HIGH FREQUENCY ENERGY INTERCHANGE DEVICE


Filed Apr. 8, 1958, Ser. No. 727,072

8 Claims. (Cl. 315—3.5)

This invention relates to high frequency energy interchange devices which depend upon the interchange of energy between an electron stream and radio frequency field to generate or amplify radio frequency waves. More particularly, this invention relates to such devices which employ electric and magnetic fields in mutually crossed relationship to support interaction between the electron stream and radio frequency fields as utilized in the M-type traveling wave tubes (traveling wave magnetrons).

The particular type of traveling wave magnetron to which the present invention relates is referred to as the M-J type traveling wave tube and is described and claimed in the co-pending patent application Serial Number 722,404, filed March 19, 1958 in the name of Charles K. Birdsall and Ward A. Haukston and assigned to the assignee of the present invention.

Traveling wave magnetrons of the type under consideration include an evacuated envelope which encloses the operating elements of the device. The operating elements generally enclosed by the envelope include a means for producing and directing a stream of electrons along a predetermined path within the envelope and a transmission line for propagating radio frequency waves and producing electromagnetic waves in interacting relationship with the electron stream. The transmission line normally takes the form of a slow wave structure so that the electromagnetic waves propagated in the direction of the electron stream path has a velocity substantially less than the velocity of electromagnetic waves in free space. The region in which interaction takes place between the electron stream and electromagnetic waves is called an interaction region.

In the particular type of crossed field device under consideration, an electric field is produced which has lines of force substantially perpendicular to the path of the electron stream and which are in such a direction that they do not intercept the slow wave transmission line. A magnetic field is also produced in the device which magnetic field has lines of force perpendicular both to the direction of travel of the electron stream and the lines of force produced by the electric field. Although the operating frequency range of crossed field traveling wave tubes is extremely wide, it has been desirable to utilize slightly different designs for operation in the various frequency bands, and further, it has been necessary to design each individual tube type for the specific operation desired. For example, it has been preferable to utilize one design for forward wave amplification and another design to generate radio frequency waves or oscillations by what is known as the backward wave mode of operation. For these reasons it has been necessary to more or less custom build each device for its desired use. As a consequence, production of these traveling wave tubes has not lent itself to present day mass production techniques.

The principal design changes required to provide for operation in different frequency bands and for the different modes of operation generally may be made in the slow wave structures.

The slow wave transmission lines for the devices must be made of a material which can be used in a vacuum without spoiling the vacuum. For example, brass, which is an alloy of tin and copper, is not highly desirable for use in slow wave structures employed in a high vacuum since it may release gasses when subjected to the operating temperatures required of high frequency energy interchange devices.

A further problem is that it is often difficult to obtain impedance matches between the slow wave circuit and specific output circuitry since the slow wave structure is enclosed within the vacuum envelope it is difficult to adjust the match.

The custom built nature of the internal circuitry for energy interchange devices of the type under consideration presents the microwave circuit systems designer with the problem of either designing systems around the available tubes or having special tubes built to incorporate desired circuitry which generally must be expensive precision built circuitry. Since the circuitry is inside the tube envelope, it must be replaced with the tube. Obviously, the devices under consideration could be made much less expensive and much more versatile if the circuitry can be made external to the tube and interchangeable.

Accordingly, it is an object of the present invention to overcome these difficulties by providing a high frequency energy interchange device of the type described wherein the slow wave structure may be disposed outside the vacuum envelope.

It is a further object of this invention to provide a high frequency energy interchange device wherein various types of circuitry may be located and interchangeably used outside the envelope.

In carrying out the present invention, a high frequency energy interchange device is provided wherein an electromagnetic wave is produced in an interaction region within an evacuated envelope containing electric and magnetic fields which are perpendicular to each other and the axis of the interaction region. The electromagnetic wave is introduced into the region by means of circuitry which is external to the evacuated envelope. A stream of electrons is directed down the interaction region at an average velocity which is greater than the velocity of the component of electromagnetic waves propagating down the interaction region in the direction of flow of the electron stream whereby interaction takes place between the electron stream and the electromagnetic waves. The elements of the device are so oriented that movement of electrons in all dimensions within the interaction region contributes to the interaction process.

Although the high frequency energy interchange device of the present invention as shown and described is employed as a backward wave oscillator, it is to be particularly understood that it may also be employed in any one of a number of ways. For example, it may be used as an amplifier or a cascade amplifier or as an oscillator combination in a fashion analogous to the way that other mutually crossed electric and magnetic field type energy interchange devices are used.

The novel features which are believed to be characteristic of this invention are set forth in the appended claims.

The invention itself, together with its organization and method of operation together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings in which:

Figure 1 is a schematic exploded view of a model utilized in describing the operation of the present invention;
Figure 2 is an exploded view of a model illustrating a basic configuration of apparatus constructed in accordance with teachings of the present invention; Figure 4 is a side elevational view partly in section of a high frequency energy interchange device constructed in accordance with the present invention; Figure 5 is an enlarged cross sectional view of the device of Figure 1 taken along section lines 5-5 of Figure 4; Figure 6 is a partial isometric view of a slow wave circuit utilized in connection with the device of Figure 1; Figure 7 is an isometric view of an alternative circuit arrangement utilized with the device of Figure 1; and Figure 8 is an Isometric view of a different configuration of high frequency energy interchange device constructed in accordance with the teachings of the present invention.

The simplified model of the high frequency energy interchange device illustrated in Figure 1 shows the relative orientation of essential component parts of a high frequency energy interchange device of the type to which the present invention is directed. A sheet of electrons 10 is formed by a conventional electron gun 11 which includes an electron emissive cathode member 12 and two spaced apart electron stream forming and directing electrodes 13 and 14. The electron gun is designed to direct the stream of electrons through an interaction region between a pair of substantially planar rectangular plates or electrodes 15 and 16 of conducting material, which occupy spaced apart parallel planes. One of the electrodes, i.e., the upper electrode 15, is referred to as the collector since it serves to collect electrons from the stream 10 when the device is in operation and the lower electrode 16 is referred to as the sole or reference electrode. The region between the collector 15 and reference electrode 16 is called the interaction region due to the fact that it constitutes the region wherein an exchange of energy, or interaction, takes place between the electron stream and electromagnetic waves.

An electric field is established between the collector and sole plates 15 and 16 by providing a unidirectional potential difference between them. Usually, the sole plate 16 is placed at ground or reference potential and the collector 15 at some voltage which is positive with respect to the reference potential. Thus, an electric field is established between the two electrodes 15 and 16 which, according to conventional theory, has lines of force perpendicular to both electrodes and in the direction from the positive collector plate 15 toward the sole plate 16, as indicated by the arrow marked E in Figure 1.

It is well known that such an electric field E produces a force on electrons passing through which force is toward the collector plate 15. Therefore, if no other forces were present to act on the electrons in the electron stream 10, they would leave the cathode 12, enter the interaction region, and be deflected upward toward the collector plate 15. In the model shown, it is most desirable to provide an equilibrium condition whereby a sheet of electrons from the cathode 12 is directed down the interaction region without intercepting either the collector 15 or sole plate 16 unless a radio frequency electromagnetic wave is introduced in the interaction region. In order to produce such a condition, a magnetic field is established in the interaction region which has lines of force in a direction perpendicular to the electric field E and also perpendicular to the longitudinal axis of the interaction region of the structure.

The equilibrium condition for the electrons in the stream is provided by introducing a magnetic field with lines of force directed into the paper as indicated by the arrow B in Figure 1. Since an electron moving normal to a magnetic field experiences a force perpendicular to the field and also normal to the direction of motion in accordance with Fleming's right hand rule, the resultant force produced on an individual electron passing through such a magnetic field is such as to move the electron toward the sole plate 16. The magnitudes of the magnetic field B and the electric field E are preferably adjusted so that the force produced on electrons passing axially down the interaction region by each is precisely equal.

Since forces produced by the electric and magnetic fields E and B are normal to the surfaces of the collector and sole plates and equal and opposite in direction, electrons from the cathode member 12 may pass throughout the length of the interaction region without being deflected. Regardless of whether or not a radio frequency field is applied, the "crossed" electric and magnetic fields have the advantage of acting upon the electrons in the stream to offset the spreading effect of space charge.

The apparatus described thus far does not differ materially from the ordinary M-type traveling wave magnetrons. The principal difference between the structure of M-type traveling wave devices and the structure of the new type of interaction mechanism of the M-J interaction) may best be seen by reference to the apparatus illustrated in Figure 2. The model illustrated in Figure 2 is almost identical to that of Figure 1 but has two major components which are not present in the model of Figure 1. The first component, illustrated as being a rectangular plate or electrode 17, which may be a sheet of conductive material similar to the sole and collector plates 15 and 16. This plate 17, as illustrated, extends along the front side of the interaction region and occupies a plane perpendicular to the sole and collector plates 15 and 16. The second component which has been added is a transmission line 18 of the type generally referred to as a slow wave circuit. The slow wave circuit 18 illustrated consists of a substantially flat back plate 20 which extends along one side of the interaction region parallel to the conductive plate 17 and plurality of planar fins 21, which are spaced apart, are perpendicular to the flat back plate 20, and extend inwardly toward the interaction region. The slow wave structure utilized is not crucial to this invention and may for example be any one of a number of interdigital, periodically loaded, or helical type slow wave circuits. The particular slow wave structure illustrated is known as a single finned structure and is described and illustrated on pages 21 through 59 of the book, Traveling-Wave Tubes, by J. R. Pierce, Van Nostrand Co., Inc., New York (1920). The flat side plate 17 in combination with the slow wave circuit 18 may be considered as the radio frequency circuit. The unidirectional potentials applied to these circuit elements are discussed in detail subsequently.

Thus, the principal structural difference between the M-J energy interchange device and conventional traveling wave magnetrons is that the slow wave circuit of the traveling wave magnetron occupies the position of the collector 15 of Figures 1 and 2, and acts as the radio frequency circuit as well as the collector of electrons whereas the slow wave circuit 18 in the present device is displaced to one side of the interaction region so that it is in a plane perpendicular to the magnetic field and is not intercepted by electrons from the stream in any appreciable amount. The more important operating or functional difference is described more fully below.

When a radio frequency electromagnetic field is introduced into the interaction region by propagating a radio frequency wave along the slow wave structure 18, the equilibrium of the electron stream is disturbed and energy is imparted to the radio frequency wave by the electron stream. The mechanism by which energy is transferred from the electron stream to the radio frequency wave is considered below from two different standpoints in order to
develop an understanding of the best known theory of operation of the mechanism. First, the operation of the apparatus is considered in terms of groups of electrons in the electron stream and later the mechanism is explained in terms of individual electron trajectories or paths in the stream. When considering operation from the standpoint of collective groups of electrons in the electron streams, the gain mechanism may be considered as three separate but intimately related interactions. The combination of these interactions make up the new type of interaction. The separate interactions as discussed are as follows:

1. M-type interaction
2. O-type interaction
3. Transverse interaction (along the magnetic field lines B)

The first type of interaction is generally considered to be an M-type interaction because it is the interaction which occurs in M-type devices. Interaction results from absorption of potential energy from the unidirectional electric field by the electron stream as electrons in the stream are moved upward toward the collector in a transfer of a portion of the energy so gained to the radio frequency wave. This interaction depends upon movement of electrons from their initial position near the sole plate toward the collector plate in the vertical direction. The process does not abstract net kinetic energy from the stream and the stream remains focused. This type of interaction is most effective when the average electron velocity is equal to the axial component of the velocity of electromagnetic waves in the interaction region. The movement of the electron stream just described can be explained in terms of the forces produced by the crossed electric and magnetic fields E and B, respectively, in the interaction region. For example, the electrons in the electron stream are free to move in three dimensions or directions. They move longitudinally along the axis of the apparatus and electrons in the stream are either accelerated or decelerated by the radio frequency field depending upon their position with respect to this field and the equilibrium condition initially set up or produced by the crossed electric and magnetic fields B and E is upset. Since the force on electrons in a magnetic field is directly dependent upon their velocity, the force exerted on accelerated electrons by the electric field exerted by the magnetic field and the decelerated electrons move in the vertical direction from the sole 16 toward the collector plate 15 to a region of higher potential. Thus, the electrons absorb or gain potential energy from the unidirectional field E and deliver energy to the radio frequency field as they move toward the collector to the region of higher potential. As electrons move upward, their instantaneous velocity is increased so that they maintain their average axial velocity and capability of delivering energy as they travel down the interaction region until they intercept the collector 15.

Simultaneously with the electron movement described above, motion of electrons may also occur along the magnetic field B, that is, in a direction perpendicular to both the electric field and the longitudinal axis of the device but this movement or motion is not essential to the operation of the ordinary M-type device and, as far as is presently known, does not contribute materially to the transfer of energy between the electron stream and the collector or slow wave circuit of an M-type traveling wave tube.

The second type of interaction occurs as a result of redistribution of electrons in the stream in the axial direction. This type of interaction is commonly referred to as the O-type interaction since it is the principal interaction mechanism in the O-type traveling wave tube. This type of interaction is characterized by the fact that as the electrons in the electron stream move axially along the interaction region, the electrons in the stream are alternately accelerated and decelerated in such a manner that bunches of electrons are formed. These electron bunches move along the stream 10 at an average velocity equal to that of the stream as determined by the accelerating voltage. If the energy transfer in the electron stream exceeds that of the electromagnetic waves propagated down the interaction region, the radio frequency field abstracts more energy from the electron stream than it gives up to the electron stream. Thus, the radio frequency wave on the slow wave circuit 18 grows as it travels down the interaction region.

The third type of interaction involves an exchange of energy due to movement of electrons in a direction which is normal or transverse to both the direction of movement of the stream (along the interaction region) and the lines of force of the electric field E. In other words, this type of interaction depends upon movement of electrons in the direction of the lines of force of the magnetic field B. Further, if the net energy transfer in this type of interaction is to be from the electron stream to the electromagnetic wave, the electrons in the stream should be moving down the interaction region at an average velocity which is greater than that of the axial component of the electromagnetic wave.

When the electron stream 10 is injected into the interaction region in the presence of a radio frequency wave and near the sole 16, it is deflected toward the collector by the slow wave circuit 18 and toward the collector 15 by the radio frequency field. Thus, the entire electron stream 10 has a stepped and snaking appearance as it moves from side to side and rises in the interaction region. The orientation of the electric and magnetic field E and B is such that the electron stream is near the slow wave circuit 18 when the radio frequency field introduced into the region is of a phase to abstract energy and away from the slow wave circuit 18 when the fields are of a phase to abstract energy from the electron stream. Since the radio frequency field is greatest near the circuit and diminishes very rapidly (exponentially) with distance from the circuit, the stream 10 gives up more energy to the radio frequency field than it receives therefrom. This aspect of interaction is aided by the fact that the relative velocities of the electrons and electromagnetic waves is such that the electrons are in a bunched condition when near the slow wave circuit 18.

From the foregoing discussion it is seen that the new interaction is similar to both the O-type and M-type interaction in some respects but differs from each. The interaction mechanism is similar to that of the travelling wave tube in that the electrons in the stream drift toward a collector plate to a region of higher potential, maintaining their drift velocity and capability of delivering energy until collected on the collector 15. The interaction mechanism of the device of the present invention is similar to the O-type interaction in that the electrons in the stream are bunched by the radio frequency fields and the electrons must have a velocity which is greater than that of the axial component of the electromagnetic waves in the interaction region, if the conditions described above are to be met. However, the mechanism is different from both of these interaction mechanisms due to the fact that it depends upon movement of the electrons in the stream toward and away from the slow wave circuit 18 to cause the radio frequency electromagnetic waves to grow.

When the electrons are injected into the interaction region at a velocity equal to the axial component of the velocity of propagation of the electromagnetic waves through the interaction region (called the synchronous velocity), there is substantially no energy exchanged between the electromagnetic waves and the electron stream for the model illustrated in the figures thus far described. At least, there are no second order effects. In practice some energy interchange does take place and when the configuration of the tube is changed or altered if the cir-
cuit shape is altered, some energy interchange also takes place.

When electrons in the stream move down the interaction region at a velocity less than the velocity of propagation of the electromagnetic waves, the electrons tend to move toward the sole 17 and take energy from the radio frequency wave so that the wave diminishes in amplitude along the length of the interaction region. At velocities much above or below synchronization there can be little or no stream deflection toward or away from the slow wave circuit 18.

Figure 3 illustrates the relationship of the output or gain of the energy interchange apparatus as a function of the velocity of the electron stream $v_{e}$ (usually expressed in volts). In this figure the velocity $v_{e}$ of the electron stream 10 is plotted along the axis of ordinates and the power output of the device is plotted along the axis of the abscissas. The broken line labeled Cold Level shows the power output when there is no electron stream in the device. The vertical axis marked $v_{s}$ indicates the synchronous velocity of the stream. That is, velocity $v_{s}$ is the stream velocity which is equal to the velocity of propagation of the axial component of the electromagnetic waves so that for this condition there is no appreciable increase in power output over the cold level.

As indicated in the description above, the figure shows that with electrons in the stream moving at velocities below synchronous velocity $v_{s}$, the output power is actually less than the cold level, and above synchronism the output power is greater than the cold level power.

A preferred embodiment of a plane or linear structure constructed in accordance with the present invention is illustrated in Figures 4, 5 and 6. The structure includes a closed and evacuated envelope or tube 23, which encloses various of the electrode elements. The electrode elements enclosed within the vacuum envelope 23 correspond in function and general orientation to those elements illustrated and described in connection with Figure 1 of the drawings. As a consequence, corresponding elements in the two drawings are given the same reference numerals to simplify both the drawings and the description.

In order to form and direct a stream of electrons down the longitudinal axis of the envelope 23, an electron gun 11 is positioned inside one end of the evacuated envelope. The electron gun 11 may be any one of a number of conventional type guns but the particular one illustrated includes an electron emissive cathode member 12 of the button type and a filamentary heater element 25 connected to a source of potential (not shown). The cathode member 12 is of the button type and comprises a disc shaped end member with a cylindrical skirt which extends downwardly and surrounds the heater member 25. The cathode 12 is supported by means of a supporting conductor 27 which extends through the wall of the envelope 25 and serves the dual purpose of supporting the cathode in position and providing a means of establishing the potential of the cathode member. The heater member 25 is also provided with support members 28 which extend out through the envelope 23. When the heater conducting support 28 is connected to a potential source, the electron emissive cathode member 24 is heated and emits a cloud of electrons.

The electron gun 11 is provided with two planar sheet-like conductive deflecting electrodes 13 and 14 which form the cloud of electrons emitted by the cathode 12 into a stream 10 and direct the stream down the length of the evacuated envelope 23. In order to accomplish this result, the electrodes 13 and 14 are spaced apart, positioned parallel to each other and to one side of the cathode 12 such a manner that the lower electrode 13 is approximately co-planar with the upper face of the cathode button 12 and the upper electrode extends out above the cathode. The deflecting electrodes 13 and 14 are held in position by conductive support members 30 and 31, respectively, which are brought out through the wall of the evacuated envelope 23. As illustrated, the supporting condutor 30 for the lower deflecting electrode 13 is connected to the cathode support 25. Thus, both the lower deflecting electrode 13 and the cathode 12 are established at the same potential (ground).

The stream of potential and deflecting potential is applied to the stream forming and directing electrode 14 by means of a source of unidirectional potential 24 which is connected to conductive support 31 in such a manner that the upper deflecting electrode 14 is positive with respect to both the lower deflecting electrode 13 and the cathode member 12.

In addition to the electron gun 11, the evacuated envelope 23 encloses a substantially planar rectangular collector electrode 15 and the sole plate or reference electrode 16 which is also a planar rectangular conductive plate. As described in connection with Figure 1, these two electrodes are spaced apart and occupy substantially parallel planes in order to provide a means for establishing an electric field in the interaction region enclosed between the two plates. The upper or collector electrode 15 is shown in the device of Figure 4 as having an end portion 15a at the opposite end of the tube from the electron gun 11 which extends down toward the sole plate 16 in order to collect any electrons which are not collected on the upper portion of the plate 15. An electric field is established between the collector 15 and the sole plate 16 as indicated by the arrow labeled E in Figures 4 and 5 by connecting the collector plate 15 to the positive terminal of a unidirectional potential source 43 and the sole plate 16 to ground or reference potential by means of conductive leads 33 and 34, respectively, which extend through the wall of the envelope 23. The conductive leads 33 and 34 also serve to support the collector and sole plate 15 and 16 in position. Other support means may also be employed in lieu of or in conjunction with the supporting leads 33 and 34 but such supports are not illustrated since they do not constitute a part of the present invention.

Magnetic lines of force are established in the interaction region between the collector and sole plates 15 and 16 as indicated by the arrows labeled B. This magnetic field is established by providing pole pieces N and S (best seen in Figure 5 of the drawings). With the exception of the pole pieces N and S, all of the apparatus described thus far is enclosed within the envelope 23. However, it is noted that the magnetic field strength B may be adjusted in such a manner that the stream of electrons travels directly down the interaction region as described in connection with Figure 1. In other words, the electric and magnetic field strengths may be adjusted externally of the evacuated envelope 23 to provide a balance of forces on electrons in the stream at any electron stream velocity as described in connection with the description of Figure 1.

In order to introduce radio frequency electromagnetic waves into the interaction region, a radio frequency circuit or the slow wave transmission line 35 is provided outside of the envelope 23. The radio frequency circuit may take any form desired and may be removed and replaced with other circuitry without disturbing the elements inside the evacuated enclosure 23. For example, as illustrated in Figure 4, a slow wave structure 35 which corresponds to the slow wave transmission line 18 of Figure 2, virtually encircles the vacuum envelope 23 and the entire interaction region. As may best be seen in the enlarged isometric view of Figure 6, the slow wave structure 35 includes a pair of substantially identical circuit members 36 and 37 of U-shaped cross section which are adapted to be fitted
around the outer periphery of the envelope 23. The leg portions of the U-shaped sections 36 and 37 include a plurality of finger or tooth-like extensions 38 and 39 respectively. The two sections are allochotically positioned opposite sides of the envelope 23 in such a manner that the fingers or teeth 38 and 39 of the two sections are inter-leaved or meshed with one another along the length of the envelope 23. Further, the inter-leaved interdigital structure so provided is positioned in such a manner that it extends along the sides of the envelope 23 in planes substantially perpendicular to the planes of the collector and sole plates 15 and 16. In this manner the conditions for M-J interaction previously described are fulfilled.

The particular interdigital type structure illustrated is well known in the art and does not constitute a part of the present invention. The slow wave circuit may be selected to obtain the particular characteristic desired since the slow wave circuit is external to the vacuum envelope 23 and may readily be exchanged with other slow wave structures or adjusted.

Radio frequency energy is coupled onto and off of the slow wave transmission line 35 by well known input coupling and output coupling means which input and output coupling means are not shown. The particular coupling means and transmission lines may be conventional coaxial cables, wave guides, or any conventional devices suitable for transmitting a high frequency energy.

However, it should be noted that one of the difficult problems in coupling radio frequency energy onto and off of a slow wave transmission line in a high frequency energy interchange device is obtaining an impedance match between the external transmission line and the internal slow wave structure. This difficulty is circumvented to a large extent in the apparatus illustrated and described herein since the impedance match is made entirely outside the evacuated envelope 23.

Thus it is seen that the components of the device illustrated in Figures 4 and 5 correspond to components illustrated in Figure 2 and further that the components are oriented in the same relative relationship. As a consequence, the apparatus illustrated in Figures 4 and 5 operates in substantially the same manner as described with respect to the apparatus of Figure 2. In other words, the electron stream is directed down the interaction region and an energy transfer takes place between electrons in the stream and radio frequency waves on the slow wave structure 35. As energy is abstracted from electrons in the stream 10, the electrons move to the collector 15 while the electrons are collected on the collector 15. Further, the electron stream snakes from side to side as it moves down the interaction region so that a judicious selection of phase relationships and phase velocities enhances operation of the device in the manner described in connection with Figure 2.

Since the radio frequency fields developed by the slow wave structure 35 decay away from the structure exponentially as a function of the distance, the slow wave structure 35 is preferably disposed as close as possible to the envelope 23. This reduces the distance between the slow wave structure and the electron stream 10 and thus maximizes the radio frequency fields in the region of the stream. The net result is that electromagnetic waves interact most effectively with the electron stream 10. The dielectric material of the envelope 23 causes a considerable effect of the radio frequency circuit. As a consequence, the envelope is preferably constructed of a relatively thin dielectric material such as glass in order to prevent an excessive decrease in the effective impedance of the longitudinal radio frequency field as encountered by the electron stream 10.

With the arrangement illustrated, the slow wave structure 35 essentially straddles the electron stream, therefore there is considerable freedom in locating the path of the stream. This is true since the net field at any point in the interaction is the sum of two fields which decay exponentially as a function of distance from the circuit. Thus, the net tendency is to hold the total field strength up in the center of the device and the collector 15 becomes a larger cylinder occupying a plane parallel to the inner cylinder, but offset therefrom by substantially the same spacing as illustrated in the linear model.

In some instances the radio frequency fields introduced by the slow wave structure may be reduced due to induced currents in the collector and sole plate 15 and 16 by transformer action between the slow wave structure and these plates. In such instances the collector anode 15 and the reference electrode 16 may be constructed of a series of fine wires occupying substantially the same planes as the plates 15 and 16 illustrated. This construction tends to prevent shorting of the longitudinal radio frequency fields.

Also, it may be desirable in particular instances, as it was in the high frequency energy interchange device illustrated in Figures 4 and 5, to provide some means to maintain a constant average or unidirectional potential in the envelope 23 and to prevent undesirable surface charge on the envelope 23. In the device illustrated, this was done by providing a coating 29 of resistive material (e.g., carbon suspension) along the interior of the envelope 23. An alternative method of accomplishing the same result is to provide a series of fine non-magnetic wires on the interior of the envelope 23 in a transverse relation to the longitudinal radio frequency field. Such a potential difference may be applied across the coating to shape the electric field distribution in the envelope. The potential of the coating is established by electrical connections which are not shown. It is to be particularly understood that these and many other changes in the specific configuration and structure of elements of the device may be made without departing from the spirit of the present invention.

In order to illustrate another type of slow wave circuit which may be used in connection with the evacuated envelope 23, the slow wave structure 35 has been replaced in the illustration of Figure 7 by a helical slow wave circuit 40 disposed adjacent to one side of the envelope 23. The helix 40 is preferably constructed in such a manner that a substantial portion of the helix can be positioned flush against one side of the envelope 23. This arrangement provides the most effective interaction with the electron stream for the same reasons as discussed in connection with the circuit 35 illustrated in Figures 4, 5 and 6. It is to be particularly noted that the helix 40 is positioned along the side of the envelope which is substantially perpendicular to the path of the collector anode 15 and reference electrode 16 and thus the interaction mechanism is again of the M-J type. It may be well to note that interaction may also be obtained by winding a helix directly around the outer periphery of the envelope 23.

The devices illustrated thus far are "plane" or linear type structures but it should be obvious that the models illustrated may be wrapped up into a cylindrical configuration without departing from the spirit of the present invention. The article "Magnetron-Type Traveling Wave Tube" by Warnecke, Kleen, LeFos, Dolher and Huber which appears in the May 1950 issue of the Proceedings of the I.R.E., starting at page 486, describes both the plane and cylindrical structures.

Figure 8 illustrates a wrapped up or circular configuration which may best be described by referring again to the models illustrated in Figures 1 and 4. The device illustrated in Figure 8 may be said to be formed by surrounding the apparatus of Figures 1 and 4 around the sole plate 16 with the collector anode 14 outside. In other words, bending the device in such a manner that the sole plate 16 becomes a small cylinder in the center of the device and the collector 15 becomes a larger cylinder occupying a plane parallel to the inner cylinder, but offset therefrom by substantially the same spacing as illustrated in the linear model.
The electron gun 11 is again positioned adjacent the end of the sole plate 16 in such a manner as to direct a stream of electrons down the interaction region between the sole and collector plates 16 and 15. The electron gun 11 and collector and sole plates are enclosed within a toroid shaped evacuated envelope 39 which envelope preferably has the attributes discussed in connection with the envelope of the device illustrated in Figures 4 and 5. Obviously the envelope 39 may take any convenient shape. Once again the electric field E is developed in the interaction region between the collector anode 15 and the sole plate 16 by establishing a potential difference between these two plates or electrodes. A magnetic field B is provided by placing substantially flat magnetic pole pieces N and S having circular peripheries at opposite ends of the cylindrical device. As illustrated, electromagnetic waves are introduced in the interaction region by radio frequency slow wave circuits at both ends of the cylindrical device and between the magnet 40 pole pieces N and S and the evacuated envelope 39.

While the configuration of the device of Figure 8 is considerably different from the apparatus of Figures 2, 4 and 5, it is clearly seen that the components and general orientation of the components of the devices are essentially the same. Consequently, it is seen that the principles of operation of these devices are the same.

While particular embodiments of the invention have been shown, it will, of course, be understood that the invention is not limited to the embodiments since many modifications both in the circuit arrangements and in the instrumentalities employed may be made.

What we claim is new and desire to secure by Letters Patent of the United States is:

1. In a high frequency energy interchange device for producing amplification and oscillation in the microwave frequency spectrum, a first pair of spaced apart and parallel conductive electrodes defining an interaction region therebetween, means to establish an electric field in said interaction region having lines of force substantially normal to said electrodes, electron gun means for producing and directing a stream of electron down the interaction region between said first pair of spaced apart electrodes, an evacuated envelope enclosing said first pair of electrodes and said electron gun, circuit means disposed outside said evacuated envelope on opposite sides of said interaction region and extending substantially the full length of the interaction region, said circuit means including at least one radio frequency slow wave transmission line for propagating electromagnetic waves down said interaction region, and means to produce a magnetic field in said interaction region having lines of force perpendicular to the lines of force of said electric field and transverse to said slow wave transmission line.

2. A high frequency energy interchange device of the traveling wave type for ultra high frequencies including the combination of a pair of spaced apart parallel conducting surfaces in substantially coaxial relationship defining an interaction region therebetween, means for impressing a unidirectional electromagnetic force between said surfaces thereby to produce an electric field in said interaction region having lines of force normal to said surfaces, electron gun means for emitting and directing electrons along said interaction region perpendicular to said lines of force of said electric field, means for producing a magnetic field in said interaction region of such a magnitude and sense as to cause electrons from said stream to travel down the length of said interaction region, an evacuated envelope enclosing said pair of parallel conducting surfaces and said electron gun means, and a circuit means disposed outside said envelope and having conducting surfaces at least on opposite sides of said interaction region whereby electromagnetic waves are propagated down said interaction region in response to radio frequency waves on said circuit means.

3. Apparatus for providing an interchange of energy between an electron stream and electromagnetic waves in an interaction region including a first pair of substantially parallel conductive electrodes defining an interaction region therebetween, electron gun means for producing and directing a stream of electrons down said interaction region, an evacuated vacuum tight envelope surrounding said parallel electrodes and said electron gun means, a slow wave transmission line disposed adjacent to at least one side of said interaction region between said pair of electrodes and externally of said envelope in energy interchange relation with the electron stream, conductive leads extending into said envelope and connected to said electron gun means and said pair of electrodes whereby the accelerating potential may be established for said electron gun means and a potential difference may be established between said pair of parallel electrodes thereby to establish an electric field in the interaction region having lines of force normal to said electrodes.

4. Apparatus for providing an interchange of energy between an electron stream and electromagnetic waves in an interaction region including a first pair of substantially planar conductive electrodes spaced apart in parallel relation to define an electron interaction region therebetween, electron gun means for producing and directing a stream of electrons down the length of the interaction region between said parallel electrodes, an evacuated vacuum tight envelope enclosing only said electrodes and said electron gun means, an elongated slow wave transmission line disposed adjacent to at least one side of said interaction region between said pair of electrodes and external to said envelope in energy interchange relation with the electron stream, and conductive leads brought out through said evacuated envelope from said electron gun means and said parallel electrodes whereby an accelerating potential may be established on said electron gun means and an electric field may be established in said interaction region having lines of force normal to said electrodes.

5. In a cartridge type electron tube for providing an interchange between an electron stream and electromagnetic waves in an interaction region, at least a pair of electrodes having the configuration of right circular cylinders, said electrodes being spaced apart in parallel relation to define an interaction region therebetween, an electron electron gun means for producing and directing a stream of electrons along the interaction region between said electrodes, and a cylindrical evacuated vacuum tight envelope surrounding said electrodes and said electron gun means, a radio frequency slow wave transmission line disposed adjacent to at least one side of said interaction region between said pair of electrodes and external to said envelope and in energy interchange relation with the electron stream, conductive leads connected to said electron gun means and to said parallel electrodes the conductive leads being brought out through said evacuated envelope whereby an electron accelerating potential may be established on said electron gun means and a unidirectional potential may be established between said electrodes whereby an electric field is established in said interaction region having lines of force normal to the surfaces of said electrodes.

6. A high frequency energy interchange device of the type which depends upon an interchange of energy between an electron stream and electromagnetic waves in a region of mutually perpendicular electric and magnetic fields comprising a reference electrode, an electron collector electrode in spaced parallel relation to said reference electrode, electron gun means and a radio frequency slow wave transmission line structure, said slow wave structure, said reference electrode and said electron collector electrode being of approximately equal length and disposed to define an interaction space therebetween for accommodating electromagnetic waves propagated by
said slow wave structure, said electron gun means being positioned to form and direct a stream of electrons down the interaction region between said electrodes and said slow wave structure, an evacuated envelope surrounding and enclosing said electron gun means and said reference and collector electrodes and having its walls interposed between said interaction region and said slow wave transmission line structure, means providing a magnetic field having lines of force in a direction parallel to the plane of said collector electrode and transverse to said slow wave transmission line structure, separate input electrical conductors connected to said collector electrode and said reference to establish the potential of said electrodes at different levels thereby to produce an electric field having lines of force extending between said electrodes and substantially perpendicular to the path of said electron beam and to the lines of force of said magnetic field.

7. In combination in a high frequency energy interchange device which depends upon an interchange of energy between an electron stream and electromagnetic waves to produce amplification and oscillation in the microwave frequency spectrum, electron gun means providing a stream of electrons, a conductive reference electrode and a conductive collector electrode disposed in substantially parallel relationship to accommodate the stream of electrons from said electron gun means, an evacuated vacuum tight envelope surrounding said electron gun means and said reference and collector electrodes, a radio frequency slow wave transmission line structure disposed to surround said evacuated envelope and propagate electromagnetic waves in the region between said reference and collector electrodes, conductor means connected to said reference and electron collector electrodes for establishing a potential difference therebetween whereby an electric field is established between said electrodes, and means for providing a magnetic field having lines of force extending substantially perpendicular to said lines of force of said electric field and transversely through a substantial portion of said slow wave structure.

8. A high frequency energy interchange device of the type which depends upon an interchange of energy between an electron stream and electromagnetic waves in a region of mutually perpendicular electric and magnetic fields including a reference electrode having the configuration of a right circular cylinder, a collector anode of the same general configuration disposed in concentric relation with respect to said reference electrode, electron gun means for producing and directing a stream of electrons along a substantially circular path between said two electrodes, an evacuated envelope having substantially the configuration of a right circular cylinder with closed planar ends surrounding said electron gun means and said electrodes, a slow wave transmission line structure disposed at least at one end of said evacuated envelope and having the configuration of a circle, means for establishing an electric field having lines of force extending between said reference electrode and said collector electrode, and means for providing a magnetic field having lines of force extending parallel to the axis of said cylindrical envelope.

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