THE ORBITAL-BEAM MULTIPLIER TUBE FOR 500-MEGACYCLE AMPLIFICATION

By W. Robert Ferris and Herbert M. Wagner*

Presented before the Club on March 13, 1941.

NOTE: This is a report prepared by the Club's editorial staff giving the chief data presented at the meeting. - Editor

SUMMARY

The construction and characteristics of a developmental amplifying tube with secondary-emission electron multiplication are described. The tube has been found useful in the reception of television relay signals at 500 megacycles. An initial transconductance of 3000 micromhos, produced in the cathode-control-grid region of the tube, is increased by a multiplication factor of five to 15,000 micromhos. Advantages of the tuoe include: (1) small loading of preceding signal circuit; (2) fact that the transconductance can be varied by deflection of the electron stream without changing the input characteristics; (3) extremely small capacitance from output plate to control grid; and (4) high quotient of transconductance by capacitance.

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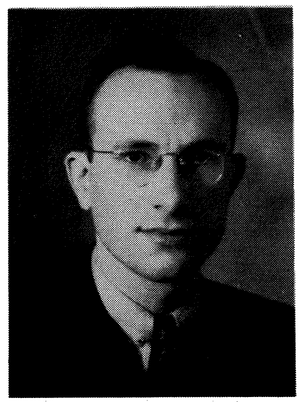

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Secondary-emission has been used commercially for several years for increasing the output of photoelectric tubes. Recently, several low-frequency grid-controlled amplifiers using this principle have been announced in Europe.(1) The present tube is original in that it employs the secondary emission at ultra-high frequency and has some important operating advantages.

The employment of the secondary-emission feature in a grid-controlled tube, as here, gives not only the advantage of large transconductance in a single envelope, but also the merits of stable and low-loss input conditions, which are important for operation at very high frequencies. A tube of the new type affords a stage gain of five times in voltage at 500 megacycles with a bandwidth of 11 megacycles, or a gain of seven times with a bandwidth of 6 megacycles, making the tube suitable for such applications as a television radio-relay system. At a frequency of 100 megacycles and a load of 10,000 ohms, there is obtainable the full amplification given by the product of the transconductance and the load impedance; since these are 15,000 micromhos and 10,000 ohms, this amounts to a voltage amplification of 150 times.

Fig. 1 shows the general appearance of the new tube. The glass bulb has a diameter of approximately 1 inch, and the envelope is described as the 1-inch acorn type.

The arrangement of the electrodes is shown in Fig. 2. Electrons originate at the heated cathode K_1 pass

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(1) See for example "Secondary-Emission Valves in Vision Receivers", Paul D. Tyers, TELEVISION AND SHORT-WAVE WORLD, January 1939, pp. 31-32.

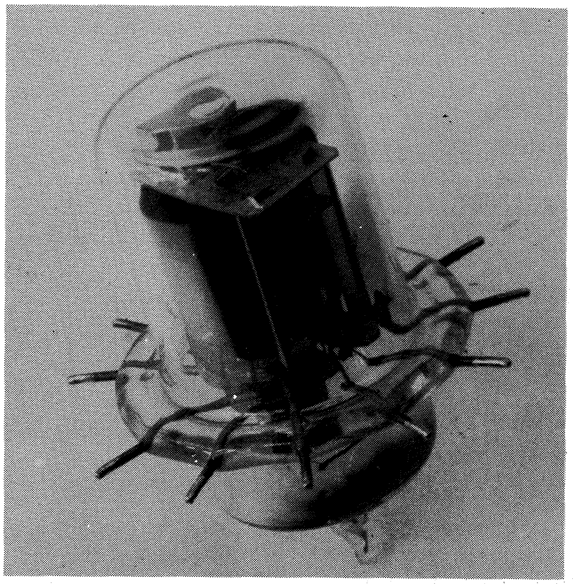

Fig. 1 - General appearance of Developmental Orbital-Beam Multiplier Tube.

through the control grid G_1, and then through the screen grid G_2, after which they proceed along the orbital paths, which are indicated, to the secondary-electron emitter K_2, which may be considered a second-cathode. At this point an electron multiplication of about five times takes place, and the augmented stream of electrons goes on to the plate P, which is the output electrode of the tube. Two focusing electrodes, J_1 and J_2, are provided and are maintained at suitable potentials, so as to produce the orbital electron path. No magnetic field is employed.

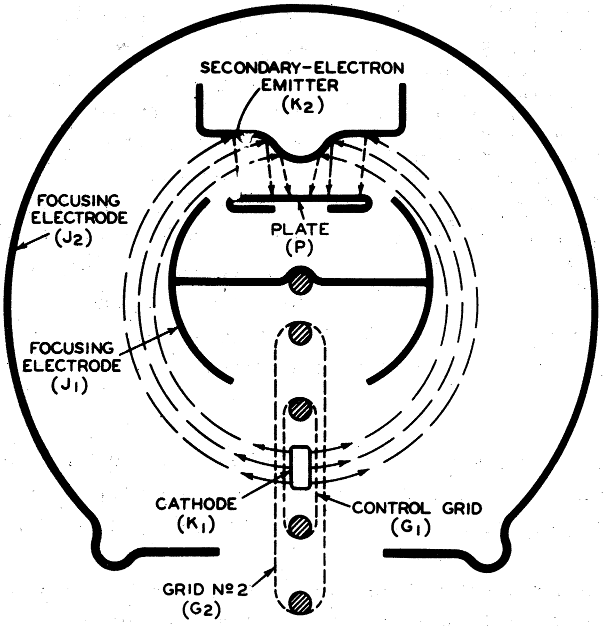

Fig. 2 - Arrangement of the Various Electrodes.

SPECIFICATIONS AND CHARACTERISTIC CURVES

Representative operating potentials for the various electrodes, and the currents, are included in the following table:

Representative Operating Conditions

Plate (Output-Anode) Potential	390 Volts
Secondary-Emitter Potential	240 Volts
Potential on Outer Focusing Electrode J_2	0 Volts
Potential on Inner Focusing Electrode J_1	345 Volts
Potential on Screen Grid	25 Volts
Potential on Control Grid	-0.25 Volt
Plate Current	12 Milliamperes
Secondary-Emitter Current	-9 Milliamperes
Cathode Current	3 Milliamperes
Transconductance from Control Grid to Plate	15,000 Micromhos
Input Capacitance, C_i	6.5 Micro-microfarads
Output Capacitance, C_o	3.5 Micro-microfarads
Ratio, $\frac{\text{Transconductance}}{\sqrt{C_i C_o}}$	3100 Micromhos per Micro-microfarad

The secondary-emitter current is entered as negative, because in the tube the augmented flow of electrons is produced at this cathode K_2.

The focusing action of the outer focusing electrode J_2 is shown by curves in Fig. 3, where the plate current is plotted as a function of the potential of this focusing electrode. This action provides a useful means of amplification control. It should possibly be mentioned that the potentials of the various electrodes in Fig. 3, and also in the following two figures, are as stated on the drawings, and are somewhat different from the values just given in the tables of typical operation conditions.

Fig. 4 is a plot of the over-all transfer characteristic of the tube. It will be seen that a curve is included for a potential of 50 volts on the screen G_2 and also for a potential of one hundred volts.

In Fig. 5 a family of curves is given showing the plate current as a function of plate potential for several values of bias on the control grid. It will be noticed that the plate current stays substantially zero until the plate potential reaches 230 volts, which is approximately the potential of the secondary cathode K_2; this is in contrast to the usual characteristics of tetrodes and pentodes.

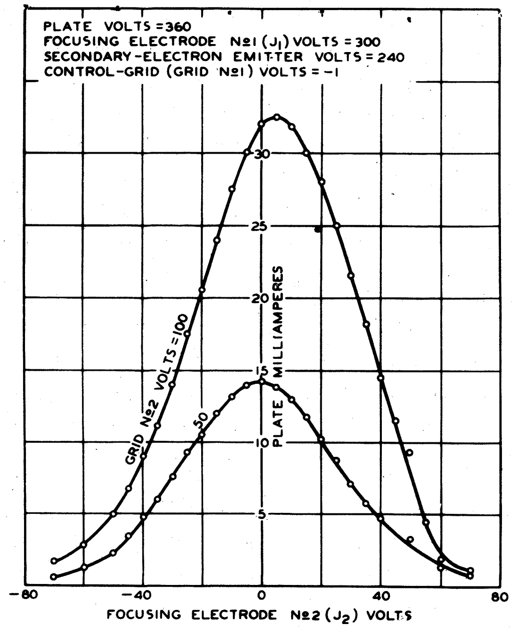

Fig. 3 - Variation of Plate Current with Potential of Outer Focusing Electrode, Showing the Focusing Action.

APPLICATION

A view of the tube operation at 500 megacycles as an amplifier between two coaxial transmission lines is given in Fig. 6. The lines are equipped with shorting plungers for tuning the grid and anode circuits. Slots are cut along the outer conductor for ease in coupling and measuring voltage along the lines. The diode vacuum-tube voltmeters shown in the figure connect between the outer and inner conductors and can be moved to different positions along the line. The amplifying tube is mounted in a low-loss socket with input leads at the left and output leads at the right. Cathode, heater, screen-grid, and focusing electrodes are by-passed to ground with small toothpick condensers.

The transit time at 500 megacycles for the passage of electrons from K_1 to K_2 is about one complete period, or a phase difference of 360 degrees, and the total spread among various electrons amounts to forty or fifty degrees. This is a sufficient degree of uniformity to permit operation up to high frequencies such as the 500 megacycle region.

For the control of the amount of amplification, the potential of the outer focusing electrods J_2 may be altered, which produces a variation of the plate current, as already seen in Fig. 3. Since such control by diversion of the electron beam does not affect the conditions at the original cathode K_1, and at grids G_1 and

ditions at the original cathode K_1, and at grids G_1 and G_2, the input capacitance and the input losses remain the same, which is an important advantage.

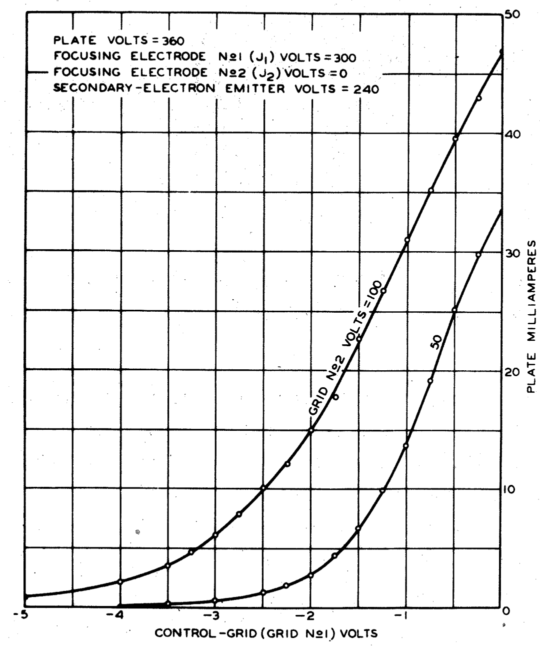

Fig. 4 - Transfer Characteristic of the Tube; Note Approximately 15 Milliamperes Change of Plate Current for One Volt Change of Grid Potential, Corresponding to 15,000 Micromhos Transconductance.

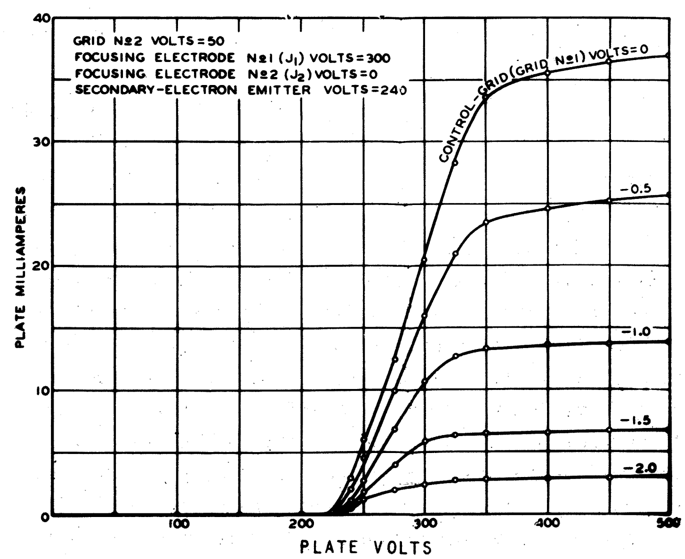

Fig. 5 - Family of Plate Curves

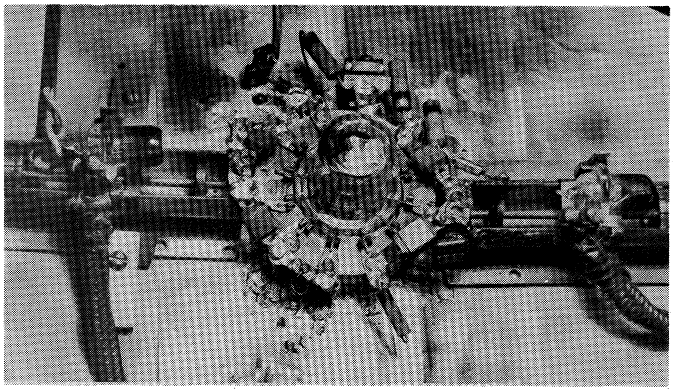

Fig. 6 - Experimental Amplifier for 500-Megacycle Measurements on Orbital-Beam Multiplier.

The direct capacitance from the output plate to the control grid is extremely small, much less than the value in ordinary screen-grid tubes. The magnitude is so small that the apparatus used to measure grid-plate capacitance in other tubes was not sensitive enough to give an indication. Inductance of the leads, however, may have an effect at high frequency. In the practical use of the tube, this throws the remaining burden of avoiding feedback on to the shielding of the leads.

The direct-current potentials on the electrodes are not critical, as might be assumed in a tube using electron focusing. No special voltage regulation is required. If all voltages change in proportion, as is the case with the usual power-supply arrangements, we know from theoretical considerations that, neglecting space charge, the focusing will not be affected. In practical use of the tube no difficulty of this sort has been found.

Although a bias of -1/4 volt is shown in the tabulated typical operation conditions, values of negative bias as great as a few volts can be used, and greater input signals can thus be accommodated when necessary. The tube has been operated without any bias voltage as a wide-band ultra-high-frequency amplifier.

With regard to tube noise, the new type might be expected to be somewhat noisier than, for example, a 6AC7/1852, but as it imposes less loading on the preceding signal-supply circuit more signal is present on the control grid. The output signal-to-noise ratio is therefore about the same. The input loading at 500 megacycles amounts to about 800 ohms between grid and cathode.

It may be added that the direct-current bias on the control grid can be obtained by the self-bias method; a separate source of bias potential is unnecessary.

APPLICATIONS OF THE INDUCTIVE-OUTPUT TUBE

By Orville E. Dow*

Presented before the Club on March 13, 1941

SUMMARY

The inductive-output tube, coded the RCA-825, supplies the need for a stable amplifier for wide-band or narrow-band service at carrier frequencies above 300 megacycles. The input circuit of the tube is conventional, but is designed to reduce the input loading due to electron transit time. The inductive-output feature of the tube results in higher output efficiency due to decreased electron transit time and reduced copper and dielectric losses. Factors to be considered in the design of an output circuit are effective output capacitance and effective gap length. The general performance of the tube, when operating as an amplifier, oscillator, and frequency-modulated generator, is described. As an oscillator for the range of 400 to 500 megacycles, an output of 40 watts is obtained with a total input power of 200 watts. Applications of the tube as a wide-band amplifier, a frequency tripler, and as a frequency converter, all developed in connection with a television repeater station, are briefly described.

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The RCA-825 inductive-output tube was designed especially for wide-band applications at ultra-high frequencies. However, it has proved useful in many other applications involving frequencies of 300 megacycles and higher. In view of the recently increased activity in the ultra-high-frequency field this tube is of particular interest.

The general arrangement of the tube is illustrated