Saga of the VACUUM TUBE

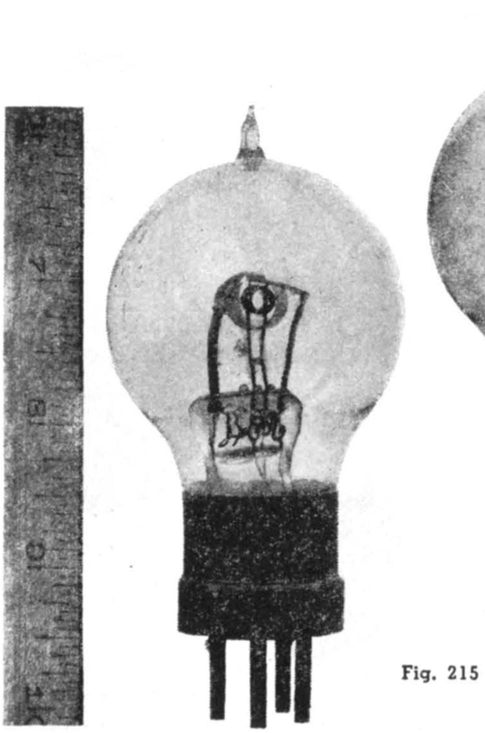

Fig. 215

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.

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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)

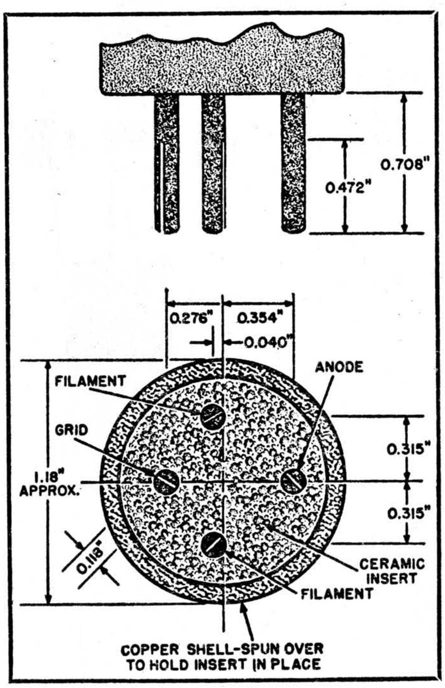


Fig 216

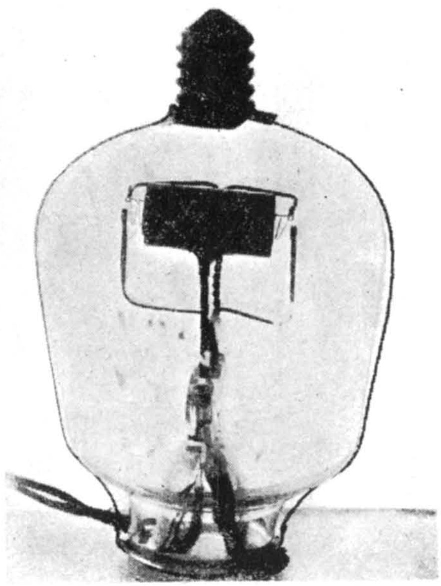


Fig. 217

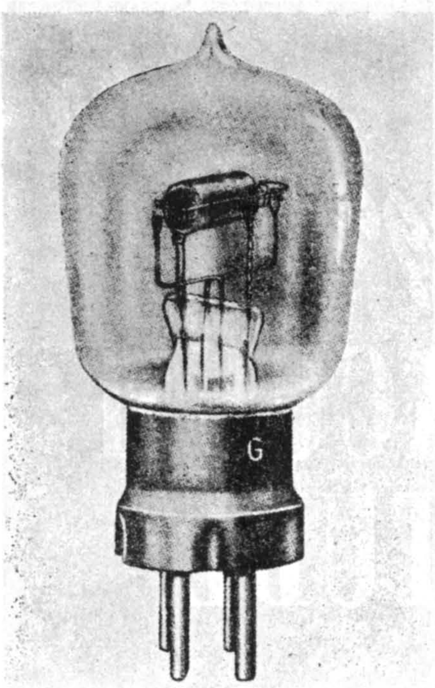


Fig. 218

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

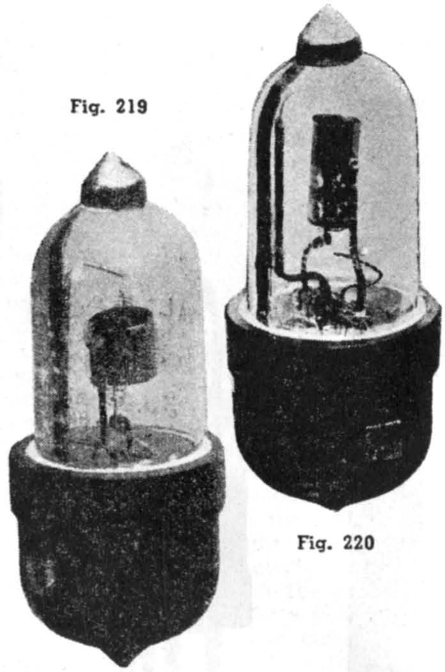


Fig. 220

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

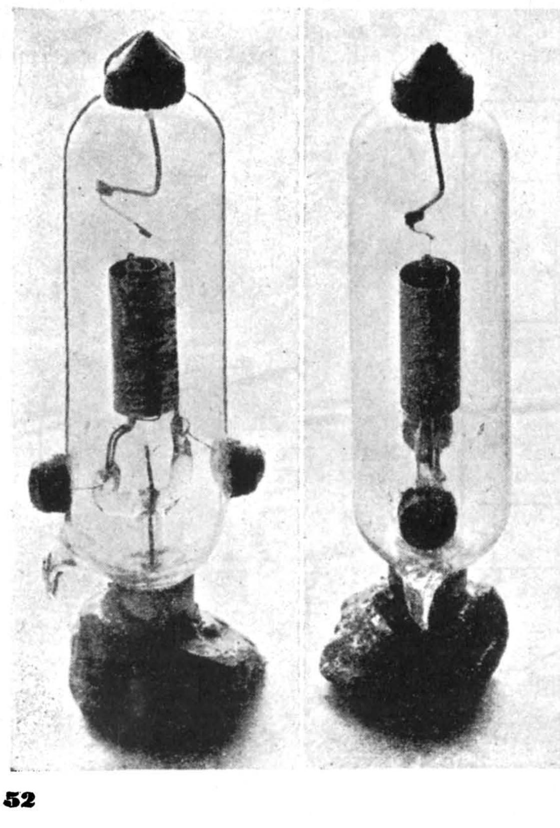
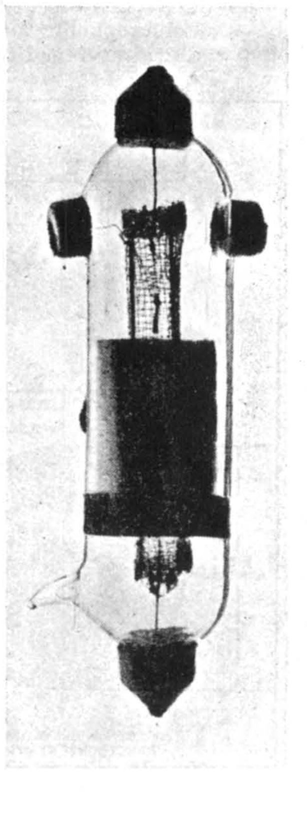


Fig. 222



ment wire changed to 2.4 mil diameter thoriated tungsten. The redesigned tube was designated R_{4A} 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_{4A} 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_{4B}, shown in Fig. 218, was designed for use in amplifiers where the noise introduced by the R_{4A} was objectionable. The element structure was practically the same as that of the R_{4A} except that the filament was of unalloyed tungsten. It operated at the same filament current as the R_{4A} 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.[299]

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_{11}.

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.

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Saga of the Vacuum Tube

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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