May 20, 1958 W. J. McBRIDE, JR 2,835,844

ELECTRON BEAM DEFLECTION TUBE

Filed Feb. 25, 1953 2 Sheets-Sheet 1

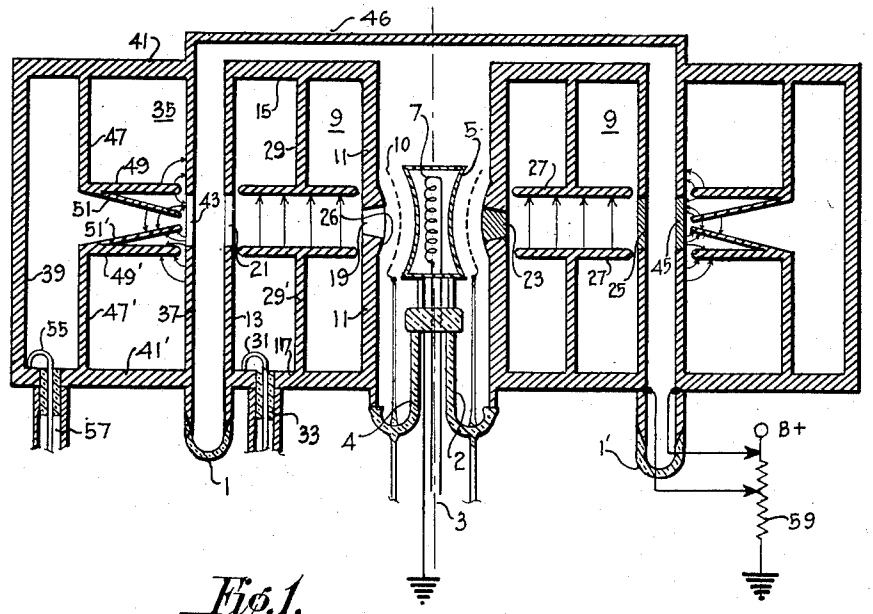


Fig. 1.

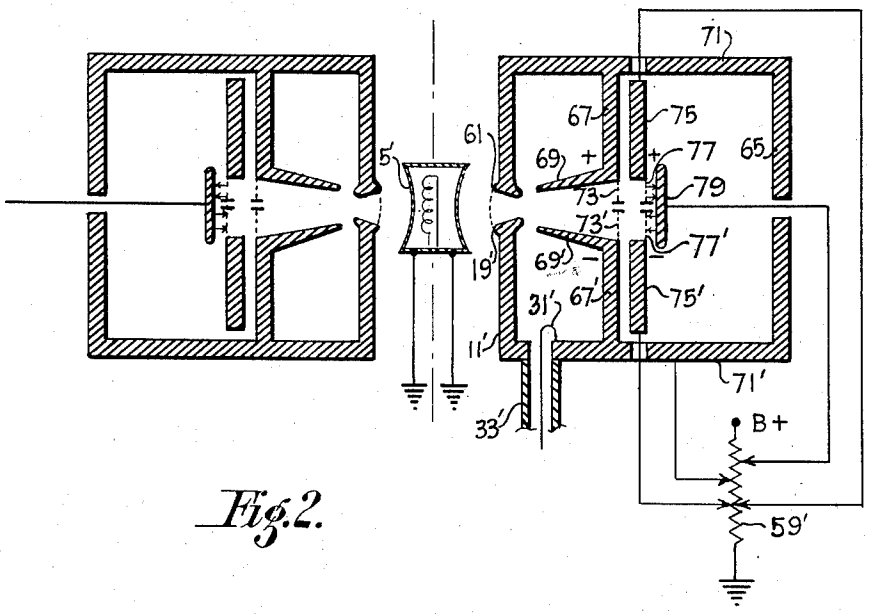


Fig. 2.

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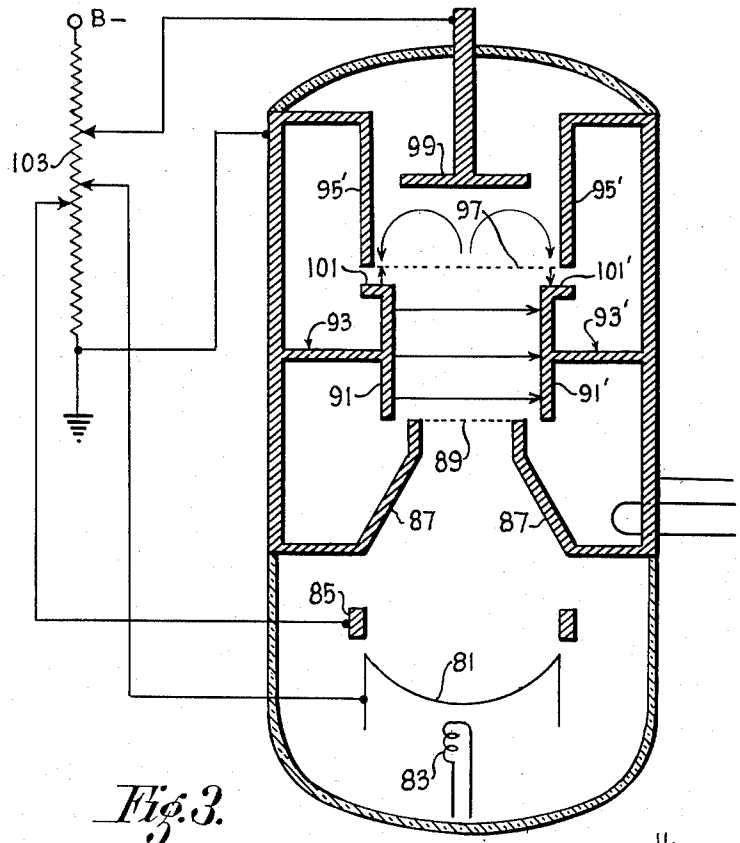


Fig. 3.

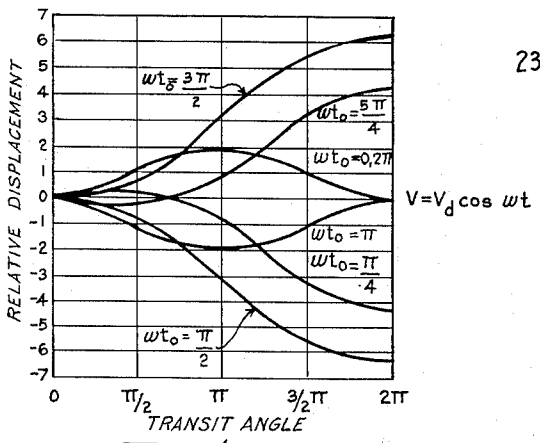


Fig. 4.

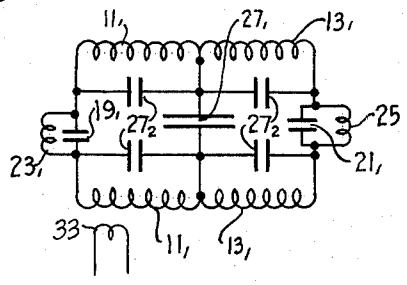


Fig. 5.

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United States Patent Office 2,835,844
Patented May 20, 1958

2,835,844

ELECTRON BEAM DEFLECTION TUBE

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Application February 25, 1953, Serial No. 338,765

7 Claims. (Cl. 315—5.27)

This invention relates to electronic amplifiers adapted primarily for operation within the microwave range of frequencies. In common with most electronic amplifiers the amplifier of this invention may be utilized as a generator of oscillations or as a modulator. Since, however, the primary features of the invention relate to its amplifying function, for which its other uses follow as a natural consequence, the major portion of this description will be devoted to the amplification characteristics.

Among the objects of this invention are to provide a microwave amplifier which is capable of developing large amounts of power at its operating frequencies. The specific and most important object and feature of the invention is to provide an amplifier for these frequencies wherein a small amount of driving power may be used to control relatively large amounts of output power; i. e., to provide an amplifier wherein the control circuit has inherently a high shunt impedance and wherein the modulation of the electron stream, through which the amplification is accomplished, absorbs a minimum of power from the driving circuit. Other objects of the invention are to provide a microwave type of amplifier having a relatively high degree of frequency stability, wherein the available output power is not critically dependent upon the applied voltages, and to provide an amplifier which may be constructed quite readily within the required degree of precision. From the viewpoint of operation a primary object of the invention is to provide a method of modulating an electron stream which theoretically absorbs no net power and which, in practice, reduces the absorption of power to a minimum.

The amplifier of this invention is of the "split anode" type, wherein the oscillating output power is developed by deflecting a beam of electrons alternately from one to another of two anode areas forming, preferably, although not necessarily, opposite poles of a resonant circuit. Preferably the anodes or anode areas are included within a cavity resonator tuned so that the resonant frequency at one of its principal modes of oscillation is the designed operating frequency of the device. In accordance with a principal feature of the invention the deflection back and forth between the two anode areas is accomplished within a resonant cavity which may or may not be directly coupled with the anode or the anode cavity. The control or input cavity is apertured to permit the passage of electrons therethrough, the aperture through which the electrons are admitted being preferably located at a region of low electric field when the cavity is excited at its designed frequency of operation. Within the cavity and integral therewith there is located a pair of deflecting plates positioned on either side of the electron stream, these plates being effectively integral with the cavity resonator itself and so positioned and proportioned that when the cavity is resonated in its operative mode a relatively high electric field is established between these plates. The parts are further so proportioned and the operating parameters are such that when the tube is in operation the transit angle of the electrons in their

passage between the plates is substantially $2\pi n$ radians, where n is an integer, i. e., that the transit time through the deflection plate region is a whole number of cycles of oscillating frequency. It is as a result of this relationship that the driving power required in the input or control cavity is small. If the relationship is met exactly an electron entering the space between the plates at the instant of zero electric field between them will be accelerated toward one plate (and substantially at right angles to its initial line of flight) during the first half cycle of its passage and in being so accelerated will absorb power from the cavity. During the next half cycle of its travel it will be decelerated, returning energy to the cavity in the process, and will therefore leave the interspace between the plates with the same velocity as that with which it entered, having absorbed no net energy from the cavity but having been displaced into a new line of flight parallel to that on which it entered the cavity, this displacement resulting in its hitting one rather than the other of the two anodes. It may be shown that as long as the transit angle of the electrons in passing between the plates is an integral multiple of 2π radians the resultant energy abstracted from the cavity by it will be zero and its emergent line of flight will be parallel to its initial line of flight irrespective of the epoch of the cycle at which it enters the deflecting field. The position of these parallel paths (and hence the anode upon which the stream impinges) depends, however, upon the phase of the oscillation within the cavity at which it entered the interspace between the deflecting plates. Those entering at successive instants of zero electric field will be deflected to the maximum degree in opposite directions. Electrons entering this space at instants of electric field maxima will traverse a substantially sinusoidal path between the plates but will leave the interspace along the same line as that on which they enter. Electrons entering at intermediate epochs of the cycle between the two specifically mentioned will be deflected to intermediate degrees. The resonant circuit, cavity or otherwise, connected to the anodes is therefore excited at the frequency of oscillation of the input cavity and energy can be withdrawn from the anode circuit as desired.

This principle of control can be used in a number of ways. Density modulating the electron stream will obviously result in an amplitude modulation of the oscillations developed between the split anodes. The electron beam after leaving the control cavity may be reflexed to anode areas which are electrically a part of the control cavity, so that the device becomes an oscillator, or the anodes may be in an entirely separate cavity coupled back to the control cavity, also to form an oscillator. These and other modifications and uses of the invention will be more apparent from a consideration of the following detailed description of several forms of the invention, taken in connection with the accompanying drawings wherein:

Fig. 1 is a diagrammatic showing of an embodiment of the invention as adapted to a microwave tube for delivering relatively large amounts of high frequency power;

Fig. 2 is a diagrammatic showing of an early embodiment of the invention, designed for experimental verification of the principles involved;

Fig. 3 is a diagrammatic showing of a tube of reflex type, constructed in accordance with the invention but designed for relatively low power output;

Fig. 4 is a diagram showing the relative displacement of electrons of the stream developed within the apparatus which enter the interspace between the deflecting plates at various epochs of the resonant cycle; and

Fig. 5 is a diagram showing a lumped constant circuit approximately equivalent to the control cavity in the tube of Fig. 1.

In the drawings illustrative of all three forms of the invention, hereinafter to be described in detail, a purely diagrammatic mode of illustration has been used, showing the electrical relationship of the parts and ignoring the details of the mechanical construction. Such details can be varied in wide degree and can be readily supplied by those skilled in the art. Furthermore a showing of such mechanical features would tend to obscure the electrical features with which this specification is primarily concerned. The diagrams of each of the three forms shown therefore are in the form of axial sections showing the spatial and electrical relationship of the electrodes and resonator structure of the tubes illustrated, the mechanical structure being only generally indicated.

Considering first Fig. 1, the enclosing envelope is comprised largely of the cavity resonators themselves, these being mechanically connected but electrically insulated by seals **1**, **1'**. As will be evident from what follows the seals are not subjected to any material high frequency fields, and need have no special shielding or other protective features.

The various elements of the tube itself are all constructed as figures of revolution around the axis **3**; i. e., the figure is an axial section through the operative elements of the tube, each of these elements being generally cylindrical in form.

Mounted on a conventional stem **4** at the axis of the tube is an indirectly heated cathode **5**. Energy for heating the cathode is supplied from a conventional heater coil **7**, and the cathode itself may be of any of the conventional indirectly heated types, examples of which are thoriated tungsten, barium oxide, or the so-called "Philips" cathode formed of mixed powders of barium and tungsten. Preferably the cathode departs from a true cylindrical form in having its sides concave as shown, so as to tend to focus the electrons emitted therefrom into a concentrated stream or sheet, narrow in its vertical dimension (as viewed in the drawing), the electrons flowing radially outward in disc-like form. The electron flow is therefore symmetrical with respect to the axis of the tube.

Surrounding the cathode and quite closely adjacent thereto is the control-cavity resonator **9**. Optionally there may be interposed between the cathode and control resonator a modulating grid **10**, its side walls curved in the axial plane concentrically with the cathode curvature. As will be seen from the drawing the side walls **11** and **13** of the cavity **9** are cylindrical, and the cavity cathode is closed, top and bottom, by annular plates **15** and **17**. The side walls **11** and **13** of the cavity are apertured as indicated at the reference characters **19** and **21** to admit the electron stream from the cathode. These apertures are in the form of circumferential slots, bridged by narrow struts spaced around the internal and external peripheries of the resonator. In order to minimize the interception of the electron stream by the struts those in the wall **11**, indicated at **23**, are alined with the struts **25** in the wall **13**. It may here be noted that aside from their mechanical function in holding the two halves of the resonator together these struts act to complete the cavity by electrically connecting the two halves thereof, and permitting the cavity to be resonated in a mode which will be described in some detail hereinafter. Here it will suffice to state that the electron stream is not subjected to material electrostatic deflection at points of ingress to and egress from the cavity, and, furthermore, radiation of power from the cavity is minimized.

At the ingress aperture a slight boss **26** on the wall **11** assists in the focusing action. With the geometry shown the electron stream converges to a minimum just within the cavity and thereafter diverges only very slightly so that practically it may be considered as an outflowing sheet of constant thickness. For some purposes it is desirable to have the electron stream converge to a minimum at the egress aperture **21**.

Annular deflecting plates **27** are mounted within the cavity **9** on either side of the path of the electron stream. As will be appreciated from the drawing the radial dimension of these plates is such that they nearly fill the width of the cavity. The plates are supported on cylindrical septa **29**, **29'**, the septa and plates being electrically integral with the cavity. Radio frequency energy is fed into the cavity for control purposes by means of a coupling loop **31** fed by a coaxial sealed coupling **33**.

The cavity is so dimensioned that the two halves into which it is divided by the septa **29**, **29'** are electrically equivalent. It is the dimensions of this cavity which determine primarily the frequency of operation of the tube. The cavity is designed to oscillate in a degenerate mode, not readily defined by either wave-guide or coaxial cavity nomenclature. A strong electric field exists between the deflecting plates. High electric fields also exist between the edges of these plates and the cavity walls **11** and **13** respectively. Much weaker electric fields also exist across the apertures **19** and **21**, but any material radiation from these latter fields is suppressed by the struts **23** and **25**, the presence of which also helps to limit the intensity of this field. The mode of oscillation can be best understood by reference to Fig. 5, which shows a lumped-constant circuit substantially equivalent to that of the control cavity. The condenser 27_1 in this diagram represents the capacity between the deflecting plates **27** and the condensers 27_2 represent the capacities between the edges of the deflecting plates and the cavity walls. These latter capacities are bridged by inductances **11**, and **13**, these being respectively the effective inductances on either side of the deflection plate region. The small inductance 23_1, represents that of the struts **23** which bridge the capacity between the edges of the aperture through which the electron stream enters, represented in the diagram by the capacity 19_1. Similarly the elements 25_1 and 21_1 represent the inductance and capacity, respectively, of the exit aperture arrangement. The input loop is represented by the inductively coupled coil 31_1. The inductive coupling between the elements 11_1 and 13_1 is very small.

When this circuit is driven at its designed operating frequency the inductive elements 11_1 are effectively in series and are effectively in parallel with the elements 13_1 which are themselves in series. The major portion of the R. F. voltage drop around the circuit is across the parallel LC circuits, so that the electric field across the aperture is very small, and there is a potential node at the center of both the entrance and exit apertures. The fields that exist in the apertures are in phase with the main deflecting field but may represent a loss of power in that they accelerate the electrons of the stream resulting in final electron path which are not, strictly parallel to the entrance paths. To minimize this effect the cavity is so designed that the aperture field is weak and the electron path through it is short in comparison with that between the main deflecting plates. Moreover the effect can be compensated in part by making the transit angle between the plates differ very slightly from $2\pi n$ radians. Edge effects, moreover are impossible to avoid in any practical structure. There will always, therefore, be some slight departure from the theoretical ideal, but these departures can be made very small and to a large degree compensatory, so that in effect the $2\pi n$ radian transit angle through the effective deflecting field can be substantially realized.

Surrounding the control cavity resonator **9** is an output or anode cavity resonator **35**. The output resonator also has a cylindrical inner wall **37** and outer wall **39**, closed top and bottom by annular plates **41**, **41'**. The wall **37** is circumferentially apertured, as shown at **43**, to admit the electron stream and, as in the case of the control cavity, the aperture is spanned by a plurality of struts **45** which are radially alined with the struts **23** and **25** to minimize interception of electrons. A cap **46** spans the opening in the annulus **41** to complete the tube envelope.

The anode cavity 35 is divided into three electrically equivalent parts by septa 47, 47' and the electron receiving areas or anodes proper which are carried by septa 47, 47'. Viewed from the cathode these anode areas comprise deep V-shaped grooves formed between a pair of flat annuli 49, 49' and a pair of frusto-conical annuli 51 and 51', the annuli 49 and 51 being mechanically and electrically joined where they are supported by the septum 47 and the annuli 49' and 51' being similarly joined at their point of support by the septum 47'. As will be seen from the diagram the inner edges of the annuli 51 and 51' are closely spaced so that there is little opportunity for the electrons to pass between them, substantially all of the flow being intercepted by one or the other of the anodes comprising the pair. The V-shaped form of the anode area is for two purposes; first, to distribute the heat liberated by the electron impact over a larger area and so avoid melting and pitting the electron receiving surface; second, to minimize the effect of secondary electron emission and prevent its direction back toward the control cavity.

The anode cavity is preferably designed so that the distance between the inner edges of the annuli 49 and 51 and the inner edges of the annuli 49' and 51' is one half wave length when measured around the cavity in a given azimuthal plane, either by wall 37 or the wall 39.

Radio frequency power is withdrawn from the cavity through a loop 55 feeding a coaxial line 57.

In operation the various elements of the tube are supplied with potentials as indicated schematically by the potentiometer 59. The most positive potential of the system is supplied to the anode cavity resonator 35. The input cavity resonator is supplied by a somewhat less positive potential, while the cathode 5 is at zero or base potential from which the other potentials are measured. In the operation of the device it is the potential difference between the cathode and the input cavity which is most critical with respect to operating efficiency. The device requires minimum driving power when this potential difference is such that the velocity imparted to the electrons between the cathode and the aperture 19 makes their transit angle in passing through the space between plates 27, a multiple of 2π radians; i. e., such that the time required by the electrons to pass between the deflecting plates is a whole number of cycles at the frequency of oscillation of the cavity. If this condition is exactly fulfilled and the R. F. electric field distribution between the plates is substantially uniformly distributed along the electron path no power is absorbed by the electron stream as it passes between the plates, the only power which need be supplied is that required to meet the I^2R losses within the cavity. If the cavity walls are of material of low resistivity (e. g., silver plated) these I^2R losses can be made very small.

In most applications of the invention that have so far been analyzed the transit angle is most conveniently made 2π radians, or a single cycle of the operating frequency. The paths of the electrons entering the space between the deflection plates at various epochs of the cycle are illustrated in Fig. 4. In this figure the deflection voltage existing between the plates is taken as $V_d \cos \omega t$ and the paths are shown for various phases at the instant of entering the interspace, the phase being indicated as ωt_0, designated on the various curves. The deflection is shown, in arbitrary units, on the axis of ordinates and the transit angle, or position of the electron with respect to the plates is indicated on the axis of abscissae. It will be seen from these graphs that, whatever the phase of the cavity oscillation at the instant of entry, the electrons leave the interspace between the plates in paths parallel to that at which they entered. Since the control cavity is so constructed that the walls at the points of entry and egress are at the same D. C. potential there is no longitudinal acceleration of the electrons as they traverse the cavity other than that caused by fringing R. F. fields. Maximum deflection of the electrons occurs when they enter the interspace at instants of zero R. F. electric field between the plates i. e., when ωt_0 is equal to

$$\frac{\pi}{2} \text{ or } \frac{3\pi}{2}$$

Under these circumstances the electrons are accelerated toward one plate or the other during the first half cycle of the oscillation, acquiring their maximum transverse velocity when they have traversed one half the distance across the cavity, with a transit angle of π. During this half cycle they are abstracting energy from the cavity. During the next half cycle they are decelerated and deliver energy back to the cavity.

These general principles hold irrespective of the phase angle of the oscillating electric field within the cavity at which any electron enters. The accelerations of the electron in passing through the cavity are equal and opposite, the electron leaves the cavity with the same energy it had when it entered, and it therefore absorbs no energy from the cavity. It is, however, displaced when passing through the cavity and the extent of this displacement and its direction determine whether it falls upon one or the other of the two electron-receiving areas of the anode. Considering the electron stream as a whole its plane of emergence from the input or control cavity varies sinusoidally at the frequency of oscillation of the cavity itself. The electron stream falls upon one or the other of the two anode areas or divides between them depending upon the general plane of its emergence. In so doing it excites the output cavity resonator at the same frequency. The output cavity should obviously be tuned to the same frequency as the input cavity if maximum response is to be obtained, but per se it has no effect upon the frequency of the output power.

In passing between the two cavities the electron stream may be further accelerated by the potential difference between the two structures, and the available power will depend upon the energy of the electron stream as it enters the cavity 35; i. e., upon its velocity and the current which it carries. Owing to the tuning of the latter cavity and the node at which it is excited the oscillating field within it extends hardly at all through the aperture 43 and the electrons are decelerated and hence give up their energy to the output cavity in falling through the field between this aperture and the anode areas.

The general nature and distribution of the oscillating field is indicated by the arrows within the output cavity, which indicate the direction of the component fields at the instant of maximum downward deflection of the electron stream entering the output cavity. It should be obvious that at this instant the entire stream should fall on the anode areas defined by the annuli 49' and 51'; if the stream is so thick that some electrons fall in the higher corresponding anode area they will be further accelerated and absorb energy from the output cavity which will be wasted as heat; however the focus of the stream can be made sufficiently accurate that this loss does not occur to any appreciable extent. In the transition time between the instants of maximum deflection some few electrons will pass through the slot between the two anode areas and the energy of these will be largely wasted. Some of these may be collected on the opposite sides of the anode annuli 51, 51' but in general the electrons so passing between the gaps between the two anode structures will pass on to strike the wall 39, where their only effect will be to heat the cavity. These, however, will comprise a very small proportion of the total electron flow. The energy of the stream is also necessarily wasted, in whole or in part, during the transition period, when the stream divides between the two anode areas unless it is pulsed, as by the grid 10, synchronously with the periods of the maximum deflection. Such pulsing is a matter of circuitry and not a function of the tube per se.

It is clear that in order to achieve maximum output from a given tube of the type here considered the deflection of the stream must be sufficient to cause it to fall entirely on one or the other of the anode areas at the epochs of maximum displacement. Where this condition is met the available output power is substantially proportional to the product of the current carried by the electron stream and the D. C. voltage between the cathode and the anode cavity resonator. Considering the latter factor alone it is immaterial how the voltage drop between the various elements is divided.

The R. F. voltage required to produce the necessary displacement of the stream depends, however, upon the number of cycles the electrons require for their transit between the plates. The total displacement is directly proportional to the number of cycles times the peak voltage. Therefore for a certain total displacement the necessary driving voltage varies inversely as the number of cycles taken in the transit between the plates and the power absorbed varied inversely as the square of the number of cycles. Considering only the factor of sensitivity to deflection it would therefore appear that the voltage gain of the tube would vary directly as n and the power gain as n^2, where n is the number of cycles in the transit angle. This analysis is based on the assumption that the circuit impedance remains the same for all cases. How much of this gain can be realized depends on how efficiently the circuit impedance can be maintained with the increased capacity in the deflection plate region.

If it be the total cathode emission that limits the electron current where $n=1$, the space charge limitation may or may not come into play with the lower accelerating potentials required to make n equal to 2 or even 3 in a given tube. Applying an accelerating voltage to the grid **10** will increase the electron current where it is equal to the space-charge limited value. The voltage so applied may be equal to or even greater than the control resonator voltage, but, particularly if the grid voltage be the greater, the focus of the electron stream may be disturbed. Increase in current to the anode circuit increases output power only to the extent that it is switched back and forth between the anode areas, and defocusing the electron stream to an extent which will cause it to divide between the areas involves unnecessary losses in efficiency and in gain. Such losses are of the same nature as those occurring when the stream is insufficiently deflected.

What design parameters are chosen therefore depend on the nature of the service to which the tube is to be applied. If the available driving power is ample maximum output may usually be realized by making $n=1$. If the available driving power be less it might be better to use a higher value of n, giving full beam deflection, and to use as much accelerating voltage on the grid **10** as is possible without making the thickness of the electron stream greater than the anode dimension. The available output power will then usually be as great as or greater than it would be if the maximum current stream were only partially switched between the anode areas, and the losses and consequent heating will be much less, since the efficiency is higher in this type of operation.

It will be noted that when the invention is used as an amplifier of amplitude-modulated signals the anode efficiency will vary widely between maximum and minimum amplitudes of the modulated signal, the losses being a maximum and the efficiency a minimum at the epochs of minimum amplitude. With a frequency-modulated or a phase modulated signal the losses in the anode circuit can be maintained substantially constant, and the anode efficiency can be maintained at a constant value which, under optimum conditions, can approach 63.6%.

When used as a modulator, with the modulating potential applied to the grid **10**, the anode efficiency need not vary materially as long as the focus of the electron stream is maintained and the drive is constant and sufficient to give full deflection of the beam.

In any case where the device is used to amplify a modulated signal there will be some variation in the driving power demanded by the control cavity. With amplitude modulation the change in amplitude between successive cycles will result in a difference between the power absorbed from the cavity by an electron in its acceleration and that returned to the cavity when decelerated. Owing to the normally large ratio of operating frequency to modulation frequency this difference will be very small, and usually not measurable. With frequency or phase modulation successive cycles will differ in length and the relation $2\pi n$ cannot be exactly maintained. Therefore, except at the nodes of the modulating frequency, the electrons will leave the control cavity with some transverse velocity and consequently some increase in energy, so that the losses in the cavity will increase. Again, because the modulation frequency is normally small compared to the operating frequency the variation in the length of the cycles cannot be great and the increase in driving power may be too small to be accurately measurable. The high Q of the control resonator obviously results in the tube being essentially a narrow-band device; neither the amplitude nor the phase of the cavity oscillations can be changed rapidly, relatively to the period of the oscillations. Where frequency modulation is employed the amplitude of the cavity oscillations decreases and thus the required drive increases with departures from the carrier frequency.

In view of the fact that minimum absorption of power by the electron stream in passing through the control cavity depends upon a transit angle of exactly $2\pi n$ radians, it might appear that the accelerating voltage between the cathode and the control cavity would be extremely critical. This transit angle, however, varies inversely as the square root of the accelerating voltage and not inversely as the voltage itself, and therefore small deviations from the ideal in this voltage do not have unduly large effects. Moreover, the theory of the zero loss condition as given above has been developed on the assumption that the field between the deflecting plates at any instant is uniform, both edge effects and the distribution of electric field across the plates having been neglected. Because of the proximity of the cavity walls to the edges of the deflecting plates the path length of the fringing fields between the plates is short and the weaker field in this region merges with the weak field in the apertures, which has been discussed in connection with the equivalent circuit. The R. F. potential distribution across the plates depends on the standing waves within the cavity; roughly it will approximate the form of the crest of a sine wave centered above the septa. The phase angle of the standing wave subtended by the distance from the center to the edges of plates with the form of cavity shown will in most designs be less than 18°, so the field strength near the edges should be 95% or more of that at the center; the major portion of the drop being across the LC circuits of the equivalent diagram, the variation in the field strength will probably be only one or two percent at most. If desired even this can be compensated by dishing the plates slightly, but usually this refinement is not warranted.

The form of device illustrated in Fig. 1 has been chosen for first discussion because in this particular embodiment of the device the functions of the anode and control electrodes and their respective cavities may be completely separated. Where this is the case the various operating parameters of the device can also be separated and considered independently. It is possible, however, to merge the cavities by various expedients and thus form a tube which is easier to construct and, for certain purposes, may be as effective as that illustrated in Fig. 1.

An early form of tube embodying this invention wherein such a combination of cavities was effected to form an

oscillator is illustrated in Fig. 2. In this case the cathode 5' and the inner wall 11' of the control cavity resonator are substantially identical with those of Fig. 1 and have accordingly been given similar reference characters. In this case, however, the aperture 19' is covered by an accelerator grid 61 instead of the struts used in the tube of Fig. 1.

The single divided cavity has an outer wall 65 and inner septa 67, 67' carrying the deflection plates 69, 69', which, in this case, extend in one direction only from the septa, toward the entrance aperture 19'. The two halves into which the cavity is divided are closed, top and bottom, by annular plates 71, 71'. Two half-grids, 73, 73' substantially cover the opening between the plates through which the electrons leave the deflection region and pass into the anode portion of the cavity.

Within this latter portion of the cavity and closely adjacent the septa 67, 67' are a pair of rings 75, 75' which are insulated from the body of the cavity but which, because of their close spacing with respect to the septa and the high capacity which results therefrom, effectively are electrically continuous with the septa at radio frequencies although they can be and are operated at different bias potentials. A pair of half-grids 77, 77', generally similar in construction to the grids 73, 73' substantially cover the aperture between the rings 75, 75'. Behind these two half-grids an anode ring 9 is mounted. The half of the cavity containing the anode is electrically equivalent to that containing the deflection plates; i. e., the distance between the adjacent edges of the half-grids 77, 77' around the outer periphery of the cavity is one half wave length at the same frequency as the distance between the inner edges of the deflecting plates 69, 69' around the inner periphery of the cavity The relative potentials at which the various elements are operated with respect to the grounded cathode, are indicated schematically by the potentiometer 59'. The R. F. output of the oscillator is by means of a coupling loop 31' and coaxial cable 33', similar in function and construction to the loop and coaxial cable 31 and 33 respectively of Fig. 1.

As in the case first discussed the deflection plates form the poles of high electric field within the cavity considered as a whole. Energy is withdrawn from the electron stream primarily in the space between the anode 79 and the half-grid 77, 77', since, owing to the construction and tuning of the cavity the anode as a whole is maintained substantially at a uniform potential, but the direction of the R. F. field is such as to abstract energy from the stream in this portion of the flow. The two anode areas are, in this case, combined into one which is at uniform potential, but the construction of the cavity is such that the R. F. deceleration of the electrons has the same effect as where the anode is physically divided. In this form of the invention the tube has the same anode efficiency as the tube shown in Fig. 1, and the principles of control are similar. For best operation of this tube the transit angle of the electrons from the half grids 73, 73' to the half-grids 77, 77' should be

$$\frac{\pi}{2} \text{ radians}$$

The half-grids 77, 77' also act as suppressors of secondary electrons. The tube is shown as it indicates the variety of structure in which the invention may be embodied.

Fig. 3 is a cross-section of a tube of a reflex type which embodies the invention. In this case the section shown is not that of a figure of revolution as in the two other cases, but that of a rectangular cavity. The cathode 81, heated indirectly by a schematically shown coil 83, is a shallow trough with a concave emitting surface to focus the electron stream into the resonator as before. There is also shown a focusing electrode 83, which is not essential and may be omitted if the cathode has the proper

curvature with respect to the relative potentials applied, but which is convenient in obtaining the best focus of the electron stream. The cavity, in this case, is reentrant, the electron stream entering the cavity through a funnel-like ingress aperture formed between converging flanges 87, the actual aperture being preferably, although not necessarily, covered by a grid 89. Immediately within the cavity the deflecting plates 91, 91' are mounted, and are supported by septa 93, 93'. The output portion of the cavity is also reentrant, flanges 95, 95' extending inwardly of the cavity to a position closely adjacent the edges of the deflecting plates, and a grid 97 joins these two flanges also. A reflecting electrode 99 is mounted in the space between the flanges and the grid 97 as viewed from the cathode.

In this tube the anode areas are flanges 101 and 101' which are integral with the deflecting plates.

The relative potentials of the various elements of the tube are indicated schematically by the position of the connectors to a potentiometer 103. In this case the cavity is operated at ground potential, with the cathode negative thereto and the reflector electrode 99 still more negative. The potential of the focusing electrode is such is to provide the best focusing and will vary with different potentials on the other electrodes. The voltage between the cathode and the cavity is such as to make the transit angle between the plates 91, 91' $2\pi n$ radius, where n is an integer, as before. The grids 89 and 97 are at the same R. F. potential and no longitudinal acceleration is therefore given to the electrons within the cavity other than that due to fringing fields. The stream emerges from the cavity at maximum velocity and the electrons are retarded and reversed in their direction of flow by the D. C. field between the cavity resonator and the reflector electrode 99, the shape of this field being such as to cause the electrons to fall back through the grid 97 on to the anode areas 101 or 101', depending upon which side of the center line the stream occupies at the instant of its emergence from the cavity into the reflex space. Preferably the potential of the reflex electrode is so adjusted that the transit angle in the reflector region is approximately

$$\frac{3\pi}{2}+2\pi n \text{ radians}$$

for maximum output power. The deleterious effects of secondary electrons can be reduced by placing grids on the anode areas 101 and 101'.

Of the three embodiments of the invention above described the first (Fig. 1) is primarily a radio frequency amplifier for high power, that of Fig. 2 is a purely experimental oscillator which was used in making measurements proving the theory as herein set forth, while the tube of Fig. 3 is obviously an oscillator, since the input and output of the resonant cavities are one and the same and hence inherently coupled. While the principles and advantages of the invention have been set forth above they may be summarized as follows:

The low driving power and high shunt impedance characteristic of the invention depends upon a number of factors. First, the factor which has already been emphasized is that the mode of deflection of the electron stream is such as to absorb a minimum of power—theoretically zero and actually, taking into account the departures from the ideal inherent in all actual apparatus, it can be made extremely small. A second feature that contributes to the low input losses is that the form of the deflection circuit makes possible the use of a cavity resonator having the high Q, low loss features of such cavities and that, further, the cavity can be designed such that the openings therein are located at points of low R. F. electric field and radiation losses therefrom can therefore be reduced to very low values. As a result of these features the impedance of the cavity in the tube of Fig. 2 was measured as between 42,000 and 50,000 ohms at

397 megacycles per second, the designed frequency of the tube.

The next feature contributing to the efficiency of the device is that it permits the use of the type of anode cavity wherein the losses are low but wherein, particularly, long electron paths are not necessary in order to obtain adequate sensitivity. Finally, where the functions of input and output cavities are not combined, and a space therefore exists between the cavities, the electron flow across this interspace is a constant at radio frequencies. R. F. deceleration of the electrons does not take place in this region and therefore radio frequency power is not liberated in this space to radiate and cause losses.

It will at once be apparent that some of these features are absent in certain forms of the device; where it is applied as an oscillator, for instance, the feature last mentioned of negligible R. F. variation in current between the cavities does not arise since input and output cavities are combined. This is still true of the reflector space, however. The basic features underlying all forms of the device is the employment of transit angles of 2π or integral multiples thereof, and it will be at once appreciated that this result can be obtained with apparatus using ordinary lumped constant circuits as well as with the cavity resonators which are characteristic of the preferred forms of the device. This principle does, however, make the use of cavity resonators with their high Q, low loss properties readily possible and this, in turn, leads to the short electron path output resonators. The fundamental principle is such that an indefinite number of tube geometries can be employed embodying the principles here set forth.

In this connection it may be noted that the interspace between the deflecting plates may be considered as a transmission line; a radial line in the embodiments illustrated in Figs. 1 and 2, a linear line in the embodiment of Fig. 3.

If the mechanism of establishing the deflecting fields be so considered, the criteria for best operation may be stated in terms which may bring them out more clearly.

First, the relative velocities of the electrons and of propagation of the deflecting field within the transmission line must be such that the transit angle of the electrons with respect to the deflecting field is substantially $2\pi n$ radians. Second, the electrons in any cross section of the stream normal to their longitudinal velocity (i. e., all electrons entering the deflecting field at the same instant) should be subjected throughout their transit therethrough to substantially the same accelerating forces.

These criteria are in some degree more general than might be deduced from consideration of any one embodiment of the device. Where electron streams of large cross section are involved they may impose severe limitations on the design parameters. With narrow, pencil-like streams a much wider choice of such parameters may be possible. Thus if the emission from the cathode in the tube of Fig. 1 were limited to an even number of narrow linear areas equally spaced around the axis, it would be possible to meet the conditions specified by establishing a circumferential mode of oscillation around the input cavity with field maxima at the radii of the streams. The direction of propagation of the waves within the transmission line wherein the deflecting fields are established therefore has no necessary relation whatever to the direction of electron flow, as long as the criteria given above are substantially met. The specific illustrations given herein are therefore not to be taken as limiting the scope of the invention, except as such limitations are embodied in the terms of the following claims.

I claim:

1. A vacuum tube amplifier comprising means for developing a stream of electrons concentrated in at least one dimension so that the constituent electrons of said stream travel in paths substantially parallel to a median plane, means for deflecting said electrons into paths substantially parallel to and displaced from their original paths comprising a cavity resonator positioned in the path of said stream and apertured to permit its passage therethrough, a pair of deflecting plates within said cavity and extending a major portion of the distance thereacross on opposite sides of said stream, supporting means for said plates connected electrically with said cavity and dividing said cavity into two electrically equivalent halves with said plates at the electrical center thereof whereby said cavity can be resonated at a mode wherein a relatively high electrical field is established between said plates, and anode structure comprising a pair of adjacent electron-receiving areas symmetrically positioned on each side of said median plane so as to receive respectively substantially all of the electrons of said stream when the electrons thereof are deflected to one side or the other of said median plane into paths parallel to their original paths.

2. A vacuum amplifier tube in accordance with claim 1 wherein the centers of the apertures for the passage of said electron stream through said cavity are located substantially one quarter electrical wave length from the edges of said plates when said cavity is resonated at said mode.

3. A vacuum tube structure in accordance with claim 1 including a second cavity resonator in the path of said stream and dimensioned to resonate at the same frequency as said first mentioned cavity when the latter is resonated at said mode, said second cavity resonator being apertured to admit said electron stream and said electron-receiving areas being positioned substantially at locations of maximum electric field when so resonated.

4. A vacuum amplifier tube comprising means for developing a stream of electrons concentrated in at least one dimension, an input cavity resonator positioned in the path of said stream and apertured to permit the passage of said stream therethrough, a pair of deflecting plates within said cavity and electrically integral therewith positioned on opposite sides of the paths of electrons constituting said stream and extending over a major portion of the length of said path within said resonator, said deflection plates being positioned substantially at a location of electrical symmetry within said cavity to adapt them to form poles of maximum electric field and to form nodes of minimum electric field at the apertures in said cavity resonator when said cavity is resonated, an output cavity resonator positioned in the path of electrons of said stream emerging from said input cavity in paths parallel to their paths of entry therein and apertured to admit said electrons, and a pair of anode areas within said output cavity substantially at the poles of maximum electric field therein when said output cavity is resonated at the same frequency as said input cavity, said anode areas being positioned to receive an increasing and decreasing number of electrons from said stream alternately as said stream is deflected by said deflecting plates.

5. An electronic amplifier comprising a source of electrons, means for developing a concentrated stream of electrons from said source, a pair of anodes positioned to receive said stream of electrons when deflected into paths parallel to their initial paths, and means for deflecting said stream to fall on said anodes alternately comprising a cavity resonator positioned in the path of said stream of electrons and apertured to permit its passage therethrough, a pair of deflecting plates positioned within and extending across a major portion of said cavity resonator in the direction of flow of said stream of electrons and on opposite sides of the paths thereof, said deflecting plates being electrically integral with said cavity and adapted to constitute the poles of electric field and to establish nodes of electric field at the apertures of said cavity resonator when said cavity is resonated at a frequency such that the distance between the edges of the opposed plates as measured around the walls of the cavity is substantially equal to an odd number of half wave lengths, the length of said plates in the direction of said path being relatively

small as compared to one half wave length whereby the strength of the electric field between said plates is substantially uniform.

6. An electronic amplifier as defined in claim 5 wherein the said distance between the edges of said plates is one half wave length when resonated at said frequency.

7. A vacuum tube amplifier comprising means for developing a stream of electrons concentrated in at least one dimension so that the constituent electrons of said stream travel in paths substantially parallel to a median plane, means for deflecting said electrons into paths substantially parallel to and displaced from their original paths comprising a cavity resonator positioned in the path of said stream and apertured to permit its passage therethrough, a pair of deflecting plates within said cavity and extending a major portion of the distance thereacross on opposite sides of said stream and so connected electrically with said cavity that an electric field is established between said plates when said cavity is excited to resonance, and anode structure comprising a pair of adjacent electron-receiving areas symmetrically positioned on each side of said median plane so as to receive respectively substantially all of the electrons of said stream when the electrons thereof are deflected to one side or the other of said median plane into paths parallel to their original paths.

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