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The Thoriated Tungsten Filament

Characteristics of the New X-L Filament, Used in the UV-201-A and UV-199 Tubes. Comparisons with the Older Pure Tungsten Type

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The papers of the Radio Club of America are being published exclusively in RADIO BROADCAST. Mr. White's discussion in this number is the second of the Club's articles to appear. The first, "Eighteen Years of Amateur Radio," by George E. Burghard, was published last month.—THE EDITOR.

IN THE design, manufacture, and use of high-vacuum receiving tubes, the electron source, in most cases, has always been the chief problem.

By far the greatest amount of scientific work on vacuum tubes and also a considerable part of the manufacturing development has been devoted to this question of the production of electrons.

Until quite recently, the pure tungsten filament and the coated filament were the only two types of electron-emitting sources in extended use in receiving tubes. Although each of these sources met the requirements of practical use, it has been found possible to reduce the filament energy and secure other characteristics equal or better than that formerly obtained.

The important desirable features which the ideal electron-emitting filament for a high-vacuum receiving tube should have, some of which are self-evident, can be listed as follows:

(1) Long operating life.
(2) Low filament energy to supply the necessary electron emission.
(3) Uniformity of electron emission during life.
(4) Uniformity of electron emission among different tubes of the same type.
(5) Quietness of operation.
(6) "Electrical robustness" of the filament.

Another most desirable feature, if not the most important, but which is not so self-evident, is the necessity for low electron emission per unit of length or, expressed in another way, the greatest length possible within reason for a given amount of electron emission and filament energy. These features of long filament length combined with long life and low filament energy were always the difficult problems in tungsten filament design for receiving tubes.

The new X-L tungsten filament meets these many, and it would almost seem, divergent requirements in a most admirable way, and although, of course, it is probably not the final development in electron-emitting sources, still it is such a big advance, particularly over the old type of pure tungsten filament, that it meets to a considerable extent the ideal requirements.

The outstanding features of this new X-L tungsten filament considered from the viewpoint of the desirable features of the ideal and in comparison with the old pure tungsten filament are as follows:

(1) For the same life, the X-L filament can have several times the electron emission, and only a fraction of the same amount of energy is required for excitation. This is best brought out by a comparison between the old UV-201 and the new UV-201-A tubes, the latter tube utilizing this new X-L tungsten filament. This comparison is a convenient one to bring out these points because the two tubes are made to be interchangeable and to operate from the same filament voltage.

	Filament			*Electron Emission*
Type	*Volts*	*Amperes*	*Watts*	*Milliamperes*
UV-201	5	1	5	7.5
UV-201-A	5	.25	1.25	45

(2) The uniformity of electron emission from the X-L filament is the same as from the old tungsten filament. This can be brought out by the fact that in the UV-199 tube, which also uses the X-L filament, measurement of electron emission has been made on every tube leaving the factories. The minimum allowable limit is six milliamperes. The average of thousands of tubes is eight milliamperes, and practically the highest that is found among the standard product is twelve milliamperes.
(3) Tube noise, a troublesome feature in the older type of tungsten tube, is practically eliminated with the X-L filament, largely because of the much lower operating temperature.

(4) The feature of increased electron emitting length is well brought out by the following tabulation, again a comparison between the UV-201 and the UV-201-A tubes:

Type	*Approximate Life*	*Filament Length*	*Approximate Mutual Conductance*	*Relative Delivered Energy*
UV-201	1000	38 mm.	300	1
UV-201-A	1000	48 mm.	475	2

From the foregoing tabulation it will be seen that there is more than fifty per cent. increase in mutual conductance due to the longer filament which allows also the use of larger plate areas. The figures under the column "Relative Delivered Energy" imply that under similar conditions the increased mutual conductance allows the UV-201-A tube to give about double the energy output as an amplifier. The figures for mutual conductance given above refer to these constants measured at rated filament voltage, a plate voltage of forty and a grid voltage of zero.

Probably this feature of increased electron emitting area with the X-L filament can be more clearly brought out by the statement that if an X-L filament tube were built operating at the same filament temperature as the UV-201-A but having the same volts and amperes as the UV-201 and the same life, the electron emission from the X-L filament would be twenty-four times as great and the length approximately double that of the pure tungsten filament.

(5) The X-L filament has a long life. Life in this case is not terminated by a burnout, but by loss of electron emission. This drop of emission does not occur continously during the life of the filament, but quite suddenly, and in a very pronounced way at the end of its useful life. The relation between life and filament voltage is not a simple relation, because operation at abnormally high voltage will destroy electron emission which, however, can be renewed by the proper procedure in the hands of the user. This question of life of the tube and the fundamental causes allowing this possibility of renewing electron emission, or reactivation, as it is termed, will be discussed more fully in the following paragraphs.

The electron emission from a given material can be expressed by a fairly simple formula and is determined by two factors, one of which is a constant that is typical of that material and the second is a function of the temperature; the electron emission increasing very rapidly with temperature. In the case of a coated filament, the constant of the material indicates a high emission, but the allowable temperature is low. In the case of the pure tungsten filament, the constant of the material indicates a relatively low electron emission at a given temperature, but there is the practicability of operating at relatively high temperatures.

It has been found that in general in the case of suitable electron emitting substance the more stable and homogeneous the material the lower the electron emission and, conversely, the lower the temperature at which the material evaporates or disintegrates the higher the electron emission. Another factor found experimentally was that in most cases the more active the material, that is, the greater the electron emission at low temperature, the more subject the material was to loss of electron emission from contamination and insufficient vacuum; certain gases or vapors in particular being very fatal to this electron emission. The problem, therefore, was one of finding a compromise between these divergent factors.

The X-L filament is a tungsten filament in which there is a small percentage, considerably under five per cent. of a material that has high electron activity. This active material in the case of the X-L filament as at present used is thorium and a chemical compound of this thorium is mixed with the tungsten early in the stage of the manufacture of the metal from which the filament wire is drawn.

When the completed filament containing this active material is operated in a vacuum at a certain high temperature, there is a change from the chemical compound to pure thorium. At another certain lower temperature, there is a constant diffusion of this thorium toward the surface of the filament. By this process, a layer of these thorium atoms one atom deep, (and only one atom deep) is formed on the surface of the filament. This atomic layer of thorium is of high electron emissivity so that ample electron emission is obtained from it at temperatures that would give practically no useful electron emission from a pure tungsten filament.

Thorium cannot remain indefinitely, however, on the surface of a hot filament, because in comparison with tungsten, it has a higher rate of evaporation, this rate, of course, increasing rapidly with the temperature. At the temperature at which the X-L filament is operated, this evaporation is relatively slow, but is quite appreciable. The instant that an

atom of thorium evaporates from the surface there is a movement of atoms inside the body of the material which places another atom in the surface layer in the position occupied by the former atom after which movement there is again equilibrium of thorium inside the filament.

A rough analogy to the actions just described is the case of a jar of liquid which is capable of forming bubbles. The production of pure thorium can be likened to the formation of air bubbles at the bottom of the jar and the diffusion of these thorium atoms to the surface of the filament can be likened to these air bubbles rising to the surface of the liquid. As in the case of the thorium atoms, these small air bubbles will distribute themselves so that the entire surface is covered with bubbles one layer deep. If more bubbles are then formed at the bottom of the jar, they will rise until they strike the under surface of the surface layer of bubbles and there will remain stationary and it is possible to thus form a thick mass of the bubbles, all stationary. The evaporation of the thorium from the surface of the filament may be likened to the evaporation of the film of some of the bubbles in the surface layer which causes these bubbles to burst and immediately other bubbles from beneath rise to the surface taking the place of the bubbles just destroyed.

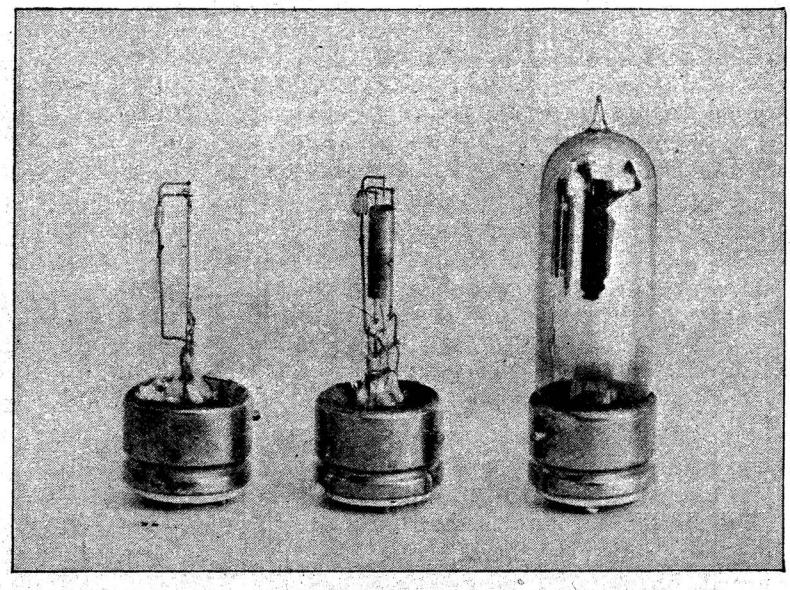

FIG. I
The UV-199 dry-cell tube. It uses the new thoriated tungsten filament

In the case of the filament, the higher the temperature the greater the evaporation of the thorium from the surface which would correspond in this analogy to the bubbles in the surface layer of the liquid bursting at more frequent intervals.

The bubble analogy is in one respect not a good one, and this point is that the volume occupied by the thorium atoms is only a very small portion of the total volume of the material near the surface of the filament, whereas, in the case of the bubbles in the jar of liquid the volume of these bubbles under the surface is much greater than the volume occupied by the liquid. Therefore, in the bubble analogy the layer of atoms one atom deep is not clearly portrayed because the bubbles underneath crowd toward the surface displacing practically all the liquid.

The reactions inside of the X-L filament when operating at its normal temperature are such that the production of thorium in the interior and the rate of its diffusion to the surface are proportioned so that at normal rated temperature they amply compensate for the loss of thorium atoms by evaporation.

There is one effect, however, which tends to prevent the practical utilization of the process in the simple form here outlined.

In an earlier paragraph it was stated that one of the disadvantages of an active electron emitting material was its liability to contamination. This contamination consists of the chemical combination of some gaseous or vapor impurity in the vacuum with the thorium at the surface of the filament, which is emitting the electrons. The X-L filament would be very sensitive to such contamination and this chemical compound formed at the surface by this contamination would not emit any electrons and would require an exceedingly high temperature, up to near the melting point of the tungsten, to remove it and leave free the surface area for the pure active material. Therefore, in the case of the X-L filament, unless some precautionary measures were taken, the electron emission would

last only a few seconds or a few minutes during which time the active surface would become so contaminated that the emission would drop to practically zero.

This problem of keeping the active surface of the filament "clean" was solved by first finding out what the contaminating agents were and then by placing inside the bulb certain substances that would have a more active chemical combination with these contaminating agents than the thorium surface on the filament. The presence of such substances prevents contamination of the filament by previously combining with the contaminating agents. It does not in any way increase the electron emission from the filament directly, but simply protects the thorium film so that the full electron emission characteristic, as would be obtained in practically a perfect vacuum, is more conveniently realized.

Keeping in mind the phenomena just described, the various characteristics of the X-L filament as an electron emitting source are explainable.

For instance, if the filament is operated at an abnormally high temperature, the electron emission at first will be very large, but the higher this abnormal temperature the quicker will this high electron emission fall off until it is below even normal value. This rapid falling of electron emission is due to the fact that the rate of evaporation of thorium from the surface is more rapid than the diffusion to the surface and, therefore, the surface of the filament is no longer covered with the active thorium, but only with pure tungsten, the electron emission from which at a given temperature is far below that from thorium. If then the filament is operated at normal temperature for a short period of time, the evaporation of thorium is reduced to normal and the diffusion from the interior rebuilds the electron emitting layer at the surface. As the surface of the filament becomes more and more completely covered with thorium, the electron emission rises until, when it has become fully covered, it returns to normal.

This brings out the point that there is an optimum temperature for operation of the X-L filament, or more properly speaking, a restricted range of temperature for satisfactory operation. If the temperature is maintained above this range, the electron emission sooner or later falls off as explained, but there is no permanent injury to the filament unless this misuse is continued, and operation again at normal value soon brings back normal electron emission. If the operation is below this useful temperature range, the electron emitting efficiency is unnecessarily low.

Under rare operating conditions, the supply of thorium in the interior of the filament might become deficient, which would reduce the supply of thorium arriving at the surface and fail to keep a complete layer at the filament surface. Under these circumstances, there is usually still a supply of the thorium compound present which was originally put into the filament metal and by operation of the filament at approximately three times normal voltage for a fraction of a minute there will be a new production of pure thorium. Then, after this new production of thorium has occurred, operation of the filament at normal temperature for a reasonable period of time will cause this new thorium to be diffused to the surface and a new complete active electron emitting layer will be formed.

Also, under abnormal conditions, such as overload of the plate, the contaminating agents may be so plentiful inside the bulb that the substances placed inside to absorb these contaminating vapors and gases may not take them up rapidly enough and so allow a contamination of the filament. Again, the cure for this condition is to operate the filament for a few seconds at about three times normal voltage which decomposes this contaminated thorium from the surface of the filament and then by operation at normal temperature for a reasonable time the normal thorium layer and normal electron emission are regained.

The length of time that the filament must be operated at normal temperature under these different conditions described in order to regain normal emission varies widely, depending upon whether or not the thorium just below the surface has been removed. If the thorium has been removed a considerable distance below the surface, a longer time is required for it to diffuse through this distance to the surface than would be required if simply the surface layer were destroyed. Therefore, if the filament has been operated at an abnormally high voltage for ten to twenty-five hours, it may require this same length of time at normal rated operating voltage in order to obtain

normal electron emission. It is, therefore, apparent that an X-L filament contains a certain amount of stored-up or potential electron capacity which under normal conditions is continuously brought to the surface and utilized in an efficient manner so as to give long life. If abnormal conditions occur, this orderly procedure is disturbed so as to cause a failure of electron emission. However, as pointed out, this potential source of electron emission is seldom permanently destroyed before the end of filament life, and the proper procedure should bring back normal electron emission.

X-L FILAMENT RADIOTRON TUBES

THE Model UV-199 Radiotron tube utilizes the X-L filament and brings out in a most striking manner its unusual characteristics and, therefore, it is of interest to describe briefly this tube and some of its characteristics and properties. The general appearance of this Radiotron tube is shown in Fig. 1. The overall length of this tube from the tip of the bulb to the bottom of the contact pins of the base is $3\frac{1}{2}''$ and its maximum diameter $1''$. One of the first features noted in an inspection of this tube is the fact that the bulb is opaque so that the electrodes are not visible. This opaqueness is caused by the materials used to prevent contamination of the filament in the manner previously described.

The outstanding advantages of this new tube are its low filament energy which is only about 75 per cent. of that of any other tube in use at the present time, its small size and excellent detector and amplifier characteristics.

The filament is operated at three volts and requires only sixty milliamperes.

The tabulation shown below indicates what service can be obtained from a set employing one, two, three, or four of these tubes in parallel operated from three good quality No. 6 dry cells connected in series. This tabulation is based on the use of the tubes two hours out of each twenty-four hours.

No. of tubes in set	*Total hours*	*Days*	*Months*
1	387	193	$6\frac{1}{2}$
2	200	100	$3\frac{1}{2}$
3	126	63	2
4	92	46	$1\frac{1}{2}$

The extremely low filament current of this UV-199 tube makes it possible to operate from flashlight cells. Operation from such

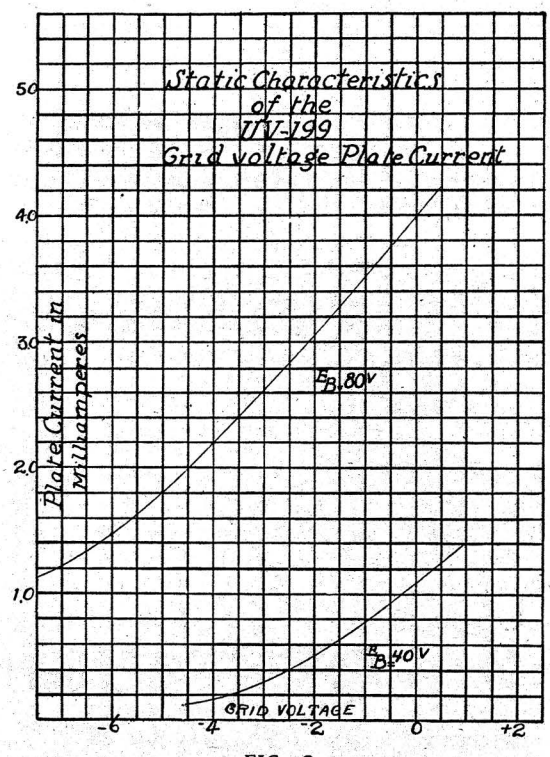

FIG. 2
The "characteristic curve" of the UV-199

small size cells is not as economical as from the six-inch size of cells. However, for portable equipments, this difference is more than offset by the light weight and small size of these flashlight cells.

One UV-199 tube may be operated from a three cell flashlight battery one hour out of each day for a little over a month. A longer period of daily operation than one hour will shorten somewhat the total useful battery life.

For portable sets containing more than one UV-199 tube one three cell flashlight battery should be used for each tube operated. Operation of the filaments of more than one tube from a single flashlight battery is not only poor economy, but the voltage drop of the cell while in use under this heavier current drain is after a short time so rapid that operation of the set is unsatisfactory.

This size of unit flashlight cell is approximately $1\frac{3}{8}''$ in diameter and $2\frac{5}{16}''$ long. Smaller sizes of flashlight cells have not been found satisfactory for use with these filaments, because not only is the economy poor but their voltage drops so rapidly that in a regenerative circuit difficulty is experienced in satisfactorily holding an adjustment.

This use of flashlight cells combined with the small size of the tube gives the possibility of making up extremely sensitive, small, and light weight portable receiving equipments.

The characteristic curve of this tube is shown in Fig. 2, and is very similar to that of the old UV-201.

In this connection, it should be kept in mind that the UV-201-A tube has a higher amplification constant and lower impedance than the UV-199 tube, and, therefore, has a greater mutual conductance so that it is inherently a better amplifier. This is to be expected, because the UV-201-A requires almost seven times as much filament energy and has bigger electrodes. The higher electron emission of the UV-201-A and the fact that it can be operated at a higher plate voltage than the UV-199 combined with its better characteristic curve make it a much better tube to use for the operation of loud speakers where an exceedingly large volume of sound is required. However, where it is desired to build a multi-tube set, the UV-199 is, of course, superior because a dry battery can be used for the filaments, whereas, the same number of UV-201-A tubes would make dry battery operation rather out of the question.

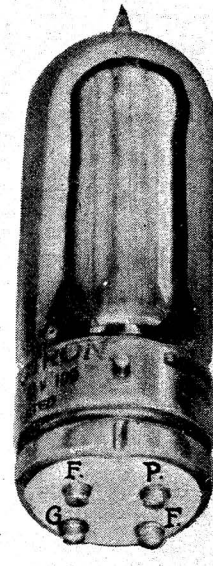

FIG. 3
Showing arrangement of contacts on the UV-199

The UV-199 tube is also very suitable for radio-frequency amplification, because the capacity between electrodes, owing to their small size, is considerably below that of any other tube available to the experimenter at the present time. To get the full advantage of this low capacity, a socket designed for the tube rather than an adapter to a standard socket should be used. Attention should also be directed to the set wiring so as to keep capacity effects at a minimum.

The arrangement of the contacts on the base of this UV-199 tube (Fig. 3) is not the same as in the case of the standard bases. This change has been made so that the wiring of the filament leads as well as the plate and grid leads can be more conveniently arranged and with less capacity effects between them than in the former pin arrangement.

One of the principal precautions to be observed in the use of the Radiotron Model UV-199 is to be certain that the rheostat used is such that the voltage of the filament source can be reduced to the proper value of three volts for the filament.

Inasmuch as three new dry cells for a very short time have a voltage of 4.5 volts, this means that 1.5 volts must at first be absorbed by the filament rheostat. A filament rheostat of thirty ohms maximum resistance is recommended for a single tube. In the case of two tubes, the filaments of which are in parallel and controlled from a single rheostat, the resistance should be fifteen ohms, and in the case of three tubes, ten ohms.

If for any reason it is desired to operate these tubes from a three cell storage battery and a connection for the voltage from two cells cannot be obtained, the rheostat resistance should be at least sixty ohms for one tube, thirty ohms for two tubes, and twenty ohms for three tubes.

In a great majority of cases, if due to improper operation these tubes show low electron emission, this electron emission can be regained by operation at normal filament voltage for a period of time roughly proportioned to the time during which the tubes were operated at an over-voltage. It is preferable during this reactivation of the filament and often hastens its recovery to disconnect the B battery so that there is no plate voltage on the tube. If this treatment fails to reactivate the filament, the tube filament may be flashed at eight to nine volts for about ten seconds and folowed by a run of several hours at rated voltage. This should, in practically all cases, cause the return of normal electron emission. These methods of reactivation will not, of course, be successful if the tube has run its normal life or has been consistently operated at excess temperature or misused.

Under normal operating conditions, these methods of reactivation are not necessary during the life of the tube.

Many modern vacuum tube receiving circuits are of extreme sensitivity, and vibration often causes the tube to introduce into the receivers a disturbing sound. This is termed microphonic effect of the tube and is a factor which must be taken care of in multi-tube UV-199 circuits in the same way as it has been

taken care of in the use of other tubes, that is, by proper cushioning of the sockets.

A plate voltage higher than that obtained from four standard block cells should not be used on this tube, as it reduces seriously the factor of safety against overload and will shorten the life. With eighty volts on the plate a negative bias of three to 4.5 volts should be used on the grid. This is conveniently obtained by two or three small flashlight cells.

It is an interesting fact that with a plate voltage as obtained from four block cells and with the proper negative bias, the plate current is approximately 2.5 milliamperes which at eighty volts gives a dissipation of energy on the plate of approximately .2 watt. As the normal filament energy is only .18 watt, this fact that the plate energy is more than the filament energy is rather a striking example of the great improvement that has been made in these tubes in regard to filament operation and electron emitting efficiency.

A fairly comprehensive examination of tubes that have become inoperative due to actual filament burnout has disclosed the fact that a very large majority of these tubes were burned out by the filament becoming connected across the plate battery. It is a common custom, but dangerous to the tubes, to make changes in the wiring or connections of the set while it is in operation or while the tubes are in the sockets and the B battery in circuit. A mistaken connection which puts the filament of a UV-199 or UV-201-A tube across a B battery of forty volts or more that is in good condition usually destroys the filament so quickly that a flash is not noticeable unless the tube is directly in the line of vision.

In view of these facts, it is particularly to be urged that wherever possible tubes be removed from their sockets or the B battery disconnected while experimenting with the circuit arrangement. An even preferable arrangement and one which allows the convenience of trying various arrangements without the preceding precaution is to insert in one lead of the B battery at one battery terminal a ten-watt, 110-volt Mazda lamp. The cold resistance of such a lamp is so low that in the great majority of circuits there will be no ill effects, but such a lamp has the valuable characteristic of increasing its resistance so that at operating temperatures it is ten or twelve times as high as when cold. A ten-watt lamp used in such a manner even with a plate voltage of eighty or more will limit the current to less than 100 milliamperes which can do absolutely no harm to even such a small filament as that used in the UV-199. A lamp used in this manner also is convenient in that it shows up, by the filament becoming incandescent, a B battery short circuit or leakage that might otherwise go unnoticed and very quickly run down this battery.

The X-L tungsten filament is not only useful in receiving tubes, but is alike applicable to the smaller sizes of transmitting tubes, resulting in a much lower requirement of filament energy.