Use of Thoriated-Tungsten Filaments in High-Power Transmitting Tubes*

R. B. AYER†, SENIOR MEMBER, IRE

Summary—**Experience gained in field and laboratory tests over the past ten years has shown that thoriated-tungsten filaments can be used in high-power transmitting tubes with life and reliability equal to that of the low-power types. This achievement can be attributed to improved materials such as oxygen-free high-conductivity copper and platinum-clad molybdenum, improved processing, and better exhaust facilities. Better appreciation of the mechanical problems and of the relationship between the carbide content, operating conditions, and life have all been important factors.**

I. Introduction

THIS paper describes the development and use of thoriated-tungsten filaments in high-power transmitting tubes, such as the RCA-5671, RCA-5770, and RCA-5771. Tubes operating with a dc plate voltage above 5,000 volts are considered to be in the high-power class.

Much has been written on the theoretical aspects of electron emission from thoriated-tungsten filaments since Langmuir[1] discovered that the emission from a tungsten filament containing 1 to 2 per cent of thorium oxide was much higher than that obtained from pure tungsten. Theoretically, the emission efficiency of a thoriated-tungsten filament is 70 to 100 milliamperes per watt of heating power, as compared with 4.25 to 8.5 milliamperes per watt for pure tungsten in the operating temperature ranges of 1,950 to 2,000 degrees K and 2,500 to 2,600 degrees K, respectively. Use has been made of this feature in the design of low-power transmitting tubes, and a long history of reliable performance has been built up over the last quarter of a century. In 1925, Warner and Pike[2] described their work on low-power types, such as the UV210, UV211, UV204A, and UV851. Since then, many more low-power types have been made available commercially to satisfy the ever-expanding application requirements.

As might be expected, many attempts have been made to use thoriated-tungsten filaments in high-power tubes, the earliest being about 1926, as far as the author is aware, but without any reported success until about 1945.[3] This early experience gave rise to the general belief that such filaments could not be used in tubes operating above 5,000 volts because of deactivation due to high-speed ion bombardment. Statements in recent literature,[4] and in books on vacuum tubes published as late as 1948,[5] indicate that this belief is still generally accepted.

Developments in radar since 1937 stimulated further work with thoriated-tungsten filaments, and their use in high-peak-power pulse-oscillator tubes during the last war has been described in a number of papers.[6–10] A recent article[11] describes the use of thoriated-tungsten filaments in high-voltage rectifiers for X-ray service.

II. Initial Work

A critical review of thoriated-tungsten-filament theory and design, early in 1940, indicated no fundamental reason why such filaments could not be used in high-power tubes, provided adequate attention was paid to mechanical strength and processing.

The RCA-207 type was selected for the initial tests. Thoriated-tungsten was used for the filament instead of pure tungsten, and barium-type getters were incorporated to assure a suitably low pressure. Two of these tubes operated in a 10- to 18-mc telegraph transmitter at a plate voltage of 10 kv for 7,953 hours before failure of one tube due to low emission. Throughout life the grid currents were very sensitive to filament input, the best performance being obtained at 517 watts instead of the usual 1,144 watts, a reduction of 55 per cent.

III. Design Considerations

A. Filament

The filament-design factors presented in this paper are based on a compromise between successful structures using pure-tungsten filaments, field experience with low-power thoriated-filament tubes, and the results of numerous life tests run at various temperatures. No attempt was made to obtain the optimum balance between power saving, mechanical strength, and life.

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† Tube Department, RCA, Lancaster, Pa.

[1] I. Langmuir, "The electron emission from thoriated-tungsten filaments," *Phys. Rev.*, vol. 22, no. 4, pp. 357–398; October, 1923.

[2] J. C. Warner and O. W. Pike, "The application of the *x-l* filament to power tubes," Proc. I.R.E., vol. 13, pp. 589–609; 1925.

[3] H. Romander, "Engineering details of OWI 200 kw units," *Electronic Ind.*, vol. 4, pp. 100–103, 158, 162; October, 1945.

[4] O. W. Pike, "Cathode design," *Communications*, vol. 21, pp. 5–8, 28; October, 1941.

[5] K. R. Spangenburg, "Vacuum Tubes," McGraw-Hill Book Co. Inc., New York, N. Y.; 1948.

[6] H. A. Zahl, J. E. Gorham, and Glenn F. Rouse, "A vacuum-contained push-pull triode transmitter," Proc. I.R.E., vol. 34, pp. 66W–69W; February, 1946.

[7] J. J. Glauber, "Radar vacuum tube development," *Elec. Commun.*, vol. XIX, no. 3; 1941.

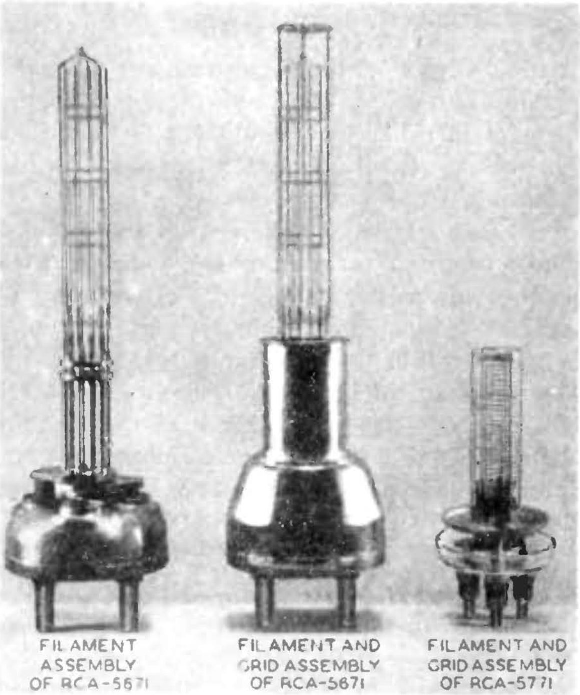
[8] J. Bell, M. R. Gavin, E. G. James, and G. A. Warren, "Triodes for very short waves," *Jour. IEE* (London), vol. 93, pt. IIIA, no. 5, pp. 833–846; 1946.

[9] I. E. Mouromtseff, "A quarter century of electronics," *Elec. Eng.*, vol. 66, pp. 171–177; February, 1947.

[10] J. E. Gorham, "Electron tubes in world war II," Proc. I.R.E., vol. 35, pp. 295–301; March, 1947.

[11] Z. J. Atlee, "Thoriated tungsten filaments in rectifiers," *Elec. Eng.*, vol. 68, no. 10, p. 863; October, 1949.

The self-supported type of multistrand structure shown in Fig. 1 was chosen because of its simplicity and reliable performance both in this country and in England.[12] The strands are connected in a series-parallel arrangement so that the heating current flows in opposite directions in adjacent strands. This effects the best balance of the magnetic forces. In addition, it permits alternate strands to be held in mechanical alignment by means of tie-wire assemblies located at any suitable number of horizontal planes. These may be seen in Fig. 1(a). The same wire size was used as for the pure-tungsten filament to assure adequate mechanical strength, and incidentally, to permit the use of available jigs and tools. The result is a simple filament structure having no springs, sliding members, center supports, or guide insulators.



(a) (b) (c)

Fig. 1(a–c)—Self-supported, multistrand, thoriated-tungsten filament assemblies (with and without grid assemblies).

In order to realize the full emission capabilities, a thoriated-tungsten filament must be flashed at approximately 2,800 degrees K for a brief period to reduce some of the thorium oxide to metallic thorium. The temperature is then reduced to 2,200 degrees K or less for a period of time to permit diffusion of the thorium to the surface where a monatomic layer is formed.[13] The operating temperature (usually 1,950 to 2,000 degrees K) must be such as to maintain a stable balance between the production of thorium atoms and their loss from the wire surface due to evaporation and to ion bombardment.

In practice, a thoriated-tungsten filament is carburized to reduce the rate of thorium evaporation and also to reduce the susceptibility to deactivation by ion bombardment.[14,15] Carburization is accomplished during manufacture by heating the filament to a high temperature in a hydrocarbon vapor or gas, such as benzine, toluene, or acetylene. The heated filament reacts gradually with the carbon in this atmosphere forming a shell of tungsten carbide around a core of tungsten, as shown in the magnified cross section in Fig. 2. This procedure has been described by Horsting.[16] The percentage of the filament cross section converted to tungsten carbide is called the "per cent carbide." During operation, the filament gradually decarburizes, and a point is finally reached where the emission can no longer be maintained.

Fig. 2—Magnified cross section of a carburized, thoriated tungsten filament.

Unfortunately, a carburized filament is considerably more brittle than an uncarburized filament. Thus, while it would be desirable to carburize a filament completely for long life, high strength would dictate no carburization at all. Therefore, a compromise is made whereby only part of the cross section is converted to the carbide. This is one reason for retaining the large wire diameter in the work being described.

Field experience and life tests have indicated that loss

[12] J. Bell, J. W. Davies, and B. S. Gossling, "High-power valves: construction, testing, and operation," *Jour. IEE* (London), vol. 83, no. 500, pp. 176–207; August, 1938.

[13] I. Langmuir, "Thoriated tungsten filaments," *Jour. Frank. Inst.*, vol. 217, no. 5, pp. 543–569; May, 1934.

[14] M. R. Andrews, "The evaporation of thorium from tungsten," *Phys. Rev.*, vol. 33, pp. 454–458; 1929.

[15] S. Dushman, "Thermionic emission," *Rev. Mod. Phys.*, vol. 2, p. 449; 1930.

[16] C. W. Horsting, "Carbide structures in carburized thoriated-tungsten filaments," *Jour. Appl. Phys.*, vol. 18, pp. 95–102; January, 1947.

of carbide and loss of emission are closely related, with operating temperature a very important factor. The carbide loss curve shown in Fig. 3, with temperatures expressed in terms of emission efficiency, was obtained from data taken on tubes of the 50-watt type having 8.5 mil filaments. This curve along with those on Fig. 4,

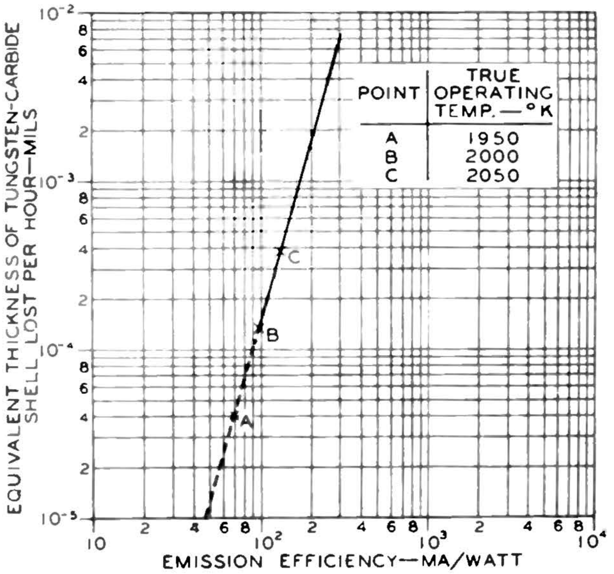


Fig. 3—Carbide loss versus operating temperature.

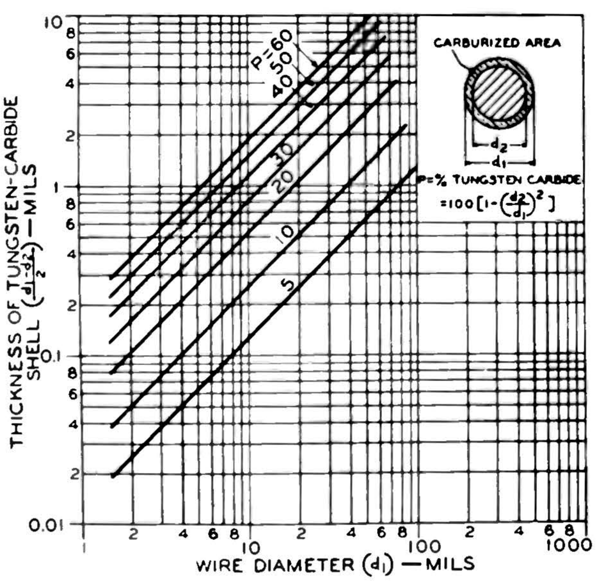


Fig. 4—Carbide shell thickness versus wire diameter and per cent carbide.

showing the relationship between carbide shell thickness, wire size, and per cent carbide, makes it possible to determine the life of any thoriated-tungsten filament. The curves of Fig. 4 were calculated on the assumption that the carbide was distributed uniformly over the wire surface. Use of these curves to predict the emission life of other tube types involving different wire sizes and carbide content have given surprisingly good results considering the structural and processing differences involved. Predictions to date on high-power types have been somewhat conservative. This is rather to be expected in view of the inherent differences between a tube completely enclosed in a glass bulb and one in which the active structure is enclosed in a metal envelope. As more experience is gained, some corrections may be necessary, but in the meantime these data are presented as additions to existing design information on thoriated-tungsten filaments.[17–19]

B. Grid

Merely changing the filament material and reducing its operating temperature by 500 to 600 degrees K is not sufficient to produce good thoriated-filament high-power tubes. Any material which enhances the emission from the filament would act similarly on the grid surface. Thus, the problem becomes one of finding a material or surface treatment which will withstand the processing temperatures and will be difficult to activate with thorium present. Some methods of attack on this problem have been described in the literature.[10,20] Early work at RCA indicated that a platinum surface was most desirable for high-power tube use. The mechanical weakness and high cost of pure platinum was overcome by using a molybdenum wire clad with a very thin layer of platinum. While this material is still quite expensive, the fact that it can be welded readily and cleaned by chemical and electrochemical means, that it does not oxidize, and that it has proven reliable over a long period of time has justified its continued use.

C. Anode

Little can be said in the way of comparison of anode materials, as only OFHC (oxygen-free high-conductivity) copper was used in all of these high-power tubes. This material has been used extensively in the electronic-tube industry for many years. Undoubtedly, its purity has contributed to the successful use of thoriated-tungsten filaments in high-power transmitting tubes.

D. Getter

Although several tubes (still operating after many thousands of hours of service) were made without any getter other than that provided by well-processed tube elements, particularly the anode, it was deemed advis-

[17] B. T. Barnes, "Properties of carbonized tungsten," *Jour. Phys. Chem.*, vol. 33, pp. 688–691; 1929.
[18] H. A. Jones and I. Langmuir, "The characteristics of tungsten filaments as a function of temperature," *Gen. Elec. Rev.*, vol. 30, pp. 310–319; June, 1927.
[19] H. J. Dailey, "Designing thoriated tungsten filaments," *Electronics*, vol. 21, pp. 107–109; January, 1948.
[20] H. E. Sorg and G. A. Becker, "Grid emission in vacuum tubes," *Electronics*, vol. 18, pp. 104–109; July, 1945.

able to provide additional means of assuring a high degree of vacuum. A small sheet of zirconium suitably located within the tube structure and heated by filament radiation was used for this purpose. The gettering properties of zirconium at elevated temperatures have been described in the literature.[21]

E. Processing

Proper processing is of utmost importance in building reliable vacuum tubes. Adequate cleanliness requires complete degreasing of parts and appropriate chemical and electrolytic cleaning, followed by complete removal of all traces of cleaning solutions. Uniform filament carburization requires suitable control of gas flow, hydrocarbon content, temperatures, and shielding. Care is required at final sealing to minimize oxidation of the metal parts. High-temperature outgassing of tube parts and limitation of maximum gas pressures are important factors in the exhaust process. The final pressure with the tube hot should be of the order of 10^{-5} to 10^{-6} mm of mercury.

IV. Types Developed

Development work on higher-power tubes with thoriated-tungsten filaments, started in 1942 and continued after the war, culminated in the commercial announcement of the RCA-5671, RCA-5770, and RCA-5771 types. Representative ratings are shown in Table I.

V. Advantages of the Thoriated-Tungsten Filament

The advantages to be gained by using thoriated-tungsten filaments in high-power transmitting tubes may be enumerated as follows:

(a) The 60- to 70-per cent reduction in heating power results in lower costs for filament transformers, controls, and other components as well as lower operating costs. A comparison of the thoriated-tungsten and equivalent pure-tungsten filament types is shown in Table II below.

[21] W. M. Raynor, "The use of zirmet for gas absorption," *Foote Prints*, vol. 18, no. 2, pp. 22–24; 1947.

TABLE II

Tube Type	Filament				Power Saving	
	Material	Volts	Amperes	Kilowatts	Kilowatts	Per Cent
9C21, 9C22	W	19.5	415	8.1	—	—
5770, 5671	Th W	11.0	285	3.1	5.0	61.7
880	W	12.6	320	4.0	—	—
5771	Th W	7.5	170	1.3	2.7	67.5

(b) The reduction in glass and seal temperatures provides greater safety factor for high-frequency operation and makes possible the elimination of forced-air cooling in certain low-frequency cases.

(c) The narrower temperature range covered in the heating and cooling cycle tends to simplify the mechanical problems.

(d) The hum level in broadcast transmitters is reduced as much as 8 db.

(e) There is less compression of the plate characteristics in the high positive-grid region.

(f) The anode dissipation can be increased by an amount equal to the reduction in filament input.

(g) The decreased number of filament leads on some types results in a lower input capacitance.

VI. Operating Experience

Several years of field experience has proven that thoriated-tungsten filaments are in every respect as reliable in high-power transmitting tubes as in the low-power types. Over 30,000 hours of trouble-free operation has been obtained in 50-kw broadcast service, with no indications of imminent failure. Operation in various industrial applications at plate voltages up to 17 kv and at frequencies up to 13 mc continues equally successful after more than 22,500 hours of service.

VII. Acknowledgments

Progress in any development is made possible by the combined efforts of many people. It is, therefore, with great pleasure that the author acknowledges the help and encouragement of the many engineers and technicians at RCA and in the field who have contributed to the success of this development.

TABLE I
Tabulation of Maximum CCS Ratings for Typical Services

Type	Class of Service	Frequency (mc)	DC Plate Voltage (volts)	Plate Current (amp)	Grid Current (amp)	Plate Input (kw)	Plate Dissipation (kw)	Typical Performance Power Output (kw)
RCA-5671	Class C Telegraphy (Plate-Modulated)	up to 10	12,500	4.5	—	55.0	17.0	40.0
RCA-5770	Class C Telegraphy	up to 20	17,000	9.0	1.25	150.0	50.0	105.0
		(1.6 to 25)	12,500	6.0	0.8	60.0	22.5	44.0
RCA-5771	Class C Telegraphy	(below 1.6)	15,000	6.0	0.8	67.5	22.5	53.0