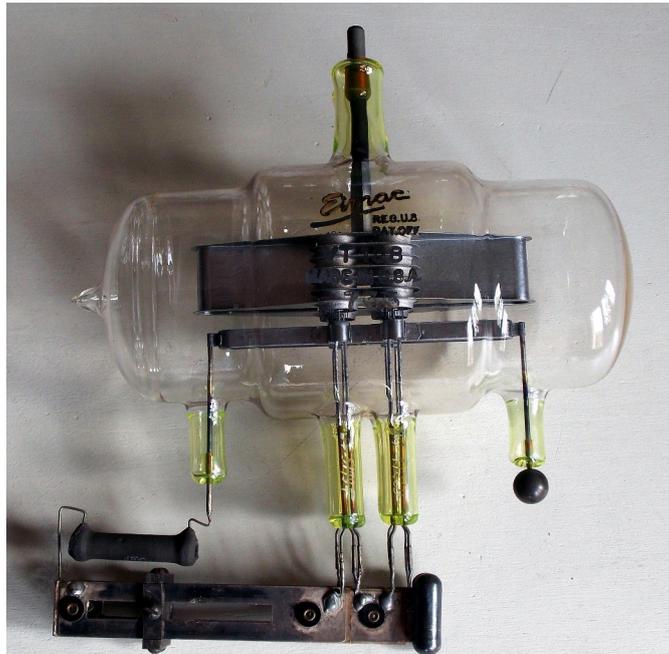# VT-158 - UHF Zahl Oscillator

The VT-158 was designed by Major Harold Zahl of the Army Signal Corps as power oscillator for a radar set capable of operation around 600 MHz. Four triodes and the associated grid and plate resonating lines forming the complete oscillator were put into a single glass bulb, triodes being connected in a parallel push-pull configuration.

In the two photos above we can see the finned anode block, which also acts as a resonating line, and the smaller grid resonating libe just below. The lines were factory tuned at 600 MHz but, when needed, the frequency could be moved from about 590 to 610 MHz by means of a shorting bar on the filament decoupling line.

The output rods were connected to the points of maximum amplitude between the anodes of the two adjacent triodes on each of the two segmrnts of the plate line. on the contrary, the grids were self-biased through a resistor connected to one of the pins coming out from the nodes of the grid line, the other one being left open. Emitters were made of quite heavy thoriated tungsten wire, spirally wound around thick rods.
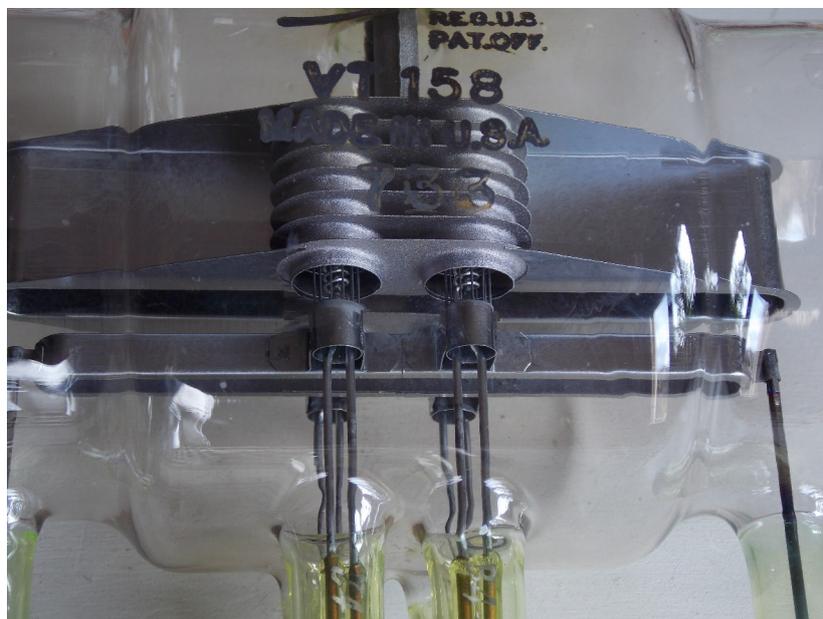
ULTRA -HIGH -FREQUENCY PULSED OSCILLATOR VT -158 data.

- **Four filaments, each requiring 10 V (9.8 to 10.2 V) at 10 A nominal. 10.5 V at 10.5 A abs. max ratings. *** Note: The four filaments are series connected outside, to operate from 40.0 V at 10.0 A supply**
- **Plate input power: 1500 kW abs. max rating**
- **Plate power dissipation: 400 W max, requiring 60 cubic feet per minute air flow.**
- **Plate max voltage: 30 kV**
- **Current emission: 70 A min**
- **600 MHz factory preset resonating frequency**
- **Self-biased through 80 ohm, 5 W grid resistor**
- **Typical life in excess of 500 hours**

Typical operation in the AN/TPS-3 radar transmitter

- **24 kV anode pulses, 1.5 µs wide, 200 pulses per second repetition rate**
- **200 kW RF output pulses**
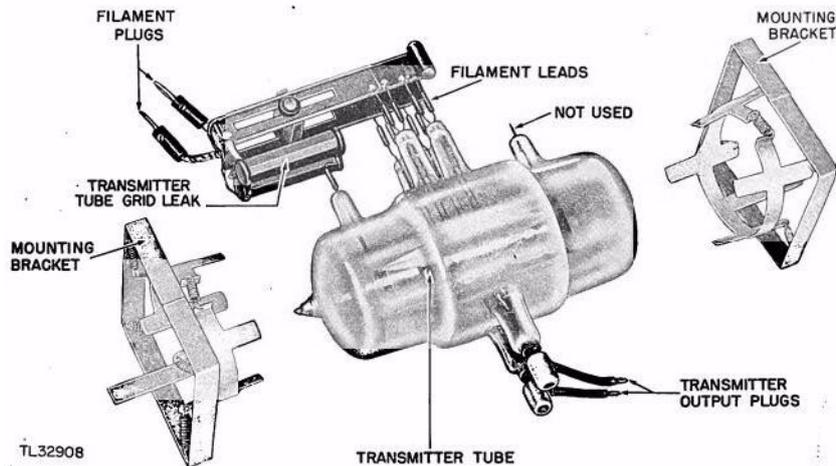- **Output frequency tunable from 590 to 610 MHz**
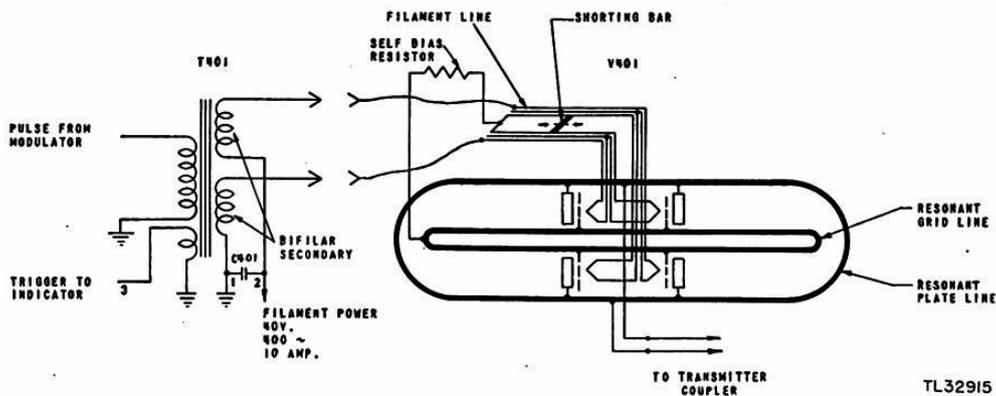

Figure 88. Transmitter tube.

Figure 16. Transmitter functional schematic.

The design of the VT-158 was carried out between 1942 and 1943, in parallel with that of the AN/TPS-3 radar. The goal was to design a compact, transportable radar

operating around 600 MHz with a pulse power of 200 kW. Due to the difficulty of producing single, high-power triode that could operate at those frequencies, it was preferred to use four smaller triodes, operating in a parallel/push-pull configuration. To prevent the parasitic parameters arising from the interconnections of four triodes, it was decided to integrate their geometries directly into the anode resonant line, which was therefore located inside the evacuated bulb. The finned plate resonating line is made of tantalum for its getter action when heated to dull red during operation. Below the plate resonator we see the grid resonating line. The grids deserve special mention, being constructed according to an innovative Eimac process defined as an 'X-grid cage'. Their appearance resembles a 'parrot cage', with vertical ribs forming a rigid skeleton around which the thin spiral wire is wound, quite similar to that of English micropups. The entire grid assembly is made of thorium-coated tantalum wires: the presence of thorium, just as it could kill filament emission in the presence of contamination, also prevented secondary emission from the grids when hot, due to heavy conduction during driving positive pulses. The four carbonized thoriated tungsten filaments appear very robust, their design preventing sagging over time. They absorb a total of 400 W, granting 80 A total emission and useful life in excess of 500 hours.

In conclusion, the VT-158 contains in a compact glass bulb all the pre-assembled critical parts of a reliable and efficient 200 kW 600 MHz pulsed transmitter.

Attached below are two papers on this almost unique embedded oscillator.

A vacuum-contained push-pull triode transmitter by Zahl, Gorham and Rouse
Grid emission in vacuum tubes, Electronics, July 1945

A Vacuum-Contained Push-Pull Triode Transmitter[*]

HAROLD A. ZAHL†, ASSOCIATE, I.R.E., JOHN E. GORHAM†, ASSOCIATE, I.R.E., AND
GLENN F. ROUSE†

Summary—A 600-megacycle transmitter is described which varies from the usual triode design in that the resonating grid and plate circuits are contained in vacuum and form an integral part of the grid and plate structures. The design described, while applicable for continuous-wave operation, covers particularly United States Army-type tube VT-158 constructed only for pulse operation. Peak powers of 200 to 300 kilowatts can be obtained under proper conditions of operation.

I. INTRODUCTION

A FEW YEARS ago Major-General Roger B. Colton, then Director of the Signal Corps Laboratories, Fort Monmouth, N. J., noticed how much difficulty was being experienced with radio-frequency sparking and loading of more or less conventional ultra-high-frequency high-power, triode oscillator circuits. He suggested that most of the troubles would be eliminated if the oscillators were constructed with the circuits contained in a vacuum. This paper will describe a transmitter which was subsequently built so as to incorporate most of the radio-frequency circuits inside the vacuum envelope.

II. DESIGN DESCRIPTION

The illustration represents a tube constructed by the authors which can be made to oscillate in a narrow frequency band between 200 and 700 megacycles. Although satisfactory continuous-wave oscillators of this type have been built, the main application has been in the field of high-power pulse oscillators capable of furnishing about two- or three-hundred kilowatts of radio-frequency power.

Fig. 1 shows a general view of one model of this type of tube. The two vertical, parallel rods at the top of the tube form a balanced-line output circuit which is coupled directly to the plate circuit. The parallel transmission line serves in a rough way as a matching circuit to connect the tube to a 50-ohm concentric line, such as is often used to transmit power in this frequency band.

The uppermost loop, or plate loop, is connected directly to the anodes in such a way as simultaneously to reduce the problem of connecting the oscillating circuit to the plates, and by virtue of the flat surface of the loop, increase the effective radiating surface and power dissipation of the plates. The plate loop, made up of

two U sections, serves to maintain the symmetry of the circuit, and of course each of the two U sections, in effect, resonates with half of the interelement capacitances. Thus for a given half-loop length and set of interelement capacitances, the tube may be made to oscillate at a higher frequency than if only one half loop was used.
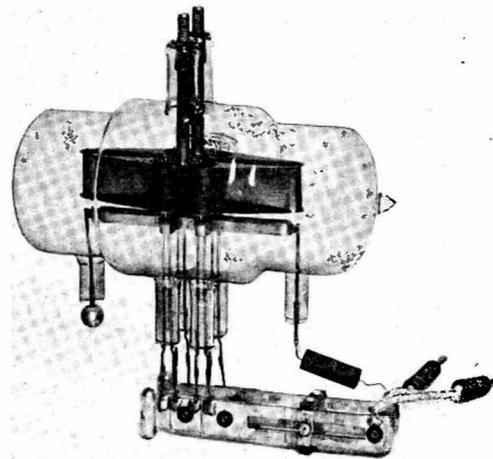

Fig. 1—Front view of transmitting tube.

It has been found advantageous to make both the upper and lower loops of tantalum, since this metal is relatively easy to work and is well known as a good getter. Production models of this general design depend entirely on the tantalum for getter action.

A word should be said about the two anodes in parallel, which in turn operate in push pull with two more anodes in parallel. Several successful continuous-wave oscillators were built with single anodes on each side, but when the tube was pulsed to obtain peak powers several thousand times larger than the average power, it was found that the main limitation in tube output was determined by the amount of available peak emission. The parallel-anode type of construction thus doubled the available peak emission for a given type of element configuration.

The lower loop is the grid loop. Its primary purpose is to obtain grid driving power from the plate circuit. It has been found that relatively little of the power dissipated in the grid cages is conducted along the grid

wires to the external loop, and therefore it can have less radiating surface than the plate loop. In normal operation, the anodes are run at a red heat, and the filaments are run at a somewhat higher temperature than is usually used. This results in having the grid cages located between two very hot elements, and they are therefore very sensitive to grid contamination and subsequent blocking during oscillation. Under such conditions when plain tantalum wire is used in the cages, the tube becomes sufficiently contaminated to be inoperative in about 24 hours. This difficulty has been overcome completely by the use of Eimac "X" grid cages,[1] and without exception the end of tube life is determined by loss of emission, as it should be, after many hundreds of hours.

high voltage applied to the filaments. The filament line is tuned so that the filaments are effectively points of zero radio-frequency voltage. It has been found that this external line may be either parallel or at right angles to the axis of the tube. While it is usually preferable to have the filament line at right angles, since radio-frequency corona is less troublesome, where space is important it is mounted parallel with the axis of the tube.

Four filaments, instead of two larger ones, were used since several advantages were thus obtained. The filament spirals could be made more compactly and therefore less susceptible to sagging, and the filament power could be dissipated in two anodes instead of one, with attendent lower element temperatures. This construc-
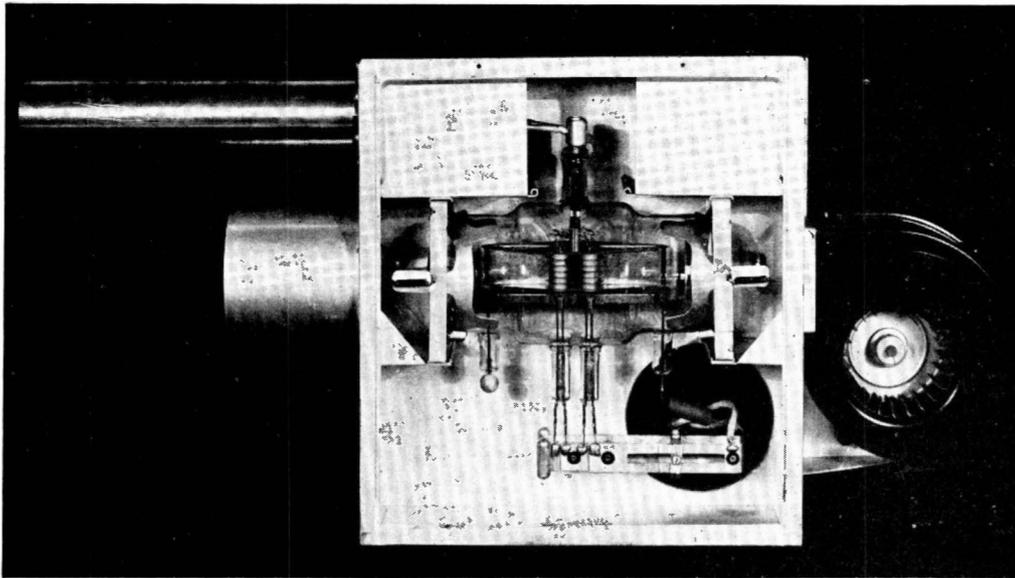

Fig. 2—Front view of transmitting tube and shield.

The filaments are made of carbonized, thoriated tungsten wire and run at a temperature which gives an emission of about 200 milliamperes per watt. In order to obtain satisfactory operation, an external, parallel transmission line is attached so that the two filaments on the same side of the tube are tied together for radio-frequency considerations. Several such transmission lines have been designed with which it is possible to run all four filaments in series if a higher voltage, lower current source is to be used. Since it is most convenient to connect the plate output directly to the output transmission line, the tube is usually run with the plate circuit at direct-current ground potential, and a negative

[1] H. E. Sorg and G. A. Becker, "Grid emission in vacuum tubes," *Electronics*, vol. 7, pp. 104–109; July, 1945.

tion also allows closer spacing of the elements, an important advantage at these frequencies where transit time must be considered. The obvious disadvantage of this multiple-filament design is its complexity, and it must be said that the highest tribute is due the several tube manufacturers for their ingenuity in overcoming the production difficulties by the development of very clever techniques, tools and jigs, and particularly to Mr. W. Eitel and Mr. J. A. McCullough of Eitel McCullough, Inc., for early assistance in establishing the mechanical design of the production-type tube.

III. SHIELDING

If the oscillator is used without a shield, about 80 per cent of the power output obtainable with a shield is

realized. In general, the shielding found most successful is shown in Fig. 2 and consists of a rectangular metal box with two central transverse shelves which serve to hold the tube, and to separate the cavity containing the tube from the cavities containing the output and filament circuits. The output cavity has been designed to act as a "bazooka" or radio-frequency choke at the end of the concentric line, and thus accomplish the transition from the balanced output of the tube to the unbalanced, concentric transmission line. The filament-line cavity serves primarily to contain the radiation, but its shape also determines the magnitude of standing waves at the point where the filament pins are sealed through the glass envelope.

In contrast with the situation at the plate output seals, the filament leads inside the envelope act as a rough transformer to produce a high radio-frequency voltage at the filament seals. At extremely high voltages and powers, this causes corona and subsequent detuning of the oscillator in an erratic manner. This can be avoided for peak powers greater than 300 kilowatts by use of a vertical, external filament line and proper design of the cavity. The frequency of the oscillator does not seem to be especially sensitive to the type of shield used.

IV. Operating Characteristics

A typical set of characteristics is shown in Table I. (Joint Army-Navy terminology is used.)

TABLE I
Description: Ultra-High-Frequency Pulsed Oscillator VT-158.

Ratings:	E_f	I_f	E_b	E_c	I_b	I_c	P_p	p_i	Modulation
Absolute:	volts	amperes	kilovolts direct current		amperes	—	watts	kilowatts	
Maximum:	10.5	10.5 (Note 1)	30 (Note 2)		70	—	400 (Note 3)	1500	Plate
Test conditions:		10.2	—	—	—	—	—	—	
Reference	*Test:*	*Test Conditions*			Minimum		*Acceptance Limits* Maximum		
F-6b(3)	*Bump: Angle = 10 degrees (Note 4)								
F-6b(4)	*Bump: Angle = 3½ degrees (Note 4)								
—	Filament voltage (Note 1)			E_f:	9.8	10.2	volts		
—	†Emission: $e_b = e_c = 3000$ volts			i_s:	70	—	amperes		
—	†Pulse operation			P_o:	150	—	kilowatts		
	$E_b = 20$ kilovolts direct; current pulse repetition rate = 240 pulses per second $F = 595$ to 600 megacycles. pulse width = 1 microsecond								
F-6p	*Capacitance:			C_{pp}:	11.8	16.0	micromicrofarads		
				C_{cf}:	11.9	16.1	micromicrofarads		
				C_{pf}:	1.25	1.69	micromicrofarads		
—	*Gas Test: pulse operation: (Note 5)								
F-4	Life Test: pulse operation:				500	—	hours		
F-4B	Life-Test end point:			P_o:	135	—	kilowatts		

Note 1: Measured for each filament separately.
Note 2: The tube is self-biased (80 ohms 5W. grid resistor).
Note 3: A minimum of 60 cubic feet of free air per minute is required across the tube for a plate dissipation of 400 watts.
Note 4: The hammer arm shall be allowed to strike the glass envelope at an angle of 90 degrees to the plane of grid leads.
Note 5: The tube shall be subjected to the pulse-operation test three times for two minutes at two-minute intervals applying all voltages including filament voltage and cooling devices, simultaneously. The temperature of the bulb of the tube shall not exceed 50 degrees centigrade at start of this test. There shall be no indications of gas or seal failure during or at the conclusion of this test.

Although the optimum output is obtained at a definite frequency, determined by the geometry of the elements inside the envelope, it has been observed that the ex-

ternal filament line may be used to shift the operating frequency over a bandwidth of 30 megacycles between half-power points. This feature is of considerable importance in allowing some tolerance in manufacturing, and in adapting the tube to several different types of radio-frequency circuits. It may be said that ordinary vacuum-tube production tolerances may be used to obtain tubes (from several different manufacturers) which all peak within a few megacycles of the same frequency.

The tube may be pulsed by biasing the grid beyond cutoff and applying suitable pulses to drive the grid positive several hundred volts for the required pulse interval. In another method of pulsing, the grid may be connected to the common radio-frequency point of the filament circuit through an appropriate resistor, and the filaments pulsed negatively with respect to the plate by as much as 30 kilovolts. Although efficiencies as high as 40 per cent have been observed for experimental tubes, the oscillator efficiency for production tubes is about 25 per cent under optimum conditions, and is constant for applied voltages greater than several kilovolts. This is interpreted as meaning that transit-time effects are negligible above this voltage, and rough calculations show that this should be the case. Frequency stability has been checked only during pulse operation, and within the uncertainty due to the Fourier components of the pulse, no instability could be found, nor could any frequency modulation be detected. An interesting feature of the tube characteristics is that the anode high-voltage filament power and blower can all be simultaneously turned on and off without any previous warm-up. No bad effects due to this practice have been observed.

V. Theory

Theoretical investigation of the properties of this type of design has proved to be difficult, primarily because of uncertainty about the current distribution in the closely spaced plate and grid loops at the frequencies mentioned. The general type of circuit is not new; similar circuits having been treated in papers by Holburn,[2] Mesny,[3] Gutton and Pierret,[4] and Denhardt,[5] and summarized in a paper by Wenstrom.[6] All of these treatments are concerned essentially with an experimental determination of the circuit characteristics.

Since in pulse operation the electron transit time is not appreciable, the tube probably should be capable of running with an efficiency of at least 50 per cent. Accordingly, the conventional-oscillator-design principles advanced by Prince about 1923 were applied to this tube by Lewis Greenwald, of this laboratory.

[2] F. Holborn, *Zeit. für Phys.*, vol. 6, pp. 328, 1921.
[3] Mesny, *L'Onde Electrique*, vol. 3, pp. 25–37; January, 1924.
[4] C. Gutton and E. Pierret, *L'Onde Electrique*, vol. 4, p. 387; 1925.
[5] A. Denhardt, *Zeits. für Hochfrequenz.*, vol. 35, pp. 212–223; June, 1930.
[6] W. H. Wenstrom, "An experimental study of regenerative ultra-short-wave oscillators," *Proc. I.R.E.*, vol. 20, pp. 113–131; January, 1932.

These principles have been found to be quite adequate for ultra-high-frequency tubes so long as the transit time is small. The interloop coupling problem was avoided by considering the two loops and external load as a four-terminal network connected to the grids and plates, as shown in Fig. 3. It was assumed that this network maintained approximately 180 degrees phase difference between grid and plate and insured push-pull operation. On this basis, approximate explanations of many observed phenomena were made possible, and some improvement in efficiency was effected by increasing the plate-filament capacitance. However, the efficiency was not made to approach the value of 50 per cent. This may be due to use of incorrect effective values of interelement capacitances or to lack of sufficient information about the operation of the loops.
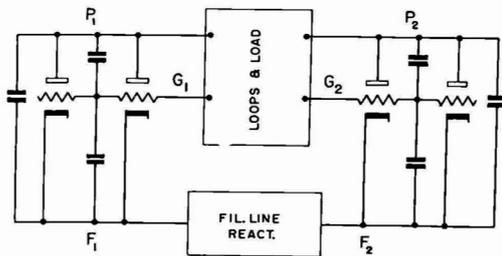
Fig. 3—Equivalent circuit of transmitting tube.

VI. Grounded-Plate, -Grid, and -Cathode Designs

It occurred to the authors, and to McCullough and Eitel in an unpublished communication, that the design herein described might be simplified by altering the internal construction so that the two anodes were tied together to have zero radio-frequency voltage difference (grounded plate). This would eliminate one internal tuned circuit, and would necessitate taking the power out at the filament line. Such a tube was built and it was found that almost exactly half the normal radio-frequency power could be obtained in this way. Subsequent tests on tuned-plate, tuned-grid tubes also showed that only half the power could be obtained from the filament lines, and work on grounded-plate tubes was then dropped without further investigation.

The authors attempted further designs involving grounded-grid and grounded-cathode construction, and the results were uniformly most unsuccessful, in that these types of tubes were never observed to oscillate. The grounded-grid construction was carried so far as to involve slits in the anodes to allow direct connection of the four grid cages by the shortest possible leads. The grounded-cathode tube was built around a rectangular box-type oxide cathode mounted between the two sides of the plate loop. In all cases, the element geometry was such as to have about the same amplification factor and transit time as for the tuned-plate, tuned-grid type of tube.

VII. Conclusion

This tuned-plate tuned-grid type of vacuum tube and circuit was developed a few years ago when low radio-frequency-impedance glass-metal seals had not been widely applied to tubes of this power and frequency. The subsequent development of such seals and corresponding tube improvement, especially in development of tubes which could be connected intimately with many different types of radio-frequency circuits which jointly covered a much wider band of frequencies, has been of great practical importance both in the war effort and in postwar applications. However, it is desired to point out one advantage of the tube of special importance for military use. Those who have seen extremely high-power pulse-transmitter circuits using the new low-impedance glass-metal-seal tubes are invariably impressed with the large size, weight, and complexity of concentric-line plumbing, a most descriptive term. Also, high-power pulse magnetrons for these frequencies are extremely large and heavy. Compared with these, the present tube is shipped from the tube manufacturer as a complete transmitter. The combined tube and shield weigh only about two pounds, occupy a much smaller volume, and are much simpler to make and assemble than are the newer type tubes and external oscillating circuits.

Tube type VT-158 was used principally in the light weight, early warning radar set AN/TPS-3, in both the European and Pacific theaters of operation.[7]

[7] H. A. Zahl and J. W. Marchetti, "Radar on 50 centimeters," *Electronics*, vol. 19, pp. 98–104; January, 1946.
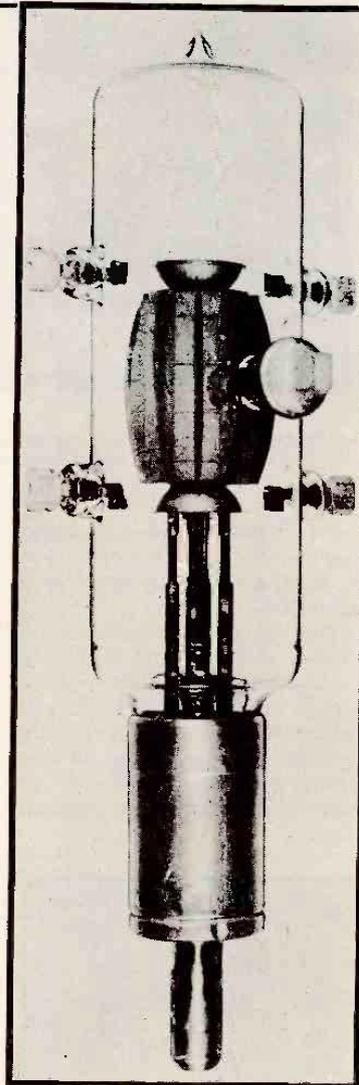
Grid Emission in
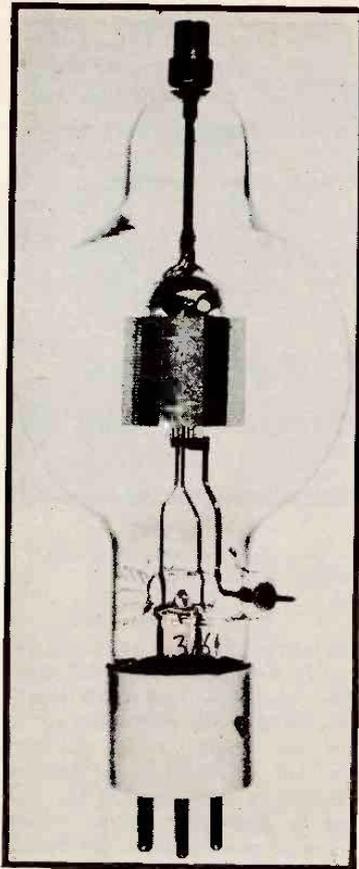
Eimac type 100T tube used as a guinea pig in many of the tests discussed here

Type 527 tube, employing an X-grid

THIS ARTICLE deals with the problem of electron emission from the control grid in a high-vacuum triode having a thoriated-tungsten filament. The specific type of cathode employed is early mentioned, because emission from the grid is directly tied up with the nature of the active material on the cathode. The remedy for grid emission in a tube having a thoriated filament, for example, is not necessarily the answer to grid emission troubles in a tube containing an oxide-coated cathode.

In its broader aspects the question involves the suppression of emission from an electrode whose normal function is best performed by selective emission, or no emission at all. The term selective emission is advisedly used because there can be two distinct kinds of emission from

a grid: primary emission and secondary emission. Much confusion has resulted by failure to distinguish between these, and to identify their causes and effects. Since electrons leave the grid by both primary and secondary mechanisms, like effects under certain conditions would naturally be expected. That the effects are not always the same has led to one cause being mistaken

for the other in a great many cases.

The primary electrons about which we are concerned are those emitted by reason of the fact that the grid runs at an elevated temperature; in other words, thermionic emission from grid. Grid heating in a power triode is caused by electron bombardment of the grid during its positive excursions, and also by thermal radiation from the filament and plate. Since primary emission from the grid is a function of grid temperature, such primary electrons as are emitted leave the grid continuously during operation of the tube. As with other continuous processes based on temperature, the effects are cumulative. This matter of continuity of emission is worth keeping in mind while distinguishing between primary and secondary emission from a grid. Mouromtseff and Kozanowski[1] describe a simple circuit for measuring primary emission.

Primary and Secondary Emission Effects

By definition, secondary electrons are those released from the grid under the impact of electrons originating from another source, such as the filament. Since the grid is bombarded when positive with respect to the filament, secondary emission occurs only during the positive half-cycle of the grid driving-voltage. Being a discontinuous process, the direct effects of secondary emission are not cumulative.

Both primary and secondary emission reduce the grid current when power tubes are operated in the positive-grid region, and may cause the grid current to reverse its normal direction of flow. In grid-leak bias circuits this results in a loss of bias, accompanied by increased plate current. The primary component of grid emission is the bad actor in this case, because a vicious circle is started. The increased plate current causes increased plate temperature, which in turn raises the grid temperature,

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Vacuum Tubes

Causes and effects of primary and secondary emission are discussed. Emission photographs of various materials, taken with an electron microscope, are presented. Tests which resulted in the development of a special grid are described

By HAROLD E. SORG and GEORGE A. BECKER
Director of Laboratory   *Research Engineer*

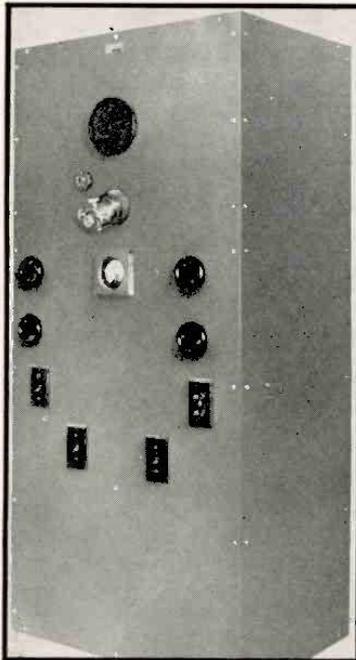*Eitel-McCullough, Inc., San Bruno, Calif.*

FIG. 1—Special electron-microscope developed to take emission photographs. The instrument is shown schematically in Fig. 2

is under control, can be beneficial because the grid current is reduced and hence the grid driving-power lowered. This apparent something-for-nothing is frequently accompanied by instability of operation, however, the tendency toward dynatron-type parasitic oscillation being enhanced. The effects of secondary emission from a control grid may be summed up by saying that secondary electrons are beneficial if moderate, but can lead to instability if excessive. For practical purposes the ideal control-grid is one which exhibits no primary emission and negligible secondary emission.

Metallurgy Provides the Key

Several years ago it was recognized that unless a solution could be found for the grid-emission problem, a serious barrier stood in the path of power-tube development, where grid temperature is an important factor. While experiment-

ing with high-vacuum tubes having thoriated-tungsten filaments and grids of refractory metals, such as tantalum and molybdenum, it was observed that primary grid-emission was materially increased by activation of the grid with thorium sputtered or otherwise deposited from the filament. After a period of operation these tubes were found to contain not only a thoriated filament but also a thoriumized grid. So activated, the grid developed primary emission.

A reverse phenomenon was also occasionally observed in the case of the filament. Some sort of contamination was reaching the filament, killing its emission. This was interesting. If something would poison the emission of a thoriated filament, why would't the same thing be good for the unhappily thoriumized-grid? With this key the search went on, resulting in the perfection of what is now known as the X-grid. Initial development work was done by Wil-

causing further increase in primary emission from the grid. The effect is cumulative, and once the grid current starts to drop the grid may lose control, allowing the tube to run away.

The effects of secondary grid-emission are less obvious. Secondary electrons are emitted by reason of electron bombardment from the filament, which occurs only during the positive half-cycle of the grid driving-voltage. The effects are not cumulative and, if primary emission
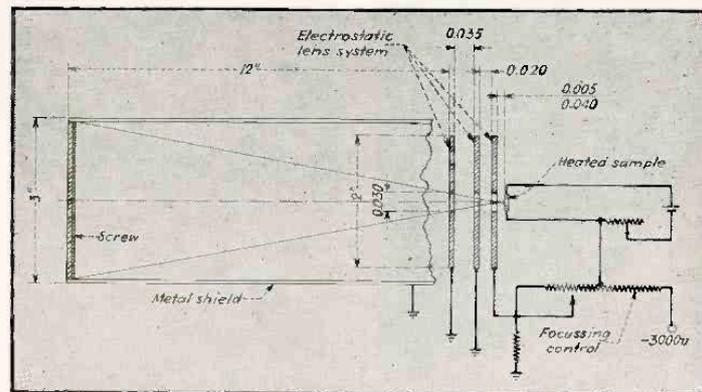

FIG. 2—Schematic of the special electron microscope pictured in Fig. 1

FIG. 3—Emission photograph of thoriated tungsten, taken at 1300 deg C. In this instance an edge of the sample was photographed, so that emission streamers are visible
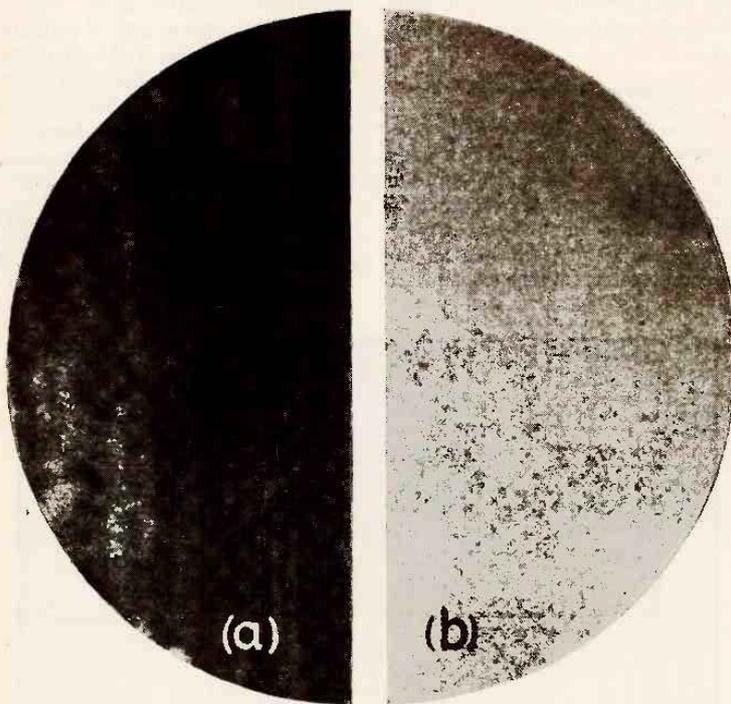

(a) (b)

FIG. 4—(a) Emission photograph of pure tantalum, taken at 1500 deg C, and (b) at 1700 deg C. Half-photographs are shown adjacent to each other to conserve space and facilitate comparison

liam W. Eitel and Jack A. McCullough. While the X-grid was developed principally to overcome primary emission, it fortunately also exhibits a low order of secondary emission.

During the course of the investigation the emission properties of numerous metals other than tantalum and molybdenum were studied. Platinum has unique properties and deserves special mention. If properly handled in tube manufacture a platinum grid will exhibit little or no primary emission during subsequent life of the tube. Resistance of platinum to activation by thorium is apparently due to an absorption phenomenon. The principal disadvantages of platinum, aside from the element of cost, are its relatively low melting-point, its poor mechanical strength compared to the more refractory metals, and its relatively high secondary-emission properties.

Special Electron Microscope Used

Much of the subject work on grid emission was done with the aid of a special electron-microscope. Figure 1 shows a photograph of the complete unit and Fig. 2 is a diagrammatic view of the essential parts. This unit provides means for visual examination of electron emission from any desired metal, and the effects of contaminants thereon, at any desired temperature. For example, a specimen containing thorium can be mounted adjacent to a specimen of grid material, and the latter contaminated with thorium vaporized from the former. The emission properties of the contaminated grid material may then be studied. Emission patterns are directly observed on the screen. For later study and record purposes, photographs and even moving pictures can be taken of the specimens.

A series of emission photographs taken with the electron microscope. are illustrated. (*Ed. Note:* All emission photographs reproduced here were originally taken at a magnification of 125. As reproduced, however, they represent a magnification of about 100.)

Figure 3 shows the emission pattern of ordinary thoriated tungsten. This photograph is included here

Emilio Ciardiello per ase.museoedelpro.org

merely because thoriated tungsten is a familiar type of emitter material and serves as a reference for comparison purposes. The photograph was taken with the specimen at 1300 deg C; all temperatures herein being brightness temperatures as indicated by an optical pyrometer. The light areas in the photograph are the actual traces produced on the screen by primary-electrons emitted from the sample, the darker areas indicating a lack of emission. This particular photograph happens to show an edge of the specimen, and the streamers present constitute electron emission from the edge.

Figures 4 (a) and 4 (b) show emission patterns of the surface of pure tantalum at 1500 deg C and 1700 deg C, respectively. Figures 5 (a) and 5 (b) show similar patterns of pure molybdenum at like temperatures. It is evident that tantalum exhibits somewhat higher primary emission than does molybdenum at a corresponding temperature. The pronounced increase in emission from both metals, for an increase of 200 deg C in the temperature region indicated, is worth noting.

Figure 6 shows the emission pattern of a sample of tantalum contaminated with thorium at 1400 deg C, the streamers visible being from an edge of the sample. The tremendous increase in primary emission seen in comparison with Fig. 4 (a) explains why a tantalum grid used with a thoriated filament often causes a tube to run away during operation. Molybdenum exhibits a similar increase in primary emission upon contamination with thorium. Curves in Fig. 7 illustrate the effects of this contamination in a tube.

Figure 8 shows the emission pattern at 1700 deg C of the surface of a sample of tantalum partially treated by the X-process. The lighter area at the left in the photograph constitutes the emission from the pure tantalum, and the darker area at the right indicates the absence of emission from the treated portion of the sample. Since the X-processed material is seen to have a lower order of primary or thermionic emission than either tantalum or molybdenum, one would expect it to have
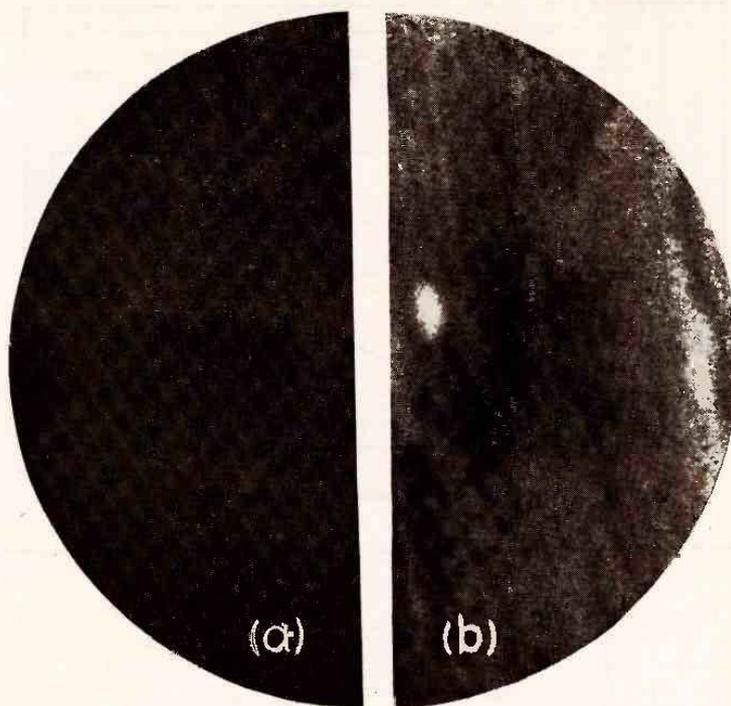

FIG. 5—(a) Emission photograph of pure molybdenum, taken at 1500 deg C, and (b) at 1700 deg C

FIG. 6—Emission photograph of tantalum contaminated by thorium, taken at 1400 deg C. The edge of the sample was photographed so emission streamers may be seen
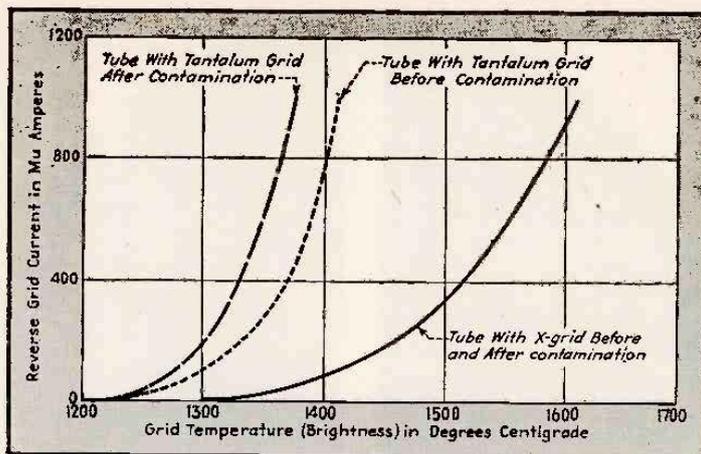
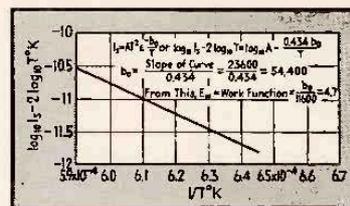FIG. 7—Primary emission grid characteristics
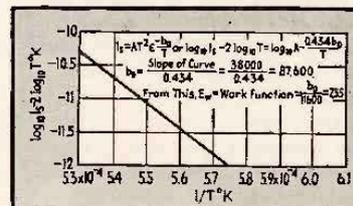

FIG. 9—Emission from a tantalum grid

FIG. 10—Primary emission from an X grid

a higher work-function. Such is the case. Figure 9 is a plot of primary emission from tantalum, from which a work function of 4.7 is derived. This value compares favorably with that previously determined by others. A similar plot is illustrated in Fig. 10 for the X-grid material, from which a work function of 7.55 is derived.

Test Results

It is now interesting to observe what happens when the X-grid is contaminated with thorium. Figures 11 (a) and 11 (b) show emission patterns of the surface of X-grid material so contaminated, taken at 1700 deg C and 1900 deg C, respectively. These evidence a negligible increase in primary emission as compared with the pronounced increase exhibited in the case of contaminated tantalum. The ability of the X-grid to render thorium inactive is responsible for this improvement.

The solid-line curve in Fig. 7 shows that contamination of an X-grid in a tube does not increase its primary emission properties. By comparison with the dashed-line curve it will be observed that if 500 μa is taken as a safe value of primary emission, a tantalum grid must be operated at a grid temperature under 1350 deg C whereas an X-grid may be operated in excess of 1500 deg C. A more striking difference will be noted at a grid temperature of 1350 deg C, where the tube with the X-grid has a reverse grid current of nearly zero, while that with a contaminated tantalum grid exhibits a reverse grid-current of about 600 μa at the same temperature.

The secondary emission properties of the X-grid, compared to platinum for example, are illustrated by curves in Fig. 12, these curves being taken on two tubes having identical geometry. The
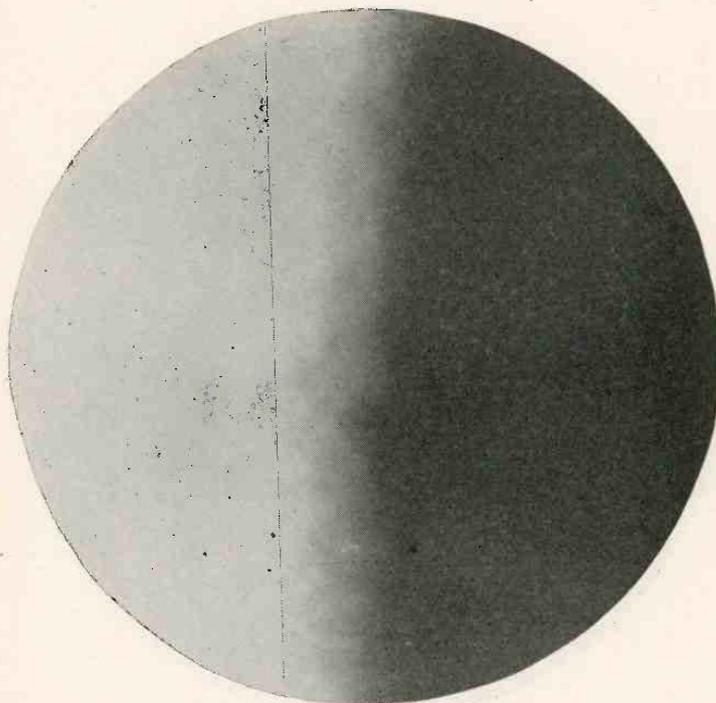

FIG. 8—Emission photograph of tantalum partially treated by X-process, taken at 1700 deg C. The left side shows the greater emission from the untreated portion, while the right side shows the reduced emission from the treated portion
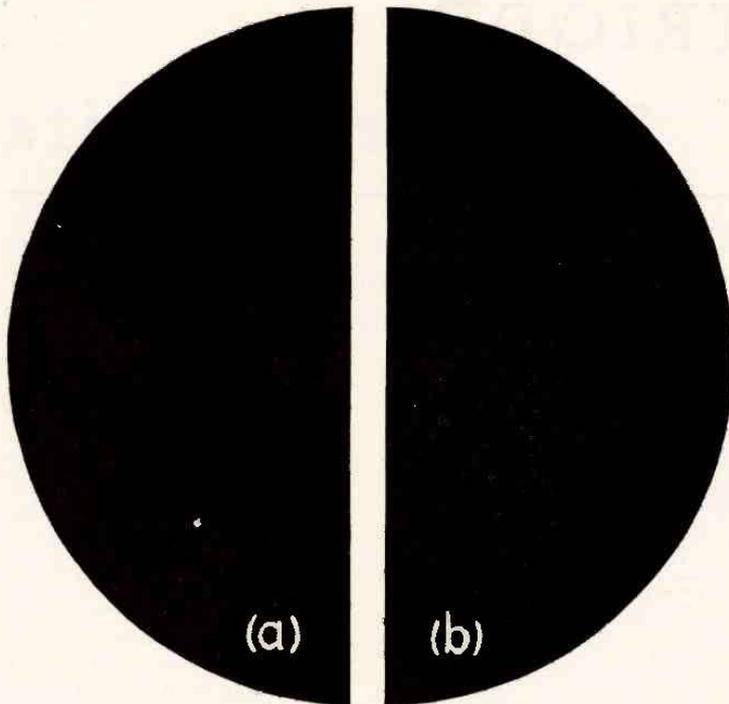
FIG. 11—(a) Emission photograph of X-processed material contaminated with thorium, taken at 1700 deg C, and (b) at 1900 deg C
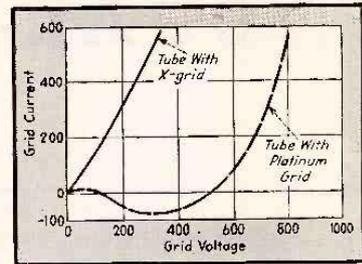

FIG. 12—Secondary emission characteristics, both tubes under test having identical geometry and operating with 2500 volts on their plates

is a chart of a tube having a platinum grid. This can be compared with the chart in Fig. 14 on a tube of identical geometry, but having an X-grid, showing the absence of such loops in the grid-current lines.

It is apparent that operation along a load line passing through the region of negative values of grid current would give a distorted wave of grid current, sufficient to cause instability and parasitic oscillations.

REFERENCES

(1) Mouromtseff, I. E., and Kozanowski, H. N., Grid Temperature as a Limiting Factor in Vacuum Tube Operation, *Proc. I. R. E.*, 24, p. 447, March, 1936.

higher order of secondary emission for platinum is indicated by lower values of grid current, which, for certain values of grid voltage in the tube used, actually become negative. Secondary emission shows up in constant-current charts as loops in the grid current lines. Figure 13
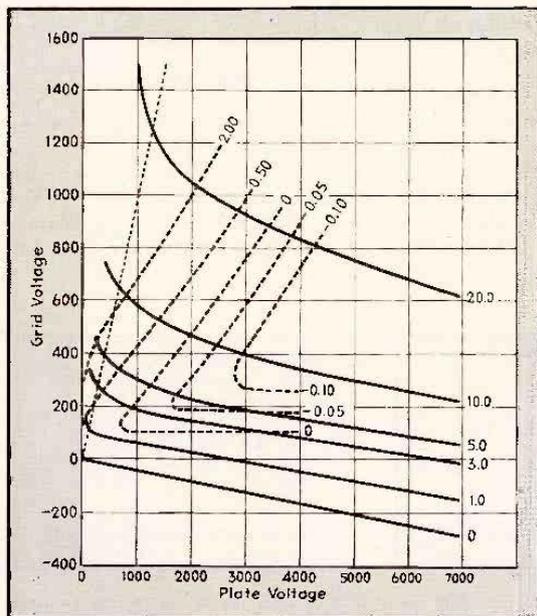

FIG. 13—Constant-current characteristics of a tube with a platinum grid. Solid-line curves represent plate current in amp; dashed-line curves represent grid current in amp
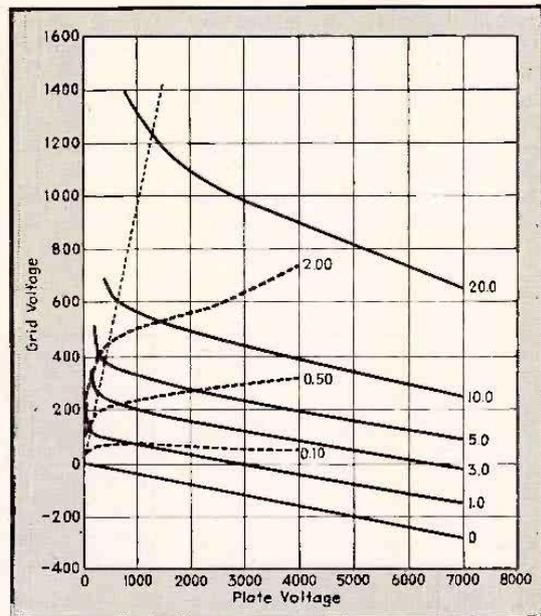

FIG. 14—Constant current characteristics of a tube with an X-grid. Solid-line curves represent plate current in amperes, while dashed-line curves represent grid current in amperes