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,

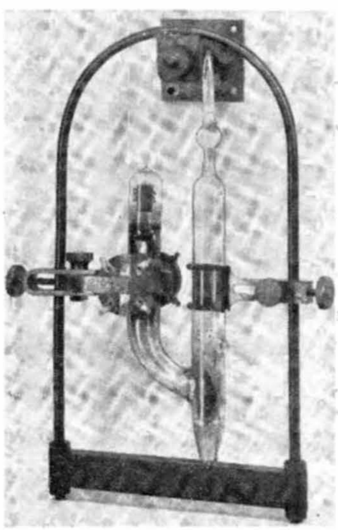

Fig. 61.

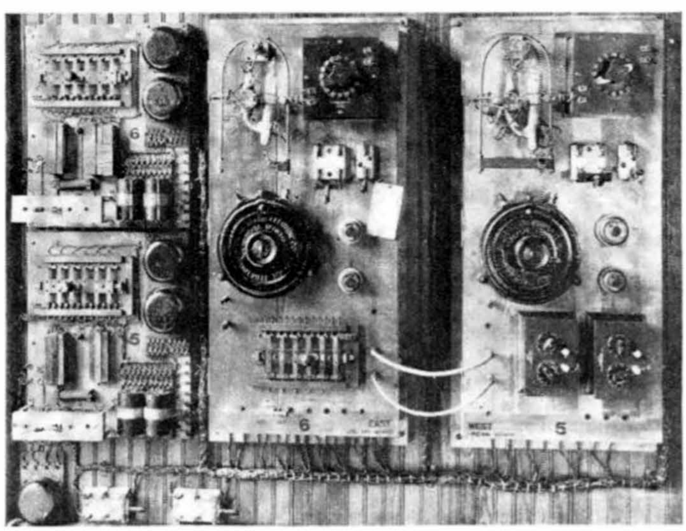

Fig. 62.

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.

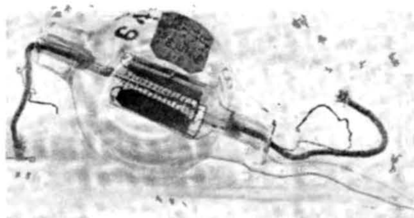
Fig. 66.

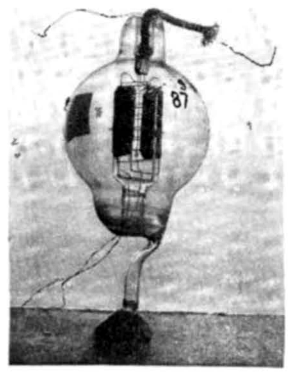
Fig. 67.

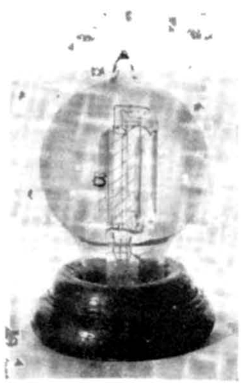
Fig. 68.


Fig. 69.


Fig. 70.

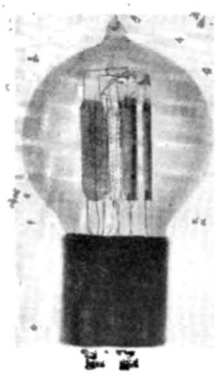
Fig. 71.


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."[166] 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[167].

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 2⅜ 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 ⅞ inch high and the lower ends were about ⅜ 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 1⅛ inches high and were of nickel. The grids were made by welding hairpin-shaped loops onto a narrow supporting strip. The grid was approximately ⅝ inch wide by 1¼ 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*)