The Design and Development of Three New Ultra-High-Frequency Transmitting Tubes*

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Summary—*A discussion and review are given of the service and design requirements of transmitting tubes intended for application in the ultra-high-frequency spectrum. These requirements fall in two classes: (1) those imposed by service conditions and (2) those imposed by the frequency at which the tube is operated. The fulfilling of these requirements has led to certain design and manufacturing problems, such as the reduction of grid emission, choice of anode material, choice of a suitable mechanical structure, etc.*

A description of the novel features of construction and the operation of three new ultra-high-frequency transmitting tubes are also given. Two of these tubes are the RCA-815 and RCA-829 which are push-pull beam tetrodes while the third tube, the RCA-826, is a triode. Some precautions necessary for obtaining satisfactory operation with these tubes are given.

THE recent activity in the development of ultra-high-frequency communication has created a demand for transmitting tubes having carrier power outputs of the order of 30 to 60 watts at frequencies as high as 150 megacycles and in some instances as high as 250 megacycles. In order to clarify the tube-design requirements it is well to enumerate the more common uses to which tubes are applied in ultra-high-frequency communication. These uses include police, aviation, marine, television, amateur, and point-to-point communication and employ continuous-wave transmission, amplitude modulation, or frequency modulation. A survey of these uses yields some interesting requirements which can be divided in two classes: (1) those imposed by service conditions; and (2) those imposed by the frequency spectrum in which the tubes are operated. The requirements of tubes suitable for operation in this frequency spectrum have been discussed at length by others[1–6] but are summarized in order that they can be considered in connection with the design and development of the three new ultra-high-frequency transmitting tubes described in this paper.

Tube-Design Requirements Imposed by Service Conditions

(1) The tube must be strongly constructed since it must withstand the mechanical shocks incident to all types of services in which it is applied, such as, for example, those which might be experienced when a police car drives over a curb or rugged terrain. It should not produce objectionable microphonics under such conditions.

(2) The tube must usually be designed for a plate voltage of less than 1000 volts and often as low as 300 volts. The use of low voltages offers many advantages to the equipment designer in insulation and weight requirements. In applications where power economy is a factor, it is desirable that all tubes of the transmitter operate at a common plate voltage in order to eliminate the need for power-consuming, voltage-dropping resistors.

(3) Air cooling must be used as the size and weight of liquid-cooling equipment is prohibitive in most cases.

(4) A tube is required which gives the highest efficiency with as low value of driving power as possible in order to reduce the size, weight, and cost of component parts of the transmitter and associated power supplies. In terms of tube design, a high-perveance tube is indicated, preferably of the screen-grid type.[7]

(5) A filament or heater operating at 6.3 or 12.6 volts should be used in those tubes intended for mobile services in order to avoid series dropping resistors and attendant loss of power.

(6) Police, marine, and aviation services usually require that the tube occupy a minimum of space and be of as small over-all length as possible.

(7) The construction must be such that the tube, in case of failure, can be replaced readily and quickly in the transmitter.

Design Requirements Imposed by Frequency of Operation

(1) Electrically the tube should lend itself readily to circuit design and what is, perhaps, more important if transmission lines are used, should not excessively shorten either the input or output lines because of its input and output capacitance. An appreciable part of the circuit must appear outside the tube.

(2) The dimensions and material of the electrode leads must be such that they will safely carry the ultra-high-frequency currents without overheating or introducing any appreciable amount of impedance.

(3) Transit-time losses must be minimized.[5,8] This

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[1] C. E. Fay and A. L. Samuel, "Vacuum tubes for generating frequencies above one hundred megacycles," Proc. I.R.E., vol. 23, pp. 199–212; March, 1935.

[2] M. J. Kelly and A. L. Samuel, "Vacuum tubes as high frequency oscillators," *Trans. A. I. E. E.* (*Elec. Eng.*, November 1934), vol. 53, pp. 1501–1517; 1934; *Bell Sys. Tech. Jour.*, vol. 14, pp. 97–134; January, 1935.

[3] W. G. Wagener, "The developmental problems and operating characteristics of two new ultra-high-frequency triodes," Proc. I.R.E., vol. 26, pp. 401–414; April, 1938.

[4] A. L. Samuel and N. E. Sowers, "A power amplifier for ultra-high frequencies," Proc. I.R.E., vol. 24, pp. 1464–1483; November, 1936; *Bell Sys. Tech. Jour.*, vol. 16, pp. 10–34; January, 1937.

[5] A. K. Wing, Jr., "A push-pull ultra-high frequency beam tetrode," *RCA Rev.*, vol. 4, pp. 62–72; July, 1939.

[6] W. G. Wagener, "The requirements of a new ultra-high-frequency power tube," *RCA Rev.*, vol. 2, pp. 258–265; October, 1937.

[7] O. H. Schade, "Beam power tubes," Proc. I.R.E., vol. 26, pp. 137–181; February, 1938.

[8] A. V. Haeff, "Effect of electron transit time on efficiency of a power amplifier," *RCA Rev.*, vol. 4, pp. 114–122; July, 1939.

implies close-spaced electrodes and, consequently, high dissipation densities per unit area.[9]

(4) The insulation between electrodes must not introduce any appreciable losses and also must not disintegrate at high frequencies or at elevated temperatures.

(5) If the tube is of screen-grid type, it must perform as a stable amplifier without neutralization. It must, therefore, have a low feedback capacitance and also must not have other characteristics, such as common impedances, which provide unwanted energy interchange. If the tube is a triode, it must be capable of satisfactory neutralization.

(6) Provisions must be made to minimize random and stray electrons which may, due to their long time of flight, cause poor efficiency. Stray electrons striking a glass envelope may lead to gas evolution directly or in more severe cases to gas evolution indirectly through glass decomposition. Furthermore, under certain conditions they can give rise to secondary emission and can, thus, cause a portion of the glass surface to assume a positive potential. This charged portion may attract more electrons and cause localized bulb heating and consequent softening of the bulb to the point where failure occurs.

Special Problems of Design and Manufacture

Departures from conventional design procedures such as reduction in size, decrease in interelectrode spacings, and the consequent increase in dissipation densities made in order to secure better high-frequency performance have given rise to some fundamental design problems. Probably the most important of these is the elimination of grid emission. Grid emission results from operation of the grid at elevated temperatures produced by the inherently high dissipation densities and may be intensified by a deposit of active material from the emitter either during manufacture or during operation. Some basic means must be provided which will make the grid operate at temperatures below that at which it emits objectionably. This reduction in temperature may be obtained through removing heat more rapidly from the grid either by (a) conduction, through the use of copper side rods for the control grid and the use of grid wire of high thermal conductivity or (b) radiation, by carbonizing any part from which heat can be radiated so that the resultant temperatures of electrodes adjacent to the grid are reduced.

Considerable improvement may be had by operation of the cathode at a temperature low enough to provide satisfactory emission but yet not high enough to cause excessive evaporation of active emitting material to the grid. Gains can also be obtained in screen-grid types of tubes by designing the screen so that its dissipation and consequently its temperature is reduced. The beam type of tube offers much advantage in this respect.[7] Finally, a strategic choice of materials has important benefits in the reduction of grid emission. It is well known in the case of oxide-coated emitters that certain nickel-base alloys behave much better than others so far as causing grid emission is concerned and it is also well known that certain grid materials are apt to emit more copiously than others.

The increase in safe anode-dissipation density can be accomplished by using an anode whose effective radiating area is increased by the use of fins or by the roughening of the surface. It may also be increased by using an auxiliary material on the surface which increases the heat-radiating properties by either producing an increase in thermal emissivity or in surface area. Although carbon has a high emissivity, its use presents some manufacturing problems in small high-frequency tubes. It is difficult to obtain a good low-resistance contact with the carbon, a very important requirement at high frequencies. In the case of oxide-coated emitters, the degassing temperature of carbon lies near or above that to which the emitter can be heated without impairing its emission properties. These disadvantages of carbon make the choice of a metal anode material preferable. For one of the new tubes described in this paper, a carbonized nickel anode is used with a fin structure which effectively doubles the power it can radiate. In another tube type, a zirconium-coated molybdenum anode is used which has a fin structure so constructed that it has a power-handling capability that approaches that of carbon.[10,11]

Operation of electrodes at higher temperatures and the larger ratio of mass of metal to volume of the envelope of the tube requires a most active and efficient getter. Batalum getter[12,13] is quite satisfactory and in the case of zirconium-coated anodes, zirconium itself exhibits a remarkable getter action.

At the higher frequencies the choice of material and the location of insulators is very important in order to avoid localized heating which in addition to the attendant loss of power may cause the release of gases and the consequent impairment of the emission characteristic.

Because of space requirements and the necessity of short direct leads, the volume of the envelope must be minimized. This requires that the glass of envelope and stem be very stable and that it also be carefully processed in order to remove surface contaminations and gases so that little or no gas be released during the life of the tube. The release of gas from glass proceeds quite rapidly at elevated temperatures or undue electron bombardment; hence, it is imperative that few

[9] B. J. Thompson, "Review of ultra-high-frequency vacuum tube problems," *RCA Rev.*, vol. 3, pp. 146–155; October, 1938.

[10] J. D. Fast, "Zirconium," *Foote-Prints*, vol. 10, pp. 1–24; December, 1937.

[11] J. D. Fast, "Zirconium as a getter," *Foote-Prints*, vol. 14, pp. 22–30; June, 1940.

[12] E. A. Lederer, "Recent advances in barium getter technique," *RCA Rev.*, vol. 4, pp. 310–318; January, 1940.

[13] E. A. Lederer and D. H. Walmsley, "Batalum—A barium getter for metal tubes," *RCA Rev.*, vol. 2, pp. 117–123; July, 1937.

stray electrons strike the glass and that it operate at not too high temperature. Forced-air cooling may be used to advantage in some instances to reduce the bulb temperature. As the mount size is reduced and leads are shortened, the problem of sealing the glass envelope to the stem without excessive oxidation or burning of the tube electrodes becomes a major problem.

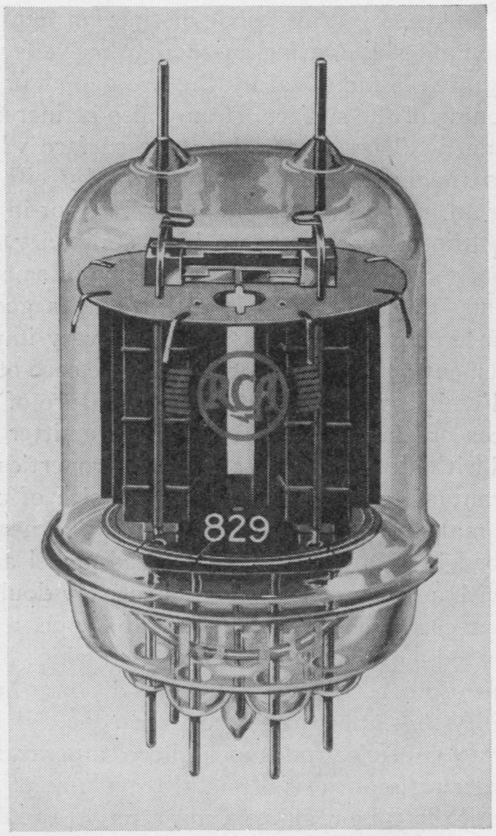


Fig. 1—A push-pull beam transmitting tube having oxide-coated cathodes and a total plate dissipation of 40 watts. It may be operated at full rating to frequencies as high as 200 megacycles.

The Three New Ultra-High-Frequency Transmitting Tubes

Three new ultra-high-frequency transmitting tubes were designed and developed in accordance with these service and frequency requirements to fulfill specific commercial needs. Two of these tubes, the RCA-829 and the RCA-815 are push-pull beam power tetrodes, and the other, the RCA-826, is a triode.

RCA-829

The RCA-829 is a push-pull beam power tetrode of the heater-cathode type. (Fig. 1.) It contains two beam power units within one envelope. The total maximum plate dissipation is 40 watts. It is capable of handling power inputs of 120 watts with very low driving power at frequencies as high as 200 megacycles and may be operated at reduced ratings at frequencies as high as 250 megacycles. The RCA-829 was developed to meet the need for a tube that would be suitable for mobile operation and would deliver a carrier power output of 50 watts at 200 megacycles.

A consideration of the fundamental requirements and experience on the type RCA-832 (a push-pull tetrode)[5] led to the choice of a structure similar in many ways to the RCA-832 but with greater power capabilities. Inasmuch as it was not desirable to raise the plate voltage above 500 volts, a longer mount structure was used in order to obtain an input current which would fulfill the output power requirements. This change led to several interesting mechanical and electrical problems in the design of the RCA-829.

In the early developmental tubes, considerable energy interchange appeared between the plate circuit and grid circuit, so much that operation of the tube as a power amplifier at 200 megacycles was very difficult. When the plate circuit was tuned through resonance, with the grid circuit excited in a normal manner and no voltage applied to the anodes of the tube, measurements showed more than 1 watt of power being fed through the tube from the grid circuit into the plate circuit. This large amount of power did not appear to be due entirely to the direct feedback capacitance of the 829. All attempts at internal neutralization of the tube were unsuccessful. Furthermore, it also appeared that neutralization in any form would be extremely difficult if not practically impossible at these ultra-high frequencies. This feed-through of power or apparent increase in feedback capacitance was found to be due to the series inductance of the tube electrodes produced by their respective lengths. This inductance caused a radio-frequency potential to exist between the top and bottom of each respective tube electrode. Such a condition was particularly objectionable in the case of the beam-plate assemblies and screens as it gave rise to an indirect feedback which produced energy interchange between the control-grid circuit and the plate circuit and prevented stable amplifier operation. The magnitude of this series inductance was very much reduced by cross-connecting the screens of each unit at both the top and bottom of the mount.[14] Similarly, the beam-plate assemblies and cathodes of each unit were cross-connected. Fig. 1 illustrates the method in which these connections are made at the top of the tube. Tubes made in this manner are quite stable when operated as power amplifiers at a frequency of 200 megacycles. After this change was made only a small fraction of a watt was fed through the tube.

The output capacitance is approximately 7.0 micromicrofarads. This value is neither excessive nor objectionable as it permits an external circuit of about 6 inches in length for operation at 200 megacycles with a quarter-wave parallel line having a surge impedance of approximately 180 ohms. The input-circuit capacitance is approximately 15 micromicrofarads. This

[14] The writer is indebted to Mr. Bernard Salzberg, formerly of the RCA Manufacturing Company (Harrison, N. J.), now of the Naval Research Laboratories (Anacostia, D. C.), for this method of reducing electrode inductance.

value at a frequency of 200 megacycles may or may not permit the use of a quarter-wavelength line depending upon the surge impedance of the line. Consideration of the factors contributing to input capacitance such as grid-to-cathode spacing, grid-to-screen spacing, cathode width, cathode length, etc., indicated that this value could not be materially reduced without seriously impairing the perveance, mechanical stability, and high-frequency characteristics.

Some means had to be provided for bracing the mount when the length was increased, which would not appreciably impair the high-frequency characteristics of the tube. This was accomplished by using staples in the top mica bearing against the inner bulb surface. The two large openings in the top mica which are spaced between the two units are provided to remove the mica from a position of high field gradient. With the tube under much higher than rated anode voltage and at a frequency of 200 megacycles, it was discovered that the mica was heated to a point of showing color in the position where the holes are now located.

Nickel side rods on the No. 1 grid which had been used satisfactorily in the type 832 were found to be

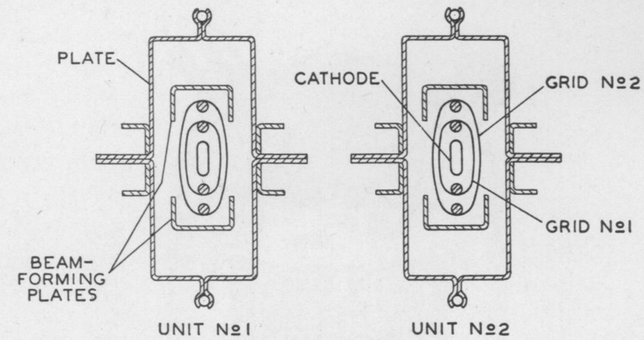


Fig. 2—Horizontal cross section of the RCA-829 electrodes.

unsuitable because of grid emission in the type RCA-829. This was due to the increased length of the grid. The center section operated at a higher temperature due to the proportionally lower amount of heat conducted away by the side rods to the grid terminals. The use of a silver-copper-alloy side rod has satisfactorily corrected this trouble. The silver-copper alloy has practically all the thermal conductivity of copper but is materially stiffened by the presence of a small amount of silver. It was found necessary to use a copper connector and radiator on the bottom of the control grid in order to permit heat flow from both side rods to the stem lead. An anode constructed with fins in a manner shown in Fig. 2 aids in reducing the anode temperature and, consequently, the operating temperature of the control grid. These fins increase the effective radiating area of the anode. Although the anode is made of carbonized nickel, great care must be exercised in order that no loose particles of carbon are left on the anode. These, under electrostatic fields, tend to migrate to the cathode and impair its emitting properties. Therefore, the anode must be brushed thoroughly to remove all loose carbon particles. The ends of the beam plates above the anode are closed over the grid-cathode structure in order to prevent stray electrons from escaping and striking the glass envelope.

Fig. 3 shows the stem used on both the RCA-829 and RCA-826. This type of stem permits of short, heavy, and low-loss leads which are quite essential at ultra-high-frequency. The 0.060-inch diameter tungsten

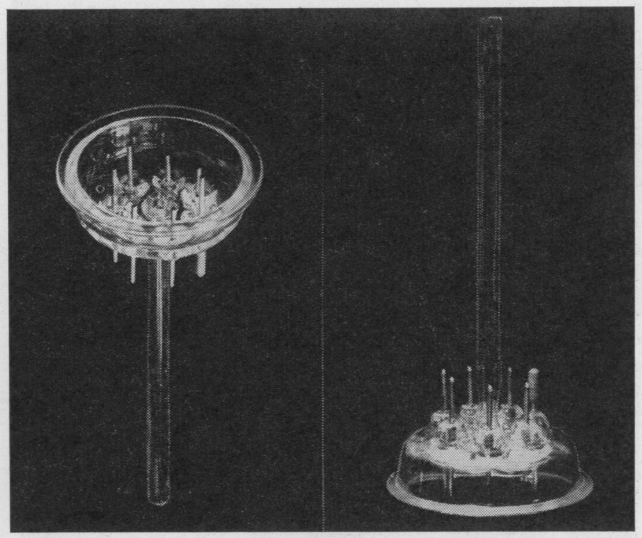


Fig. 3—Molded-flare stem as used on the RCA-826 and RCA-829.

leads of the stem afford an excellent means of transferring heat away from the control grid by conduction to the socket terminals.

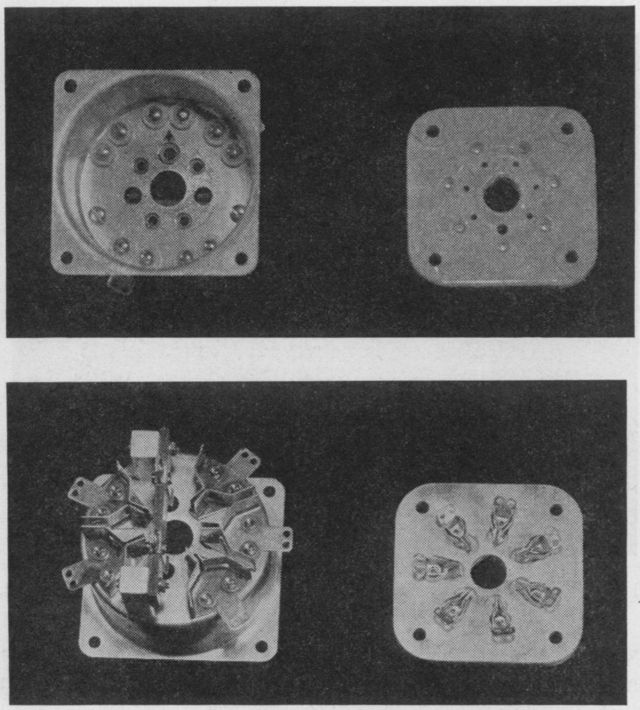
The maximum ratings of the RCA-829 are given in Table I. Forced-air cooling must be used when the

TABLE I
MAXIMUM RATINGS

	RCA-829	*RCA-815*	*RCA-826*
Class C Telephony (Carrier Condition)			
Direct plate voltage	425	325	800 volts
Direct screen voltage	225	200	— volts
Direct grid voltage	−175	−175	−500 volts
Direct plate current	212	125	95 milliamperes
Direct grid current	15	6	40 milliamperes
Plate input	90	40	75 watts
Screen input	7	2.7	— watts
Plate dissipation	28	13.5	40 watts
Class C Telegraphy			
Direct plate voltage	500	400	1000 volts
Direct screen voltage	225	200	— volts
Direct grid voltage	−175	−175	−500 volts
Direct plate current	240	150	125 milliamperes
Direct grid current	15	6	35 milliamperes
Plate input	120	60	125 watts
Screen input	7	4	— watts
Plate dissipation	40	20	60 watts

tube is operated at full rated input. With a circuit employing grid and plate transmission lines, a carrier power output of 53 watts (as measured in a lamp load) was obtained at 200 megacycles for a plate voltage of 425 volts and a current of 210 milliamperes. Measurements have indicated that the output circuit loss was approximately 10 watts. The circuit loss was estimated by attaching a thermocouple to the tube envelope opposite one anode. The temperature was noted under normal operating conditions in order to obtain an index of anode dissipation. The load was then removed and with the plate circuit tuned and with normal plate voltage maintained the input current was varied by adjusting the screen voltage until the same bulb temperature as previously noted was obtained. The plate

(a)



(b)

Fig. 4—(a) Top view of the UT-106 and UT-107 sockets.
(b) Bottom view of the UT-106 and UT-107 sockets.

circuit was then detuned and the same process repeated. The difference in the input power required to give the same envelope temperature with the unloaded circuit tuned and detuned gives an approximate measure of circuit loss. Since the plate-circuit losses are proportional to the square of the anode voltage, the plate-circuit efficiency should not rise as fast as predicted from voltage considerations. That such is the case has been verified in that little or no improvement in efficiency was obtained by increasing the anode operating voltage on the RCA-829 from 400 to 500 volts.

In order to realize the full capabilities of the RCA-829 it is necessary that all radio-frequency by-passing be as near the tube terminals as possible. It is desirable to have the by-pass condensers made an integral part of the socket assembly. Fig. 4 illustrates a socket (UT-107) that was developed commercially for this tube. For stable amplifier operation it is essential that the input circuit be well shielded from the output circuit. It is also important at ultra-high-frequencies to provide low-loss terminal connections to the tube.

RCA-815

The good performance and exceptional operating characteristics of the RCA-829 led to the consideration of a new tube that would be more adaptable to quantity production and that could be produced at a cost below that of the RCA-829. Such a tube should fulfill a need existing in the radio amateur field for a small tube suitable for 112-megacycle operation.

The RCA-815 is a twin beam tetrode designed for a maximum input of 60 watts at frequencies as high as 150 megacycles. (Table I.) The RCA-815 like the RCA-829 contains two beam power units except that the envelope is of soft glass instead of hard glass and the units are somewhat smaller than for the RCA-829 electrode assembly (Fig. 5). The total maximum plate dissipation is 20 watts instead of 40 watts but like its prototype it has a heater arrangement permitting either 12.6- or 6.3-volt operation. The two units may be operated either in parallel or push-pull as a modulator, oscillator, or radio-frequency amplifier. This tube is well suited for use as a frequency multiplier or driver for another RCA-815, or for the RCA-829.

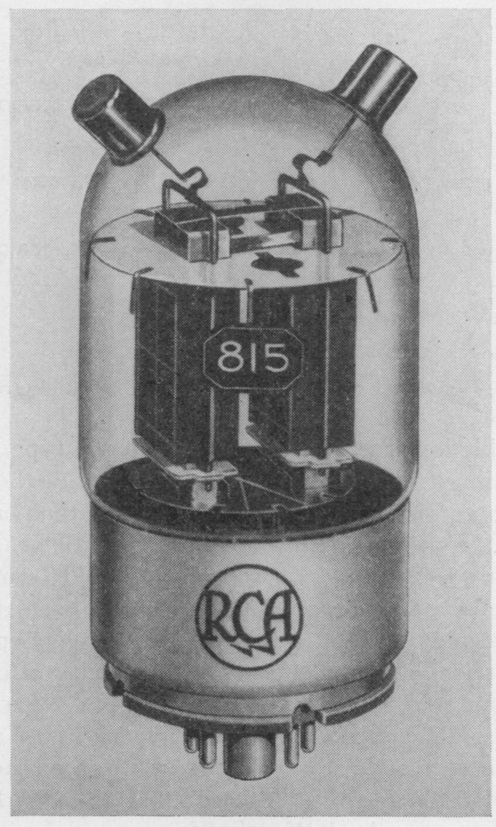


Fig. 5—A push-pull beam transmitting tube having oxide-coated cathodes and a total plate dissipation of 20 watts. It may be operated at full rating to frequencies as high as 150 megacycles.

The button stem shown in Fig. 6 is used to provide short lead length. The RCA-815 is made with a metal-shell micanol-wafer base which permits the use of conventional low-loss octal sockets since the maximum frequency is but 150 megacycles. Plate connections are made through conventional top caps. In order to minimize the inductance of the electrodes, use of a structure quite similar to that of the RCA-829 was obvious. The RCA-815 has substantially one half of the power-handling capabilities of the RCA-829.

In properly designed circuits a carrier power output of 30 watts may be obtained at a frequency of 150 megacycles. Forced-air cooling is not required.

RCA-826

In some fixed-frequency ultra-high-frequency transmitters the simplicity of triodes and their associated circuits offer an advantage over screen-grid types. The RCA-826 (Fig. 7) was developed to serve this field. It may be operated at maximum ratings at frequencies as high as 250 megacycles. (See Table I.)

This tube has a double-helix thoriated-tungsten filament, a zirconium-coated molybdenum anode, and a molybdenum grid. The anode has 8 fins to increase its total effective radiating area and is assembled by weld-

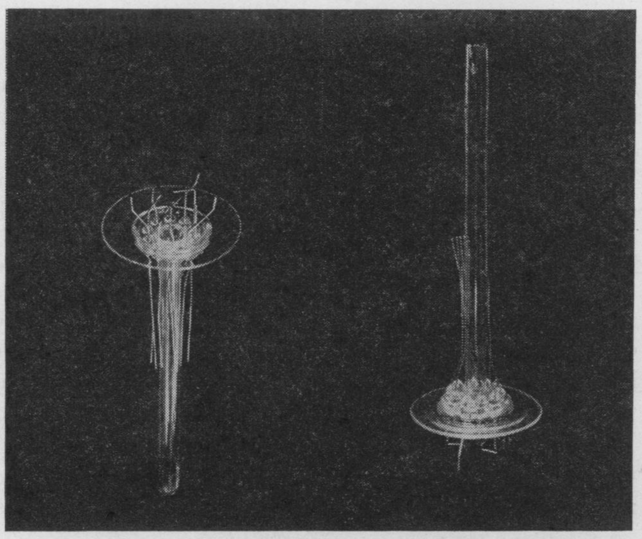


Fig. 6—Glass-button stem as used on the RCA-815.

ing 8 preformed molybdenum channels together. Sides of two adjacent channels form one fin, thus giving good heat conductivity from the barrel of the anode to the fin. The molybdenum is coated with zirconium for the twofold purpose of increasing the thermal emissivity over that of the conventional sandblasted molybdenum and to obtain the getter action of zirconium. Although this tube also has a conventional getter, developmental tubes without any getter other than the zirconium have been made, which were satisfactory on life test. This anode will safely withstand a momentary dissipation equal to several times rated plate input, without injuring the zirconium surface or impairing the quality of the tube. No insulation is used between the electrodes other than that of the molded-glass stem. Shields are placed on each of the structures to reduce stray electrons. These shields are mounted on the filament center support so that they will be at filament potential and will not collect any current during operation of the tube. A dual set of leads is brought

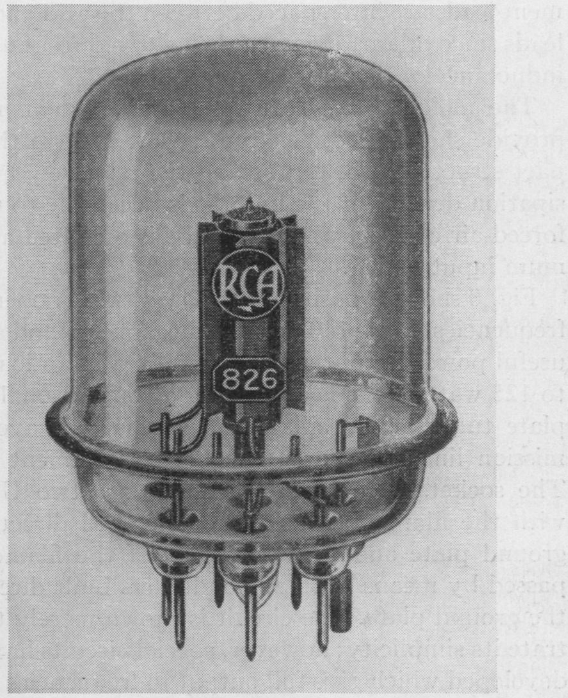


Fig. 7—A transmitting triode having a thoriated-tungsten filament and a total plate dissipation of 60 watts. This tube may be operated at full rating to frequencies as high as 250 megacycles.

out from the grid and plate, these leads ordinarily being arranged in parallel to reduce lead inductance and improve the ease of high-frequency operation. If desired, one set of leads may be used for neutralizing

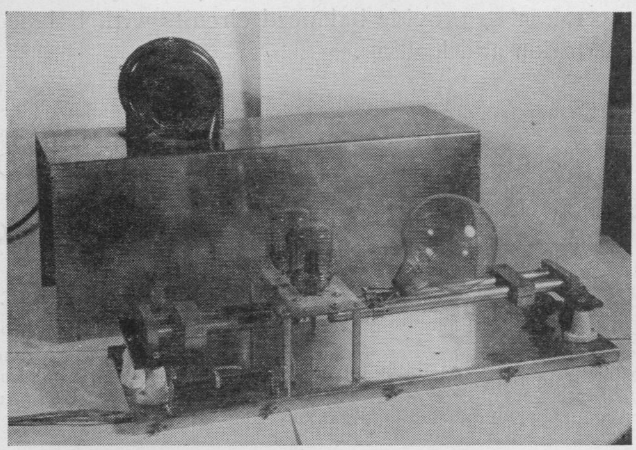


Fig. 8—A push-pull oscillator using RCA-826's.

and the other for handling power. This arrangement tends to minimize the trouble sometimes experienced in neutralizing where a considerable portion of the neutralizing circuit is common to the power-handling or controlling circuit. These dual leads are symmetrical about a diametrical plane through the filament center tap. This arrangement fulfills the frequent request for a right- and left-handed tube for push-pull operation in order to obtain short symmetrical leads. The filament leads are interspaced between the grid and anode leads since this arrangement helps to reduce the mutual inductance of these two latter leads.

The molded-glass flare used in this stem helps to provide short direct electrode leads. Due to the compact structure of the tube and the relatively high dissipation density of the bulb, it is necessary to provide forced-air cooling, when the tube is operated at maximum input rating.

Fig. 8 shows a push-pull oscillator which operates at frequencies from 140 to 200 megacycles and gives a useful power output as measured in a lamp load of 90 to 125 watts. This is essentially a conventional tuned-plate tuned-grid oscillator using quarter-wave transmission lines with no tuning of the filament circuit. The sockets used in this instance are two UT-106's with the filament center tap connected directly to a ground plate and with each side of the filament by-passed by means of small condensers built directly on the ground plate. The circuit is shown merely to illustrate its simplicity; however, special circuits have been developed which give full output to frequencies as high as 250 megacycles.

Application

In the application of these and other ultra-high-frequency tubes, it may be advisable to enumerate several precautions which are necessary to obtain satisfactory operation. These are:

1. Most push-pull amplifiers or oscillators are apt to have parallel oscillations unless special precautions are taken to provide balanced circuits with balanced excitation and loading.

2. Circuits used at ultra-high-frequencies should be silver-plated in order to minimize circuit losses.

3. Radiation should be minimized. This can be accomplished by a proper choice of shielding and the use of symmetrical circuits. Instances have been noted where full power output was not obtained because of resonance of the transmitter structure.

4. Adequate by-passing should be provided. The RCA UT-107, or its equivalent socket, should be used with the RCA-829. The UT-106 with postage-stamp mica condensers for by-passing should not be used with the 829 at ultra-high-frequencies.

5. Sockets should have large nonoxidizing contacts since a corroded or oxidized contact not only causes a reduction of output at ultra-high frequency but may cause severe circuit unbalance.

6. Since only one screen terminal is provided it is recommended that the individual units of either the RCA-815 or RCA-829 not be used as separate amplifiers, since it is quite difficult to determine the actual division of the screen input for other than push-pull or parallel arrangements of the units.

7. A vacuum-type incandescent lamp should be used in preference to the gaseous type for power-output measurements in order to avoid losses due to the ionization and arcing of the gas at high frequency. It may also be necessary to try a variety of sizes and structures of lamps before a satisfactory load is obtained.

Acknowledgment

In conclusion the author wishes to express his appreciation to his fellow members of the RCA Manufacturing Company, Inc., for their aid in the development of these tubes and in particular to Messrs. J. C. Hapgood, H. R. Nelson, C. F. Nesslage, and R. B. Vandegrift for their aid in the solution of many design and manufacturing problems.

Radiating System for 75-Megacycle Cone-of-Silence Marker*

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Summary—*A brief description is given of a new 75-megacycle cone-of-silence marker radiating system developed for use on the Canadian airways. This system provides a sharper marker beam and reduces orientation error over previous marker radiating systems.*

ACCUMULATED civil-aviation experience with early types of cone-of-silence markers[1] has revealed certain deficiencies which pilots felt were compromising their usefulness somewhat. It was desirable to reduce these deficiencies by further development of the radiating system. A sharper vertical beam and less orientation effect with the typical horizontal linear marker-receiver antenna were the objectives sought.

A radiating system having the theoretical radiation characteristics shown in Fig. 1 appeared to offer the desired improvements. The mechanical form appeared to have acceptable cost and practicability characteristics. The authors undertook a collaborative development of the system in behalf of their respective organizations at the St. Hubert radio range station near Montreal in June, 1940. The development effort

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† RCA-Victor Company, Ltd., Montreal, Quebec, Canada.
‡ Department of Transport, Ottawa, Ontario, Canada.
1 Department of Commerce, Bureau of Air Commerce, Safety and Planning Division Report No. 16.