Moorhead tubes continued to be signed by the "Pacific Laboratories Sales Department."

In this month Moorhead sent to the

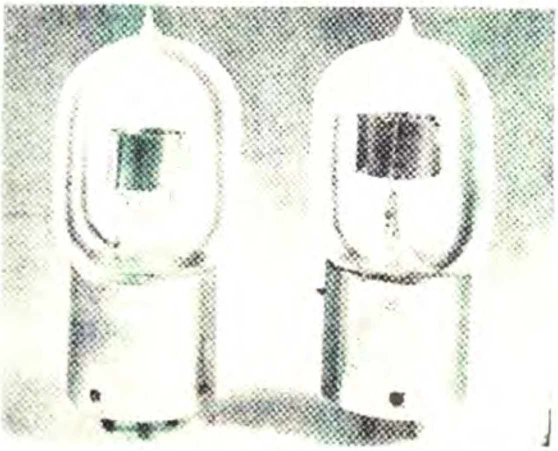


Fig. 181.

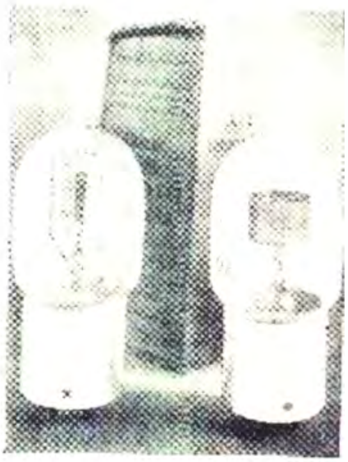


Fig. 182.

Fig. 183.

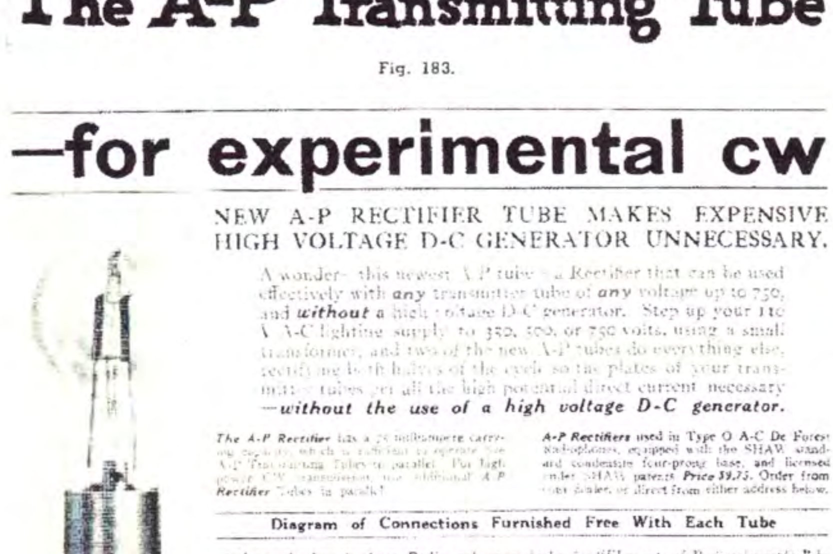


Fig. 184.

Institute of Radio Engineers a paper entitled "The Manufacture of Vacuum Detectors." [242] In this paper he described the processes used in the manufacture of the Electron Relay. In the light of present-day knowledge of the factors affecting the electrical characteristics of vacuum tubes, one statement contained in that paper is of interest. On page 429 Moorhead says:

"The spacing between the elements is not very critical in this type of device but it is best to wind the grid to a large enough diameter so that it will strike the plate rather than the filament when the tube is jarred."

With the Presidential Proclamation of April 6, 1917 all amateur activity ceased and the amateur market for this apparatus practically disappeared.

During World War I Moorhead made tubes for the U. S. Navy and for the British Government.[243] Those made for Great Britain were high-vacuum tubes patterned after the British "R" type valve. These tubes could be operated at 6 volts and .84 ampere filament. At 400 volts on the anode the tube was required to dissipate 15 watts for three minutes. When operated at 4-volts filament it had a life of 800 hours. The earlier models, one of which is shown in Fig. 179, had the axis of the element assembly vertical but later they were made with horizontal elements, to conform with the British and French practice. It should be noted that the bulb is spherical, also to conform with foreign practice.

The SE-1444 made for the U. S. Navy during World War I was designed by the Navy Department and made for the Navy by Moorhead. It was similar in construction to the tube made for British use except that the bulb was cylindrical and the element assembly vertical. It is shown in Fig. 180. The filament of this tube operated at 4.5 volts with a current of .65 ampere. It had a mutual conductance of 180 micromhos, amplification factor of 9 and anode impedance of 50,000 ohms. It was usually operated at 40 volts anode and − 1.3-volts grid.

After the war there existed a stalemate in tube manufacture because of the decision in the Fleming-de Forest patent suit. The first step toward breaking this stalemate was taken on November 30, 1918 when the Marconi Company granted to the Moorhead Laboratories a nonexclusive license to make and sell apparatus under the Fleming patent, for sale to amateurs and to any Government. By the terms of this agreement the Moorhead Laboratories admitted its past infringements, paid damages, and agreed to pay royalties to the Marconi Company on future products. With this agreement in hand the Moorhead Laboratories approached de Forest, with a view to obtaining a license under the de Forest Audion patents.

The end result of negotiations conducted over a considerable period was a series of agreements [244] between the Marconi Company, de Forest, Moorhead Laboratories, and Otis B. Moorhead as an individual. These agreements were first concluded on April 30, 1919, and later modified on June 6, 1919. They provided that Otis B. Moorhead and the Moorhead Laboratories were to manufacture tubes for de Forest. De Forest in turn agreed to sell all such tubes to the Marconi Company. The Marconi Company agreed to sell tubes back to the de Forest Radio Telephone and Telegraph Company, to be sold by them to the public for amateur and experimental use in radio reception and amplification. These agreements were to run until February 18, 1925, the date of expiration of the Audion patent, except that they could be cancelled by either party on six months' notice.

The vacuum tubes to be made under these agreements were of several types, described as follows:

Type A—This was a hard amplifier tube, the same as had been supplied to the U. S. Navy during World War I under the designation SE-1444. It had a cylindrical bulb and a standard Navy 4-pin base of the Shaw type. The filament was of drawn tungsten wire, approximately .0024 inch in diameter and about 13/16 inch long. The grid was an 11-turn spiral of nickel wire, with an internal diameter of .167 inch. The plate was of sheet nickel, about .009 inch thick rolled into a cylinder of about 3/8-inch internal diameter. The tube operated with a filament current of about .7 ampere at 4 to 5 volts, and with an anode voltage of 60 to 90 volts.

Type B—This was similar to tube "A" but with low vacuum for opera-

(Continued on page 144)

an analogy. It is a fact that every automobile manufacturer who has attempted to put on the market an automobile considerably lower in price than the cheapest models available had to either withdraw it or go bankrupt. Car quality is something one can discover by use, despite all the salesman's glowing promises, and it is my opinion that the same will hold true for television; picture quality is an item everyone will be able to judge as the movies have already set standards for us. To return once more to the automobile industry we find that manufacturers produced thousands of cars per year (3,698,328 in 1940) at a price of approximately $1,000.00 each. A large percentage of these cars were bought for pleasure use, and of these the greater part was purchased by people of average means. This was made possible by the medium of installment buying, a highly successful American institution. If the public was only eager to buy the lowest-priced cars, the large percentage of "de Luxe" and "Custom de Luxe" sales would have been impossible. It is my firm belief that once the public has been educated to the point where they conclusively will know that they cannot expect quality below a certain price level, buying of television receivers, will speed up, helped, of course, by the "deferred payment plan."

Good programs will have to be provided simultaneously, just as good roads spurred the automobile sales skyward. To sum up, it is my opinion that the industry is on the wrong track in trying to provide "cheap" television, that the public probably will not accept. Educational advertising has worked miracles before, and can still be relied upon to put commercial television over the top.

—30—

Saga of the Vacuum Tube

(*Continued from page 54*)

tion as a detector with 18 to 40 volts on the anode.

Type C—This was similar to type "A" except that the grid was of molybdenum instead of nickel of 22 turns with a pitch of .030 inch. It was to operate at anode voltage of 80 to 500.

Type D—This was the same as the unbased "Electron Relay" previously made by Moorhead.

Type E—This was the British Standard Type "R." It was similar to type "A" except that it employed a spherical bulb, and was based with the British standard 4-pin base.

Type F—This was similar to type "E" but with low vacuum, like type "B."

Type G—This was similar to type "C" but in a spherical bulb and with British standard 4-pin base. This was the same as the British Standard Type "B" tube.

The tubes advertised and sold by the Marconi Company in 1919 and early 1920 as the "Marconi VT" were Type "A" and Type "B" as described above. In the advertisements Type "A" was designated as "Marconi VT—Class II" and Type "B" as "Marconi VT—Class I."[245] A life of 1500 hours was claimed for these tubes.[246]

The first group of these tubes, about 25,000 in number, which were delivered to the Marconi Company, bore no Marconi or de Forest markings. They were stamped on the glass with the legend "Moorhead Audion—San Francisco." The cartons in which they were packed were marked to restrict their use to amateur and experimental purposes. About 8,000 of these tubes were sold. The balance had the words "Patented Nov. 7, 1905—Sold

A Golf Course serves as an ideal location for Tobe Deutschmann filter engineers in field-testing a military power plant, using a newly designed Filterette.

only for amateur and experimental use" stamped on the bulb before being sold.

Subsequently, the brass bases carried both the Marconi and de Forest markings, Fleming and de Forest patent numbers, and the restrictive legend. See Figs. 181 and 182.

The contracts between Moorhead Laboratories, the de Forest Radio Telephone and Telegraph Company, and the Marconi Company were cancelled on January 30, 1920 by the Marconi Company, the cancellation being effective, in accordance with the six months' clause, on July 30, 1920. This was probably done because the necessary de Forest license was in a fair way of being acquired by the Marconi Company's successor, The Radio Corporation of America, by virtue of the cross-license agreements between RCA, AT&T Co. and General Electric Company, concluded on July 1, 1920, a month before the cancellation finally became effective. A contributing factor to this cancellation undoubtedly was the fact that the Marconi Company experienced great difficulty in obtaining from the Moorhead Laboratories deliveries of sufficient satisfactory tubes to meet their demand. All the shipments received contained a large percentage of defective tubes, in some cases as high as 75%, which had to be weeded out before deliveries could be made to customers.

Meantime, the Moorhead Laboratories, early in 1920, underwent a reorganization and de Forest became associated with them.[247] Two distributing companies were formed, the "Pacific Radio Supplies Company" to handle business in the West and the "Atlantic Radio Supplies Company" to be the East Coast distributors.

The first tubes offered for sale by this combination were the unbased Electron Relay, shown in Fig. 178, and the "Moorhead VT Amplifier-Oscillator."[248] The unbased Electron Relay was soon replaced by another soft tube, also denoted as the "Moorhead Electron Relay."[249] Early designs of this tube had a cylindrical anode and spiral grid. Both grid and anode were supported only from the press, the upper ends being left free. This construction was extremely sensitive to mechanical disturbances, since the grid and anode were free to vibrate under mechanical impulses. Two tubes of this construction are shown in Fig. 181. They differ in the fact that the surfaces of the anodes are unlike. That at the left in the figure has a glossy, almost polished, surface, whereas the one at the right has a dull, possibly oxidized finish. It will be noted also that the diameter of the anode was somewhat greater than that used in the hard amplifier tube.

A later type of Moorhead Electron Relay, in which steps have been taken to reduce the sensitivity to mechanical disturbances, is shown in Fig. 182. In this tube the anode structure has been extended at the top to permit the addition of a mica spacer to position the grid more accurately with respect to the anode and to provide mechanical support. Also the bottom of the anode has been extended in the form of two tabs which are bent to rest against the sides of the press, and thus provide stiffening for the element assembly to some extent.

The other tube which was offered for sale at this time, the "Moorhead VT Amplifier-Oscillator," was the same as the Marconi VT—Class II.

Beginning with the August, 1920[250] advertisement, these tubes were designated as the "A-P Electron Relay" and "A-P Amplifier-Oscillator" and were represented as being licensed under the de Forest and Fleming patents. This was misrepresentation, since the license under the Fleming patent had been cancelled as of July 30, 1920. The December advertisements[251] announced the "A-P Transmitting Tube," which was the same tube as had been made for the Marconi Company under the designation "Type C" above. This also was represented as being licensed under the Fleming and de Forest patents. See Fig. 183. Still another tube, designated as the "A-P Rectifier" was advertised as shown in Fig. 184, in May and June of 1921.[252] It will be noted, however, that this advertisement makes no claim as to license.

Shortly after these advertisements began to appear the Moorhead Laboratories were notified by the Radio Corporation of America, successor to the Marconi Company, that these tubes were not licensed under either the Fleming or de Forest patents. The finances of the Moorhead Laboratories were in a chaotic condition, and the business was being managed by a stockholders-creditors committee, of which Henry S. Shaw was the Chairman. Considerable stocks of raw materials were on hand and the indebtedness was large. In order that the situation might be cleared up to the benefit of all concerned negotiations were entered into and the Radio Corporation granted to the Moorhead Laboratories a license, dated January 25, 1921, under the Fleming and de Forest patents, for the manufacture and sale of a limited number of tubes. This license was delivered to the Moorhead Laboratories in July of 1921, and subsequent advertisements stated correctly that the tubes were being made and sold under license from RCA.

After this license had run its course the Moorhead Laboratories consented to an injunction restraining from the further manufacture or sale of vacuum tubes.

References

233. *Moorhead, O. B.—"The Electron Relay," Pacific Radio News, Vol. 1, No. 4, April, 1917, pp. 166-167, 183.*

234. *Transcript of Record—General Electric Company vs. de Forest Radio Company, U. S. Circuit Court of Appeals, Third District—Nos. 3799, 3800, 3801—March Term 1928. Testimony of Ralph Hyde. Vol. 2, pp. 999-1001.*

235. *Advertisement of Pacific Research Laboratories, Electrical Experimenter, Vol. 4, No. 3, July, 1916, page 193. See also QST, Vol. 1, No. 8, July, 1916, page 190.*

236. *See Reference 234.*

237. *Moorhead, O. B.—"Dr. Lee de Forest vs. O. B. Moorhead," Pacific Radio News, Vol. 1, No. 1, January, 1917, pp. 10-13.*

238. *Advertisement of Pacific Laboratories' Sales Department, Electrical Experimenter, Vol. 4, No. 4, August, 1916, page 273.*

239. *Advertisement of Pacific Laboratories Sales Department, Electrical Experimenter, Vol. 4, No. 5, September, 1915, page 355. See also QST, Vol. 1, No. 10, September, 1916, advertising section.*

240. *Advertisement Pacific Laboratories Sales Department, Pacific Radio News, Vol. 1, No. 1, January, 1917, inside front cover.*

241. *Advertisement of Moorhead Laboratories, Inc., Pacific Radio News, Vol. 1, No. 2, February, 1917, inside front cover.*

242. *Moorhead, O. B. "The Manufacture of Vacuum Detectors," Proc. I.R.E., Vol. 5, No. 6, December, 1917, pp. 427-432.*

243. *Moorhead, O. B., and Lange, E. C.—"The Specifications and Characteristics of Moorhead Valves," Proc. I.R.E., Vol. 9, April, 1921, pp. 95-129.*

244. *Radio Vacuum Tube Litigation Is Settled," Radio Amateur News, Vol. 1, No. 2, August, 1919, page 77.*

245. *Advertisement of Marconi Wireless Telegraph Company of America, Radio Amateur News, Vol. 1, No. 3, September, 1919, page 100. QST, Vol. 3, No. 3, October, 1919, page 40.*

246. *"The Marconi VT—A Three Electrode Oscillation Detector of Approved Operating Characteristics." Wireless Age, August, 1919, pp. 33-34.*

247. *"The Reorganization of the Moorhead Laboratories." Pacific Radio News, Vol. 1, No. 11, June, 1920, pp. 387-389. "Big Radio Deal Closed," Pacific Radio News, Vol. 1, No. 11, June, 1920, pp. 389, 407, 408.*

248. *Advertisement of Pacific Radio Supplies Company. Pacific Radio News, Vol. 1, No. 10, May, 1920, inside back cover.*

249. *Advertisement of Pacific Radio Supplies Company, Pacific Radio News, Vol. 1, No. 11, June, 1920, inside back cover. Radio Amateur News, Vol. 1, No. 12, page 711. QST, Vol. 3, No. 11, June, 1920, page 73.*

250. *Advertisement of Pacific Radio Supplies Company,* RADIO NEWS, *Vol. 2, No. 2, August, 1920, page 119.*

251. *Advertisement of Pacific Radio Supplies Company.* RADIO NEWS, *Vol. 2, No. 6, December, 1920, page 389. QST, Vol. 4, No. 10, December, 1920, page 99.*

252. *Advertisement of Pacific Radio Supplies Company,* RADIO NEWS, *Vol. 2, No. 11, May, 1921, page 833. QST, Vol. 1, No. 10, May, 1921, page 99.*

CAPTIONS FOR ILLUSTRATIONS

Fig. 176. Advertisement announcing Moorhead Tube with external control electrode. Reproduced from page 355 of September, 1916, Electrical Experimenter.

Fig. 177. Moorhead Tube with external control electrode. Bottom—with control electrode removed. Note raised marking on anode. Top—complete tube assembly. Photograph courtesy Bell Telephone Laboratories.

Fig. 178. Moorhead Electron Relay, original unbased type. Note marking "ER" on anode. Photograph courtesy Bell Telephone Laboratories.

Fig. 179. Moorhead version of British Type "R" in spherical bulb.

Fig. 180. Marconi VT.

Fig. 181. A-P Electron Relays. Left—with glossy surfaced anode. Right—with dull surfaced anode.

Fig. 182. A-P Electron Relays. Right—same tube as at right in Fig. 181, but turned 180 degrees to show de Forest marking on base. Left—improved construction with mica spacer and bracing tabs. Anode is aluminum.

Fig. 183. Advertisement announcing A-P Transmitting tube. Reproduced from page 389 of December, 1920 RADIO NEWS.

Fig. 184. Announcement of A-P Rectifier Tube. Reproduced from page 911 of June, 1921 RADIO NEWS.

(To be continued in May issue)

Fig. 185.

Fig. 186.

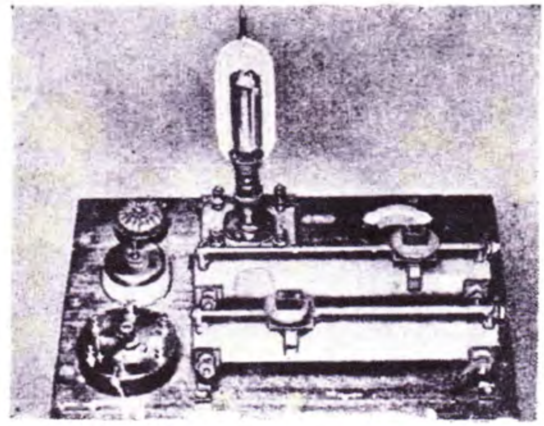


Fig. 187.

THE SAGA OF THE VACUUM TUBE

By GERALD F. J. TYNE
Research Engineer, N. Y.

Part 17. A study of repeater tube developments in local and long-distance telephonic transmissions.

THE problem of telephonic transmission over long distances was not as acute in Great Britain and on the European Continent as it was in the United States. This was due chiefly to the shorter distances involved. Such distances as lay within the borders of any one country, presumably all that would be required at that time to be covered by any one telephone system, could be spanned by the use of heavy gauge conductors and loading. Nevertheless, the advantages from the economic standpoint of a satisfactory repeater were realized and efforts were being made to develop such a device in Great Britain and in Germany.

A study of repeater and repeater-tube developments in Europe brings out the contrasts between the European and American telephone systems. In America the local and long-distance telephone systems are, for the most part, under a single central control, which is a public service corporation, subject to government regulation in the public interest. This corporation, the American Telephone and Telegraph Company, has numerous subsidiaries: operating, developmental, and manufacturing. Such an arrangement is a powerful impetus to systematic development and standardization. Such a connected development procedure is well exemplified in the earlier installments in this series in which the evolution of the American telephone repeater tube has been traced and studied.

In Great Britain and on the continent, on the other hand, the telephone and telegraph systems are, in general, controlled and operated directly by the governments of the respective countries. In these cases, while the earlier steps in new developments may come from either the government research organizations or in-

Fig. 188.

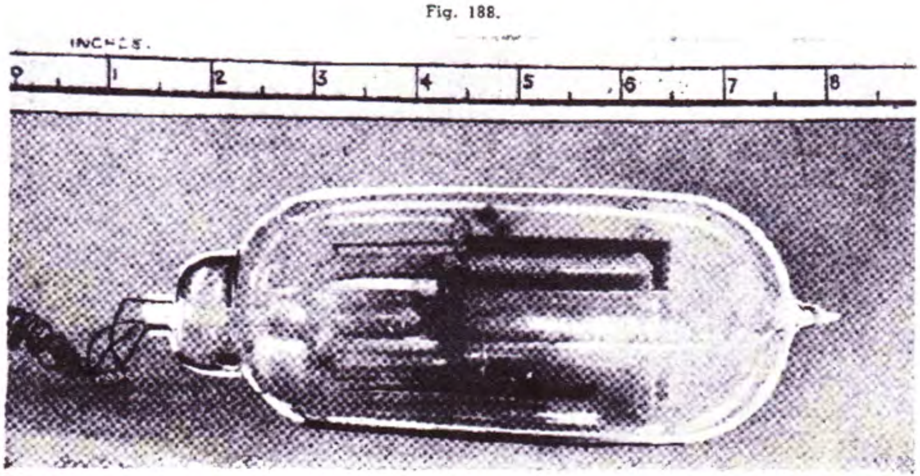


Fig. 189.

dustry, the providing of the actual equipment for use is by competitive manufacturing organizations. When a new installation, such as a long-distance cable, is to be made, the requirements which this installation is to meet are laid down by the authorities and bids for the installation are invited from various manufacturers. Hence, while a suitable system for the project may be installed by the successful bidder, it may differ considerably in equipment from previously installed systems, meeting similar requirements, but purchased from some other manufacturer. This delays standardization of equipment in the early stages of development and hence we find different repeaters and different repeater tubes in use simultaneously in various parts of a country.

The method of attack on the repeater problem in Great Britain was similar to that used in the United States in that efforts for a time were confined to attempts to develop a satisfactory receiver-microphone device. In America the so-called "Shreeve Repeater" came in for attention; in Great Britain a "telephone relay" along these same lines was devised by S. G. Brown. There were several varieties of this relay, one of which, known as "Type G" is shown in Fig. 185.

In this relay the received currents flowed through an electromagnet which actuated a steel reed. The vibration of this reed was applied to the carbon granules of a microphone unit and caused telephonic variations in the microphone current. Since in the carbon microphone the electrical output can be greater than the acoustical or mechanical input, such a device can be made to function as an amplifier or telephone repeater. It is claimed that the Brown "Type G" Relay gave a gain of about 20 times. Under favorable conditions as many as three of these devices could be used in tandem on a one-way circuit but at the expense of some distortion. The inherent disadvantages of the device were that the frequency range which could be repeated was limited by the mechanical characteristics of the moving element, and that there were difficulties in getting and maintaining the proper mechanical adjustments. Nevertheless, some installations were made, and the first of these was in Leeds in 1914, on a London-Glasgow circuit.[253] This was a one-way repeater, and was used in connection with a so-called "jumping switch." This "jumping switch" was a voice-operated relay which automatically made the necessary changes in connections to permit of two-way operation. Its use caused undesirable "clipping" of the conversation.

The engineers of the British Post Office were well aware of the limitations of the mechanical repeater, and in 1908 a small group of research workers, who were studying cathode-ray phenomena in the Post Office Research Laboratory, conceived the idea of developing a telephone relay of the

Fig. 190.

Fig. 191.

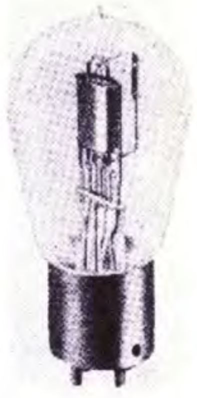


Fig. 192.

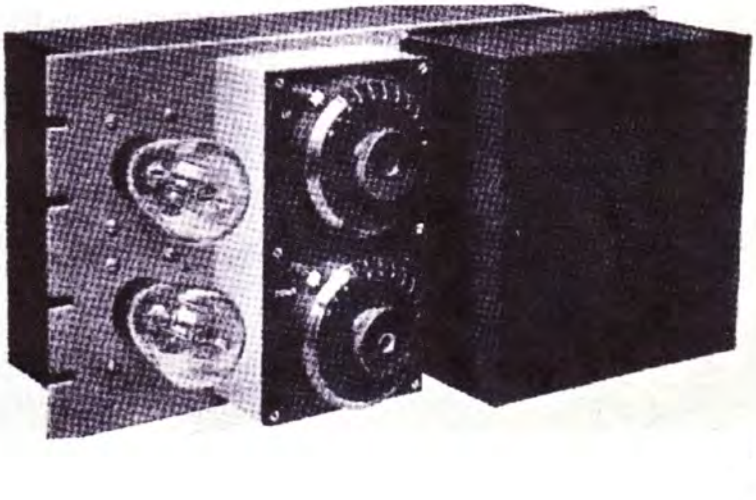
cathode-ray type.[254] Possibly their thinking had been stimulated by the issuance, in 1906, of the von Lieben patent on just such a device. The necessary machinery for making and evacuating such tubes was purchased and installed. Unfortunately the group was broken up by staff changes shortly thereafter, and the work was overshadowed by the possibilities of the mechanical amplifier which promised quicker results, even though of less satisfactory quality.

Interest in the thermionic repeater was reawakened in 1913, however, when the work of de Forest, Lieben and Reisz, Round, and others had brought the thermionic amplifier out of the research laboratory into the realm of commercial practicability. Fortunately, one of that small group dispersed in 1908 returned to the research laboratory about that time and resumed the suspended experiments. Samples of tubes were obtained from de Forest, Lieben and Reisz, and Round, and examined to see if they could meet the requirements of telephone work. New experimental tubes were constructed, incorporating such special features as might adapt them to telephone requirements.

The Round type of "soft" tube at first seemed to be the best and a number of these were produced in the laboratory. They were somewhat larger than the original Round tubes, in order to handle the necessary power. Fig. 186 is a photograph of one of these tubes, the first type to be used in telephone service in England. Fig. 187 shows the repeater unit in which it was used. The essential features of this type of tube are (1) the cathode is of the Wehnelt, or oxide-coated, type; (2) the grid is a fine mesh completely surrounding the filament; (3) the anode is a cylinder surrounding the grid; and (4) there is a tubulation containing a wad of asbestos extending upward from the top of the bulb. This grid construction was adopted to prevent electrification of the inner surface of the glass bulb by electrons expelled from the filament, and the asbestos in the tubulation was used as a source of gas to restore the pressure when the tube became hard. The asbestos gave off small quantities of gas when heat was applied externally to the tubulation.

It is said that these tubes were rather stable in operation and gave a good quality of reproduction. When new they would start up from cold in about three seconds, but when older and as the internal pressure decreased they sometimes required some time to

Fig. 193.



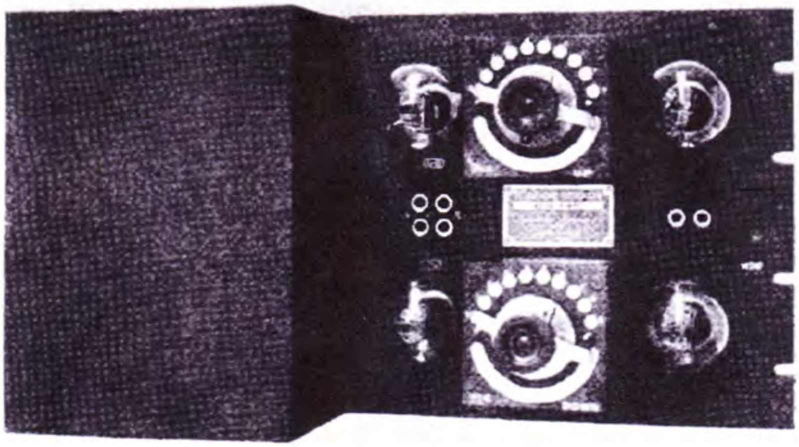


Fig. 194.

reach their full amplification. The pressure could be restored by heating the tubulation, in most cases. The life, when only moderate gains were required, was on the average about 600 hours.[255]

These soft tubes were difficult to manufacture with any degree of uniformity and were soon replaced by a "hard," or high-vacuum tube, the earliest form of which is shown in Fig. 188. In this tube the cathode was either tungsten or the oxide-coated type and was supported on a U-shaped glass frame. The grid was of nickel gauze, similar to that used in the soft tubes, and was fitted over the glass frame which carried the cathode. The anode consisted of two plates of nickel, supported by glass arbors, one on either side of the grid-cathode assembly. This tube was exhausted to such a vacuum that it showed no indication of ionization when worked at an anode voltage of 400 volts.

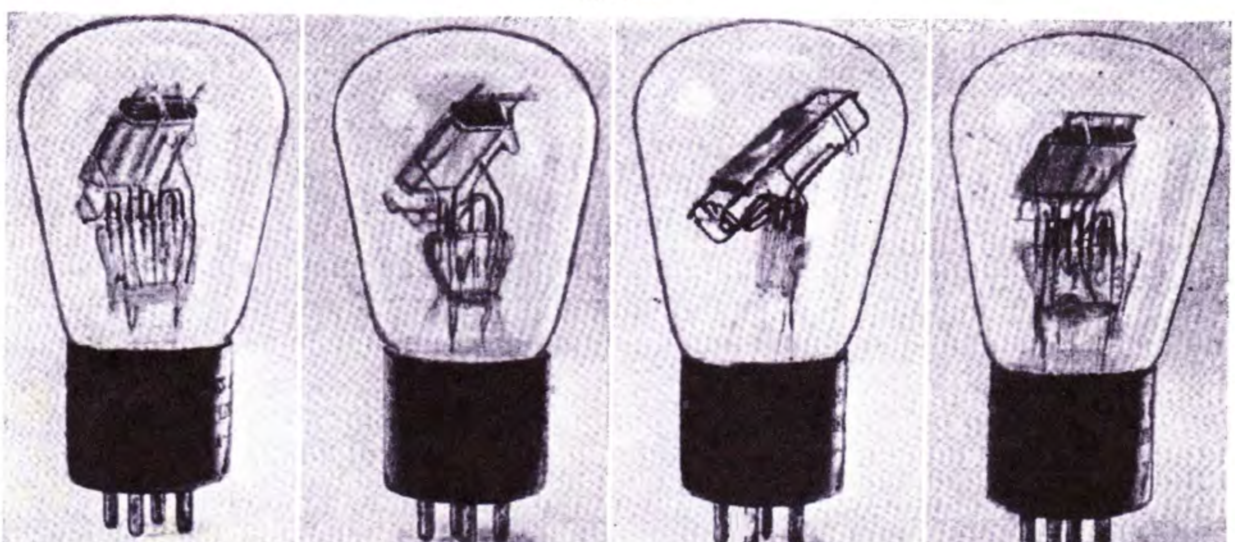
The glass work of this tube was rather troublesome to make[256] and subsequently the Post Office engineers inclined toward the use of a tube similar to that developed by the French Military Telegraphic Service under General Ferrie, and commonly known as the "French" tube. The version of this tube which was arrived at by the Post Office became the first "Standard Repeater Valve," and was officially known as "Valve, Amplifying, No. 1." It is shown in Fig. 189.

The filament of this tube was a fine spiral of tungsten wire. The grid was a somewhat more open spiral, at first of tungsten and later of alloy wire, mounted concentrically with the filament and about ¼ inch in diameter. The anode was a spiralled helix of tungsten wire mounted concentrically with the grid and filament, and with a radial spacing of $\frac{1}{16}$ to ⅛ inch. Later (1919) models of this tube had the anode made of sheet nickel, and one of these later tubes is shown in Fig. 190. The bulb, spherical in shape, was mounted on a red fibre base which carried the four terminal connections. These were flat strips of brass, arranged to be clamped under binding posts on the repeater unit. This method of mounting was used in preference to the four-pin base used on the "French" tube because of the necessity of keeping contact resistance to a minimum. The anode terminal strip was painted red "for reasons that will be appreciated by anyone who touches it while the valve is in operation."[257] The repeater in which this tube was used was known as "Repeater, Telephonic, No. 2," and is shown in Fig. 191.

The filament of this tube was designed to give a total space current of not less than 10 milliamperes when a potential of 150 volts was applied between filament and grid-anode connected together. The normal operating value of the anode current was 1 to 2 milliamperes. The working temperature of the filament was chosen to give a working life of about 2000 hours.[258] The tube had a mutual conductance of 450 micromhos and an internal impedance of about 20,000 ohms In order to insure obtaining a reasonably straight-line plate current-grid voltage curve, one of the requirements of this tube was that between grid voltages of −8 and zero, the mutual conductance must not vary more than 20% from the value at −4.5 volts, the grid bias existing in Repeater No. 2.

In order to insure meeting the other requirements, the proper filament current for each of these tubes was determined for the individual tube.[259] This was done by putting the tube into a test circuit and increasing the filament current until the mutual conductance reached a predetermined value. At this point the filament voltage was noted and thereafter the filament was operated at that voltage. The usual value of heating current was between the limits of .7 and .8 ampere, and the filament voltage was about 4.7 volts. Under these conditions the filament resistance was about 10 times its resistance when cold. The usual anode voltage was 200-220 volts.

Fig. 195.



By 1926 there were 26 repeater stations in Great Britain with a total of about 670 repeaters in service.[260] One of the "standard" amplifying tubes used in such repeaters was designated by the Post Office as "Valve, Thermionic, No. 25" and is shown in Fig. 192. It was made by the General Electric Co., Ltd. of London,[1] and was a further development of the "R" type tube used for radio applications. It was also used as an output tube in radio receivers under the designation "L.S. 5." It operated with a filament current of .82 ampere at a voltage of 4.5 volts in telephone equipment, and had a life of 1000-2000 hours. [261] This tube was used in both 2-wire and 4-wire repeaters, one of the 2-wire type being shown in Fig. 193.

Another type of repeater of about this same vintage is that installed on the London-Glasgow cable, which was placed in service about 1926. The repeater equipment of this cable was furnished and installed by Standard Telephones and Cables, Ltd., and one of the repeaters is shown in Fig. 194.[264] The tubes used were the Standard Telephones and Cables types 4101D and 4102D, designated by the Post Office as "V.T. No. 31" and "V.T. No. 32" respectively, which are essentially the same as the Western Electric (U.S.A.) 101D and 102D tubes previously described, using oxide-coated filaments. This similarity came about because the Standard Telephones and Cables, Ltd. had originally been the Western Electric Company, Ltd., an affiliate of the Western Electric Company of the United States, and the British product thus closely paralleled the American practice, and reflected the progress of American development.

Subsequently, other repeater tubes which operated at lower filament currents, permitting economies in repeater-station power plant and station wiring, were developed by Standard Telephones and Cables.[263] A group of these repeater tubes, which became available about 1932, is shown in Fig. 195.

The 4019A had plate characteristics in general similar to those of the 4101D, and could be used to replace it in existing equipment, with a slight increase in gain. The 4020A was intended to replace the 4102D. The 4021A replaced the 4104D with, again, some increase in gain. The 4022A was really a higher gain 4019A. The filament and plate voltages for the new tubes were about the same as for the replaced tubes. The 4019A, 4020A, and 4022A had a life exceeding 10,000 hours, while the life of the 4021A was in excess of 3000 hours.

The need for telephone repeaters did not arise as early in France as in other countries. This was partly at least due to the limited use of the telephone in that country. The attitude of the French might be typified as that of one Frenchman who, in 1915, when an at-

[1] The General Electric Co. Ltd. of London is not affiliated with the General Electric Co. of U.S.A.

tempt was made to explain to him the American telephone system and its slogan "Universal Service," is reported to have replied that he couldn't see any sense in telephones anyhow, all the people he wanted to talk to in a hurry lived with him, the others didn't matter, and a letter was quick enough in any case.

There was little standardization of equipment. The subscriber supplied his own equipment, which resulted in a diversity of station sets, chosen according to the whims of the individual. Its electrical characteristics were the last thing he considered. No two central offices were alike in construction or operated in the same way.[264] Long-distance telephony was practically nonexistent until late in World War I. Even as late as 1921 distances of the order of 500 miles were spanned only with difficulty and under the most favorable conditions.[265]

The first repeater used in France was installed and operated on an experimental basis at Lyons on a Paris-Marseille circuit in 1917. It was a two-stage affair, using tubes of the type previously denoted as "French" tubes, developed primarily for military use in radio work.[266] Following the success of this experimental installation an increase in the use of repeaters was proposed with the suggestion that the first step be taken by the installation of cord-circuit repeaters in Paris.[267]

By 1920, however, there were only 30 repeaters available. Of these, three were of the French type, using French tubes, eight were British repeaters installed at Abbeville and Lyon by the British Army during World War I, and the other 19 (of which 7 were of the cord-circuit type) were American repeaters of Western Electric manufacture. These last had been obtained from the stocks of the American Army in France.[268] The increase in the number of repeaters was slow, since early in 1923 there were but 38 in use. Of these 26 were cut in on specific circuits, while 12 were of the cord-circuit type.[269]

At the end of 1923, however, the French Administration contracted for a loaded and repeatered cable between Paris and Strasbourg. This cable was completely in service late in 1926. The repeaters used on this installation were supplied by Standard Telephones and Cables, Ltd. through their French subsidiary, the "Société Anonyme, Lignes Télégraphiques et Téléphoniques." These repeaters were of the type previously mentioned in connection with the London-Glasgow cable and were equipped with S. T. & C. tubes of the 4101D and 4102D types.[270]

Hence it may be said that, up to this time, no vacuum tubes designed especially to meet the requirements of telephone repeater service, and of French development and manufacture, had been used in France. This is not to say, however, that the French lagged behind other nations in the

(*Continued on page* 128)

Saga of the Vacuum Tube

(*Continued from page 64*)

development of vacuum tubes for other applications. In fact, development of the "French" tube by the French Military Telegraphic service early in World War I was one of the outstanding communications achievements of the War.

References

253. *Timmis, A. C.—"Recent Developments in Long Distance Telephony," Journal of the Institution of Electrical Engineers, Vol. 78, June 1936, pp. 601-628.*

254. *Hart, A. B.—"The Telephone Repeater," Post Office Electrical Engineers Journal, Vol. 12, 1919, pp. 1-11.*

255. *Robinson, C. and Chamney, R.M.—"Gas Discharge Telephone Relays and Their Applications to Commercial Circuits," Part I of Paper No. 76 of the Institution of Post Office Electrical Engineers, p. 31.*

256. *Robinson, C. and Chamney, R.M.—"Technical Development of Telephonic Repeaters since 1917," Part II of Paper No. 76 of the Institution of Post Office Electrical Engineers, p. 65.*

257. *Hart, A. B.—"Telephonic Repeaters," Paper No. 75 of the Institution of Post Office Electrical Engineers, pp. 11-12.*

258. *Noble, Sir William—"The Long Distance Telephone System of the United Kingdom," Journal of the Institution of Electrical Engineers, Vol. 59, 1921, pp. 389-408.*

259. *See Reference 256, pp. 68 and 100.*

260. *Manning, Major F. E. A.—"Recent Repeater Station Installations," Paper No. 151 of the Institution of Post Office Electrical Engineers.*

261. *Fleming, J. A.—"The Thermionic Tube and Its Developments in Radiotelegraphy and Telephony," 2nd edition, 1924, p. 383.*

262. *Hart, A. B.—"The London-Glasgow Trunk Telephone Cable and Its Repeater Installations," Post Office Electrical Engineers Journal, Vol. 19, part 2, July 1926, pp. 103-104. See also Electrical Communication, Vol. 5, No. 2, October 1926, pp. 119-155.*

263. *Benham, W. E., Lyall, J. S., and Rendall, A. R. A.—"The New Quarter Ampere Repeater Tube and Its Applications," Electrical Communication, Vol. II, No. 2, October 1932, pp. 74-79.*

264. *Valensi, G.—"Le Telephone en France et a l'etranger," Annales des Postes, Telegraphes et Telephones, Vol. 12, 1923, pp. 565-599.*

265. *Martin, G.—"La Telephonie à grande distance en Europe," Annales des Postes, Telegraphes et Telephones, Vol. I, 11-81, pp. 263-270.*

266. *"Les Relais Telephoniques employes par l'Administration Français," Annales des Postes, Telegraphes et Telephones, Vol. 7, 1918, pp. 403-410.*

267. *Valensi, G.—"Application des Amplificateurs à l'exploitation telephonique," Annales des Postes, Telegraphes et Telephones, Vol. 6, 1917, pp. 595-613.*

268. *Ruat—"Les Relais Telephoniques en France," Annales des Postes, Telegraphes et Telephones, Vol. 9, 1920, pp. 429-431.*

269. *"Utilisation des relais amplificateurs dans le reseau telephonique français," Annales des Postes, Telegraphes et Telephones, Vol. 12, 1923. pp. 768-769.*

270. *"Paris-Strasbourg Cable," Electrical Communication, Vol. 6, No. 1, July 1927. pp. 35-53.*

CAPTIONS FOR ILLUSTRATIONS

Fig. 185. S. G. Brown's "Type G" Telephone Relay. Photograph courtesy Bell Telephone Laboratories.

Fig. 186. Original Post Office Amplifying Valve (Round's Type). Reproduced from Post Office Electrical Engineers Journal—1919.

Fig. 187. Post Office Repeater using Round's Valve. Reproduced from Paper No. 76 of the Institution of Post Office Electrical Engineers.

Fig. 188. Earliest type of high-vacuum telephone repeater tube used by

British Post Office. Reproduced from Paper No. 76 of the Institution of Post Office Electrical Engineers.

Fig. 189. Original form of "Valve, Amplifying, No. 1," Photograph courtesy R. McV. Weston.

Fig. 190. Later form of "Valve Amplifying, No. 1" Photograph courtesy Bell Telephone Laboratories.

Fig. 191. "Repeater, Telephonic, No. 2" Reproduced from Post Office Electrical Engineers Journal—1919.

Fig. 192. "Valve, Thermionic, No. 25" made by General Electric Co. Ltd. of London. Reproduced from J. A. Fleming's "The Thermionic Valve and its Developments in Radiotelegraphy and Telephony"—2nd edition.

Fig. 193. Two-wire repeater using "V.T. No. 25" Amplifying Valves. Reproduced from Paper No. 99 of the Institution of Post Office Electrical Engineers.

Fig. 194. Standard Telephones and Cables Type 4202F Repeater using 4101D and 4102D tubes. Reproduced from Post Office Electrical Engineers Journal—1926.

Fig. 195. Quarter Ampere Repeater Tubes made by Standard Telephones and Cables, Ltd. from 1932. Reproduced from Electrical Communication—1932.

(*To be continued*)

Television Antennas

(*Continued from page 42*)

only .1 to .15 wavelength behind the dipole. However, for television this would mean a sharp reduction in antenna resistance and consequent loss of wide-band response. The length of the reflector for various bands is shown in the dimension chart, and is approximately 5% longer than the dipole. Thus, in the above example, our quarter-wave spacing would be three feet seven inches, and the length of the reflector seven feet two inches.

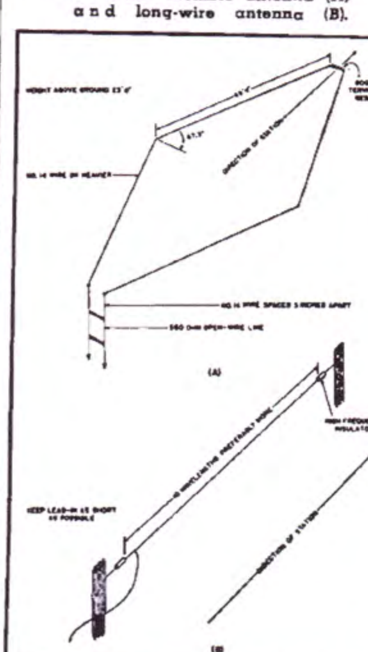
2. *Folded Dipole.*

The folded dipole, Fig. 4A, has a higher surge impedance and a lower rate of reactance increase as the frequency departs from resonance. Surge impedance of the folded dipole, four times larger than the impedance of a single dipole, is approximately 300 ohms and can be conveniently matched with a parallel coaxial line, each coaxial line having an impedance of approximately 150 ohms. In this case, if we use a one-inch outer conductor, from our coaxial line chart, our inner conductor should be made of #12 wire. Center-to-center spacing is not critical and is approximately two to three inches. Spacing between the legs of the dipole is approximately r/8 or less. The flat frequency characteristic of the folded dipole permits both use of a reflector and director with improved sensitivity, plus the use of smaller size tubing for the dipole itself. The parasitic elements must not be folded; actual construction is shown in Fig. 4B.

3. *Stacked Array.*

The stacked array, consisting of various elements stacked vertically, is a more efficient antenna, for it more ef-

Fig. 8. Mechanical requirements of 60-mc. rhombic antenna (A) and long-wire antenna (B).



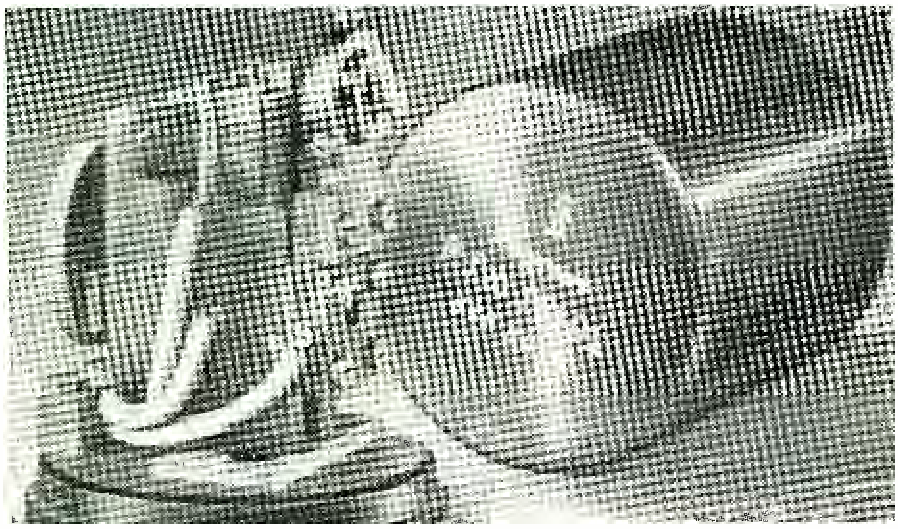


Fig. 196

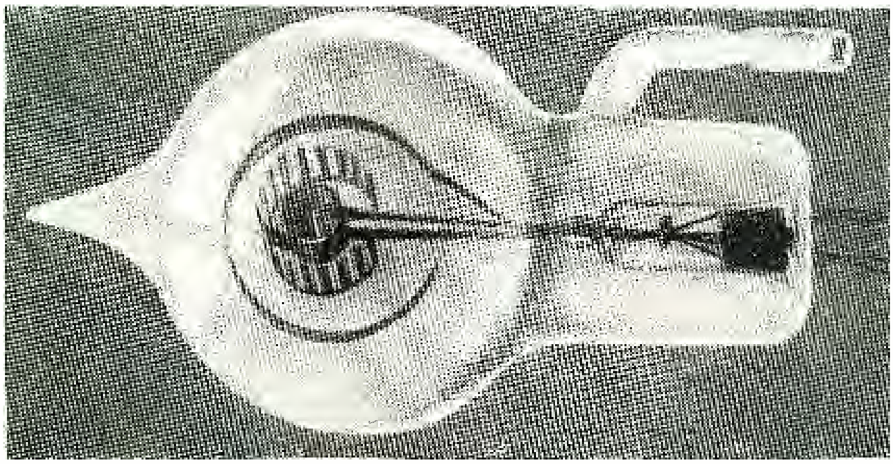
THE SAGA OF THE VACUUM TUBE

By GERALD F. J. TYNE

Research Engineer, N. Y.

Part 18. Continuing our study of telephone repeater-tube developments in this country and abroad and their application during the first World War.

Fig. 197



THE early development of the telephone repeater in Germany followed much the same path as in Great Britain and the United States. Early in 1910 the firm of Siemens & Halske attacked the problem along the line of producing a receiver-microphone type of amplifying device. They had secured the rights to the receiver-microphone repeater which had been developed by S. G. Brown in England. Using this as a basis, they succeeded in producing an improved mechanical repeater which could be adjusted to operate for some months without excessive maintenance.[271] This mechanical repeater is shown in Fig. 196. Its frequency response was not as good as was desired, however, and the search for a better amplifier continued.

In August, 1911, Robert von Lieben demonstrated the von Lieben-Reisz-Strauss tube (the LRS Relay described in a previous installment) to a group of representatives of the leading German electrical manufacturers. The demonstration, which was conducted in the auditorium of the "Institut fur physikalische Chemie der Universitat Berlin" was so impressive that four of these concerns—Allgemeine Elektricitäts Gesellschaft (A.E.G.), Siemens & Halske, Felten & Guilleaume Carlswerk A.G., and the Gesellschaft fur drahtlose Telegraphie (Telefunken)—jointly founded a laboratory, called the "Liebens Konsortium."[272] This laboratory proceeded with the LRS Relay development and studied its applications. In addition, three of the firms undertook development in their own laboratories.

In less than a year this development had proceeded to the point where the results were presented for consideration and test to the State Telegraph Administration by the A.E.G., acting for the Konsortium. These tests showed that while the tube was not perfect the defects did not present insurmountable difficulties. The chief difficulty was that of variation in performance with changes in temperature, and it was overcome to a certain extent by operating the tube in a constant-temperature enclosure. In comparison with the de Forest Audion which had also been under consideration, the LRS Relay had a lower output impedance and greater power-handling capabilities. It was used, before World War I broke out, on some long nonloaded open-wire circuits such as those connecting Koenigsberg (Prussia), Frankfort (Main), Cologne, Danzig, and elsewhere.[273]

After the outbreak of the war there was an urgent demand for reliable, good quality communications between battle areas and the headquarters of the Army and Navy. As early as 1914 circuits using the LRS Relay repeaters were in use to connect the Eastern Front with the Western Front and Berlin. Conversation was successfully transmitted over a distance of about 750 miles between the headquarters at Luxembourg and the Hindenburg Army in East Prussia. This was ac-

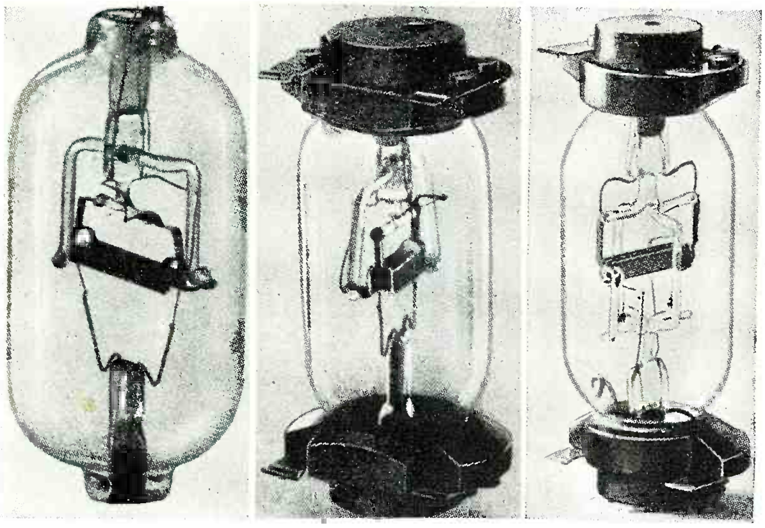


Fig. 198

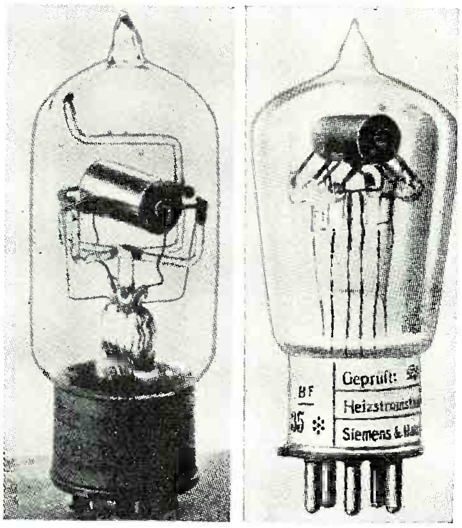


Fig. 199

complished by the use of a single repeater in Berlin. As the fighting fronts advanced this single repeater proved inadequate, and the rapidly increasing length of circuits required the use of several repeaters in tandem. This necessitated the use of the four-wire type of circuit (which was first proposed by the Dutch engineer, Van Kesteren) in which the tubes were used for unidirectional amplification only. By this arrangement good speech transmission was maintained between the Headquarters Staff and Constantinople, and with the armies in Macedonia, Rumania, and Russia. By the end of the war there were about 100 repeaters, of both 2-wire and 4-wire types, in use, which sufficed to take care of the urgent military demands.

In 1917, a program of research was instituted with a view to adapting repeaters to general civilian use, particularly on cable circuits. After making a study of the action of the Lieben tube, the elements were re-arranged and a concentric cylindrical element assembly, shown in Fig. 197, was adopted.[274] The mercury vapor filling was still retained, however. This means that the difficulties of operation caused by variations in atmospheric temperature were still to be overcome. These difficulties indicated

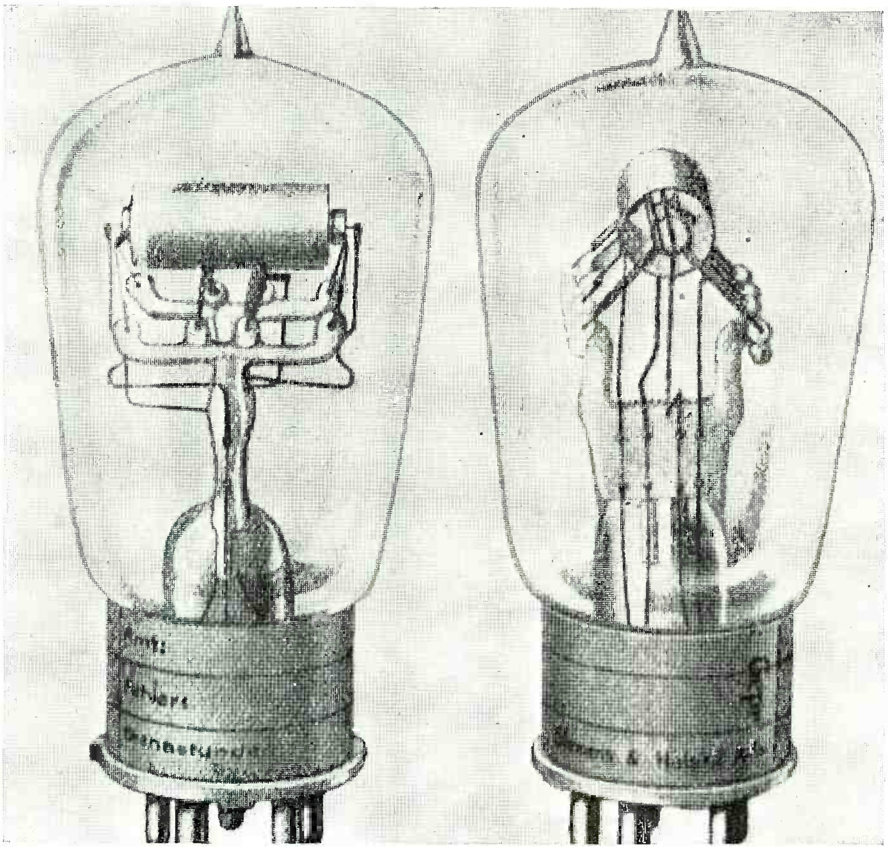
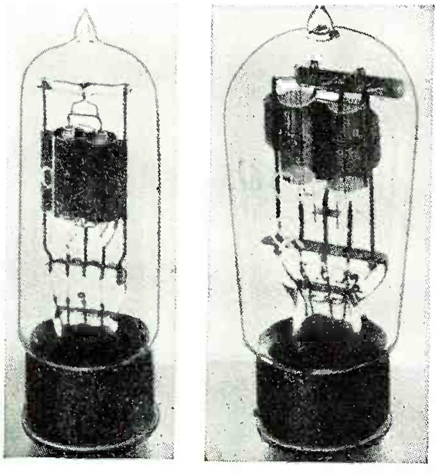


Fig. 200

Fig. 201



that a repeater tube which would be independent of gas ionization would be much to be preferred, and the change to a high-vacuum type of tube was decided upon. The first attempts were actually made by the Telefunken Company with the co-operation of Professor M. Pirani, in the incandescent lamp factory of Siemens & Halske.[275]

The Siemens & Halske Company evolved a high-vacuum tube with a tungsten filament, known as the type "Mc," and the A.E.G. produced the "K6" tube. Both these tubes were used during the latter part of the war for special telephone circuits for military use. The Mc tube, shown in Fig. 198, operated with a filament current of about 2.1 amperes at a voltage of about 4 volts, and the K6 with a filament current of 1.1 ampere at about 7 volts. Both operated at an anode voltage of about 220 volts, and had a space current of about 10 milliamperes. The Mc had an amplification factor of 6.7 and an internal impedance of about 10,000 ohms. The output was about 60 milliwatts.[276] The U-shaped electrode assembly of the Mc tube was adopted in order to obviate the necessity of centering the filament. At that time it was considered impossible to accomplish this centering by the application of tension to the

Fig. 202

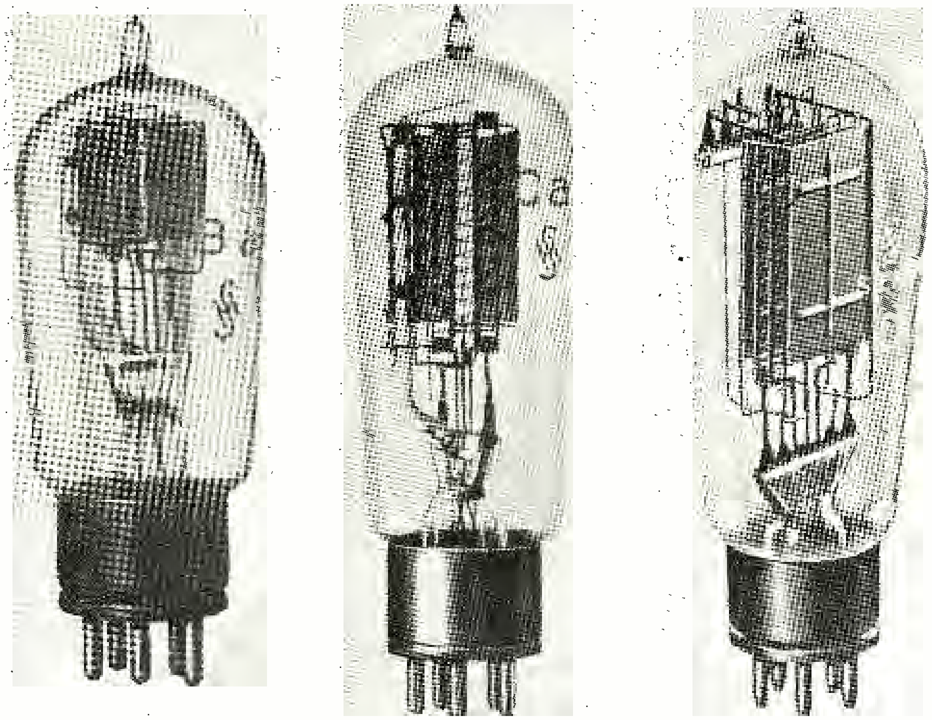


Fig. 203

ends of the straight filament wire. The K6 tube employed an assembly of plane parallel electrodes.[277]

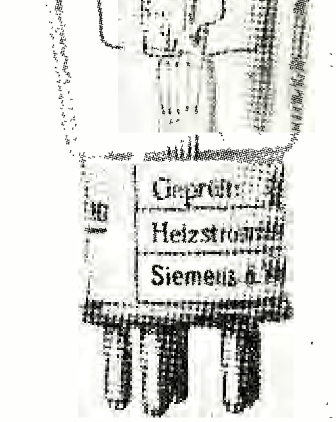
Since the power output required in ordinary repeater work is less than the output of these tubes, they were replaced, after the war, with smaller ones designed especially for telephone-repeater work. For this purpose equivalent tubes were made by several manufacturers, among them Siemens & Halske, A.E.G., Suddeutsche Telefon-, Kabel-, und Draht Werke (Nurnberg), C. Lorenz A.G., and Dr. Erich F. Huth Gesellschaft. With the exception of those made by Huth, which used plane parallel electrodes, all these tubes had a cylindrical electrode system.

The Siemens & Halske tube designated as type "BF" may be taken as an example of these tubes. It is shown in Fig. 199. This tube had a tungsten filament operating with a current of 1.1 amperes at 3.6 volts, thus consuming only half the filament power of the Mc. The anode voltage was 220 volts, and the saturation current about 8 milliamperes.[278] The amplification factor was about 12, internal impedance about 25,000 ohms, it had a mutual conductance of about 500 micromhos when operated at −6 volts on the grid, and it gave an output of about 30 milliwatts. The average life initially was about 600 hours, but was later raised to 1000 hours.

The BF tube was the first tube to be designed from the ground up with a view to meeting the rigid requirements of a telephone repeater tube, and it was the standard tube for use in all the Reichspost amplifiers from its introduction in 1920 until 1925. The cylindrical electrode system and glass supporting structure for the electrodes were carefully worked out to secure exact maintenance of the relative electrode spacings, and it was found to have a low sensitivity to microphonic disturbances.[279]

Meantime, the advantages offered for telephone repeater work by an oxide-coated cathode of the Wehnelt type, particularly as to constancy of filament operating characteristics during the useful life of the tubes, were appreciated. Siemens & Halske had begun work on this type of cathode (which was used in the LRS Relay) in 1912 and developed a tube with plate characteristics and power-handling capabilities similar to the BF, but using a Wehnelt cathode with a platinum-iridium core. This tube was designated as the type "BO" and was first introduced on a trial basis in the Post Office Amplifiers in 1923.[280] It is shown in Fig. 200.

Fig. 204



The BO operated with a filament current of 1.1 amperes at 1.8 volts, thus requiring only about one-half the filament power of its predecessor, the BF. It operated at an anode voltage of 220 volts, and had a mutual conductance of 700 micromhos and an amplification factor of about 15. It was superior to the BF in that it was not nearly so sensitive to changes in the filament current. The BF required that the filament current be held to within plus or minus 5% of the nominal value, whereas the BO would function satisfactorily with variations as high as plus or minus 15%. The BO was also an improvement on the BF in the matter of useful life, which was at least 3,000 hours, an increase of 200%. Similar tubes were made by the other manufacturers noted above.

These tubes were satisfactory until the need arose for amplifiers of higher power output for use in connection with submarine cable work. For this application the Siemens & Halske type "OCK" tube, shown in Fig. 201, was developed in 1926. It had an output power of about four times that of the BO tube. In obtaining this output the amplification factor was reduced to about 6, the internal impedance to about 5,000 ohms, and the mutual conductance was increased. The filament was longer, and the filament power required (1.1 amperes at 2.4 volts) was greater than that of the BO. In this tube a new grid construction was adopted, which involved the use of grid wires of very small diameter. Difficulties were encountered in the process of welding these grid wires to the supporting rings. The difficulties were overcome by eliminating the welding operation and pressing the hard tungsten grid wires into the relatively soft nickel supporting rings. The cylindrical anode was of wire mesh, and was blackened to increase its radiating ability, and to lessen the chances of grid emission. This tube was later superseded by the type "Ca," shown in Fig. 203, which had greater reliability.

The next telephone tube to make its appearance was the type "CO" shown in Fig. 202. It had an amplification factor of 4 and an internal impedance of 1400 ohms. It gave an output of about 1 watt and was used chiefly as an oscillator output tube. It was similar in construction to the OCK tube, and was later replaced by the type "Da," shown in Fig. 203, which had a longer life.

The type "Ba," also shown in Fig. 203, began to replace the BO about 1933. It operated at a filament current of .5 ampere, and with 220 volts anode potential. It required the same heating energy as the BO, however. For some applications a similar tube, designated as the "Be," which operated at 130 volts anode potential was also used. The advantage of these tubes lay in the reduced filament current, even though the filament power was the same. The lower current resulted in economies in the power supply and wiring of the repeater stations. These tubes also had a longer life than the BO, their life being considerably above 5,000 hours.

In addition to the telephone repeater tubes discussed above, there was another type of tube used during World War I by the German Postal Administration for terminal amplifiers. This was a double grid type of tube developed by Schottky.[281] Two varieties were used, one made by Siemens & Halske and designated type "110" (shown in Fig. 204) and the other by A.E.G. and denoted "K26." The filament current was .55 ampere at 3.2 volts for the 110, and it operated at 12-24 volts on both the anode and auxiliary grid.[282] The amplification factor was about 6 and the internal impedance about 9,000 ohms. The output was small but the tube was particularly adapted to the producing of the desired gains at low anode potentials. This was essential for their use in military work, since the terminal amplifiers were self-contained portable devices operated from their own batteries. After the war these fell into disuse, since there was no further need for the gains which they produced. In fact, high gain would have been a distinct disadvantage, because of the difficulties involved in making full use of it. It still survived for applications where low anode voltages were necessary, as in some types of measuring apparatus.

All the tubes subsequent to the CO

having an oxide-coated cathode used a platinum-nickel alloy wire for the filament core, in place of the platinum-iridium alloy formerly used. The change was introduced about 1935 and the new alloy core had several advantages. The oxide coating of the old core presented a large and variable resistance to the flow of the space current, in the case of the BO tube the resistance being of the order of 1,000 ohms, depending on the temperature and the condition of the cathode surface. The use of platinum-nickel in the core facilitated the application of new coating processes and resulted in a thinner and more uniform coating with greatly reduced transverse resistance. It also tended toward stabilizing the resistance of the filament during its operating life.

It will also be noted that the later tubes used a system of plane parallel electrodes. This permits the use of a W-shaped filament with consequent increase in the cathode emitting area. The cylindrical construction with axial filament previously used limited the filament to a single length. Increasing the length of the element structure was the only satisfactory way of increasing the emission. This involved mechanical difficulties particularly in tubes where the grid was placed close to the filament. An example of this is the OCK tube which had a filament length of about 1½ inches, which had to be kept accurately centered in a spiral grid only .118 inch in diameter. The plane parallel electrode system has the disadvantage that more power is required to maintain the cathode at the proper temperature since the radiation losses are greater. The open construction, however, facilitates the cooling of the grid and thus reduces the chance of grid emission.

With the introduction of the new cathode there was instituted a new method of nomenclature, suggested by the Postal Administration, and exemplified in the tubes shown in Fig. 203. It involved a designation composed of a capital or upper case letter, followed by a small or lower case letter. The capital letter indicates the output rating of the tube and the small letter indicates the place of the tube in the series of that output. Thus the "Aa" tube is the first of the "A" or lowest output series. The "Ba" is the first of the series with the next higher output rating. The "Ca," "Da," and "Ea" have respectively greater outputs, the last mentioned being a 5-watt tube.

It is interesting to compare German and American repeater-tube development. Both started at about the same time (1911) utilizing gaseous devices; the Arnold arc in America and the LRS Relay in Germany. In 1913 the American development of the high-vacuum tube with oxide-coated cathode got well under way, whereas the decision to use high-vacuum tubes was not made in Germany until 1917. The early German high-vacuum tubes used

(*Continued on page* 150)

Speaker Enclosures
(Continued from page 49)

with hair felt if possible. This can be obtained from auto supply houses as it is used under car floor mats, or may be the felt pad intended for ironing boards. In the absence of these, a blanket can be made with rock wool insulation and a piece of cloth or, as a last resort, a piece of celotex could be used. The idea is to absorb the high frequency radiations from the back of the speaker so they will not be able to reflect from the back of the baffle and, being out of phase with the speaker cone, cancel out some wanted frequencies therefrom.

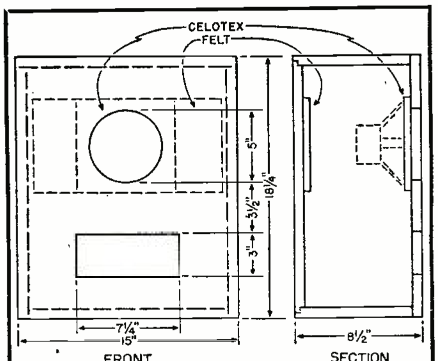
If a less elaborate enclosure is desired, the dimensions for a smaller, simpler model are given in Fig. 5. This houses a single heavy duty six-inch speaker. The author has been using this identical speaker system as a monitor speaker on a 15-watt, 2A3 amplifier, and the results are very good.

The approximate dimensions for bass reflex enclosures for different size speakers are given in Fig. 5, and you will see that even the largest enclosures are not too big for an average living room. Of course, an enclosure might be concealed in a bookcase or closet. The variations are practically limitless. You can arrange it to suit your own personal needs.

(Ed. Note: For further information on phasing of loud speakers, we refer you to an article appearing in the April, 1945 issue of Radio News, entitled "Phasing of Loud Speakers.")

—30—

Fig. 5. Mechanical dimensions for an enclosure employing a 6" speaker. Table shows cabinet size for other speaker sizes.



12" (or two 8") speakers	12" x 22" x 31"
15" (or two 10") speakers	13" x 25" x 33"
18" (or two 12") speakers	14" x 27" x 35"

All dimensions are o.d., assuming ¾" plywood.

Saga of the Vacuum Tube
(Continued from page 62)

a cylindrical element assembly with axial tungsten filament and having a life of 600-1,000 hours, whereas the American tubes were of plane parallel electrode construction, using oxide-coated cathodes with platinum-iridium cores, and with an operating life of 1,500 hours.

The first German oxide-coated cathode tubes using platinum-iridium cores appeared about 1923, with a life of 3,000 hours, and were not in full use until 1925. By 1922, however, the American tubes had been equipped with platinum-nickel cores, with a life of 20,000 hours. The use of platinum-nickel filament cores and plane parallel electrode systems was introduced into German practice about 1933, by which time the American practice had abandoned the open construction and was using a completely enclosed electrode system, of oval section to permit the utilization of a W-shaped filament. The filament current in the standard American repeater tubes was reduced to .5 ampere in 1927, with the same performance, whereas this did not take place in German practice until 1933.

The corresponding development in Germany of the vacuum tube as applied to radio, as distinct from wire practice, will be covered in a subsequent installment in this series.

References

271. *Gruschke, Dr. G.—"Die Entwicklung der Fernsprechverstärker" Siemens Zeitschrift, Vol.* 3, *No.* 3, *March* 1923, *pp.* 113-119.

272. Fritz, G. A.—"Wie die Verstärkerrohre vor 20 Jahren in die Praxis eingeführt wurde" Europaischer Fernsprechdienst, No. 34, January 1934, pp. 38-42.

273. Hopfner, K.—"Entwicklung und gegenwärtiger Stand der Verstärkertechnik in Deutschland" Elektrotechnische Zeitschrift, Vol. 45 No. 7, February 14, 1924, pp. 109-113.

274. Skowronnek, Karl—"Die Entwicklung der Elektronenverstärker-Rohre (Lieben Rohre)" Archiv fur Geschichte der Mathematik, der Naturwissenschaften, und der Technik, Vol. 13, 1930-1931, pp. 225-276.

275. Rukop, Hans—"Die Telefunkenrohren und ihre Geschichte" Telefunken Festschrift, 1928, pp. 114-154.

276. Vogel, F. and Haag, A.—"30 Jahre Siemens Fernsprechverstärker" Siemens Zeitschrift, Vol. 21, No. 1, January-February 1941, pp. 26-36.

277. Kollatz, C. W.—"Die Fernsprechtechnik" Georg Siemens, Berlin, 1922. P. 247.

278. Pohlmann, B. and Gehrts, Dr. A.—"Die Verstärkerrohre der Fernmeldtechnik" Siemens Zeitschrift, Vol. 2, 1922, No. 5/6, pp. 282-291.

279. Nebel, C.—"Die Entwicklung der Siemens Fernsprechrohre" Siemens & Halske Veröffentlichungen aus dem Gebiete der Nachtrichtentechnik, 5th year, 4th issue, 1935, pp. 215-226.

280. Pohlmann, B. and Gehrts, Dr. A.—"Werdegang einer Verstärkerrohre" Elektrische Nachrichtentechnik, Vol. 2, No. 3, March 1925, pp. 65-74.

281. Schottky, W.—"Uber hochvakuum Verstärker. III Teil. Mehrgitterrohren" Archic fur Elektrotechnik, Vol. 8, No. 9, 1919, pp. 299-328.

282. Gehrts, A.—"Elektronenrochren—Kennelinien und Betriebsdaten" Taschenbuch der drahtlosen Telegraphie und Telephonie, Springer, Berlin, 1927.

CAPTIONS FOR ILLUSTRATIONS

Fig. 196. Siemens & Halske Mechanical Repeater. Reproduced from Siemens Zeitschrift—1941.

Fig. 197. Modified von Lieben tube with concentric element assembly. Reproduced from Archiv fur Geschichte der Mathematik, der Naturwissenschaften und der Technik—1930-31.

Fig. 198. Siemens & Halske type "Mc" telephone repeater tube. Left—Experimental model. Center and Right—Production type tubes. Reproduced from S. & H. Veröffentlichungen, 1935.

Fig. 199. Siemens & Halske type "BF" tube. Left—Experimental model (1920) using glass star. Right—Production type tube. Reproduced from S. & H. Veröffentlichungen, 1935.

Fig. 200. Siemens & Halske type "BO" tube. Reproduced from Elektrische Nachtichtentechnik—1925.

Fig. 201. Siemens & Halske type "OCK" tube. Left—Early construction with glass bracket for cathode attachment. The grid is unsupported at the upper end. Right—Later construction with better reinforcement. Reproduced from Siemens & Halske Veröffentlichungen—1935.

Fig. 202. Siemens & Halske type "CO" tube. Reproduced from S. & H. Veröffentlichungen, 1935.

Fig. 203. Latest developments (1935) in telephone amplifier tubes made by Siemens & Halske. Left—Type "Ba," which replaced "BO." Center—Type "Ca," which replaced "OCK." Right—Type "Da," which replaced "CO." Reproduced from S. & H. Veröffentlichungen—1935.

Fig. 204. Siemens & Halske type "110" tube. Reproduced from "Taschenbuch der drahtlosen Telegraphie und Telephonie" edited by Banneitz, published by Springer, Berlin, 1927.

(To be continued)

Photo Credits

Page	Credit
25	Western Electric
26 (top), 28 (top)	Chris Craft
26 (bottom)	Bludworth-Marine Inst. Co.
28 (bottom), 106	Radio Marine Corp. of America
32 (left), 33 (bottom)	CBS
37	Frank Ross, Staff Photographer
44, 86	The Mathieson Alkali Works
45 (top), 76	Galvin Mfg. Corporation
45 (bottom)	Standard Freight Lines, Inc.
53	NBC

SAGA OF THE VACUUM TUBE

By GERALD F. J. TYNE

Research Engineer, N. Y.

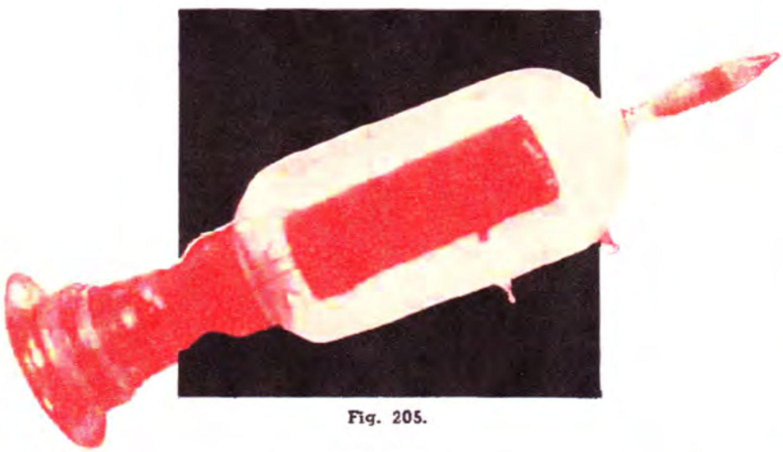


Fig. 205.

Part 19. Covering developments and applications of tubes in England from 1911 through World War I.

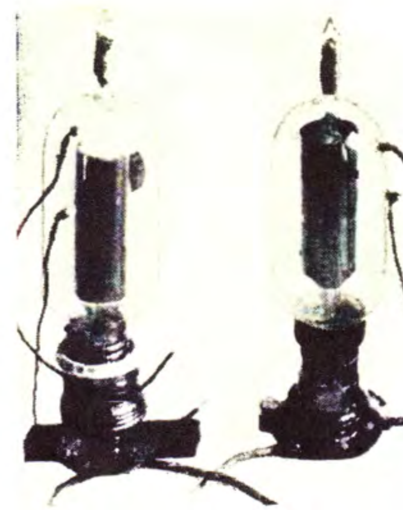


Fig. 206.

WE HAVE considered the evolution of the vacuum tube as a telephone repeater element in Great Britain. The early telephone repeater tubes engineered in Britain apparently were adapted from the radio art and were not developed primarily for telephone use. The early British radio tubes were of the gaseous type and seem to have been inspired largely by the work of von Lieben and Reisz in Germany. True, Fleming had obtained a sample of the de Forest Audion as early as 1907, but we have no records showing that he or any one else in Britain was activated by it immediately.

The first work in tube development in England seems to have been done about 1911 by Captain H. J. Round of the British Marconi Company. It appears to have been done in collaboration with Telefunken, probably as a result of the recently concluded Tele-

Fig. 207.

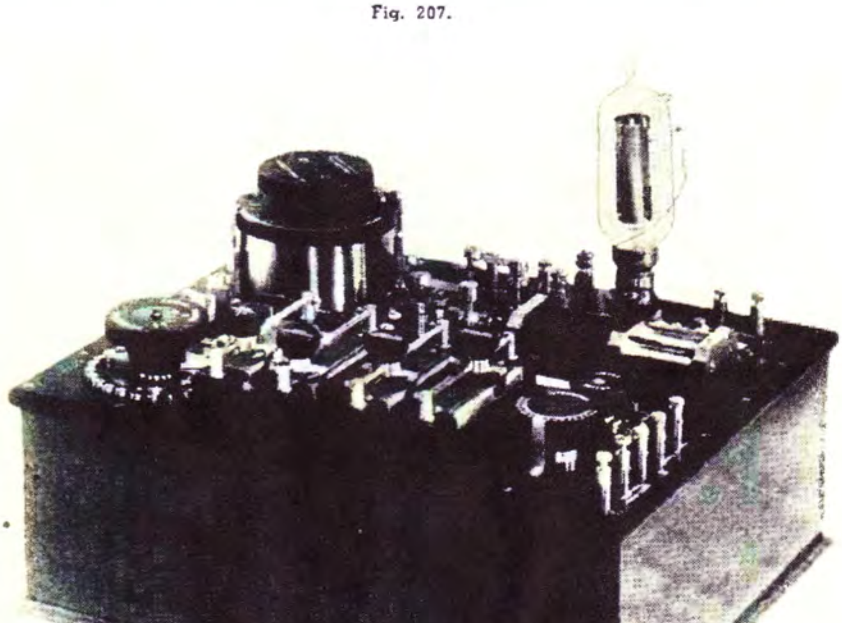


Fig. 208.

funken-Marconi patent agreement. Little has been published concerning Round's early work, hence it is difficult to trace with any degree of authority the evolution of the Round tube. Round speaks intimately of the work of Alexander Meissner of the Telefunken Company in an article on wireless telephone published in 1915,[283] but the article deals chiefly with circuits and applications, and no mention is made of the Round version of the LRS Relay.

The Round tubes differed from the Meissner version of the LRS Relay chiefly in details of design.[284] They were first employed by Round as high-frequency amplifiers, and later as oscillators as well. They were remarkably good amplifiers when operated under optimum conditions. The gain obtainable from the Round type "C" was equivalent to approximately three stages of the best "hard" tube of that time, the so-called "French" tube.[285] The Round type "C" is shown in Fig. 205.

The Round tubes were characterized by coated cathodes, wire mesh grids forming a practically complete enclosure for the filament, a long tubulation containing means for adjusting the vacuum, and cylindrical anodes with a large ratio of anode-filament to grid-filament distance. The filaments were usually of hair-pin shape, with the hottest part at the top. Round considered it necessary for stability of operation that the grid completely enclose the filament. If this were not done the inside of the glass bulb would become charged by bombardment from the filament. If the charge, so accumulated, produced an appreciable electrostatic field at the filament, it would be necessary to readjust the grid potentiometer to compensate. Hence, unless a completely enclosing grid were used this rather critical parameter would require frequent readjustment, an undesirable operating limitation.[286]

There were several types of Round tubes, of which the type "N" and type "T," the latter first produced in 1913,[287] may be taken as representative. Fig. 206 shows two versions of the type "N" and Fig. 207 shows the Marconi Type 27 Receiver with one of these tubes in use as a high-frequency amplifier. The Round type "T" is shown in Fig. 208. Fig. 209 is a view looking down on the type "T" (with the tubulation removed) and shows the internal construction.

The type "N" had a single lime-coated filament which took 3 to 4 amperes at 2 to 2.5 volts. It operated with 40 to 80 volts on the anode, and was used in the famous Marconi No. 16 Circuit, which used a carborundum detector. The tube functioned in this circuit as an r.f. and a.f. amplifier, the circuit being of the reflex type. A variant of the type "N" was the type "CA" shown in Fig. 210, which had an extremely fine mesh grid and operated with filament current of 2.5 amperes and anode voltages up to 200 volts.[288]

The type "T" also had two variants, one with coarse and one with fine mesh grid. One of these was known as the type "TN" and operated at 200 volts on the anode. There were three separate filaments, of the oxide-coated type, which were used in succession. The filament current was 4 to 4.5 amperes at about 6 volts. The type "TN" was used in the "Short Distance Wireless Telephone Transmitter and Receiver" made in 1914 by the British Marconi Company,[289] and shown in Fig. 211. It, like the other Round tubes, was manufactured by the Edison & Swan Electric Company.

The first actual use of the three-electrode tube in the British armed services was by Round, in December 1914, in a Marconi Direction Finder.[290]

Many of the Round tubes were used by the Royal Flying Corps (later the Royal Air Force) in the earlier wireless sets for plane-to-ground communication during World War I. Discussing their use shortly after the War, one of the R.A.F. officers said:[291]

"The soft valves used in the early days were provided with a regulating device in the form of a pip containing a crystal of asbestos or other mineral. This when heated reduced the vacuum in the valve. It was the custom to heat the pip before a flight took place but it often happened that when in the air one found that the valve had become too hard to oscillate. In order to overcome the danger of applying a naked flame, a small electric heater was devised which could be placed over the regulating pip."

The Round tubes were used to a considerable extent because of their high gain and power handling capabilities in British communications equipment during the war. They were difficult to manufacture and required highly trained operators to utilize their capabilities. Concerning their

Fig. 209.

Fig. 210.

Fig. 211.

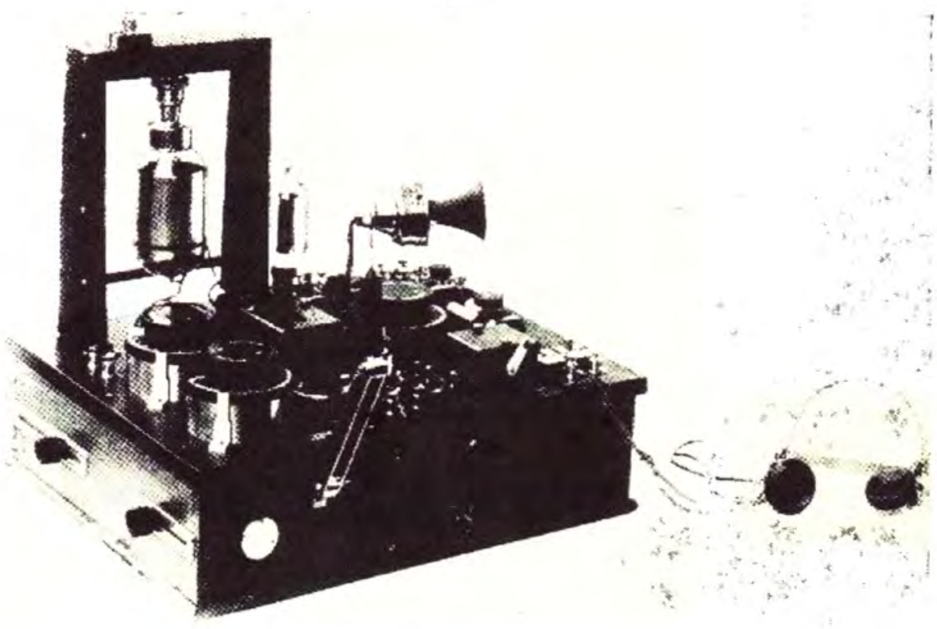


Fig. 212.

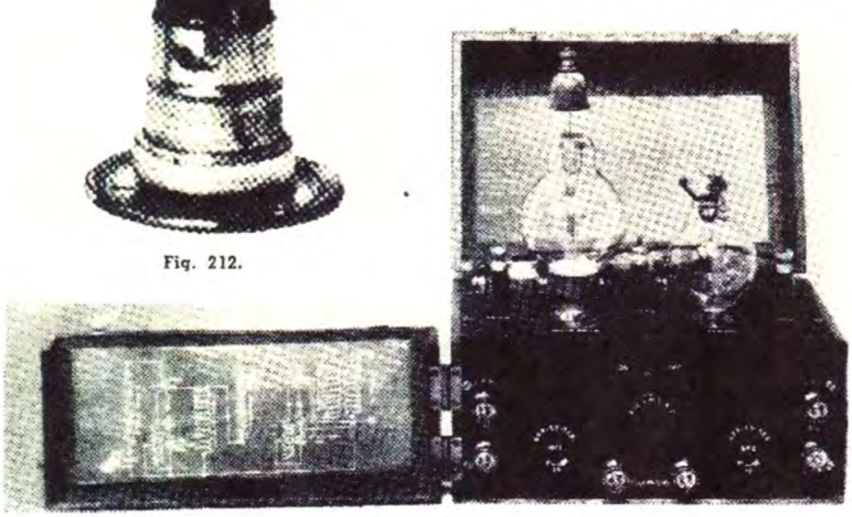


Fig. 213.

manufacture, Round once wrote:[292]

"I have mentioned that the production of valves at that time required special men. Even then it was a terrible process. Again and again we lost the knack of making good tubes owing to some slight change in the materials used in their manufacture. A thorough investigation was impossible, as all hands were out on the stations. On several occasions we were down to our last dozen tubes."

Another soft tube, used to a limited extent by the British armed services during World War I, was called the "White" valve. It resulted from work done at the Cavendish Laboratory, Cambridge, under the direction of Sir J. J. Thomson. The earlier experiments were by Wright and Ogden, but the later developments were by G. W. White, whence the designation.[293]

White worked for some time on the use of cold-cathode tubes and succeeded in making some which operated satisfactorily in wireless work.[294] These tubes were not as sensitive as those of the hot-cathode type although they did possess some advantages. No filament heating battery was required, and their action was not sensitive to small changes in the internal pressure.

Probably because of the increased sensitivity obtainable, White eventually abandoned the cold cathode and went to an incandescent cathode construction. A White tube of the type which came into practical use in 1916 is shown in Fig. 212. The filament is of oxide-coated platinum, operating with 2.8 amperes at 6 volts. The grid is a disc of perforated copper and the anode is of iron amalgamated with mercury. It operated at anode potentials from 25 to 75 volts. The base is of the bayonet type and the grid connection is made through the base shell. The anode connection is made to the knurled nut at the top of the tube. This tube was used in the Mark III Amplifier, which was designed by the British Signals Experimental Establishment for field use, and was first manufactured in 1917.[295] Two tubes were used in this amplifier, the second being a de Forest Audion. The amplifier, which is shown in Fig. 213, was of the high frequency type using regeneration, and was intended for use in connection with the Mark III Short Wave Tuner.

It will be observed that, measured by present day standards, the soft tubes made by Round and White were of comparatively large physical size, as was the original LRS Relay. This was necessary in the interest of stability of operation. Any attempt to reduce the volume of the tube meant an increase in the ratio of electrode area to the volume of the gas present, so that the variations in electrode temperature had a greater effect on the residual gas. The smaller the gas volume, the more erratic was the tube.[296]

It was appreciated, even as these developments were carried out, that the high vacuum tube had great advantages in military work, because of the stability of its characteristics and the uniformity of the manufactured product. Yet the soft tube possessed such a high sensitivity that much development effort was expended in an attempt to make of it a stable, reliable device, which could be applied in military work, where the skill of the operator could not be guaranteed.

The manufacture of soft tubes was undertaken by the British Thomson-Houston Company at Rugby during the summer of 1916 and the first production was of the Audion type, but with much better life expectancy. Serious difficulties were experienced early in 1917, and as a result of investigation the Audion structure was abandoned and a soft tube similar in construction to the hard "R" tube was developed. This tube was known as the "R2 valve" and at first was nitrogen filled to a pressure of 0.06 mm. mercury. The pressure was measured during manufacture by measuring the width of the dark space in an auxiliary cold cathode tube. After development the specifications on this tube were released to several manufacturers, and the first quantity production was achieved by the Osram-Robertson Works of the General Electric Company, Ltd., in June of 1917.

Difficulties were encountered in maintaining the gas pressure, because of the absorption of nitrogen by the electrodes. Later R2 tubes were helium-filled to a higher pressure, about 0.6 mm. mercury. The manufacture of the helium-filled R2 was begun in September 1917.

The filament of the R2 tube was of drawn tungsten wire. It was 0.79 inch long and 3.3 mils in diameter. It operated at 1.1 amperes with a potential drop of about 3.3 volts. The anode was of sheet nickel, bent into the form of a complete cylinder, approximately 0.6 inch long and 0.35 inch in diameter. The grid was a helix of molybdenum wire of 16 mils diameter, wound with a pitch of 14 turns per inch, and the internal diameter of the helix was about 0.18 inch. The anode operated at 24 to 40 volts, and the grid bias was

Fig. 214.

adjusted by means of a potentiometer to the optimum operating value while in use. An R2 tube is shown in Fig. 214. This tube was made by General Electric (Osram), British Thomson-Houston, and Edison & Swan.

A modification of this tube, known as the R2A, manufactured chiefly by Marconi-Osram, was used in the British naval installations during the last years of World War I. It marked the final development of the soft tube in England. It operated under the same conditions as the R2 except that it had a somewhat narrower range of anode voltage, 28 to 38 volts.

Another soft tube used to a limited extent for aircraft work was known as the "Air Force Type D," and will be touched upon in a later installment.

Before leaving the consideration of soft tubes of British origin, mention should be made of one other. This is the so-called "NPL" valve, described by Stanley in 1919, in the following words:

"In this valve the plate was a thin sheet of circular metal; above this was the grid consisting of a perforated sheet of metal, beyond which was the bowed tungsten filament. This was a bad design; the grid was too heavy and the flow of electrons from the filament was not uniform along its length but was concentrated at the center. The design is now out of date.—"

Apparently this was a soft tube, since the characteristics given by Stanley show kinks ascribed by him to the presence of mercury vapor, and he records the presence of an amalgam of mercury on the anode. The author has never seen any mention of this tube except that referred to above. It may be possible the "NPL" was another designation for the White valve previously described. If the reader compares the description given by Stanley with the White valve shown in Fig. 212, he will see that if the White valve be mounted with its base uppermost Stanley's description reads rather well on it.

References

283. *Round, H. J.—"Wireless Telephony" Yearbook of Wireless Telegraphy,* 1915. *pages* 572-582.

284. *Leggett, Bernard—"Wireless Telegraphy with Special Reference to the Quenched Spark System" E. P. Dutton & Co. New York,* 1915, *page* 164.

285. *Round, H. J.—"Direction and Position Finding" Jour. I.E.E., Vol* 58, 1919-1920, *pages* 224-257.

286. *Howe, G. W. O.—"The Marconi-Mullard Valve Patent Litigation" Electrician Vol.* 90, *May* 11, 1923, *page* 500.

287. *Picken, W. J.—"Wireless Section—Chairman's Address" Jour. I.E.E., Vol* 88, *Part I,* 1941, *pages* 38-46.

288. *Dowsett, H. M.—"Wireless Telegraphy and Telephony: First Principles, Present Practice, and Testing" Wireless Press,* 1920, *page* 131.

289. *See reference* 288, *page* 143.

290. *Cusins, Lt.-Col. A. G. T.—"The Development of Army Wireless during the War" Electrician Vol.* 82, *April* 25, 1919, *pages* 493-494.

291. *Prince, Major C. E.—"Wireless Telephony on Airplanes" Jour. I.E.E., Vol* 58, 1919-1920, *pages* 377-390.

292. *See reference* 285, *page* 233.

293. *Gossling, B. S.—"The Development of Thermionic Valves for Naval Uses" Jour. I.E.E., Vol.* 58, 1919-1920, *pages* 670-703.

(Continued on page 124)

flected by water surrounding a sea-borne radar set.

Spark gap—An arrangement of two fixed electrodes between which a high-voltage arc discharge takes place.

Squaring amplifier—See Overdriven amplifier.

Squegging oscillator—An extreme form of grid blocking in an r.f. tuned-grid tuned-plate circuit.

Synchronism—The relationship between two or more periodic or recurrent wave forms, when the phase difference between them is zero.

Synchronizer—See Electronic timer.

Tail—Attenuated decay of an r.f. pulse.

Target—Any object which produces a radar echo.

Time base—The trace produced on the screen of a cathode ray tube by deflection of the electron beam.

Time constant—An indication of the speed with which a circuit can be charged or discharged.

Timer—See Electronic timer.

Transmitter pulse—Burst of r.f. energy radiated by the radar transmitter. The pulse appears as a strong signal at the left end of the oscilloscope time base. —30—

Saga of the Vacuum Tube

(Continued from page 58)

294. *White, G. W.—"The 'Discharge Tube' Used as a Wireless Valve" Electrician* Vol 76, October 22, 1915, page 103.

295. *Denman, R. P.—"Catalogue of the Collections in the Science Museum. Electrical Communication. II Wireless Telegraphy and Telephony"* H. M. Stationery Office London, 1925, page 14.

296. *See reference 284, page 165.*

CAPTIONS FOR ILLUSTRATIONS

Fig. 205. Round type "C" Valve. Photograph courtesy R. McV. Weston.

Fig. 206. Left—Round type "N" Valve with screw base. Right—Round type "N" Valve with Ediswan bayonet base. Photograph courtesy Marconi's Wireless Telegraph Co., Ltd.

Fig. 207. Marconi type "27" Receiver, 1914-1918, using Round type "N" Valve. Photograph courtesy Marconi's Wireless Telegraph Co., Ltd.

Fig. 208. Round type "T" with multiple cathodes. Photograph courtesy R. McV. Weston.

Fig. 209. Top view of Round type "T" with tubulation removed, showing characteristic Round mesh type grid.

Fig. 210. Round type "CA" Valve. Photograph courtesy Radio Corporation of America.

Fig. 211. Marconi Short Distance Wireless Telephone Transmitter and Receiver. The tube in the gallows frame is the Round type "TN" used for transmitting. The tube at the right rear is the Round type "C" used for receiving. Photograph courtesy Marconi's Wireless Telegraph Co., Ltd.

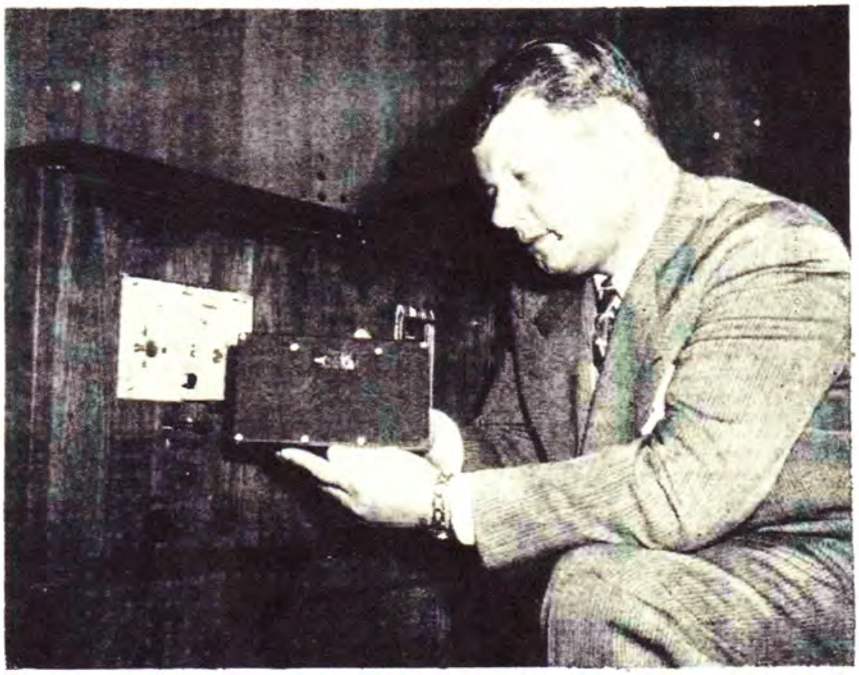
Fig. 212. White Valve. Photograph courtesy R. McV. Weston.

Fig. 213. Mark III Amplifier using White Valve and de Forest Audion. Photograph copyright by H. M. Stationery Office.

Fig. 214. Osram R2A Valve, fitted with candelabra base for use in naval apparatus designed for de Forest Audion. This valve was usually supplied unbased, the user applying whatever base he saw fit. Photograph courtesy Bell Telephone Laboratories.

(To be continued)

William P. Lear, President of Lear, Inc., holding the "magazine" of a radio and wire recorder combination shown recently at a special preview given to the press and science writers. The "magazine" does away with threading the wire; it can be changed as easily as slipping a pack of cigarettes into your pocket. Wire recorders will become a part of many postwar home receivers and they will also be offered as a separate unit, to be attached to present sets, as well as for other commercial entertainment, educational, and industrial uses.



Saga of the VACUUM TUBE

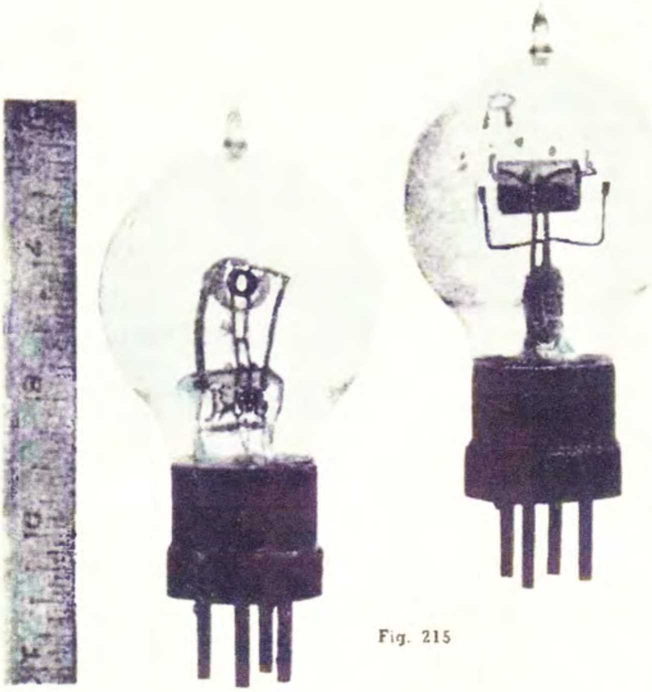


Fig. 215

Part 20. Continuing the study of the evolution of the vacuum tube and the many mechanical problems that were confronted in their manufacture during World War I.

By
GERALD F. J. TYNE
Research Engineer, N. Y.

THE manifold difficulties in the manufacture and in the utilization of soft tubes, because of the non-uniformity of the manufactured product and the erratic behavior of individual tubes, eventually compelled the adoption by the British armed services of hard tubes even though their comparative insensitivity necessitated the use of multistage amplifiers. The exact time when this decision was reached is unknown but Gossling states that[297] a study was made of some "oscillions" imported from America in 1915 by the Admiralty and that the most illuminating data was obtained in 1916 by H. M. Signal School at Portsmouth on re-exhausted audions of the flat plate and zigzag wire grid type. Later in 1916 further study was made of a "pliotron" made by the American General Electric Company.[298]

Meantime, the British Thomson-Houston Company had been studying the so-called "French" valve, developed by the French Military Telegraphic Service. From all this work came a receiving tube designated as the *R* valve. This tube was widely used in its various embodiments. Fig. 215 shows two views of an *R* valve made by Osram. Tubes of this pattern were made by all of the British manufacturers.

The *R* tube had an anode of sheet nickel, bent in the form of a cylinder about 5/8 inch long and .41 inch in diameter. The grid was an 11 turn helix about .2 inch in diameter, the wire being .005 inch in diameter. The filament was of tungsten and operated with .7 ampere at about 4 volts. The anode voltage was 30 to 100 volts, anode resistance 35,000 to 40,000 ohms, and amplification factor about 9.

The earliest models of this tube had a simple helix form of grid patterned after the French tube. This proved to be very microphonic and later tubes had the grid stiffened by means of a catenary suspension. Such was the construction of the B.T.H. Type *A* tube.

The base usually applied to the *R* tube was of the type originally developed for the French tube. It has been called by various names such as "Burndept," "Continental," and "European." The dimensions and pin spacings are given in Fig. 216. The outer metallic shell was of copper or (later)

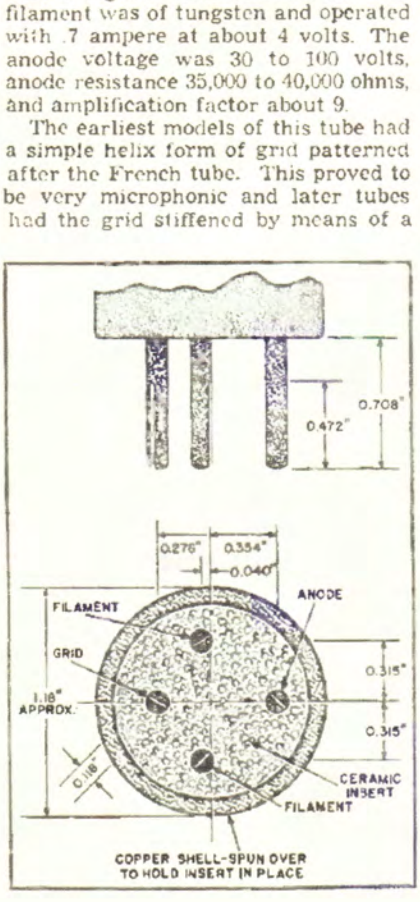


Fig 216

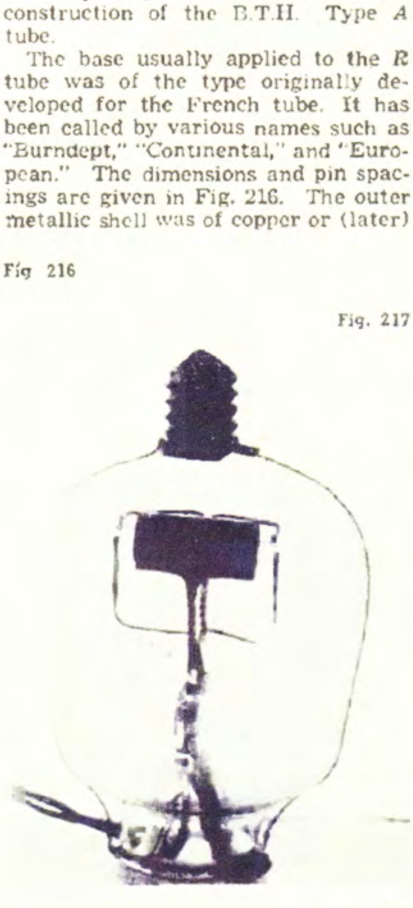


Fig. 217

Fig. 218

brass, and the pins were set in a ceramic insert.

The *R2* tube, second in the *R* series, has been discussed in a previous instalment. The author has been unable to obtain any information concerning the *R3* and does not know whether or not it was ever manufactured commercially.

Now it must be remembered that this tube development was going on in the midst of a world war. Engineers and scientists were working under pressure to satisfy the incessant demand for more and better communications equipment. The chief naval communications problem in the early part of World War I was to get good c.w. reception. Audions and other soft tubes were used in naval installations as local oscillators in heterodyne c.w. reception. The audion first came into prominence in naval work for this application. The extent of its use is indicated by the fact that there were 800 audions of de Forest manufacture in service for the Admiralty in 1917. Small arc generators had previously been used as local oscillators but were troublesome, and even the smallest which could be conveniently operated gave a much higher output than was desirable. The Audion and the Round tube operated satisfactorily over the entire range of frequencies required, but were short-lived and difficult to handle.

Up to this time, the British Thomson-Houston Company had been successful in the manufacture of *R* type tubes, but the standard *R* tube would not oscillate over the complete frequency range used in this work. They now proposed to develop a high-vacuum tube to replace the Audion and other soft tubes in use. The *R4* was born of observations made by Mr. Edmundsen of the B.T.H. Co. in the course of this work. A number of modifications of the *R* tube were made up for trial, and by accident one of these experimental tubes had a distorted filament. The distortion was such as to bring the filament and grid very close together. Mr. Edmundsen observed that this tube was very satisfactory in operation, being capable of meeting all the requirements for this application. But it was not reproducible. The *R4* was an attempt to duplicate, in a commercially manufacturable tube, the characteristics of this "freak."

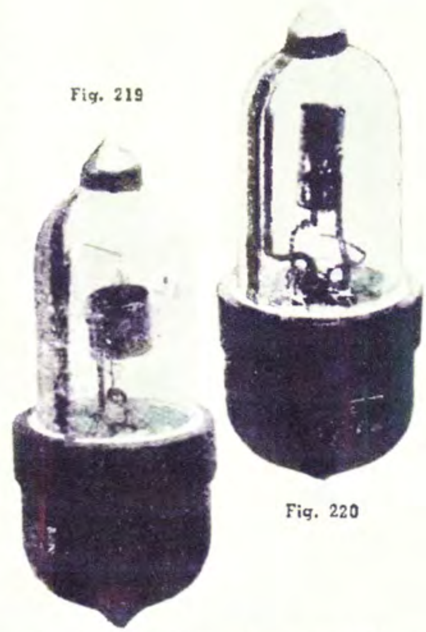


Fig. 219

Fig. 220

The grid diameter was made as small as possible, the diameter and pitch being chosen to accomplish the desired effect. The anode was of nickel sheet about .006 inch thick, bent in the form of a cylinder .36 inch in diameter and .68 inch long. The helical grid was of molybdenum wire, .006 inch in diameter, wound with a pitch of 25 turns per inch, had an internal diameter of .14 inch and a length of .79 inch. The filament was of tungsten wire containing 1% of thorium, about 3.5 miles in diameter and 1 inch long, and crimped to eliminate tensile strains. The filament operated with about 1.1 amperes at 3.5 to 4 volts. The anode voltage ranged from 45 to 55. This low anode voltage greatly eased the requirements on the hardness of the vacuum to be obtained.

The characteristics of this tube compared very favorably with those of the soft *R2*. The working temperature of the filament was sufficiently low so that the crackling noises, usually experienced when thorium was used, were not present.

The first of these tubes, made by the B.T.H. Company, had a life of about 1500 hours and attempts were made by other manufacturers to improve the tube and attain longer life. This was finally achieved by the Osram-Robertson Works, by the development of an extremely hard exhaust which could be obtained with a minimum of bombardment. The commercial product of these tubes was long-lived, some lasting for 8000 hours, while the general run had a life of several thousand hours. The *R4* was also made by Ediswan, and Stearn Lamp Company.

The *R4* was redesigned about a year later to reduce the filament power required. The diameter and length of the anode were reduced, the pitch of the grid increased slightly and the fila-

Fig. 221

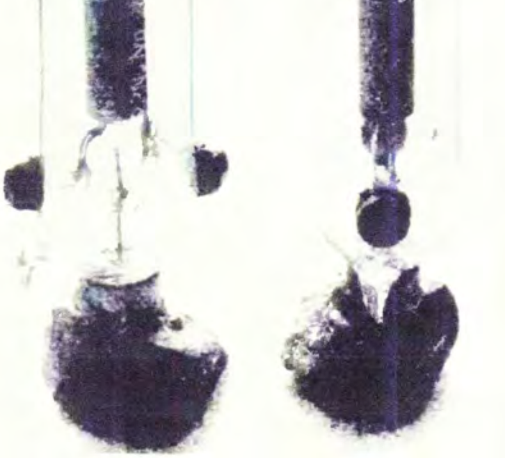


Fig. 222

ment wire changed to 2.4 mil diameter thoriated tungsten. The redesigned tube was designated R_{14} and is shown in Fig. 217. It operated with a filament current of about .65 ampere at 2.5 to 4 volts. The life of the R_{14} was was about 1500 hours. The filament operated at a somewhat higher temperature than that of the R_4 and, hence, the tube was somewhat noiser.

The R_{18}, shown in Fig. 218, was designed for use in amplifiers where the noise introduced by the R_{14} was objectionable. The element structure was practically the same as that of the R_{14} except that the filament was of unalloyed tungsten. It operated at the same filament current as the R_{14} but at a somewhat higher filament voltage, the range of voltage being 3.4 to 3.9 volts.

The final development of high vacuum receiving tubes for British Naval Service, during World War I, was the R_5, manufactured by the "Z" Electric Lamp Company (among others) and shown in Fig. 219. This tube was evolved experimentally from the R series and followed in its general design one of the high vacuum receiving tubes developed by Captain Round, which will be discussed later. The first quantity production did not come up to expectations and the tube was redesigned to increase the ratio of saturation current to working current. With this change it was satisfactory. The anode was of nickel sheet, .006 inch thick, in the form of a cylinder .36 inch long and .36 inch in diameter. The helical grid was composed of 14 turns of .004 inch diameter molybdenum wire, with a pitch of about 22 turns per inch and an internal diameter of .115 inch. The filament was of pure tungsten, approximately 2.5 mils in diameter and .87 inch long. It operated with a current of about .65 ampere at about 3.6 volts. The anode potential used was 30 to 60 volts.

It will be noted from the photograph that this tube differed from the rest of the R series in its method of mounting. The bulb and cap used on this tube were developed by Captain Mullard for the use of the R.F.C. The ratio of diameter to length of the anode is also different from other tubes of the R series, being greater. This change was made to reduce grid-anode capacitance. This capacitance was about 2 $\mu\mu$fd. when the tube was cold and somewhat less when the filament was in operation. One drawback was found. Leakage developed between the electrode leads outside the glass, due to the cement used to attach the caps being hygroscopic.[239]

The design of this tube was inadequate in some other respects. The thin spring wire after heating lost its elasticity and the lack of suitable spring action caused considerable filament breakage while tubes were still on the exhaust pump. The adjustment of spring tension was quite critical. If the tension was too great the filament would break, if too little it would sag and touch the grid.

There were two other tubes made

for use in Air Force equipment, which were similar mechanically to the *R5*. These were known as the "Air Force *C* Valve" and "Air Force *D* Valve." An Air Force *C* Valve made by Osram is shown in Fig. 220. This tube was first introduced about September, 1918. It was a high-vacuum triode for receiving purposes and had a pure tungsten filament which operated at 5 volts and .75 ampere. It had an amplification factor of about 6 and anode impedance of 16,000 to 30,000 ohms. The anode voltages used were between 50 and 70.

The Air Force *D*, which was a soft tube for use as a detector, was first employed about January, 1919. It resembled the *C* in external appearance and mounting but the anode was of larger diameter and the grid was of gauze rather than the helical wire type.

The design of the *R5* was based on a high-vacuum tube which had first been produced for the British Marconi Company in 1916 by Captain Round, and designated by them as *V24*. It is shown in Fig. 221. The *V24* was intended specifically for use as a high frequency amplifier, since it had been found that it was impracticable to build a satisfactory multi-stage amplifier using *R* type and similar tubes of the single-ended construction with the conventional base. The common type of multi-stage amplifier at that time was resistance-capacitance coupled, and the interelectrode capacitances of the *R* tube were a considerable shunt on the resistance. Accordingly, in the design of the *V24*, Captain Round strove to reduce these capacitances as much as possible by separating the leads as far as possible. This was accomplished by using a cylindrical bulb and bringing out leads to the axial filament at opposite ends, while the anode and grid connections were brought out on caps on the sides of the bulb. This tube, which had a spring tensioned filament, operated with a filament current of .75 ampere at about 5 volts. The anode voltage used varied between 20 and 60 volts. The amplification factor was about 6 and the internal impedance 15,000 to 20,00 ohms. Six of these tubes were used in the famous Marconi D-55 Amplifier as high frequency amplifiers. This amplifier was widely used in marine work. In fact this tube was still being made, by hand, for replacement purposes in these amplifiers, up to about 1937.

A companion tube to the *V24* was the Marconi type *Q*, which was used in the D-55 Amplifier as a detector, following the six stages of high-frequency amplification. This tube was similar in appearance and mounting to the *V24*, as may be seen from Fig. 222. It differed chiefly in the construction of the grid, which was of fine mesh gauze, and which was carried on two glass beads through which the filament leads passed. This tube had a higher amplification factor and internal impedance than the *V24*, the values being 50 and 150,000 ohms respectively. It also re-

(*Continued on page* 129)

the 10,000 ohm resistors across the windings of the i.f. transformers should be replaced with ones of higher value. 50,000 ohms represents a good compromise value. If this change is made, it is well to loosen the coupling of the i.f. transformers by spacing the windings 1" to prevent double peaks.

The *S* meter indicates relative signal strength and may be calibrated in arbitrary units to suit the user. In use the reading will never fall completely to the zero mark even with a strong signal, as there is always some plate current flow, even when the a.v.c. circuit develops a high grid bias. This is not troublesome as the meter may be set to give an optimum reading on a strong signal by adjusting the meter resistor R_{10}.

Future plans for the receiver call for the addition of a provision for FM reception, as well as some means of varying the selectivity by means of a panel control. There is also a possibility that the r.f. coils may be made plug in to allow coverage of additional bands.

-30-

Saga of the Vacuum Tube

(Continued from page 56)

quired a higher anode voltage (up to 150 volts) for good operation.

World War I, with its imperative demands for communication equipment, brought about forced draft development in Britain as well as in America. When the need for vacuum tubes in quantities became manifest, the British military communications officers could turn only to the incandescent lamp manufacturers for production in quantity. These manufacturers, like the General Electric Company in America, made use of the materials and techniques with which they were familiar, and the background of the makers was reflected in the product. They abandoned the oxide-coated cathode of Round and went to a filament of tungsten, in the working of which they were experienced. This channeled the development along incandescent lamp lines, in order to permit of quantity production in the shortest possible time.

In America, where the high vacuum tube was developed from 1913, the situation was different. For military purposes, the American government had another source of supply in the Western Electric Company, who by the time of the war were already manufacturing high vacuum tubes for use in the telephone system. Their development had followed a different line. Their thinking was also conditioned, not by experience in the manufacture of similiar devices but by the objective of insuring the operation of the device over long periods, with complete reliability and uniformity of characteristics, and with only infrequent routine attention. In the quest of this desideratum, they had surveyed the possibilities and had focussed their effort on the oxide-coated cathode as being the best suited to these requirements. Hence, in this country, development had proceeded along both paths and in the end both types of tubes were used by the armed services.

The result of these parallel lines of development is that there are excellent cathodes of either type available today. The tungsten filament has proven to be peculiarly well fitted for use in large transmitting tubes while most of the tubes used in the home radio receiver are of the oxide-coated cathode type.

CAPTIONS FOR ILLUSTRATIONS

Fig. 215. Osram type "R" with European base. Photograph courtesy Bell Telephone Laboratories.

Fig. 216. Dimensions of European base.

Fig. 217. Osram R4A valve equipped with candelabra base. Photograph courtesy Bell Telephone Laboratories.

Fig. 218. Osram R4B valve with European base. Photograph reproduced from page 646 of Wireless World for August 19, 1922.

Fig. 219. Osram R5 valve. Photograph courtesy Bell Telephone Laboratories.

Fig. 220. Air Force "C" valve. Photograph courtesy Bell Telephone Laboratories.

Fig. 221. Two views of Marconi V24. Photograph courtesy Bell Telephone Laboratories.

Fig. 222. Marconi type "Q" valve. Photograph courtesy Bell Telephone Laboratories.

References

297. *Gossling, B. S.—"The Development of Thermionic Valves for Naval Uses" Jour. I.E.E., Vol. 58,* 1919-1920, pages 670-703.

298. *Fortescue, C. L.—"The Three Electrode Thermionic Valve as an A.C. Generator" Electrician, Vol. 83, September* 19, 1919, *pages* 294-295.

299. *See reference* 297, *page* 699.

300. *Round, H. J. "The Shielded Four-Electrode Valve" Cassell & Co. Ltd., London,* 1927, *page* 8.

(To be continued)

Electronic Volt-Ohmmeter

(Continued from page 50)

lating tube, sometimes called a cathode follower. This cathode follower is a simple resistance coupled amplifier, the entire load resistance of which appears in the cathode circuit. Any input voltage applied to the grid of the tube will cause an increase in current through the tube and a consequent increase in the voltage at the cathode. This increasing voltage is in opposition to the action of the initial applied voltage, consequently reducing the effective amplification of the tube. The final result is that the tube does not amplify at all; the voltage at the cathode "follows" that at the grid, to a close approximation. However, one useful purpose has been achieved. The *input* resistor for the cathode follower stage can be made very high. The *cathode* resistor can be of the order of

Fig. 223

Saga of the VACUUM TUBE

Part 21. Vacuum tube developments that were carried on in France and Germany during the first World War.

By GERALD F. J. TYNE
Research Eng., New York

VACUUM tube development on the Continent during World War I was carried on chiefly in France and Germany, although the Dutch and Russians were also active. The work in France, as has previously been mentioned was done almost entirely by the French Military Telegraphic Service under the able guidance of Colonel (later General) Ferrie.

Early in the war, the French realized the manifold advantages of wireless telegraphy as a medium of communication in military work. Since military stations, of necessity, must be portable, the transmitters and receivers must be light weight, which necessitates a minimum of power consumption. The need for reliable communication under all conditions could be met by using high power transmitters and relatively low sensitivity receivers. Since the weight and bulk of transmitting equipment increases rapidly with the requirements for radiated power, this solution was not a satisfactory one. The use of low or medium power transmitters in conjunction with high sensitivity receivers was much more desirable, even necessary. To increase receiver sensitivity some form of amplifying device must be used. The three electrode vacuum tube was, by far, the best device available.

In August, 1914, the French Military Telegraphic Service instituted an intensive development program with a view to obtaining a vacuum tube suitable for military applications. While development of a number of types was followed, problems of supply and distribution dictated the provision of a *universal* tube, one which could be used as high or low frequency amplifier, detector, or oscillator.

The design of such a tube was settled upon early in the program and quantity production was undertaken in 1915-1916.[391] It was a *hard* tube, known usually as the *French tube*, although it was also designated as the *Type S* tube. There were minor variations in construction, depending on the manufacturer.

Fig. 224 shows one of these tubes. The element assembly was of the concentric cylindrical type, mounted with the axis of the assembly horizontal. The anode was a cylinder of sheet nickel, .59 inch long and .39 inch in diameter. The filament was of pure tungsten about .83 inch long and when operated at the normal voltage of 4 volts ran at a temperature of about 2400° K. The variations in construction of models, made by different manufacturers, were chiefly in the helical grid structure. In the *Lampe Fotos*, the grid was of .008 inch molybdenum wire, wound with a pitch of .051 inch and of 12 turns, the total

Fig. 224 ←

→ Fig. 225

length being .63 inch. Its diameter was about .18 inch. In the *Lampe Metal,* the grid was of .011 inch diameter nickel wire wound with a pitch of .067 inch and had 11 turns, with a total length of .75 inch. The diameter of the helix was about .16 inch.[302] The base was usually of sheet metal with a ceramic insert which carried the pins. The fastening arrangement for the pins was not a very secure one, and they frequently worked loose in the base. The bulb was about 2.2 inches in diameter.

This tube was operated for receiving applications at its normal filament voltage of 4 volts, and filament current of .6 to .8 ampere. When used for transmitting purposes, the filament voltage was increased to 5 or 5.5 volts with consequent increase in output and reduction in operating life. The maximum permissible anode voltage, when used for transmitting, was 400 volts, while anode voltages of 15 to 50 were used in receiving.

When attempts were made to utilize this tube in a multistage radio frequency amplifier, difficulties were encountered. The amplifiers used at that time were of the resistance-capacitance coupled type and the high input capacitance (15 μμfd.) of this tube limited its use to frequencies below about 600 kc. This upper limit was extended to about 1500 kc. by the use of a modification of this tube known to the French as the *Lampe aux cornes,* and to others as the *horned valve* or *Kamerad valve.*[303] One of these tubes is shown in Fig. 223. The grid and anode are supported from wires which are embedded into projections on the press, and the electrical connections are brought to caps on the top of the bulb, separated by a considerable distance. This construction considerably reduced the tubes input capacitance.

Fig. 226.

Fig. 227.

There were also a number of other and higher-powered tubes of this same general construction developed for military transmitter applications. One of these is the 50-watt output transmitting tube shown in Fig. 225.

In Germany, the first attempts at the use of tubes for radio work were conducted with the von Lieben-Reisz-Strauss tube known as the *LRS Relay,* which was described in a preceding article. The LRS Relay was employed both as an oscillator and as a high-frequency amplifier in addition to its originally intended use, that of an audio frequency amplifier. Fig. 226 shows the general arrangement for using this tube as a high-frequency amplifier and Fig. 227 shows a close-up of the assembly with some of the box covers removed.

The first German high-vacuum tubes were developed shortly before the beginning of World War I and their refinement and improvement were greatly accelerated by military necessity. One of the first uses to which they were put was that of *listening-in* devices used to pick up enemy conversations. The first of these tubes, known as the Siemens & Halske Type A is shown in Fig. 228 in its various stages of development.[304] It followed, in general, the construction of the de Forest Audion and like it was a very inefficient device. Unlike its progenitor however, it was quite free from noise and microphonic action, chiefly because of its mechanical construction. The circular disk anode and spiral grid were held rigidly in place by means of glass spacers into which

Fig. 228.

(A) (B) (C) (D)

Fig. 229.

the elements were pressed. The bowed filament operated with .52 ampere at about 2.2 volts; the tube had an amplification factor of about 15 and an anode resistance of about 120,000 ohms. It had the advantage of taking a very small anode current, so that the anode batteries could be small and light.

While Fig. 228A shows the earliest stage of development, the tube as actually used in field equipment, even at this stage, was fitted with end mountings similar to those shown in Fig. 228B.[306]

Fig. 228B shows the second stage (attained in 1916) in the evolution of this tube. In it is shown the first step toward the punched grid which was finally used. The grid has been changed from spiral to zig-zag, still mounted in glass supports; the anode is rectangular to conform to the changed shape of the grid, and the filament has been changed to one parallel with the plane of the grid and equipped with a tensioning spring. The next step, shown in Fig. 228C, which was attained in 1917, utilizes a punched grid to replace the zig-zag wire. The final stage in this series is shown in Fig. 228D, in which the tube has been changed to single-ended construction with a single press, and a conventional 4-pin base employed.

Another early type, made by *A.E.G.* (*Allegemeine Elektricitats Gesellschaft*), followed more closely the design of the original de Forest Audion. It too was double-ended and had end fittings similar to the Siemens & Halske Type *A*. In the *A.E.G.* tube the hairpin shaped filament was surrounded by a zig-zag grid wound on formed glass arbors, and both filament and grid were supported from the bottom press. The anode was shaped like an inverted *U*, was supported from the upper press, and fitted rather closely over the filament-grid assembly. This tube was identified as the *A.E.G. K3* tube, and was used in the final stages of the *A.E.G. K¼ Amplifier*, shown in Fig. 229.[300]

The Telefunken laboratories, as distinguished from those of Siemens & Halske and *A.E.G.*, had been working on high-vacuum tubes since about the middle of 1913 and by early 1914 had standardized on the use of the high-vacuum tube for radio reception.[307]

These tubes had a construction similar to the Siemens & Halske tube described above; that is, plane anode, spiral grid, and bowed filament, in this case of helically wound tungsten wire. The *EVN129* was provided with metal plates on each side of the filament in order to prevent the emitted electrons from reaching the walls of the tube, to which they might be impelled by the magnetic field resulting from the filament current.[308]

The first application of the *EVN94* was in the *EV89* Amplifier shown in Fig. 230. This amplifier was first produced in July 1914.[309] The *EVN129* was originally developed for use as a heterodyne oscillator but was also used as a low-powered transmitting tube in sets of the type shown in Fig. 231, which were first made in June of 1915. The designation *EVN* indicates that the tube was intended for use in a receiver (*E = Empfanger*) as an amplifier (*V — Verstärker*) at low frequencies (*N — Niederfrequenz*).[310]

Another tube also intended for use in low-frequency amplifiers was the *EVN171*, shown in Fig. 232. This tube operated with a filament current of .5 to .55 ampere at 2.7 volts and used 80-100 volts on the anode. It had an amplification factor of about 10, a mutual conductance of about 100 micromhos, and an internal resistance of about 100,000 ohms.[311]

By 1914 the Telefunken engineers had decided to change over to a cylindrical element assembly and one of the first of the new type tubes, intended for use in the *EVE211* Amplifier, was designated *EVE173*. This tube is shown in Fig. 233. It was intended to duplicate the characteristics of the *EVN171* and, for a time, both tubes were made, eventually the *EVN 171* being abandoned. Like its predecessors, the earlier *EVE173*s used nickel in the anode and the grid. The grid was of thin nickel ribbon with a stiffening rib applied longitudinally. Later production of this tube, about 1918, influenced by the shortages of material which had developed in Germany by that time, had anodes of copper, and sometimes grids of copper as well. The copper used was chemically treated to eliminate surface impurities and make the tubes uniform in their operating characteristics.

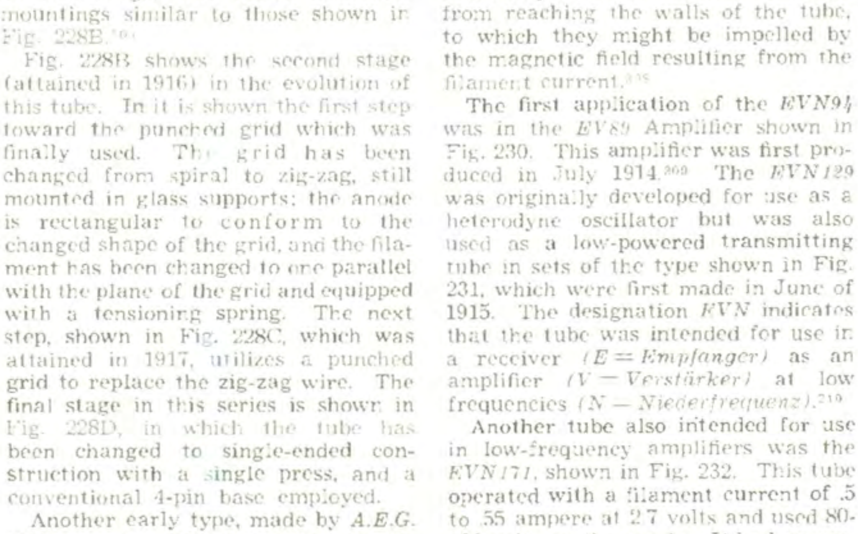


Fig. 230.

CAPTIONS FOR ILLUSTRATIONS

Fig. 223. French Kamerad type, in display socket. Photograph courtesy Bell Telephone Laboratories.

Fig. 224. French Type "S" made by Fotos. Photograph courtesy Radio Corporation of America.

Fig. 225. 50 watt transmitting tube of the Horned type. Photograph courtesy R. McV. Weston and Electric Communication.

Fig. 226. High-frequency amplifier using LRS Relay. Reproduced from "Handbuch der drahtlosen Telegraphie und Telephonie" by Eugen Nesper.

Fig. 227. Close-up of LRS Relay used as a high frequency amplifier showing interior of apparatus. Photograph courtesy Clark Historical Library.

Fig. 228. Development series of Siemens & Halske Type "A" Tube. Reproduced from "Veroffentlichungen aus dem Gebiete der Nachrichtentechnik"—1935.

Fig. 229. A.E.G. Type K¼ Amplifier, showing use of type K3 tubes in last stages. Reproduced from Zenneck-Rukop "Lehrbuch der drahtlosen Telegraphie"—1925.

Fig. 230. Telefunken EVN89 Amplifier using EVN94 tubes. Reproduced from Zenneck-Rukop "Lehrbuch der drahtlosen Telegraphie"—1925.

Fig. 231. Telefunken transmitter made in 1915, using EVN129 tube. Reproduced from Zenneck-Rukop "Lehrbuch der drahtlosen Telegraphie"—1925.

Fig. 232. EVN171 tube. Reproduced from Telefunken Festschrift—1928.

Fig. 233. EVE173 tube. Reproduced from Telefunken Festschrift—1928.

References

301. *Ferrie, General. "L'emploi des audions ou lampes a trois electrodes pendant la guerre." Revue Generale de l'Electricite,* Vol. 6, No. 26, December 27, 1919, pp. 933-935.

(*Continued on page* 130)

Saga of the Vacuum Tube
(Continued from page 56)

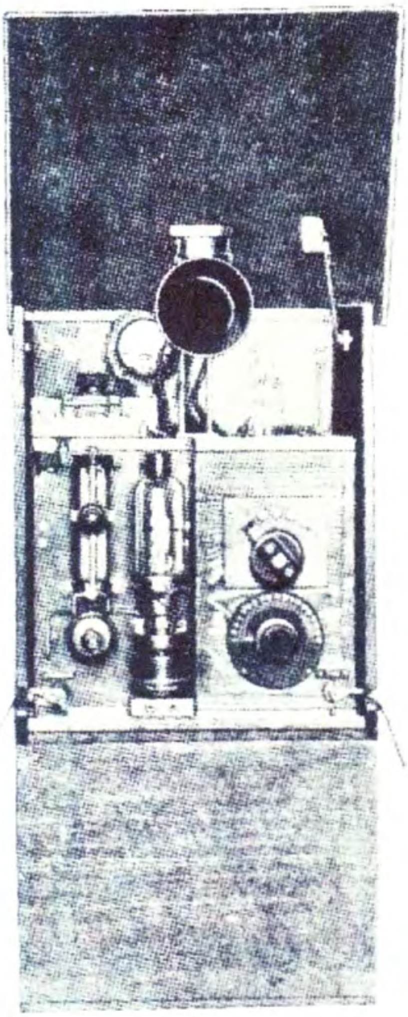


Fig. 231

302. Gutton, C—"La lampe-valve a trois electrodes" Revue Generale de l'Electricite, Vol. 5, April 26, 1919, pp. 629-640.
See also Gutton's "La lampe a trois electrodes" Librairie Scientifiques Albert Blanchard—Paris—1925, pp. 23-24.

Fig. 232

Fig. 233

303. "Notice sur les lampes-valves a 3 electrodes et leurs applications" Ministere de la Guerre—Etablissement Central du Materiel de la Radiotelegraphie Militaire—April 1918.
304. Nebel, C.—"Die Entwicklung der Siemens Fernsprechrohrer" Veroffentlichungen aus dem Gebiete der Nachrichtentechnik—1935, Vol. 5, No. 4, pp. 215-228.
305. Stanley, Rupert — "Textbook of Wireless Telegraphy Vol. II—Valves and Valve Apparatus" 2nd edition, Longmans Green—1915, p. 182.
306. Zenneck, Jonathan and Rukop, Hans—"Lehrbuch der drahtlosen Telegraphie" 5th edition, 1925, Verlag von Ferdinand Enke—Stuttgart, p. 787.
307. Meissner, A.—"The development of tube transmitters by the Telefunken Company" Proceedings I.R.E., Vol. 10, February 1922, pp. 3-23.
308. See reference 307, p. 5.
309. Rukop, Hans—"25 Jahre Telefunken—Die Telefunkenrohren und ihre Geschichte" Telefunken Festschrift, 1928, p. 115.
310. See reference 309, p. 118.
311. Groszkowski, J.—"Les lampes a plusieurs electrodes et leurs applications en radiotechnique" Etienne Chiron—Paris—1925, p. 126.

(To be continued)

Spot Radio News
(Continued from page 14)

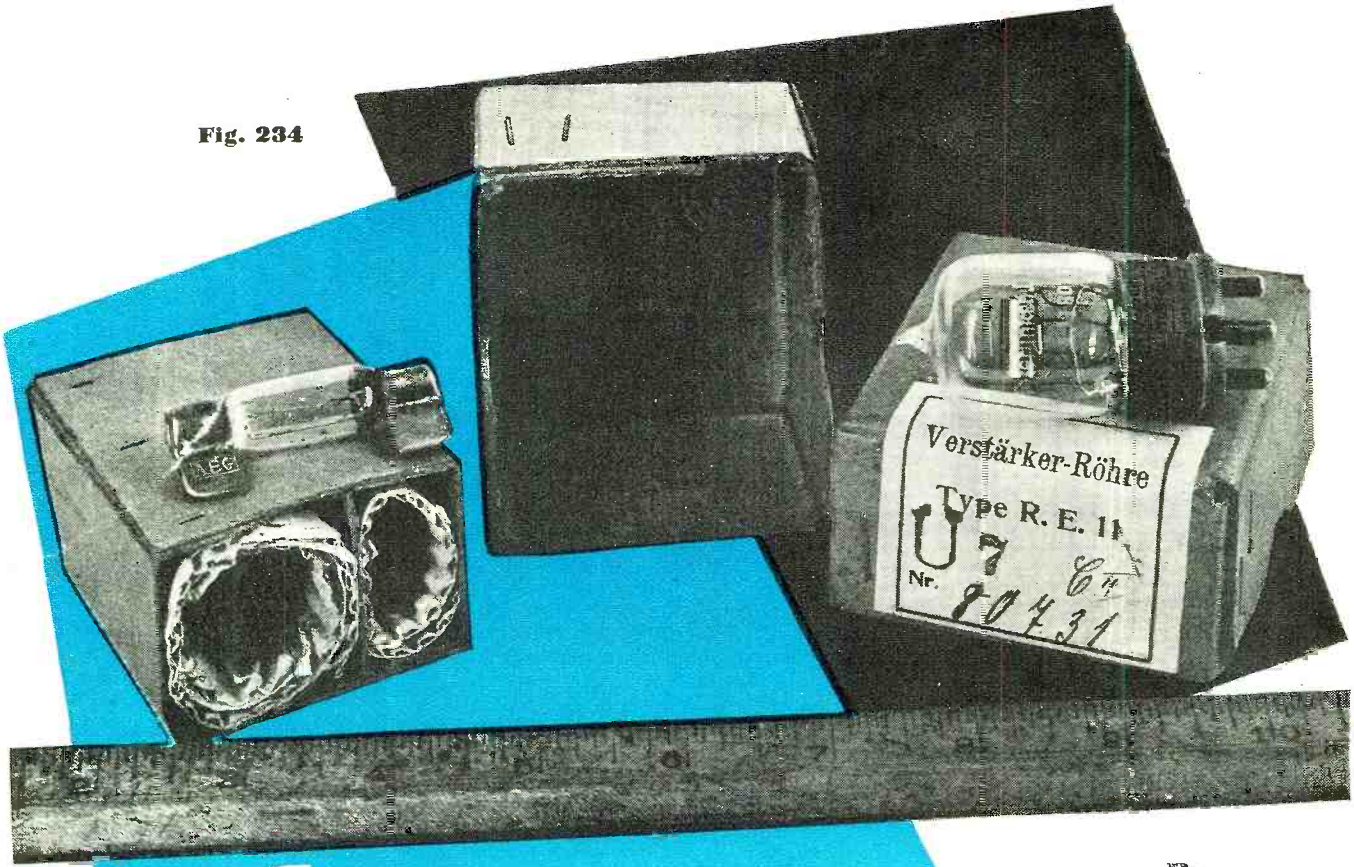
ference with representatives of the National Association of Broadcasters. Under that system, the first channel frequency (88.1 mc.) will be numbered 201; the second frequency (88.3 mc.) will be numbered 202, and so on up to and including channel number 300 (107.9 mc.). This will give all FM stations in the 88-108 mc. band, and in probable extensions of that band, channel numbers with three digits. Incomplete returns from a questionnaire sent to set manufacturers by RMA show that all but a few manufacturers intend to adopt the channel numbers.

ALTHOUGH THE RECONSTRUCTION FINANCE CORPORATION expects a large assortment of surplus handie-talkie and walkie-talkie transceivers, William L. Foss, chief of the electronics division, says no practical disposition of them has been developed. Contrary to general public belief, these military sets cannot be used in the proposed FCC citizens' community services because they were made to transmit and receive on frequencies assigned to and held by the military services. Some military handie-talkies were put on the market several months ago, but RFC stopped all sales when it was discovered they were of no use to civilians.

Radio and electronic war surplus so far declared is small, Foss reports. About 100 million dollars worth, on the basis of original price, has been made available to RFC. The first supply of radio receivers, the SX-28, while equipped to tune in the broadcast and international short-wave bands, are not likely to be converted into home sets. But they may be adapted for use by communications operators.

Radio tubes, both transmission and receiving, are moving well from the surplus stocks to consumers through manufacturer agents. The transmitter tube market has been flooded, Foss reports, and a large number of the re-

Fig. 234



Saga of the VACUUM TUBE

By
GERALD F. J. TYNE
Research Eng.

Part 22. Concluding article of a historical series which has covered the development of the vacuum tube from its conception to the end of World War I.

NOT long after the EVE173 tube was put into production the system of nomenclature was changed and German receiving tubes were denoted by the prefix RE (= Rohre Empfanger), transmitting tubes by RS (= Rohre Sende), and two new prefixes came into being RG (= Rohre Gleichrichter) for rectifiers and RV (= Rohre Endverstarker) for output tubes.[312]

Probably the first of these tubes to be made in any quantity, 250 per day in 1918,[313] was the RE11, shown in Fig. 234. This tube like most of its predecessors was used with an iron wire ballast resistor in the filament circuit and one of these ballast resistors is also shown in the figure. This tube had a tungsten filament of about the same characteristics as the EVE173 (.55 ampere at 2.8 volts), but operated at an anode voltage of 40 to 70 volts and had an amplification factor of 8 and mutual conductance of 120-150 micromhos, slightly higher than that of the EVE173.[314] It was a general purpose tube.

Another general purpose tube, bearing a closer resemblance to the EVE173, was the RE16 shown in Fig. 244. This was used chiefly as a detector for c.w. work.[315] The extent of its use may be gauged by the fact that in the summer of 1918 *Telefunken* was producing them at the rate of 1000 per day.[313] It had a filament which took 0.5-0.6 ampere at 4.0 volts. The usual anode voltage was 65 and the mutual conductance about 200 micromhos, the internal resistance being about 24,000 ohms. This tube had about the same anode characteristics as the French tube described in the preceding installment although it required less filament power. The normal anode current was about 1 milliampere.

Triode tubes were also made during this period by other German manufacturers, among them *Huth*,[316] *Seddig*,[317] and *Auer*.[318] Some of these tubes are shown in Figs. 238 and 239. It will be observed that the *Huth* tube shown was of plane parallel electrode construction. Earlier *Huth* tubes used a cylindrical element assembly but *Huth* was compelled to change to the plane electrodes because of patent difficulties. The earlier *Huth* tubes bore RE numbers similar to those of *Telefunken*, but those with plane electrode systems were designated by LE numbers.[319]

It is during this period also that we find considerable research effort being expended in Germany on the multiple electrode tube. It was early realized by Dr. Walter Schottky[320] of the *Siemens & Halske Company* that there were limits to the amplification which could be attained by the use of a triode and he set out to devise a tube which would be capable of high amplification with the low anode potentials available in Army field equipment.

Accordingly he investigated the possibility of modifying the high vacuum triode by the insertion of additional electrodes. He patented the space charge principle in 1915[321] and the "protective network" type in 1916.[322] His first patent on a multiple electrode tube was German patent D.R.P. 300617, issued June 1, 1916, and covered a tube designated by Schottky as a "protective network" (Schutznetz) type. Another patent, D.R.P. 300192 issued June 21, 1916, covered another double grid arrangement. Patent D.R.P. 300191 for a tube having a space charge grid in which both grids were characterized by being composed of strips of sheet metal placed with edges toward the cathode was issued on January 24, 1917.

The first production of the multiple electrode Schottky tubes were tetrodes of the protective network type, known as the SSI, SSII, and SSIII. While the protective network was a grid inserted between the control grid and the anode these tubes differed from the modern "screen-grid" type in that no attempt was made to use the additional grid to minimize the electrostatic capacitance between the anode and the control grid. This difference is relatively unimportant for low-frequency work, but is of great importance in high-frequency applications. As Schottky himself pointed out, his tubes were not suitable for use at high frequencies.[323]

The early model and later quantity-production type of the SS tubes are shown in Fig. 241. Fig. 241 (left) shows the earliest construction of this type. The electrode assembly was cylindrical, the grids were of the "squirrel cage" type, and a double press was used. The electrodes were slotted so that it was possible to insert the filament assembly into the electrode assembly after fabricating the two separately. Fig. 241 (right) shows a single-ended production type tube with glass "star" as the support of the electrode system.

The SSI was first manufactured in 1917. It had a filament which operated with 0.4 ampere at 2.4 volts. The anode potential was 35 volts and the potential of the protective network was 15 volts. When so operated it gave an amplification of about 50 and had a mutual conductance of 250 micromhos.

The SSII, also known as the RE97,[324] was a lower powered, lower gain tube, operating with a filament current of 0.24 ampere at 1.9 to 2.2 volts, and with 10.5 volts on both the anode and the protective network. It had an amplification factor of 30 and mutual conductance of 30 micromhos.

The SSIII, also known as the RE114, drew a filament current of 0.55 ampere at 3.2 volts and operated with 120 volts on the anode and 45 volts on the protective network. It had an amplification factor of about 100 and a mutual conductance of 250 micromhos. The internal resistance was about 250,000 ohms.

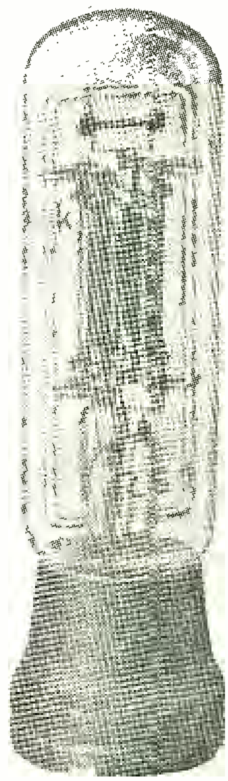


Fig. 235

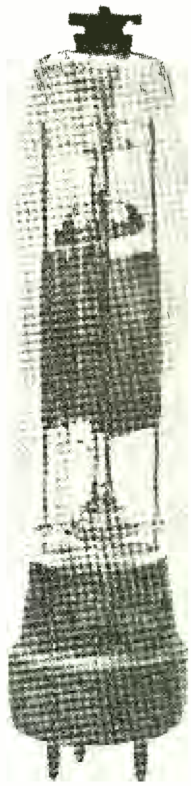


Fig. 236

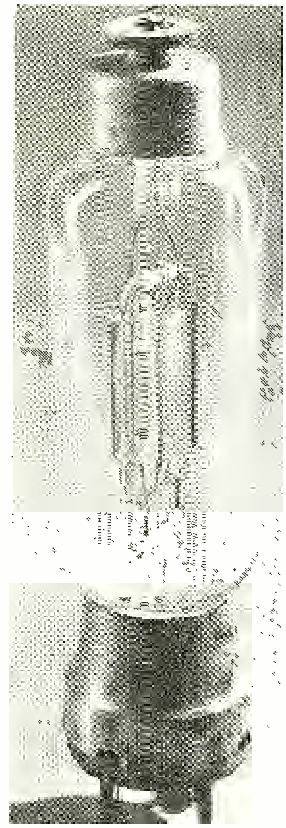


Fig. 237

Tubes of the space-charge grid type were also manufactured during this period. Typical examples of the smaller ones are the *Telefunken* RE20 and RE26, shown in Fig. 242. Both these tubes had tungsten filaments operating at 0.5 ampere at 2.8 and 4.0 volts respectively. They operated at 12 to 18 volts on the anode and space charge grid, had an amplification factor of about 8 and mutual conductance of about 350. Since they had 5 prong bases they required special sockets.

Larger tubes of the space-charge grid type were also developed and Fig. 243 shows the development series of one such tube. Figs. 243(A) and 243(B) show the early models. The grids are of wire netting. The space charge grid is small in diameter while the control grid is very close to the anode. Fig. 243(C) shows a production type tube of the vintage of 1919, still with the double press, Fig. 243(D) illustrates the final construction which was put into production about 1920.

Combination space charge and protective network tubes with three grids were also developed and some of these are shown in Fig. 245. The tube at the left is an experimental type with three grids using a double press and slotted electrodes. That at the right is a production type similar to the SS series.

In parallel with the work on receiving tubes *Telefunken* and the other German concerns had also been carrying on the development of transmitting tubes. The first of these to be made in quantities was the RS1, shown

Fig. 238

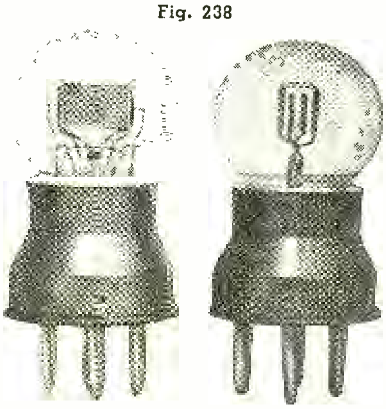
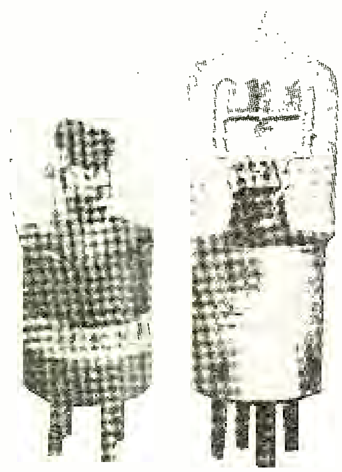


Fig. 239



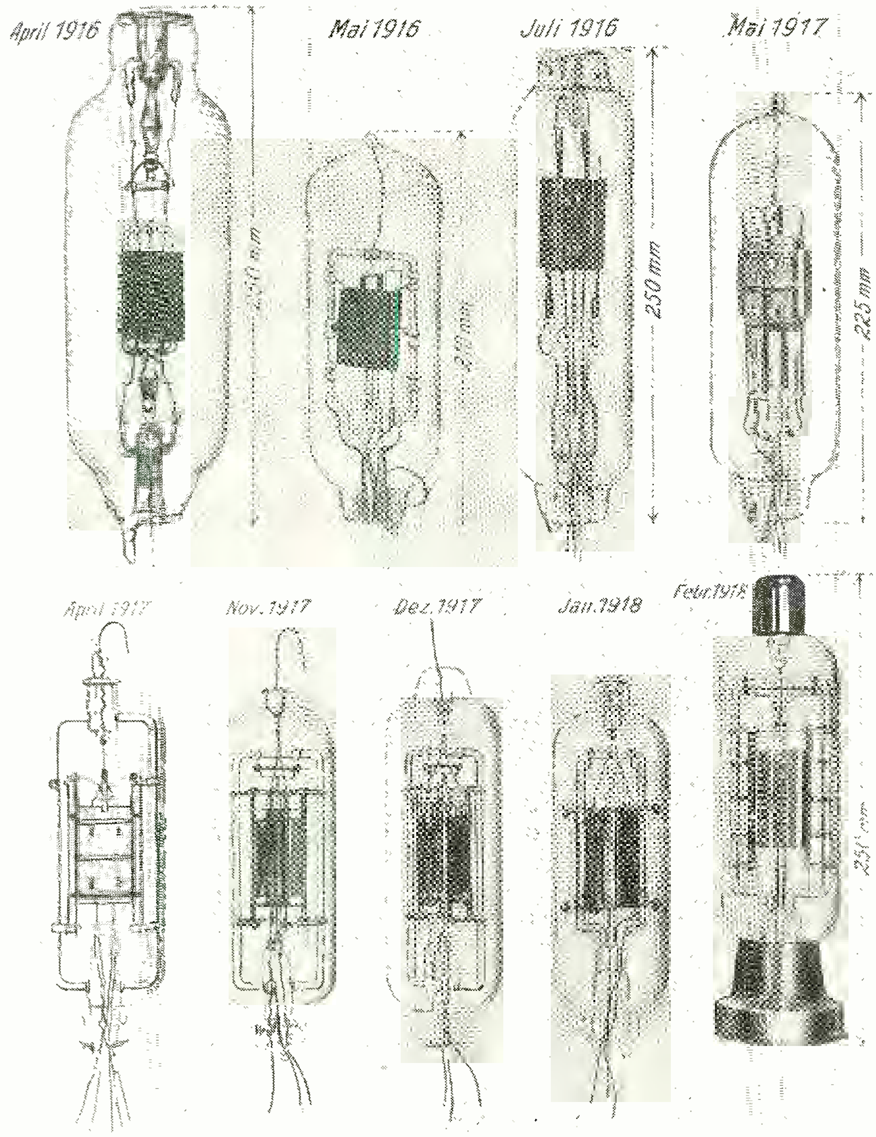


Fig. 240

in Fig. 235. It gave about three watts output when operated with 400 volts on the anode, in the apparatus in which it was first used, an Army trench transmitter. It was capable of operation at higher anode voltages, and at 600 to 800 volts would put out 10 to 20 watts.[325] The RS2 and RS3 were of no particular importance. The RS4 was a higher powered tube giving 50 to 75 watts output at 1000 to 2000 volts on the anode, and had a filament which took 3 amperes at 9 volts. The RS5, shown in Fig. 236, was an RS4 with improved characteristics. It took a filament current of 3 amperes at about 8 volts. The successor to the RS4 was the RS17, the evolution of which is shown graphically in Fig. 240.

All these transmitting tubes were characterized by the excellent glass work shown in their internal construction. This construction was common to all of the small transmitter tubes of early German manufacture, and is again exemplified in the TKD ST-12 shown in Fig. 237.[326] This tube again shows the effect of metal shortages. The interior portion of the base, in which the connecting pins are mounted, is of wood and the shell is of iron, with a poor nickel plate.

This series of articles has been presented to trace the development which took place up to the end of World War I along a particular branch of the network of roads which led to the modern radio tube. It has attempted to trace the evolution from studies of the interactions between heat and electricity as pursued by the early philosophers and by the physicists who followed them. These limitations have been adopted in an attempt to report the work done in the years where there is a dearth of readily available published material.

In any field of human activity books and periodicals are published by and for those interested. Such was the case in the early days of radio, with which the vacuum tube is so inextricably bound up. Much of the widespread interest in radio in the United States may be traced to the band of eager enthusiasts who made up the amateur fraternity in the days before World War I. The ham of those days spent his spare, and often not-so-spare, cash, burned his midnight electricity, and experimented unceasingly to fathom the mysteries of transmission and reception. Much progress came from interchange of ideas and experiences with others of like inclination. But unlike the situation existing today the facilities for such interchange were very limited. Books and periodicals dealing with such matters were few

(*Continued on page* 132)

Fig. 241

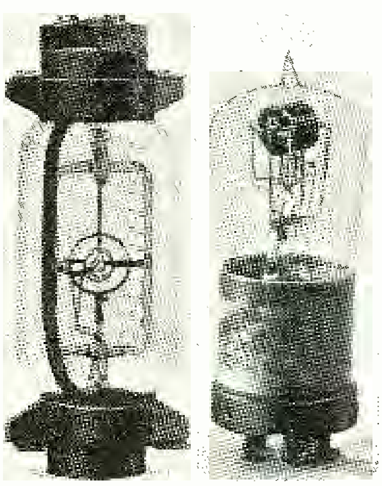


Fig. 242

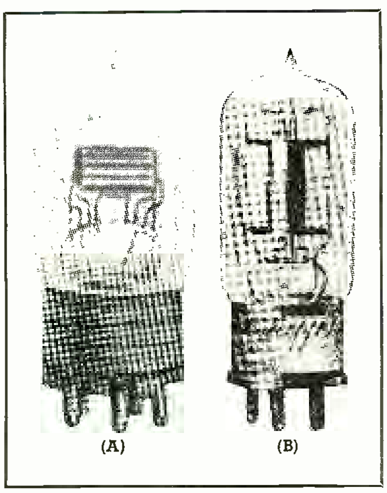
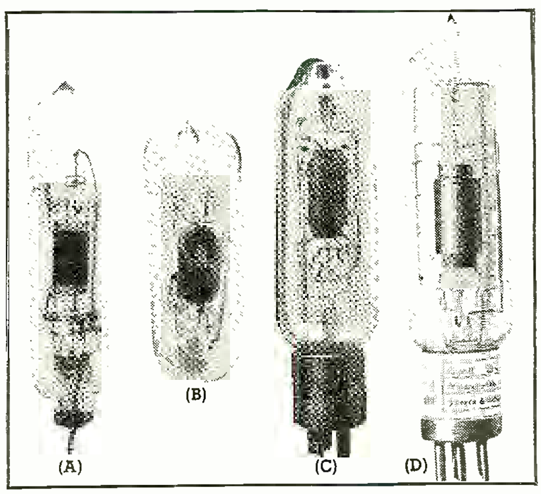


Fig. 243



Saga of the Vacuum Tube

(*Continued from page* 54)

and far between. Periodicals in particular were of limited circulation, aimed at the experimenter of high-school age and pocketbook and, except in a few cases, were not deemed of sufficient importance to be included in the permanent files of public libraries. Few books were written, since the men who were doing the work were too busy doing it to write about it.

With the advent of broadcasting and the great increase in adult popular interest in radio there came into being a number of widely circulated periodicals, technical and popular, both here and abroad, which published large quantities of information on current radio and vacuum tube development. These were preserved in most libraries of any size and are usually available to the earnest student of vacuum tube history.

For this reason little space has been devoted to cold-cathode, cathode ray, multi-grid, and higher powered transmitting tubes, such as the silica envelope type made by *Philips-Mullard,* the water-cooled copper-to-glass seal type developed by *Housekeeper,* and the larger radiation cooled types. Information on these phases of development can be obtained from these sources by the student or collector who seeks information on a specific type, and its collation and republication here is considered unjustified.

Fig. 244

References

312. *Martin—"Telefunken Rohrentypen" Telefunken Zeitung, Vol.* 4, *No.* 32/33, *September* 1923, *pp.* 51-55.

313. *Rukop, Hans—"25 Jahre Telefunken—Die Telefunkenrohren und ihre Geschichte" Telefunken Festschrift*—1928, *p.* 49.

314. *Banneitz, F.—"Taschenbuch der drahtlosen Telegraphie und Telephonie" Springer—Berlin*—1927, *p.* 476.

315. *Harper, A. E.—"Amplifying Bulbs" QST, Vol.* 4, *No.* 7, *February* 1921, *pp.* 27-28.

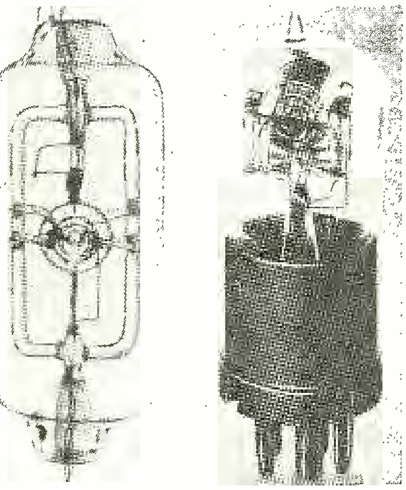


Fig. 245

316. *Dr. Erich F. Huth Gesellschaft fur Funkentelegraphie.*
317. *(R.I.W.) Seddig, Wurzburg.*
318. *Auer Studiengesellschaft fur elektrische Leuchtrohren.*
319. *Groskowski, J.—"Les lampes a plusieurs electrodes et leurs applications en radiotechnique" Etienne Chiron—Paris—*1925, *p.* 125.
320. *Schottky. W.—"Uber Hochvakuum Verstarker III Teil: Mehrgitterrohren" Archiv fur Elektrotechnik. Vol.* 8, *No.* 9, *December* 8, 1919, *pp.* 299-328.
321. *D.R.P.* 310605, *issued March* 19, 1915.
322. *D.R.P.* 87745, *issued May* 31, 1916.
323. *See reference* 323, *p.* 320.
324. *Pohlmann. B. and Gehrts. A.—"Werdegang einer Verstarkerrohre" Elektrische Nachrichten-Technik, Vol.* 2, *No.* 3, *March* 1925, *pp.* 65-74.
325. *See reference* 316, *p.* 142.
326. *"TKD" is the trade mark of Suddeutsche Telefon-, Apparate-, Kabel-, und Draht-Werke, Nurnberg.*

CAPTIONS FOR ILLUSTRATIONS

Fig. 234. RE11 tube with ballast resistor. Photograph courtesy Bell Telephone Laboratories.

Fig. 235. Telefunken RS1. Reproduced from Telefunken Festschrift—1928.

Fig. 236. Telefunken RS5. Photograph courtesy R. McV. Weston and Electrical Communication.

Fig. 237. TKD ST-12 tube.

Fig. 238. Huth LE219 tube, front and side views. Reproduced from Nespers' "Der Radio Amateur"—1924.

Fig. 239. Left—Seddig tube. Filament 0.56 ampere at 2.8 volts. Right—Auer receiving tube.

Fig. 240. Development of Telefunken RS17. Reproduced from Niemann's "Funkentelegraphie fur Flugzeuge"—1921.

Fig. 241. Development of the SS (Siemens-Schottky) type tube. Reproduced from "Veroffentlichungen aus dem Gebiete der Nachrichtentechnik"—1935.

Fig. 242. Left RE20 tube. Right—RE26 tube. Reproduced from Banneitz "Taschenbuch der drahtlosen Telegraphie"—1927.

Fig. 243. Development of the space charge grid tube. Reproduced from "Veroffentlichungen aus dem Gebiete der Nachrichtentechnik"—1935.

Fig. 244. RE16 tube. The top is painted red. Reproduced from Nesper's "Der Radio Amateur"—1924.