

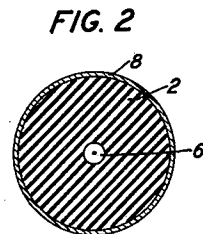
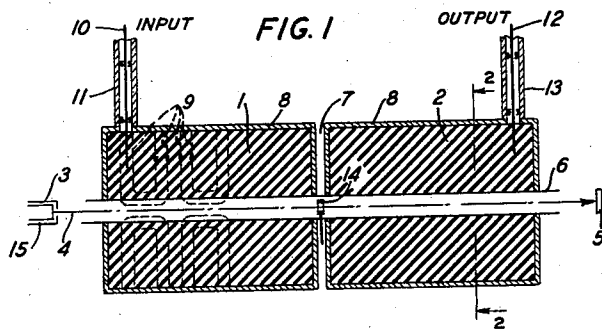
Jan. 16, 1945.

F. B. LLEWELLYN
ELECTRON DISCHARGE DEVICE

Filed May 17, 1940

2,367,295

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

FIG. 3

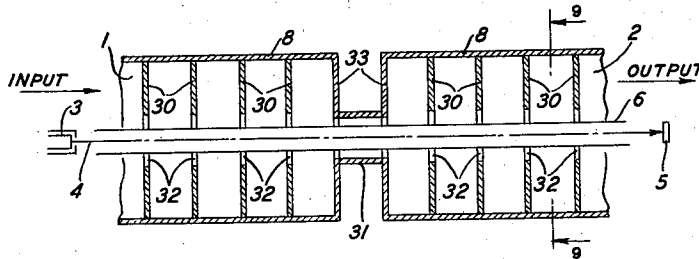


FIG. 4

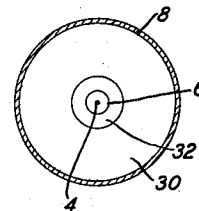


FIG. 5

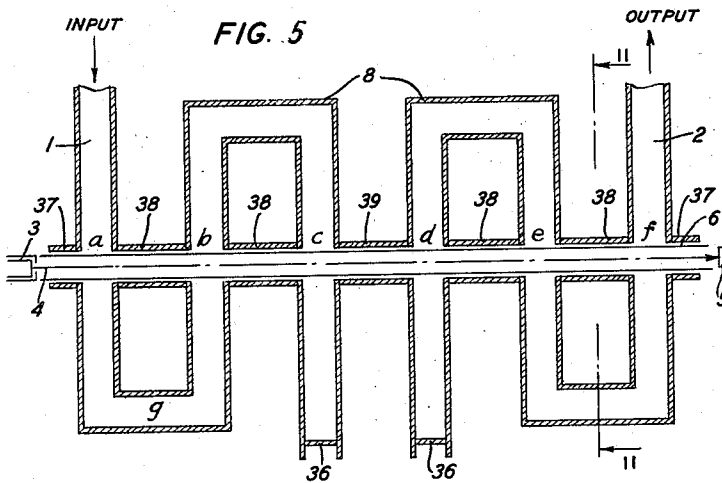


FIG. 6

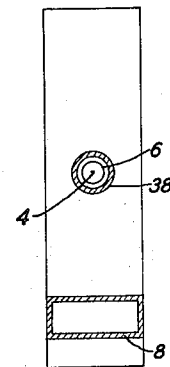


FIG. 7

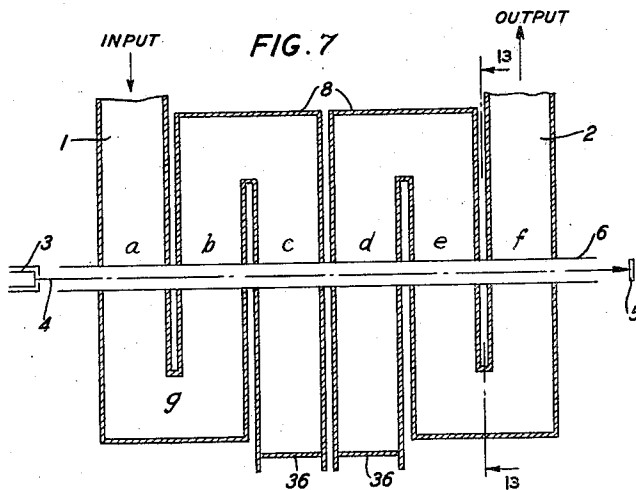
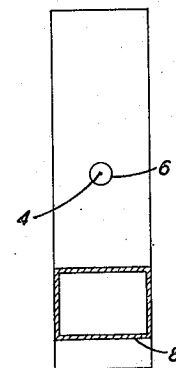


FIG. 8



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3 Sheets-Sheet 3

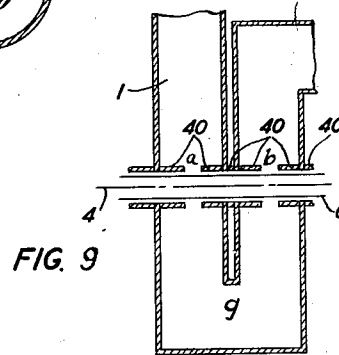
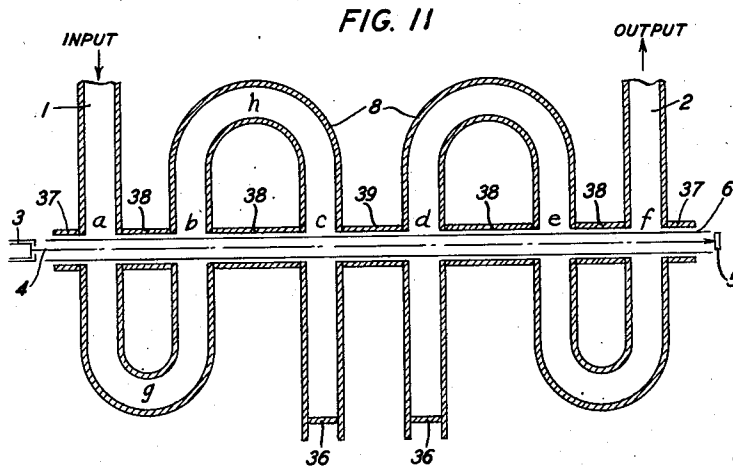
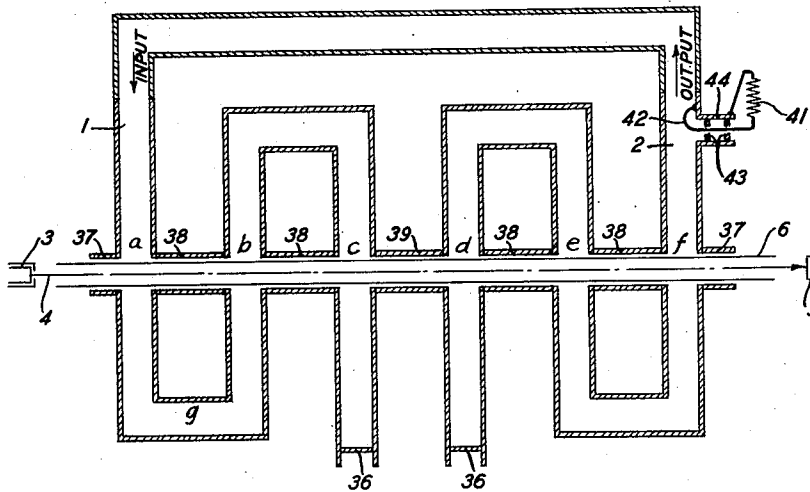


FIG. 10



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ELECTRON DISCHARGE DEVICE

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Application May 17, 1940, Serial No. 335,660

22 Claims. (Cl. 178-44)

This invention relates to resonant wave guide circuits employing electron discharge apparatus for amplification and oscillation production.

A general object of the invention is to secure a useful cooperative relation between the alternating electric field within the guide and electrons traversing that field. The relation may be either such that energy is delivered by the moving electrons to the electric field or such that the field exerts forces to control the moving electrons for the purpose of producing amplified oscillations corresponding to those producing the controlling field.

In one embodiment the electron path follows that of the electric wave in the guide and the wave-length of the electric field is made to be so related to the electron velocity that the electrons traverse a half wave-length in the guide in a half cycle and may therefore be subjected to similar retarding or accelerating forces continuously over a whole or several wave-lengths in the guide. In another embodiment, the wave guide is made to follow a path which is coincident with the electron path only at desired consecutive points of interaction where the electrons are caused to traverse the electric field in the guide, the distance between these points of interaction being greater through the guide than along the electron path so relating the wave propagation time and the electron transit time that the electrons remain in substantially the same phase in successive transits of the field in the guide.

The various objects and features of the invention will be more fully understood from the following detailed description of the illustrative embodiments shown in the accompanying drawings.

In the drawings:

Fig. 1 shows the use in a resonant wave guide of material with a high dielectric constant for the purpose of keeping the velocity of wave propagation sufficiently low to be comparable with the velocity of an electron stream from which high frequency energy is to be derived;

Fig. 2 shows a transverse section of one of the wave guide portions of Fig. 1;

Fig. 3 shows the use of apertured conducting baffles each partially closing the wave guide for the purpose of reducing the velocity of wave propagation and the physical length required for a given number of wave-lengths of field within the guide;

Fig. 4 shows a transverse section of Fig. 3;

Fig. 5 shows a folded wave guide with a stream

of electrons directed to pass through it transversely at a number of consecutive points such that an electron encounters the same field phase condition at each point;

Fig. 6 shows a transverse section of Fig. 5;

Fig. 7 shows a variation of Fig. 5 wherein the folds of wave guide are very close together;

Fig. 8 shows a transverse section of Fig. 7;

Fig. 9 shows a method of improving the structure of Fig. 7 by adding shielding for portions of the electron path;

Fig. 10 shows a modification of Fig. 5, which is applicable also to Fig. 1, Fig. 3 and Fig. 7, to permit self-oscillation in the circuits; and

Fig. 11 shows a variation of the structure of Fig. 5 and, in addition, a means of compensating for changes in the average velocity of the electron stream.

In Fig. 1 and Fig. 2 are shown an amplifier arrangement using two portions of resonant wave guide, 1 and 2, in which the dielectric is a material having a high dielectric constant. The purpose of employing material with a high dielectric constant, rather than air for instance, is to obtain a relatively low velocity of wave propagation through the guide so that the standing wave pattern produced by the electromagnetic field within the guide may have a wave-length sufficiently short that electrons can be made to travel with sufficient velocity to traverse a half wave-length during the period of one-half cycle, thus matching the phase velocity of the wave and maintaining their phase relations to the field for a number of cycles to obtain a cumulative effect. In Fig. 1 the portions of wave guide are shown as axial sections and transmission is assumed to be from left to right. The guides may be of any desired shape in cross-section though here a cylindrical shape is assumed as indicated by the cross-sectional view, Fig. 2. Guide portion 1 serves as the input circuit of the amplifier. It is assumed to be energized from the coaxial line 10, 11 coupled as shown at the left of Fig. 1 and to have a field in which the electric lines of force are as indicated at 9, having a component parallel to the axis of the guide and to the electron stream 4 which is projected through a glass enclosed tubular space 6 from cathode 3 along the axis to collector 5. The type of wave, described as type E₀ in an article by G. C. Southworth in the Bell System Technical Journal, vol. XV, pages 284-309, April 1936, producing this form of electric field may be produced in a wave guide, such as 2, by a stream of electrons moving along the

axis in groups. Guide portion 2 serves as the output circuit of the amplifier and is shown coupled to the output coaxial line 12, 13 at the right of Fig. 1. As indicated above, the electric field produced in 2 is similar to that in 1 where the direction of the electric lines of force is shown at 9. The electron stream 4 is projected through the two wave guide portions 1 and 2 from cathode 3 to collector 5. Practically the electron path in the guide portions may be as long as desired within the capabilities of the electron projecting means though extreme length may introduce undesirable phase changes, as will be referred to later. As the electron projecting means, any electron gun structure which will produce an electron stream of the desired current strength and velocity may be employed. Since such electron gun structures are generally well known, complete details of the gun and its power supply circuits are not shown either on this drawing or on the similar drawings which follow in order to avoid unnecessary complication. The evacuated tubular chamber 6 of the gun carrying the electron stream through the guide portions may be of glass but it should be of as small diameter as possible and should fit closely the hole in the dielectric of the guide portions through which it passes. The dielectric material of the guide is preferably covered on the outer surface with conducting material 8 to decrease radiation.

In operation, the stream of electrons 4 from cathode 3 may be velocity modulated and the electrons grouped in passing through wave guide portion 1. Electrons entering 1 during one phase of the field are accelerated while those entering during the opposite phase are retarded. These effects are cumulative over several cycles throughout the several wave-lengths travel of the electrons through the guide portion by virtue of the fact that the average electron velocity has been adjusted to correspond with the velocity of the wave through the guide so that an electron encounters approximately the same field phase condition throughout the length of the guide portion. As indicated previously, this coordination is facilitated by the use of the high dielectric constant material which by decreasing the velocity of wave propagation through the guide, decreases the required electron velocity. The space 7 between 1 and 2 may be provided or not, as desired. Its purpose when used is to provide a drift space to permit additional grouping of the electrons leaving 1. In passing through 1, and 7 if provided, the accelerated electrons tend to overtake preceding retarded electrons so that there occurs a grouping of them and the resulting cyclic variation in electron density constitutes density modulation of the electron stream in accordance with the input wave which excites 1. The density modulated electron stream in passing through 2 reacts upon the electric field therein to deliver energy to it. The electrons lose velocity in this process and are then collected at 5. The energy transferred from the electron stream to the electric field in 2 is in accord with the input to guide portion 1 representing therefore an amplification of it.

It may be noted here that if the changes in the average electron velocity, due to the transfer of energy to the field in guide portion 2 and to the absorption of energy from the field in guide portion 1, should be large, because of the force of interactions or because long electron paths in the guide portions permit long period

of interaction, there would be a tendency for the electrons to lose synchronism with the fields in each guide portion. This is normally not of great importance, neither is compensation for such an effect essential. However, under such a condition a compensation, if desired, may be provided by graduating or sloping appropriately the direct current accelerating field, by graduating the transmission characteristic of the guide or, where partially separate paths are provided for the electron stream and the electric waves, as will be described later, by graduating appropriately the relative path lengths. Of the first two methods the preferred one of sloping the direct current accelerating field is illustrated in Fig. 1 by provision of the auxiliary accelerating electrode 14 in the electron path between the two guide portions. This electrode is to be polarized at a potential below the potential of the accelerating electrode 15 at the end of the guide portion 1 where the electron stream enters. Then the collecting electrode 5 is polarized to be at a higher potential than that of 14. By such potential differences the potential gradient of the direct current accelerating field is caused to decrease from 15 toward 14 and to increase from 14 toward 5, thereby counteracting the tendencies for the average velocity of the electron stream to be increased in guide portion 1 and decreased in guide portion 2. The application of the second suggested method, that of graduating the transmission characteristic of the guide to vary the velocity of the wave, requires graduating along the length of the guide portion whatever means is employed to decrease the velocity of the high frequency wave. In connection with Fig. 1, for example, this would involve graduating the dielectric constant of the material of which the guide is composed, to increase the wave velocity in guide portion 1 and to decrease the wave velocity in guide portion 2. An illustration of the use of the third suggested method, that of adjusting relative path lengths, will be shown later in connection with Fig. 11.

As has been indicated, the wave guide portions 1 and 2 of Fig. 1 are shown relatively short, closed at both ends and with coaxial lines coupled thereto conduct the input and output energies. Other arrangements are possible. For instance, wave guides may be substituted for the coaxial lines 10, 11 and 12, 13 and coupled to the guide portions 1 and 2 in any well-known manner, for example, such as described in Patent 2,106,769, issued to G. C. Southworth.

Another alternative is to let the guide portions 1 and 2 be parts of incoming and outgoing wave guides, the input guide, of which 1 would be a part, extending indefinitely to the left and the output guide, of which 2 would be a part, extending indefinitely to the right. Fig. 3 showing a different type of guide structure indicates such indefinite extension of the guide portions. It is to be understood that any of the above-mentioned or other suitable methods of conducting energy to and from the guide portions may be employed with any of the various guide structures.

Another method of decreasing the effective wave-length of the field within a wave guide is shown in Fig. 3. Here transverse apertured baffles of conducting material are spaced along the axis inside the guide over the distance throughout which it is desired to compress the waves. Each baffle completely closes the guide

except at the aperture. Fig. 3 shows an axial section of two portions of hollow cylindrical wave guides 1 and 2, and a cross-sectional view of 2 is shown in Fig. 4. Inside of the conducting walls 8 and making contact with the walls are the baffles 30 with central apertures 32. The diameter of these apertures is preferably made about equal to the spacing of the baffles for if the spacings are too small with respect to the apertures, the field in the center of the guide becomes undesirably weak for coupling with an electron stream directed along the axis. The openings in the end closures 33 are made just large enough to admit the envelope 6 of the electron gun employed to direct the stream of electrons 4 through the two guide portions. To further reduce radiation and coupling between 1 and 2 through the access openings in closures 33, the conducting tube 31 is used to connect guide portions 1 and 2 and enclose the electron stream as it passes between them. A tube such as 31 may be used similarly in Fig. 1. The action of the baffles 30 in Fig. 3 is to reduce the effective velocity of wave propagation through the guide portions 1 and 2 as does the high dielectric material in Fig. 1. In this case, however, the reduction in wave velocity results from the series inductive loading introduced by the baffles, the inductive loading having the same effect in this respect as is usual in other types of transmission lines. This permits an electron to traverse several wave-lengths in succession in substantially the same field phase condition as described in connection with Fig. 1. The arrangement of Fig. 3 will therefore function as an amplifier in just the same manner as that of Fig. 1 and described in connection therewith. The electron stream 4 is velocity modulated and the electrons grouped by interaction with the electric field over successive wave-lengths in wave guide portion 1 and then delivers energy to the wave guide portion 2 by interaction with the electric field over successive wave-lengths there, the input to the amplifier being the wave in guide portion 1 and the output from the amplifier being the wave in guide portion 2.

Fig. 5 and Fig. 6 illustrate the use in an amplifier arrangement of folded wave guide portions for obtaining several successive points of interaction between an electron stream and the electric field in the guide portions, such as are obtained with the types of guide shown in Fig. 1 and Fig. 3. Fig. 5 shows longitudinal axial sections of two hollow rectangular wave guide portions, each of which is folded back and forth upon itself so that an electron stream may be directed transversely through several successive folds. A cross-section as indicated is shown in Fig. 6. Guide portions 1 and 2 having walls of conducting material 8 constitute the input and output circuits of an amplifier as in the previous figures referred to above. As before, 6 represents a portion of the envelope of an electron gun for projecting a stream of electrons 4 from the cathode 3 through the guide portions to the collector 5. Fig. 5 shows for convenience only three folds in each wave guide portion and therefore only three points of interaction in each between the electron stream and the electric field in the guide. Obviously other numbers of folds and resulting points of interaction may be used. Also, while in the figure wave guides of rectangular cross-section are indicated, guides of other cross-sections may be used. It will be observed that the waves in the guides must fol-

low zig-zag paths, the lengths of which are dependent upon the lengths of the folds in the guides while the slower moving electrons follow a straight path, the length of which is independent of the guide length. For this reason suitably relating the time of travel of electrons between points of reaction such as *a* and *b* and the time of travel of the wave in the guide between the same points over the longer route *a*, *g*, *b* is made possible by properly proportioning the lengths of the paths *a*, *b* and *a*, *g*, *b*. The lengths of these two paths are made different because the wave velocity in a hollow guide exceeds possible velocities of electron streams. Of course, final adjustment of the relative time of travel of the waves and the electron stream between points of interaction, such as *a* and *b*, is possible through adjustment of the accelerating voltages acting on the electron stream. The input guide 1 and output guide 2 are terminated by closures 36 and interaction takes place between the electron stream and the input wave at positions *a*, *b* and *c* and between the electron stream and the output wave at positions *d*, *e* and *f*. The terminating closures 36, when constructed of conducting material, are preferably spaced from the adjacent points of interaction such as *c* and *d* at distances approximately equal to one-quarter, three-quarters or five-quarters, etc., wave-length so that the reflected waves reinforce the fields at *c* and *d* to give maximum fields for reaction with the electron stream. Otherwise, the distance should be regulated in accordance with the effective impedance of the end closures. If that impedance is equal to the surge impedance of the guide, then the location of the end closure with respect to *c* and *d* becomes unimportant so long as the closure is farther away than the width of the guide cross-section. The input guide 1 is assumed to have a field in which the electric lines of force have components transverse to the axis of the guide and in the direction to be parallel to the electron stream projected from cathode 3 to collector 5. This is the type of field associated with the wave described as type H_1 in the article by G. C. Southworth in the Bell System Technical Journal, vol. XV, pages 284-309, April 1936, which is the type of wave produced in a wave guide such as 2 by a stream of electrons in groups moving transversely across the guide as shown in Fig. 5 and Fig. 7. Guide portion 2 serves as the output circuit of the amplifier and is assumed to be part of an outgoing wave guide as indicated at the end marked output. In operation the electron stream is modulated by the field in the input guide 1 at points *a*, *b* and *c*. The electrons are velocity modulated and grouped cumulatively in passing through these regions *a*, *b* and *c* because each electron encounters substantially the same field phase condition in each. The grouped electrons then deliver energy to the output guide 2 through interaction with the electric field at the regions *d*, *e* and *f* where the effects are similarly cumulative. This mode of operation is similar to that described in connection with previous Figures 1 and 3, the common principle being that cumulative interactions between moving electrons and an electric field are had by controlling relatively the periods of travel of electron stream and the electric wave with which the field is associated.

In Fig. 5 the folds of the guides are not close together and the path of the electron stream between folds is enclosed in shielding cylinders

38, also the stream is enclosed where it passes between the two guides in a similar cylinder 39 and at the ends of its path through the guides by cylinders 37. These cylinders may be made with diameters too small to propagate the electromagnetic waves in the guides and thus prevent radiation and coupling through the openings through which the electron stream passes. Then the only coupling between points in the guides such as *a* and *b* is the normal one around the fold *g* for the wave itself plus the electron stream itself which passes through the cylinder 38 directly from *a* to *b*. The guides may be made narrow so that the transit time of electrons across each fold, and therefore the period of interaction at each point *a*, *b*, *c*, *d*, *e* and *f*, is small compared with the high frequency period and the electron transit time from *a* to *b* through cylinder 38 may be related to the wave propagation time from *a* to *b* via *g* in a variety of ways. The shortest time of wave propagation between folds, such as from *a* to *b*, which will permit repetition of phase relationships at each point such as *a*, *b* and *c* is that equal to the period of one-half cycle of the high frequency and, on account of the reversal in direction in space of wave propagation produced by each fold in the guide which in effect reverses the direction of the electron stream through the field, the corresponding electron transit time from *a* to *b* through cylinder 38 should be equal to the period of one cycle in order to have an electron meet the same field phase condition at *b* as at *a*. Thus the electron transit time from *a* to *b* must differ from the time of wave propagation from *a* to *b* through the guide by the period of at least one-half cycle. It is obvious that the phase relations will not be altered by changing the transit time from *a* to *b* of either the electrons through cylinder 38 or the electric wave through the guide by the period of a whole cycle so that proper phase relations between the electron stream and the electric wave will exist at *a*, *b* and *c* whenever the difference in transit times between those points is equal to the period of an odd number of half cycles. This holds, of course, also for the output guide 2 in which the points of interaction are *d*, *e* and *f*. In an amplifier arrangement the length of cylinder 39 is unimportant so long as it is not of such length as to permit degroupping of the electrons through dispersion of those having different velocities as a result of velocity modulation at *a*, *b* and *c*.

Fig. 7 and Fig. 8 show a limiting form of the structure of Fig. 5 in which the folds of the guides are very close together eliminating the cylinders shown at 38 and 39 in Fig. 5. This arrangement operates the same as that of Fig. 5. It has the disadvantage, however, that with the closely adjacent folds the electrons are under the influence of the field in the guide practically the whole time so that with the half cycle wave propagation time between *a* and *b* via *g* and the whole cycle transit time of electrons from *a* to *b* directly, as previously explained necessary, an electron is exposed to the field during nearly a whole cycle as it passes corresponding points, such as *a* and *b* in successive folds of the guide. A net desired effect is had but the electrons meet an unfavorable field phase condition during part of each transit through the guide. In the preferable form of arrangement shown in Fig. 5 the unfavorable field phase conditions at points of interaction with electrons are avoided by limiting the period of interaction and providing for

the shielded portions of electron path in the cylinders 38. A method of accomplishing a similar result with a closely folded guide, such as that shown in Fig. 7, is illustrated in Fig. 9 where the shields 40 are added to limit the period of reaction at points such as *a* and *b* making operation similar to that of Fig. 5. For this illustration a portion only of Fig. 7 is reproduced in Fig. 9.

The Figures 1, 3, 5 and 7 show amplifier arrangements. Any of these can, of course, be modified to produce self-oscillations by coupling the input to the output to obtain self-excitation. As an example of how this may be done, Fig. 10 shows a modification of Fig. 5 to include such a coupling. It will be apparent that any of the amplifier arrangements shown in the above-mentioned figures may be similarly modified. In Fig. 10 the coupling to transfer energy from the output to supply input excitation is provided by the length of wave guide 45 which connects the output guide 2 to the input guide 1. The wave thus introduced into guide portion 1 modulates the electron stream at regions *a*, *b* and *c*, after which the electron stream delivers energy to the wave in guide portion 2 at regions *d*, *e* and *f* just as described in connection with Fig. 5. In Fig. 10, however, the length of guide 45 and the velocity of the electron stream must be correlated in that the time required for the electric wave to travel in the guide from *f* to *a* and the electron transit time from *c* to *d* must be such that the electric fields associated with the input and output waves at *a* and *f*, respectively, are in proper phase relation to cooperate in sustaining oscillations. Any of the known methods of coupling to wave guide may be employed to connect a load circuit to such an oscillator system. One method is shown in Fig. 10 where the lead 42 forms a coupling loop within the guide and is then carried by insulating spacers 43 through the shield 44 to the load 41, 44 and the shell of the wave guide completing the circuit between the ends of 41 and 42.

Fig. 11, which is a modification of Fig. 5, shows the use of curved bends in the wave guide folds as an alternative to the bends with square corners as shown in the previous figures illustrating folded wave guides. This figure also shows a method of compensating for changes in the average velocity of the electron stream due to the transfers of energy between it and the electric waves in the guide portions as previously referred to in connection with Fig. 1. Here, as in Fig. 5, different paths are provided for the electron stream and the electric waves between the points of interaction *a*, *b*, *c*, *d*, *e* and *f*. For instance, while the electron stream follows the straight paths from *a* to *b* and from *b* to *c* the electric wave must follow the longer routes *a*, *g*, *b* and *b*, *h*, *c*, respectively. To compensate, according to this figure, for the increase in velocity of the electron stream due to interactions with the electric wave in the input guide portion 1, the distances along the path of the electron stream between successive points of interaction are made greater, that is, the distance *b*, *c* is made greater than the distance *a*, *b*. To compensate for the decrease in velocity of the electron stream due to interactions with the electric wave in the output guide portion 2, the distances along the path of the electron stream between successive points of interaction are made less, that is, the distance *e*, *f* is made less than the distance *d*, *e*. It is obvious that a similar form of compensation may

be had by appropriately altering the path lengths of the electric waves rather than the path lengths of the electron stream. For instance, instead of, as above, making the distance b, c greater than the distance a, b , the distance b, h, c may be made less than the distance a, g, b with a similar result.

For the purpose of this specification and its appended claims the expression "wave guide" is to be understood as connoting a wave transmission medium whereby electromagnetic energy may be dielectrically guided from one point to a remote point consisting of a homogeneous region of space bounded by an electrical discontinuity, extending longitudinally between the points and of which a transverse section exhibits a single continuous boundary, as, for example, is characteristic of the transverse section of a hollow pipe or a solid rod but not of that of a coaxial conductor transmission line.

What is claimed is:

1. A high frequency electronic device comprising portions of resonant wave guide structure, and means for projecting an electron stream therethrough, the structure of at least one of the portions of guide being folded back and forth upon itself so that the electromagnetic wave therein is oppositely directed in space in adjacent folds, and the electron stream passes transversely through the folds so that it may interact with the electromagnetic field at each point of traversal of the guide structure.

2. A device according to claim 1 characterized in that two or more of the electron paths between adjacent points of interaction with the electric wave are of different lengths.

3. A device according to claim 1 characterized in that the lengths of two or more of the folds of wave guide as measured between adjacent points of interaction between the electric wave and the electron stream are different.

4. A device according to claim 1 in which the apertures in the guide portions through which the electron stream is projected are provided with tubular flanges to determine the lengths of the gaps traversed by the electron stream.

5. A high frequency electronic device comprising portions of resonant wave guide structure, and means for projecting an electron stream therethrough, the structure of each of at least two of the portions of guide being folded back and forth upon itself so that the electromagnetic wave therein is oppositely directed in space in adjacent folds and the electron stream passes transversely through the folds so that it may interact with the electromagnetic field at each point of traversal of the guide structure, the length of the folds of the structure and the velocity of the electron stream being such that the time for propagation of the electromagnetic wave from one point of interaction to the next is the period of one or more half cycles of the high frequency and the electron transit time between the same points of interaction is different by the period of an odd number of half cycles of the high frequency whereby the interaction in each successive fold in one portion of guide acts to increase the modulation of the electron stream and the interaction in each successive fold in another portion of guide acts to transfer energy from the modulated electron stream to the high frequency electromagnetic wave.

6. A high frequency electronic device according to claim 5 in which the electron stream is enclosed in one or more shielding cylinders of conducting material between points of interaction

between the electron stream and the electromagnetic fields in the guide portions, each shielding cylinder being connected to the shell of the guide portion and closing except for the internal space of the cylinder the openings in the shell of the guide through which the electron stream passes from one point of interaction to another.

7. A high frequency electronic device comprising portions of resonant wave guide structure, and means for projecting an electron stream through the portions of guide in the direction of wave propagation, at least one of the guide portions having longitudinally recurring variations in the transverse internal dimensions such that the transverse dimensions are alternately decreased and increased so that the length of the shortest path over the internal surface of the guide from end to end of a given axial length of the guide portion, including such variations and traversed by the electron stream, exceeds the axial length, whereby the rates of travel, through the guide of the electron stream and the electromagnetic wave, are made substantially the same.

8. A transmission system for electric waves comprising an electric wave guide along which electric wave energy may be propagated with a propagation velocity dependent upon physical characteristics of the guide, means for directing a stream of electrons along a course having a number of regions in which the electrons are exposed to interaction with the field associated with an electromagnetic wave propagated along the guide, the boundary of the wave guide being so predesigned between interaction regions and the electron transit time of the electron stream between the same regions being so predetermined that with a dielectric medium having a dielectric constant substantially unity within the boundary of the guide a cumulative energy control interaction occurs as the stream successively interacts with the wave at the interaction regions.

9. A transmission system according to claim 8 in which the electronic means comprises a plurality of electron accelerating elements spaced along the path of the electron stream and means for maintaining the accelerating elements at different potentials whereby the velocity of the electron stream over different portions of its path may be regulated.

10. A transmission system according to claim 8, characterized in this that the structure of the wave guide which determines the propagation velocity of the wave therealong is varied along its length whereby the propagation velocity of the wave is caused to be different at different points along the guide.

11. A transmission system for electric waves comprising an electric wave guide along which electric wave energy may be propagated, with a propagation velocity dependent upon physical characteristics of the guide, means comprising a plurality of discrete longitudinally spaced variations in the boundary of the guide for reducing the propagation velocity of electric wave energy along the guide, means for directing an electron stream to interact at a plurality of points along the wave guide with the field associated with an electromagnetic wave propagated along the guide, the reduced velocity of the waves along the guide being so related to the velocity of the electrons in their course between the points of interaction that electrons experiencing a certain effect in their reaction with the field at one of the points experience a cumulative effect in their re-

actions with the field at points farther along their course.

12. In combination, a guide for electric wave energy comprising an elongated physical structure utilizing a medium with a dielectric constant substantially unity and having a length considerably in excess of a wave-length as measured along the structure in the direction of energy propagation, an electron discharge device having a cathode, an electron collector and means for projecting a beam of electrons between the cathode and the collector, the guide having such a conformation that its field intercepts the electron stream at a plurality of discrete points which are so spaced along the guide that the propagation time of waves along the guide from any one point of interception with the electron stream to any other such point is substantially equal to the transit time of electrons from the first point to the second.

13. A high frequency system comprising a wave guide along which electric wave energy may be propagated, means for directing an electron stream through the field of the guide in a plurality of different regions whereby the stream reacts successively a number of times with the field of the guide, and means for increasing the time required for the electromagnetic wave to travel along the guide comprising means for making the length of the shortest path between any of the said regions over the interior surface of the guide boundary substantially greater than the length of the electron path between those same regions whereby the total interaction between the electrons of the stream and the electromagnetic field of the guide may be cumulative.

14. A device according to claim 7 in which the variations in the transverse internal dimensions comprise centrally apertured transverse constrictions, each of which completely closes the guide except at the aperture, spaced longitudinally along the guide, the apertures being in alignment along the axis of the guide.

15. A device according to claim 7 in which the variations in the transverse internal dimensions comprise centrally apertured transverse constrictions, each of which completely closes the guide except at the aperture, spaced longitudinally along the guide, the apertures being in alignment along the axis of the guide and the diameters of the apertures being substantially equal to the spacings of the constrictions.

16. A transmission system for electric waves comprising an electric wave guide along which electric wave energy may be propagated with a propagation velocity depending upon physical characteristics of the guide, means for directing a stream of electrons along a course having a number of regions in which the electrons are exposed to interaction with the field associated with an electromagnetic wave propagated along the guide, the boundary of the wave guide being predesigned to make the axial length of the guide between interaction regions substantially exceed the length of the electron path between those same regions whereby the time of propagation of an electric wave and the electron transit time between those regions are so related that a cumulative energy control interaction occurs as the stream successively interacts with the wave at the interaction regions.

17. A transmission system for electric waves comprising an electric wave guide along which electric wave energy may be propagated with a propagation velocity depending upon physical

characteristics of the guide, means for directing a stream of electrons along a course having a number of regions in which the electrons are exposed to interaction with the field associated with an electromagnetic wave propagated along the guide, the boundary of the wave guide being predesigned to make the axis of the guide and the electron path coincide between interaction regions but at the same time to make the length of the shortest path over the internal surface of the boundary of the guide between interaction regions substantially greater than the length of the electron path between those same regions whereby the axial velocity of the electric wave and the velocity of the electron stream are substantially the same and a cumulative energy control interaction occurs as the stream successively interacts with the wave.

18. In combination, a guide for electric wave energy comprising an elongated physical structure utilizing a medium with a dielectric constant substantially unity and having a length considerably in excess of a wave-length as measured along the structure in the direction of energy propagation, an electron discharge device having a cathode, an electron collector and means for projecting a beam of electrons between the cathode and the collector, the guide having such a conformation that its field intercepts the electron stream at a plurality of discrete points which are so spaced along the guide that the propagation time of waves along the guide from any one point of interception with the electron stream to any other such point is so related to the electron transit time between those same points that the interactions between the electrons and the field at the various points are cumulative in their effect.

19. A transmission system for electric waves comprising an electric wave guide along which electric wave energy may be propagated with a propagation velocity dependent upon physical characteristics of the guide, means for directing a stream of electrons along a course having a number of regions in which the electrons are exposed to interaction with the field associated with an electromagnetic wave propagated along the guide, the boundary of the wave guide being so predesigned between interaction regions that the length of the shortest path between any of the said regions over the interior surface of the guide boundary is substantially greater than the length of the electron path between those same regions.

20. A high frequency electronic device having a high frequency input system and a high frequency output system, at least one of these systems comprising an electric wave guide along which electric wave energy may be propagated with a propagation velocity dependent upon physical characteristics of the guide, means for directing a stream of electrons along a course having a number of regions in which the electrons are exposed to interaction with the field associated with an electromagnetic wave propagated along the guide, the boundary of the wave guide being so predesigned between interaction regions that the length of the shortest path between any of the said regions over the interior surface of the guide boundary is substantially greater than the length of the electron path between those same regions.

21. A high frequency electronic device having a high frequency input system and a high frequency output system, at least one of these systems comprising a portion of resonant wave guide

structure and means for projecting an electron stream therethrough, the structure of the portion of guide being folded back and forth upon itself so that the electromagnetic wave therein is oppositely directed in space in adjacent folds and the electron stream passes transversely through the folds so that it may interact with the electromagnetic field at each point of traversal of the guide structure, the length of the folds of the structure and the velocity of the electron stream being such that the time for propagation of the electromagnetic wave from one point of interaction to the next is substantially the period of one or more half cycles of the high frequency and the electron transit time between the same points of interaction is different by the period of an odd

number of half cycles of the high frequency whereby the interaction in successive folds is cumulative.

22. A high frequency electronic device according to claim 21 in which the electron stream is enclosed in one or more shielding cylinders of conducting material between points of interaction between the electron stream and the electromagnetic fields in the guide portions, each shielding cylinder being connected to the shell of the guide portion and closing except for the internal space of the cylinder the openings in the shell of the guide through which the electron stream passes from one point of interaction to another.

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