A Vacuum-Contained Push-Pull Triode Transmitter*

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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 kilowattsof 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.

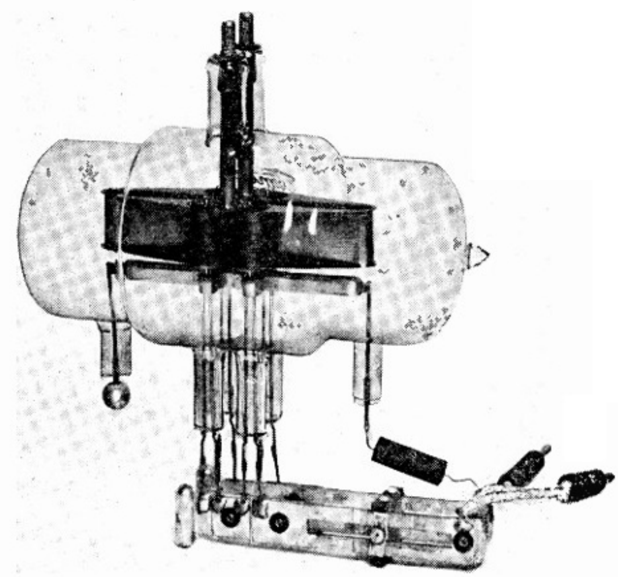

Fig. 1—Front view of transmitting tube.

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

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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.

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 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 construction 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.

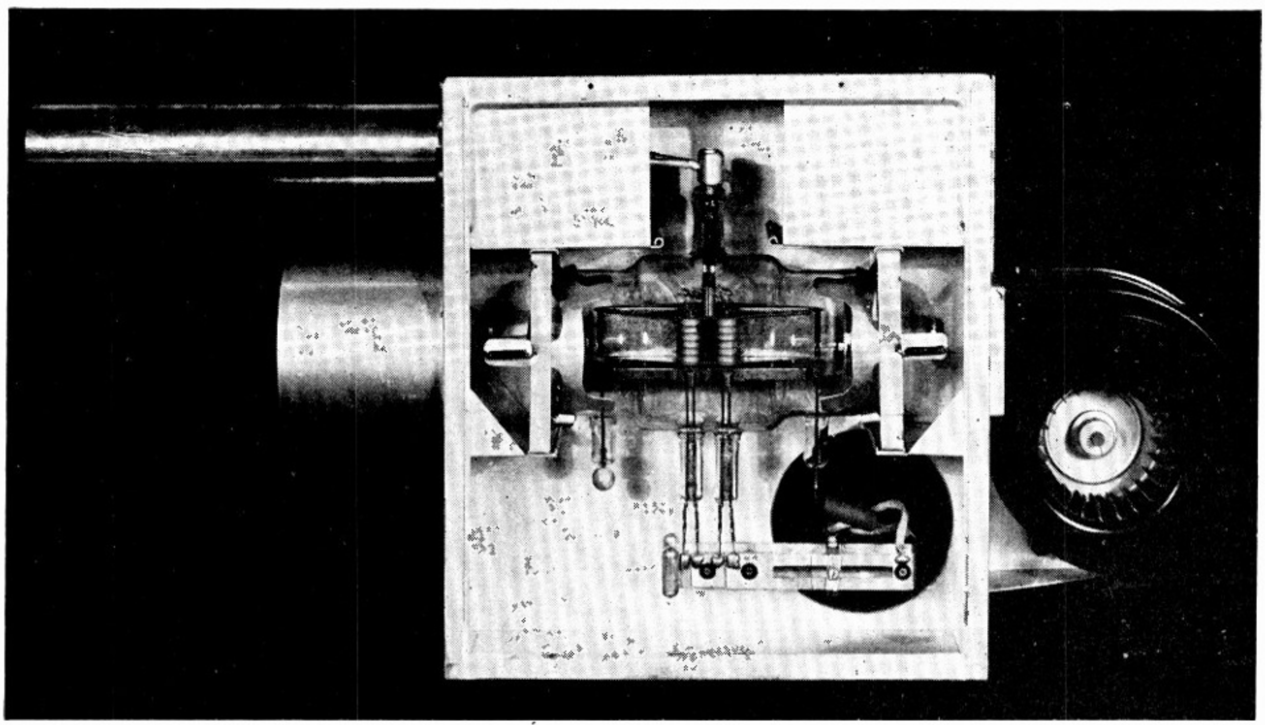

Fig. 2—Front view of transmitting tube and shield.

III. Shielding

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

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

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*		*Acceptance Limits* *Minimum*	*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 $E_b = 20$ kilovolts direct; current pulse repetition rate = 240 pulses per second $F = 595$ to 600 megacycles, pulse width = 1 microsecond	P_o:	150	—	kilowatts
F-6p	*Capacitance:	C_{gp}:	11.8	16.0	micromicrofarads
		C_{gf}:	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 external 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.

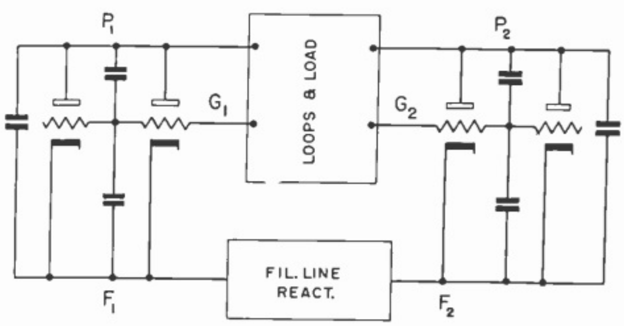

Fig. 3—Equivalent circuit of transmitting tube.

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.