

March 3, 1953

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2,630,547

PLURAL BEAM GROWING-WAVE TUBE

Filed July 27, 1949

2 SHEETS—SHEET 1

Fig 1

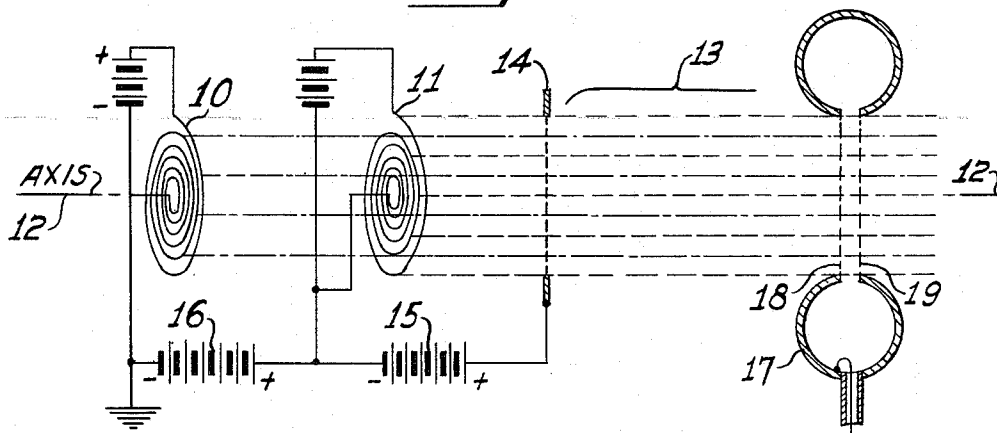


Fig 2

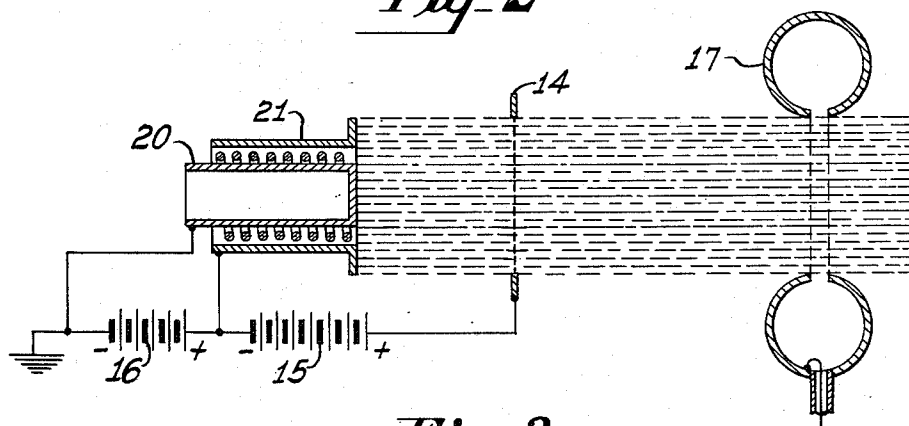
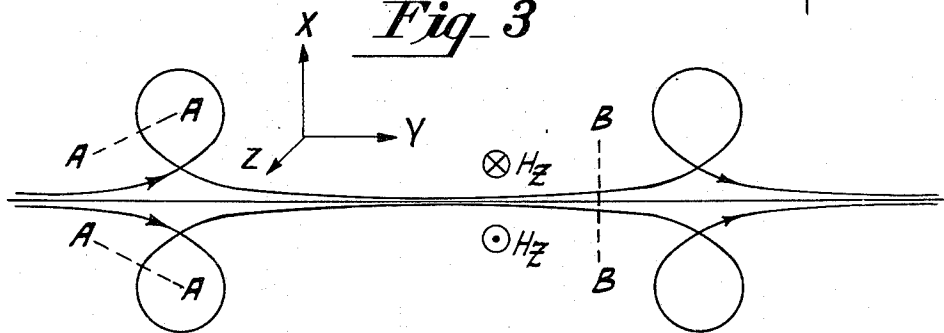


Fig 3



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2 SHEETS—SHEET 2

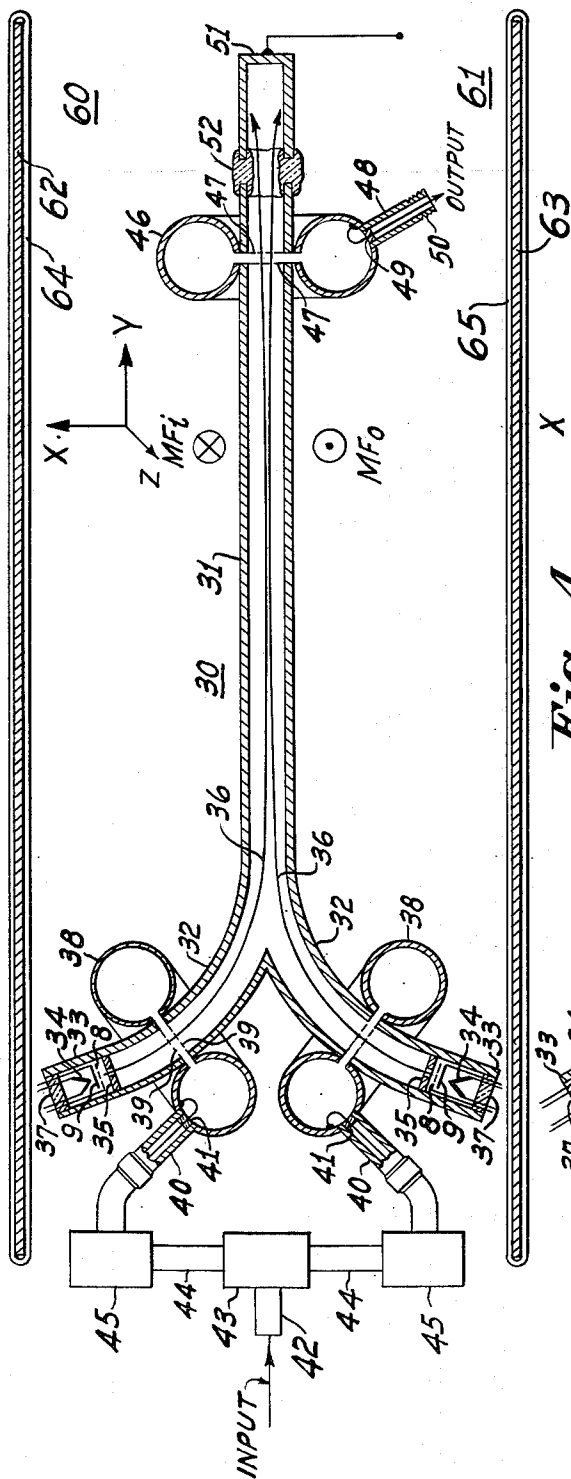


Fig. 4

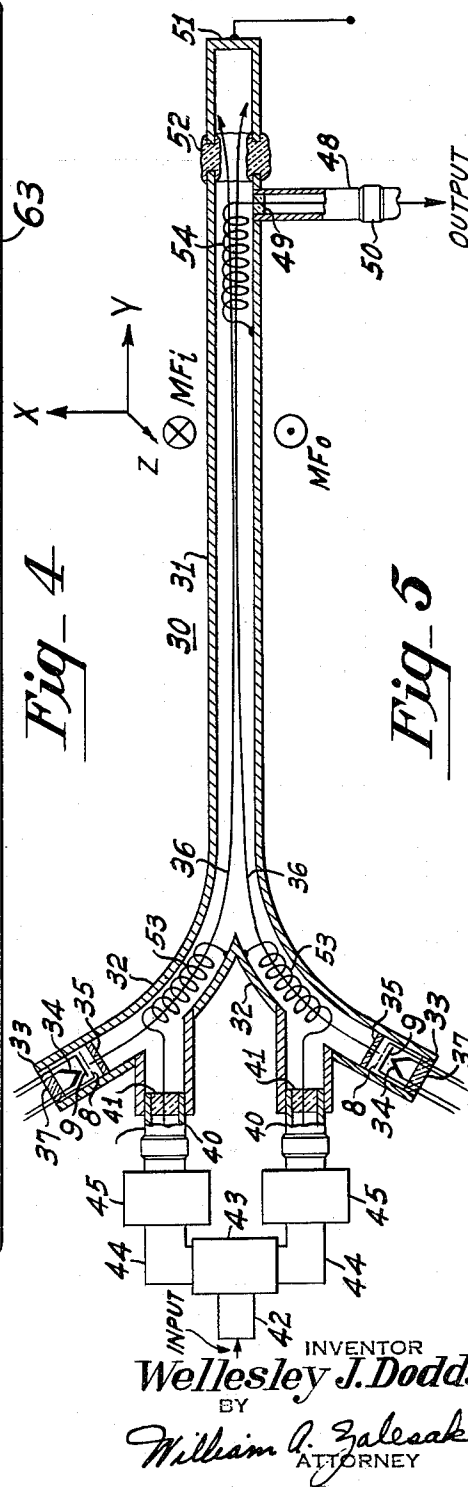


Fig. 5

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PLURAL-BEAM GROWING-WAVE TUBE

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12 Claims. (Cl. 315-6)

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This invention relates to improvements in electron discharge devices for generating and amplifying energy in the ultra and super high frequency regions. More particularly, it relates to improvements in traveling wave tubes of the type variously known as plural beam tubes, mixed-beam growing-wave tubes, and electron wave tubes.

This type of tube represents a significant advance in the traveling wave tube art because of its remarkable property of achieving energy amplification without the use of field-supporting or wave-guiding structures in the amplifying region of the tube, i. e., in the drift space. In it provision is made whereby the function of carrying high frequency waves slowly along a drift space in close proximity to a stream of moving electrons (herein referred to as a first group of electrons) is effectively performed by other moving electrons (herein referred to as a second group of electrons) instead of by a passive circuit element such as a delay line or helix. Under the influence of input signals applied to a control element at least one of the groups of electrons is made to form itself into waves which grow as they move through the drift space, the increase in wave energy being attained at the cost of a lessening of an initial differential which is caused to exist between the kinetic energies of the two groups of electrons and by a phenomenon which has been described as a mechanism of elastic collisions between fast and slow electrons. In actual practice both groups of electrons are caused to form themselves into waves, rather than to shoot one of them through the drift space as a D. C. stream, as this seems to cause the above mentioned mechanism of collisions to operate to greatest effect, i. e., to afford the greatest gain.

In the prior art, as typified by the article on page 4 of the January 1949 issue of the Proceedings of the I. R. E., volume 31, No. 1, the stream of intermixed "groups" of electrons of different speeds has been formed in either of two ways. One way has been to produce a single inhomogeneous beam in which, due to space charge effects, the outer electrons (one group) travel with greater velocity than the inner electrons (another group). The other way has been to produce a plurality of beams, each of which may be homogeneous, by arrangements including the use of separate cathodes which are so positioned, either behind one another or closely juxtaposed side-by-side, that the beams will intermix. The practice of accepting the limitation of neces-

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sarily producing the intermixed stream in one of these ways has resulted in a number of disadvantageous structural arrangements for these tubes. For example, in every prior art arrangement for a tube of this kind the groups of electrons are intermixed in a region which they enter soon after they leave their common or respective cathodes (as the case may be) and thereafter it is not until they have traveled for some distance as an intermixed stream that they pass through a control element such as a resonant input cavity or an input helix, where they can be influenced by the input signals. This results in more growing-wave amplification for noise than for useful signals, since noise waves of intermixed electrons travel further in the drift space than do signal waves. Of course, if it were possible for the respective intermixed beams to have absolutely constant currents and velocities, then there would be no noise amplification at all since they only interact upon each other if at least one of them includes wave components. But, as is known, this is not possible since the electrons from each cathode will be emitted from it with the usual random irregularities of initial direction and velocity, which are responsible for "shot" noise. As a result noise waves will be present in each admixed beam and these waves will already be interacting to produce gain in the portion of the drift space between the place where intermixing starts and that where the input signal is impressed on the intermixed stream. For this reason in prior art mixed-beam traveling-wave tubes the signal to noise ratios have been lower than those which, as will be seen, are now attainable according to the present invention.

It can be mathematically demonstrated that the amount by which the signal-to-noise ratio of prior art electron wave tubes suffers is quite substantial. This is due to the fact that the gain of this type of tube is a function of the length of drift space in which interaction for a particular signal takes place. This function is set forth in extenso in the article "Analysis of a simple model of a two-beam growing-wave tube," by L. S. Nergaard, RCA Review, December 1948. Because of the infinite frequency spectrum of noise currents very effective interaction occurs between two sets of shot noise electron waves. The distance over which pre-amplification of noise may thus occur in prior art tubes is frequently of the order of 10 per cent of the entire drift space. (See Figs. 10 and 12 of the article which is identified above as appearing in the

January 1949 issue of the Proceedings of the I. R. E.) On this basis the shot noise which originates at the cathodes of a tube which affords a gain of 60 decibels would be substantially 6 decibels greater on reaching the signal input point than when the beams first intermingled, thus worsening the tube noise factor by 6 decibels.

Moreover, particular kinds of prior art tubes have additional disadvantages. In one such kind two spiral cathodes are used, one being positioned behind the other, and intermixing is attained in that the group of electrons produced from the first cathode passes through the open structure of the second cathode. This has the disadvantage that the second cathode draws some of the current from the first one. In addition, any adjustment of the polarizing potential applied to one cathode will effectively alter the adjustment of that applied to the other. A final difficulty with this kind of tube is that partition noise will be generated as a result of partial interception of electron current from the first cathode by the structure of the second one.

Accordingly, it is an object of the present invention to devise improvements in mixed-beam growing-wave tubes whereby the groups of electrons which are to interact with each other in the drift space of the tube will not be intermixed until after the input signals have been impressed on each of them.

It is a further object of the present invention to devise improvements in mixed-beam growing-wave tubes for keeping down the generation of partition noise and for permitting adjustments of the velocity and current of any one electron beam without thereby unduly influencing the velocity and current of any other beam, the improvements being attained by novel arrangements in which none of the electron beams to be intermixed passes through any structural element of the electron gun producing any of the others.

It is a further object of the present invention to devise improved mixed-beam growing-wave tubes in which the drift path for each of the beams includes a first and individual portion in which the beam moves alone without intermingling with any other and a final and common portion in which all of the beams intermingle, move together, and interact with each other, and in which a means is provided for impressing the input signal on all of the beams in the individual first portions of their drift paths in order to attain signal wave interaction and amplification over all of the common final portions of their paths.

It is a further object of this invention to devise mixed-beam growing-wave tubes as set forth in the preceding paragraph in which said last mentioned means comprises a separate means for modulating each of the beams with an input signal whereby, in addition to attaining good signal-to-noise ratio, it will be possible to employ a separate means in the external circuit which is used to impress the input signal on each beam for determining the phase and magnitude of the electron waves to be formed on it.

It is a further object of this invention to devise improvements for mixed-beam growing-wave tubes in which individual electron guns are provided for respectively producing the several beams, each gun including means for adjusting the current and velocity of the beam which it produces and being spaced from all of the other

guns so that said means may be adjusted without affecting the beam produced by any of them.

Other objects, features and advantages of this invention will be apparent to those skilled in the art from the following detailed description of preferred embodiments of this invention and from the drawing in which:

Figs. 1 and 2 illustrate schematically two representative prior art arrangements for producing an intermixed electron beam in a traveling wave tube;

Fig. 3 represents the trajectories of two electrons traveling at a uniform rate of speed in a non-uniform magnetic field, which varies according to a simple law, and illustrates a principle which underlies the present invention;

Fig. 4 is a sectional view of one embodiment of the present invention; and

Fig. 5 is a sectional view of an alternate embodiment of the present invention.

Fig. 1 represents a prior art arrangement for producing a beam of two intermixed groups of electrons. Two flat, spiral cathodes 10 and 11 are arranged along an axis 12 of a growing-wave tube, not fully shown in Fig. 1, in such a way that electrons emitted by the cathode 10 can penetrate between the turns of the spiral of the cathode 11 in order to reach the drift space 13 (of which only the portion near to the electron source is shown). In the arrangement of Fig. 1 a single accelerating electrode 14 is employed. The emitted electrons are caused to follow paths parallel to the axis 12 by means of a strong axial magnetic field produced by a source of magnetic flux which is not shown.

A source 15 of an accelerating potential of n volts is applied between the cathode 10 and the electrode 14 to cause the electrons from the cathode 11 to attain a velocity of n volts before they enter the drift space 13. Another source, 16, which provides a potential of m volts is connected in series with the source 15 between the cathode 10 and the electrode 14 so that the electrons from the cathode 10 enter the drift space at the velocity $m+n$ volts. Accordingly, two groups of electrons move together through the drift space each group with a different velocity and each group having a predetermined current density controllable in any suitable known manner. This arrangement of "semi-transparent" cathodes has the advantage that it affords a very thorough mixing of the two electron streams. An input cavity 17 is placed so that its grids 18 and 19 lie athwart the path of the electrons, i. e., are transverse to the drift space. When properly excited the input cavity will act in a known manner to velocity modulate the two beams of electrons which move between its grids 18, 19, thus forming two sets of electron waves. While it is true that over a certain length of drift space each electron wave may grow in magnitude as a result of bunching, far greater growth is possible as due to interaction between the two sets of waves.

It should be noted that in this arrangement the two electron beams are intermixed for the entire distance from the cathode 11 to the grid 18 before any input signal acts upon them. Because of this, shot noise waves carried by these beams will undergo a certain amount of amplification before the input signal is impressed on the beams. This may preclude the use of this tube in cases where the input signal is expected to be of the order of a few micro volts, e. g., where it is to be used as the R. F. input stage for certain

kinds of super high frequency receivers, and this is especially unfortunate because of its potentially very great sensitivity. Nor would the situation be corrected simply by putting another input cavity between the two cathodes 10 and 11 since the waves which the added cavity could be made to impress on the electrons from cathode 10 would not receive any substantial amplification by interaction with the beam of electrons from cathode 11 until they reached the cavity 17, i. e. until the point where signal waves were also formed on this beam. This is true because the plural-beam growing-wave phenomenon results primarily from the interaction of a plurality of waves. In fact, the situation would be worsened since the partition noise, which would be generated by partial interception of the electrons from the cathode 10 by the added input cavity, would produce noise waves which, due to their infinite spectrum, would be amplified in the region between the cathode 11 and the grid 18.

The prior art arrangement of Fig. 2 has much in common with that of Fig. 1 except that the cathodes 20 and 21, instead of being directly heated spirals placed one behind the other along the tube axis, consist of indirectly heated structures which have concentric emissive surfaces lying in approximately the same plane and are insulatingly supported with respect to each other. In this arrangement the problem of partition noise is lessened considerably. However, as in Fig. 1 a substantial amount of noise amplification will take place before the input signal is impressed on the intermixed beams.

In general, according to the present invention: the electron beams which are to be intermixed are produced by separate electron guns which are not juxtaposed but rather are spaced apart in regions where they will not influence each other and in an arrangement which permits each beam to be individually controlled as to the density and mean velocity of its electrons and to be individually influenced by the input signal; the tube envelope encloses space providing a single common drift path in which the beams may move together after they have been intermixed, and a number of individual drift paths between the respective guns and a region where the beams converge into the common drift path; and a non-uniform magnetic field is used for causing the electron beams thus produced at widely separated points to converge to the common drift path and thereafter to move in substantially the same direction along it.

It can be shown that charged particles, in particular electrons, can be caused to follow trajectories such as those shown in Fig. 3, if they have a constant velocity and move in a magnetic field perpendicular to the plane of Fig. 3 which is constant in every Z-Y plane but which varies in a predetermined manner in every Z-X plane. This is shown, for example, in the article by Cogshall and Muskat which appears in Physical Review, volume 66, Nos. 7 and 8, pp. 187-198, October 1 and 15, 1944. In this article an analysis is made of the behavior of charged particles which move at constant velocities into magnetic fields which vary in certain fairly simple ways which are amenable to analysis in terms of Cartesian or polar co-ordinates.

The present invention makes use of the fact that two electrons can be made to follow respective paths such as those shown in Fig. 3 and in particular the portions of those paths between the lines A-A and B-B. Accordingly for each

of the embodiments of growing wave tubes, i. e. for each of the embodiments respectively shown in Figs. 4 and 5, the evacuated envelope 30, which serves as an electrostatic shielding means, is formed to provide one common drift space into which the paths of a number of beams may converge, and along which they may then follow approximately the same course, and a number of individual drift spaces each affording a path of travel for one of the beams from its point of origin to its point of convergence into the common drift space. To this end envelope 30, which is shown herein by way of example, comprises a main tubular enclosure 31, which surrounds the common drift space, and a number of branch tubular enclosures 32 (such as two) each of which surrounds one of the individual drift spaces. Each branch tubular enclosure 32 has one end smoothly joined to the input end of the main tubular enclosure 31 and all of the branch enclosures extend from said input end in divergent curved directions far enough so that their other ends, 33 are in regions offset from the axis of the main tubular enclosure and are substantially spaced from one another.

Each of the branch enclosures 32 encloses in the region near to its end 33 an electron gun comprising a heater 34, an indirectly heated cathode 9, a control and/or accelerating grid 8, and a final accelerating electrode 35. Each electron gun 34 should be designed, as is possible in accordance with principles which are well known in the art, to produce a beam of electrons which emerges from the final accelerating electrode at a predetermined drift velocity and in a predetermined direction. Due to the electrostatic shielding effect of the various parts of the envelope 30, the individual electron guns are shielded from each other, and all of the drift spaces within the envelope 30, including those in its branch tubular enclosures 32 and that in its main tubular enclosure 31, are field-free so that once any group of electrons have left their gun it will tend to move with a constant average velocity. In other words, no added electrostatic acceleration is employed after the different beams of electrons leave their respective guns. For this reason in the operation of a tube of this kind the final accelerating electrode of each gun will usually be maintained at the same potential as the envelope 30 and the other gun elements will be at lower (less positive or more negative) potentials.

Preferably the final accelerating electrode 35 should contain an orifice for defining the cross-sectional shape of the beam. In the drawing each of these electrodes is shown as a thin conductive partition mounted transversely across the inside of its respective branch enclosure 32 between the end portion thereof which encloses all of the other gun elements and the remaining portion thereof which encloses a curved individual drift space to be followed by the beam after it emerges from the beam-defining orifice. To form a suitable beam defining orifice one may cut through the partition a thin slit the axis of which is perpendicular to the plane of the drawing so that the beam will assume the form of a thin sheet of electrons. Accordingly the line 36 by which each electron beam is represented in the drawing may be considered as the edge of the ribbon-shaped beam. The axis of each electron gun should be directed so that, in the absence of any magnetic influence, its beam, on emerging from the electrode 35, will tend to travel in the direction of a tangent to a particular point on a particular

curve, i. e., to a point in the center of the beam-defining orifice on a curve which may be determined according to the teachings of Coggs and Muskat *ut supra* and which according to the present invention defines the initial path along which the beam is intended to travel in order to reach the input of the common drift space. If the gun is so directed, then, under the influence of an appropriate magnetic field, each beam will begin to follow the intended curved path of travel immediately upon its emergence from the beam-defining orifice and its entry into the field-free space within the envelope 30.

If all of the beams were to travel at exactly the same velocity in the appropriate magnetic field and if that velocity were the correct one for producing trajectories as in Fig. 3, then each of the beams would approach very close to the tube axis (in the case of sheet-shaped beams, very close to a plane which includes the tube axis and is perpendicular to the plane of the drawing) and they would thus travel side by side in close proximity to one another over a considerable portion of the common drift space. Such proximity in combination with the intermingling of fringing electrons would at least partially satisfy the requirement as to intermingling which must be met if the beams are to interact to cause traveling-wave growth. However, another requirement must also be met, namely, the beams must travel at slightly different velocities. It is an advantage of a tube arranged according to the present invention that when steps are taken to satisfy the last-mentioned requirement, the first-mentioned requirement automatically becomes better satisfied. That is to say, it is possible to adjust the velocities of the beams to values slightly different from the correct ones for producing the exact trajectories shown in Fig. 3 so as simultaneously to improve intermixing, by causing the trajectories to coincide or cross over one another in their central regions, and to obtain the velocity differential which is needed for strong interaction.

In practice the beam velocities and currents ordinarily will be controlled by adjusting the magnitudes of negative potentials applied respectively to the different elements of the different guns while the final accelerating elements 35, the envelope 30, and the positive terminal of the source of direct potential are all at ground potential. Though certain theoretical considerations indicate that each of the electrodes 35 should always be exactly at the potential of the envelope 30, in practice it will often prove to be advantageous to establish a very small (adjustable) potential difference between them, such as a difference of one or two volts. For this reason and in order to provide an added control parameter, it may be advantageous to insulate each final accelerating electrode 35 from the inner walls of its branch tubular enclosure 32 and to provide a lead which extends from it through a vacuum seal to the outside of the envelope 30 to provide a terminal suitable for connection to an external circuit.

At the end 33 of each branch tubular enclosure 32 there is an insulating vacuum seal 37 through which leads may be fused for connecting the electron gun elements to external circuits including sources of potential.

A means is provided for impressing the input signal on each beam while it is still moving in the branch tubular enclosure 32 in which it originated. In the embodiment of Fig. 4 each of

these means consists of an input resonant cavity 38 which is connected between two portions of a respective branch tubular enclosure by vacuum-tight junctures which extend unbroken all around the peripheries of the grids 39 of the cavity, in a manner known in the art of velocity-modulated inductive-output tubes, so that the body of the cavity constitutes a part of the evacuated envelope of the tube.

Since the beam produced by the embodiment of Fig. 4 is sheet-shaped, the main tubular enclosure 31 and each of the branch tubular enclosures 32 should have a cross-section, such as an oval or rectangle, which has one transverse axis which is much longer than the other (the longer of the axes being disposed in a direction which is perpendicular out of the plane of the drawing) and each of the resonant cavities 38 should be appropriately formed to fit around such a branch enclosure. In other words, an outside view of one of the cavities taken from a position near one of the ends 33 should reveal it to have an oval or rectangular shape.

Each of the input cavities 38 is provided with an input coaxial line 40 the inner conductor of which may be inductively coupled to a portion of the space inside of the cavity, each coaxial line 40 has an electromagnetic-energy-permeable vacuum-tight bushing 41 sealed between its inner and outer conductors. To illustrate one way of using this type of tube the input lines are shown connected to an appropriate common external input circuit. The external input circuit, shown herein only by way of example, comprises a lead-in coaxial line 42, a T connector 43, by which energy supplied over the lead-in line 42 will be delivered to two branch lead-in lines 44, and two phase-and/or-magnitude controlling devices 45, each of which has an input connected to one of the branch lead-in lines 44 and an output connected to one of the input coaxial lines 40. This arrangement makes it possible individually to control with what magnitudes and/or phases the input signal will be applied to the different beams.

It is apparent that in a growing-wave tube according to this invention signal waves are impressed on all of the beams before they are intermixed as a result of which the signal waves will receive as much amplification in the common drift space as will noise waves.

At the output end of the main tubular enclosure 31 there is located an output resonant cavity 46 which, in a known manner, will extract energy from the waves of intermixed electrons which pass between its grids 47. The output cavity is provided with an output coaxial line 48 which has its inner conductor inductively coupled to the space inside of the cavity; has an electromagnetic-energy-permeable vacuum-tight bushing 49 sealed between its inner and outer conductors; and is provided with a connector fitting 50 by which a load may be connected to the tube. Beyond the output cavity 46, in the direction of electron travel, there is a collector 51 which is insulatively adjoined to the end of the main tubular enclosure 31 by a vacuum-tight seal 52.

The fullest utilization of the interaction between the intermixed beams, and therefore the maximum gain, will be attained by making the common drift space so long that the beams will start to be divergent in the region between the output cavity 46 and the collector 51. The divergence will not be objectionable even if it is

so large that the beams strike the inner walls of the collector 51, since, as a matter of fact, it is the function intended for this element that it intercept all of the electrons which have passed through the drift space so as to start them on their return (through the power supply) to the cathodes of the different electron guns. As is usual practice, the collector will be operated at a potential somewhat higher than that of the electrons, i. e., somewhat more positive than the tube envelope 30.

In the operation of this tube it is necessary for each beam of electrons to be magnetically influenced in order to cause it to follow a curved path until it reaches the input end of the common drift space and thereafter to follow an almost rectilinear path along the common drift space. To this end the entire envelope of this tube is fabricated of a non-magnetic material and, during its operation it is immersed into a magnetic field of the kind described by Cogshall and Muskat as causing charged particles to follow the trajectories shown in Fig. 3. A non-magnetic material is required, for example, copper, so that a steady-state magnetic flux can readily penetrate the envelope to traverse the drift spaces which it surrounds and so that it can do this without having the magnetic field configuration materially distorted.

An appropriate source of magnetic flux and an appropriate magnetic circuit may be designed according to any of a number of well-known principles by the use of electromagnets, as represented at 60 and 61, or permanent magnets, or combinations of both. In the drawing I have broadly indicated the directions of magnetic flux lines of the field into which the tube is immersed during its operation, i. e., by a symbol near to the reference character, MF_i (magnetic flux in), which indicates that on the upper side of the envelope, as shown in Figs. 4 and 5, the flux lines are normal to and downward into the plane of the drawing, and by a symbol near to the reference character, MF_o (magnetic flux out), which indicates that on the lower side of the envelope the flux lines are normal to and upward out of the plane of the drawing.

The magnetic field should be large enough so that all portions of the tube structure, including its branch enclosures 32, all the way back to their respective electron guns, can be fully immersed in it. In fact, its fringe portions should be located well beyond the ends of the tube so that exactly the desired magnetic flux distribution can be attained for all of the magnetic field into which the tube is immersed. The flux density of the portion of the field which passes through the tube envelope should be constant in each plane which is perpendicular to the plane of the drawing and extends in the Z-Y direction and it should be unequal in adjacent ones of said planes increasing progressively in moving in the Z-X direction. Since the flux lines are upward on one side of the envelope and downward on the other there will be a trough of zero flux in a plane, herein designated the axial plane of the tube, which is vertical to the plane of the drawing and extends along the central longitudinal axis of the tube.

As represented in Fig. 4, an appropriate magnetic flux source and circuit may comprise one long, flat core piece 62 or 63 placed on each side of the tube to extend somewhat beyond both ends thereof and to lie in a plane parallel to

the axial plane of the tube. Obviously to be thus positioned each core piece must be positioned at least as far away from said plane as the outermost protrusion (such as an electron gun lead) from the end 33 of the branch enclosure 32 which is on the same side of the tube axis. Windings, represented respectively at 64 and 65, are wound longitudinally around each core piece with each turn thereof substantially parallel to the plane of the drawing so that direct current excitation will induce magnetic lines of force which are perpendicular to the plane of the drawing. In order to make it possible to adjust the flux gradient between the center of the core piece and the above-mentioned trough of zero flux, any suitable mechanical means may be provided whereby the electro-magnet may be moved, as a whole, toward or away from the tube (while at the same time maintaining its above mentioned parallelism with the axial plane of the tube), and any suitable conventional means may be provided for varying the D. C. current through the magnet. In addition, if necessary the magnetic circuit may be made further adjustable by a trial-and-error procedure including inserting one at a time or in different combinations longitudinal laminations, not shown, which have different characteristics, such as different reluctance values and/or thicknesses, at different positions between the core pieces and parallel thereto to attain the desired field configuration.

The embodiment of Fig. 5 is in all respects similar to that of Fig. 4 with the exception that its two signal input devices and its one signal output device consist respectively of helices 53, 53 and 54, rather than of resonant cavities. As shown in Fig. 5, each of these helices may be connected in a conventional manner, i. e., one of its ends may be connected to the inner conductor of the input coaxial line which feeds it and the other may be connected to its outer conductor via a portion of the conductive inner surface of the envelope 30. As is known, each helix must be sufficiently spaced from the adjacent conductive inner wall of the envelope to avoid inductively short-circuiting any signal which it is carrying.

While the view of each of the helices which is afforded by Fig. 5 may cause its turns to seem circular, actually they are nearer to oval or rectangular in shape in order to provide a clear passageway for the sheet-like electron beam which it is intended to modulate. Obviously, however, this would not be necessary if the present invention were embodied in a tube using electron beams having narrow cross-sections, i. e., cross-sections not much wider than they are thick.

It is a common practice in the traveling wave tube art to employ strong axial magnetic fields for the purpose of compelling the beam electrons to move substantially rectilinearly along the drift space despite any influences, such as any initial radial velocity and/or the influence of the electron space charge of the beam, which tend to cause spreading of the beam and impingement of its electrons on the helix. Even though the present form of traveling wave tube does not include a helix, nevertheless uncontrolled spreading of any of the beams would be very undesirable if it could lead to impingement of electrons on inner wall 5 of the envelope 31. Obviously it is not permissible to use any axial magnetic field for controlling the electron flow as such a field would lose its identity by becoming combined with

the transverse field, which is used for producing the converging electron trajectories, and the two would be replaced by a single resultant field inappropriate either for producing such trajectories or for effecting rectilinear flow.

However, the arrangement which has been described herein will perform satisfactorily without the use of an axial magnetic field. This is due, on the one hand, to the fact that the transverse magnetic field will restrict the electrons from spreading in directions to thicken the sheet-like forms of their respective beams, i. e., in moving through the common drift space the electrons will tend to be confined within the trough of zero flux, and, on the other hand, to the fact that the magnitude of any spreading of the sheet-shaped beam in its width dimension will be relatively quite small since the rate at which spreading occurs is very small in terms of the transit time through the common drift space and since, unlike the helix in a single-beam growing-wave tube, the envelope does not have to be fitted closely around the beam.

While I have shown envelopes each of which comprises a main closure and a number of branch closures, to provide a common drift path and a number of individual drift paths, it would be entirely possible to form the envelope with only one large main closure which surrounds enough evacuated space to provide room for all of the different drift paths.

Likewise, the envelopes of tubes of this type need not necessarily be formed of metal but may be of glass. In such an embodiment a non-magnetic conductive coating could be applied to the envelope to serve as the electrostatic shield required to produce a field-free space inside the envelope.

It is obvious that a tube of the type shown in Fig. 4 will be operative over a narrower band of frequencies than that shown in Fig. 5. For this reason the embodiment of Fig. 4 might more often be preferred for use as a part of an oscillator, i. e., in an arrangement including a feedback line of suitable length connected between the output and the input. On the other hand, the embodiment of Fig. 5 is operable over an unusually wide band of frequencies so that on this account, and due to its great sensitivity and improved signal-to-noise ratio, it might often be preferred as an amplifier to be utilized over wide bands at super high frequencies.

While I have indicated the preferred embodiments of my invention of which I am now aware and have also indicated only certain specific applications for which my invention may be employed, it will be apparent that this invention is by no means limited to the exact forms illustrated or the uses indicated, but that in practicing it many variations may be made in the particular structures and the particular uses therefor which are disclosed herein without departing from the scope of my invention as set forth in the appended claims.

What is claimed is:

1. A growing-wave electron-beam tube comprising an evacuated envelope enclosing a number of electron guns in spaced relationship to each other and defining the boundaries of a space affording unobstructed paths including an elongated substantially rectilinear common drift path and a number of individual curved drift paths each of which extends between the beam output end of a respective one of said guns and the beam input end of the common drift path, each of said

electron guns being electrostatically shielded from the others, means providing electrostatic shielding around all of said paths, each of said guns being positioned so that its beam axis is tangential to the curved path extending between it and said common path, said envelope comprising portions which surround all of said paths and are made of non-magnetic material.

2. A plural-beam growing-wave tube comprising an envelope including a main enclosure surrounding a common drift path and a number of branch enclosures each surrounding an individual curved drift path which is convergent into said common drift path, an electron gun positioned in each of the branch enclosures to direct a beam of electrons tangentially toward a point on the curved drift path surrounded by the enclosure, in each of the branch enclosures means for modulating the beam of electrons, which traverses its curved path, at a point which is located between the respective electron gun for that branch enclosure and its point of juncture with said main enclosure.

3. A plural-beam growing-wave tube as in claim 2 and including an inductive output means near the opposite end of the main enclosure.

4. A plural-beam growing-wave tube comprising a substantially rectilinear main tubular enclosure, two branch tubular enclosures extending from an input end of the main enclosure to regions in spaced relationship to each other, an electron gun in each of the branch enclosures in one of said regions, an input resonant cavity connected between two portions of each branch enclosure by junctures so formed that the cavity and the branch enclosure comprise parts of the evacuated envelope of the tube, each input cavity being positioned in the branch enclosure between said region thereof where an electron gun is enclosed and the point of juncture thereof with the main enclosure, and an output resonant cavity connected to the main enclosure near to its opposite end by junctures similar to those above recited with reference to the connection of each input cavity into a branch enclosure.

5. A plural-beam growing-wave tube as in claim 4 which further comprises a collector adjoined to the end of the main enclosure beyond the location of the output cavity, the collector being adjoined to said opposite end by an insulating vacuum-tight seal, and electrostatic shielding means between the curved paths of the different beams.

6. A plural-beam growing-wave tube as in claim 5 in which each of said input cavities has an individual input coaxial line.

7. A plural-beam growing-wave tube comprising a substantially rectilinear main tubular enclosure and two curved branch tubular enclosures extending therefrom in opposite directions to regions which are spaced from one another, an electron gun supported in each of the branch enclosures in one of said regions, each electron gun being positioned with its axis tangential to a central axis of its respective branch enclosure.

8. An electron discharge device of the growing-wave type including an elongated envelope, a plurality of cathode means in spaced relationship to each other at one end thereof for directing a plurality of electron beams along predetermined paths, each of said paths being individual in a first portion thereof, which is near to a respective cathode, and common along a second portion thereof, a collector at the other end of said envelope and of said common portions of

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said paths, conductive non-magnetic shielding means surrounding all portions of all of said paths, a plurality of signal input means each mounted across the individual portion of the path of a different one of said beams for individually modulating that beam, and magnetic means mounted externally of said envelope to produce a magnetic field having a flux which is transverse to any of said paths, is non-uniform in accordance with a predetermined law in the regions along the individual first portion of each of the paths and has a trough of substantially zero density along the common second portions of said paths.

9. An electron discharge device as in claim 8 and including a signal output means located near to said other end of the envelope for extracting amplified signal energy from electron waves moving therein.

10. An electron discharge device comprising a plurality of spaced electron guns for producing respective electron beams in regions substantially separated from each other, output means at a greater distance from any of said guns than the distance between any two of them, deflection means consisting solely of magnetic means adjacent said guns for causing each of said beams to follow a curved path which merges with the path of each other beam and to extend along a common rectilinear path, said common path being of substantial length with respect to the separation between the guns and terminating near said output means.

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11. An electron discharge device comprising two spaced-apart electron guns for producing two beams along initially individual respective paths lying in a common plane, magnetic deflection means adjacent the guns for causing said individual paths to converge into a common rectilinear path of substantial length with respect to the spacing between said guns, said guns being immersed in the flux provided by said means and said flux extending at right angles to said plane in the regions of said individual and common paths and in the regions wherein said guns are immersed in it and output means near the end of said common rectilinear path.

12. An electron discharge device as in claim 10, further including non-magnetic conductive means electrostatically shielding said electron guns from each other and providing electrostatic shielding around all of said paths.

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