April 16, 1957 CHAO C. WANG 2,789,246

HIGH FREQUENCY APPARATUS

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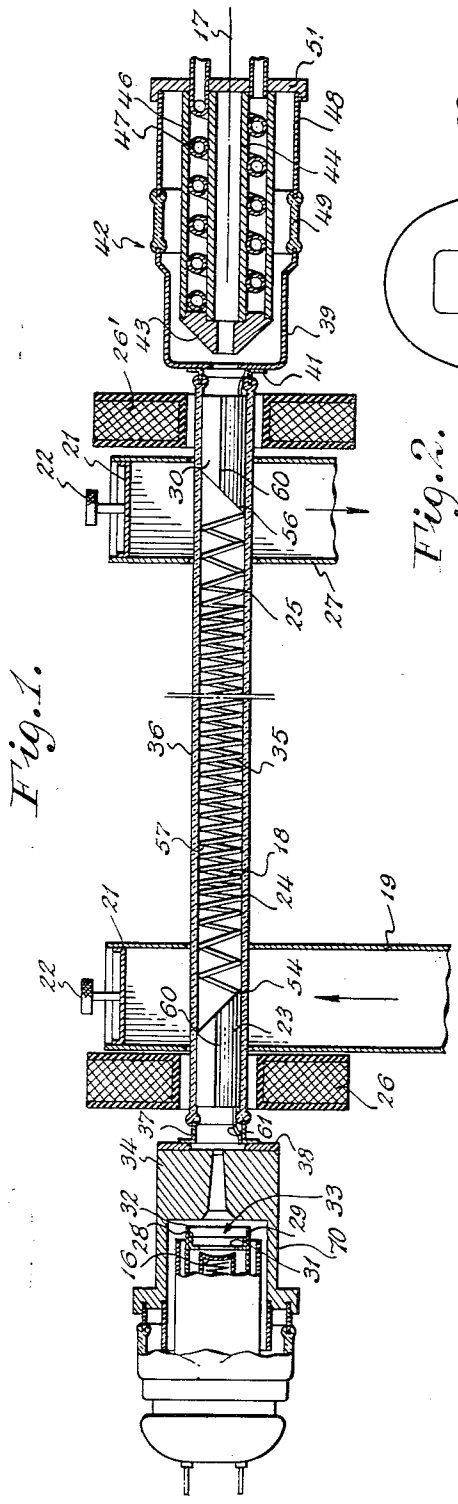


Fig. 1.

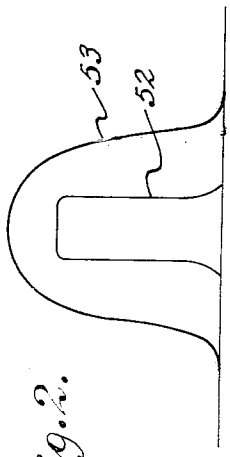


Fig. 2.

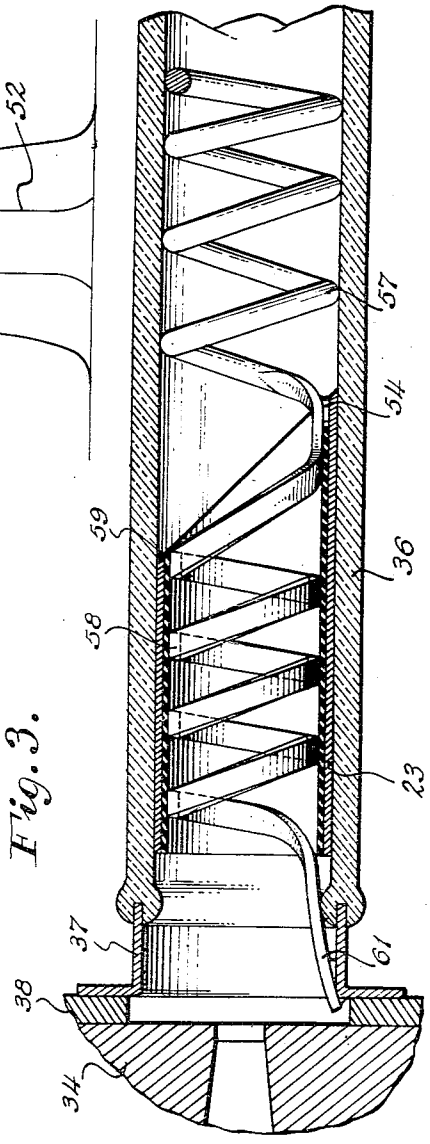


Fig. 3.

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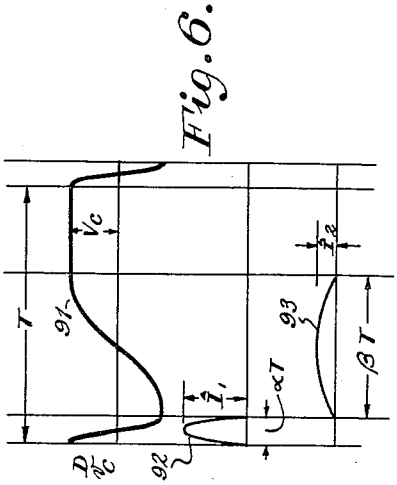


Fig. 6.

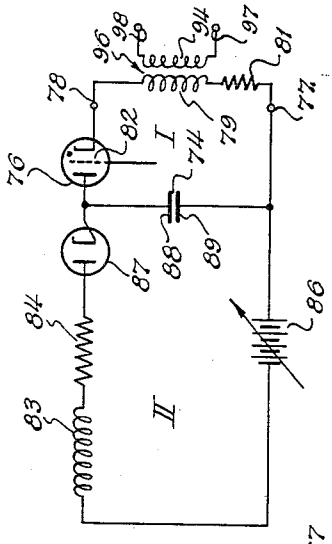


Fig. 5.

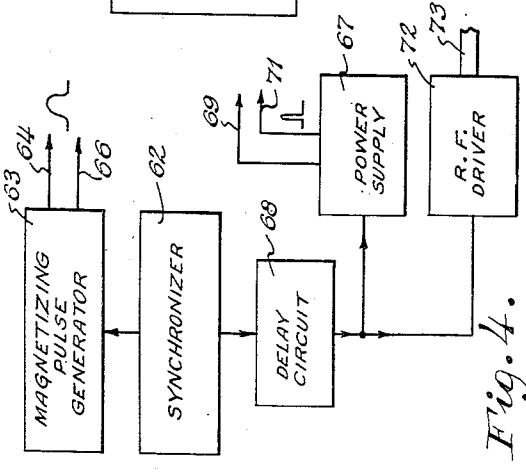


Fig. 4.

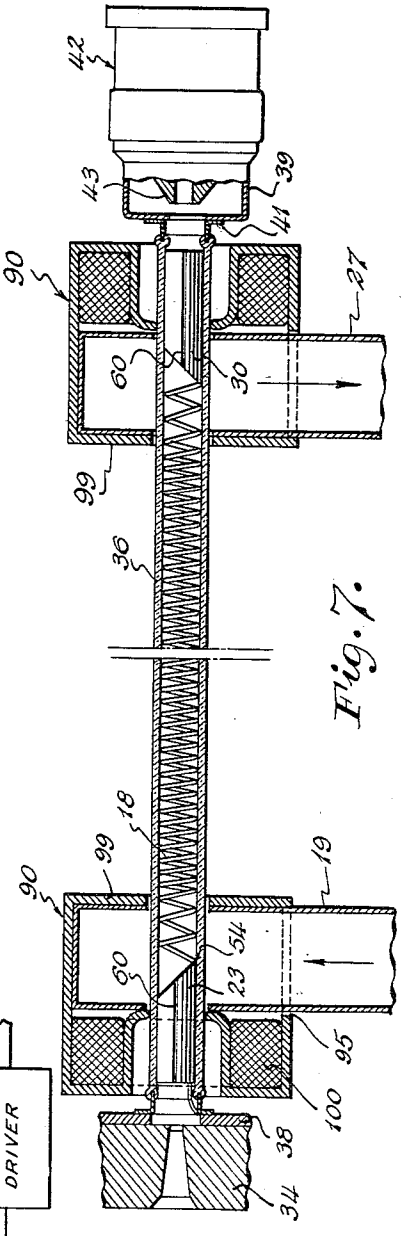


Fig. 7.

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Fig. 9.

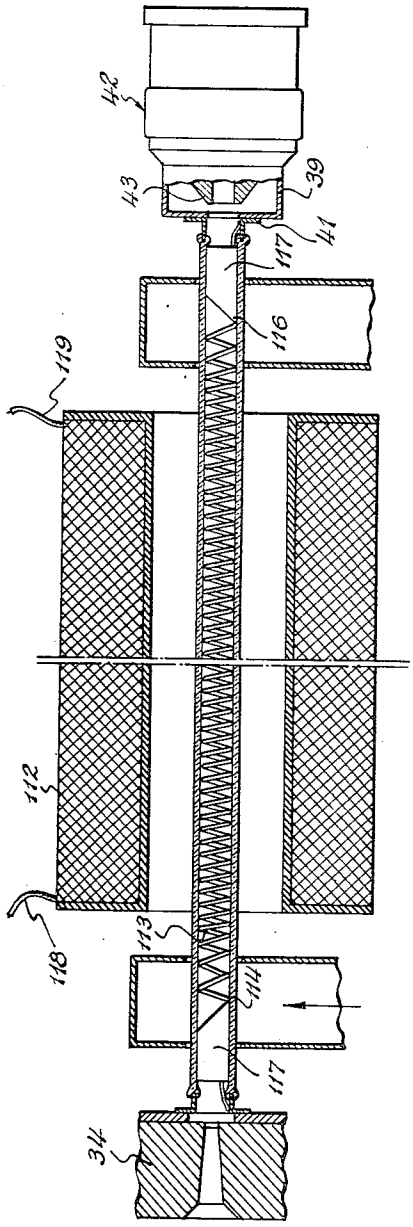
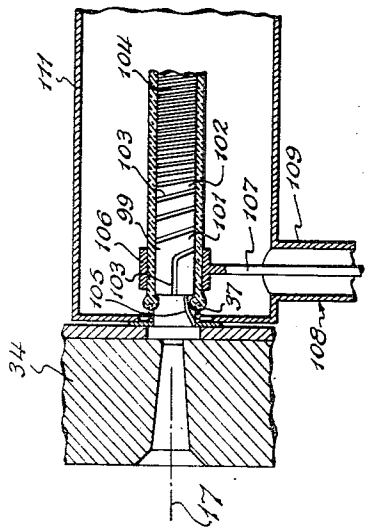


Fig. 8.



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Fig. 10.

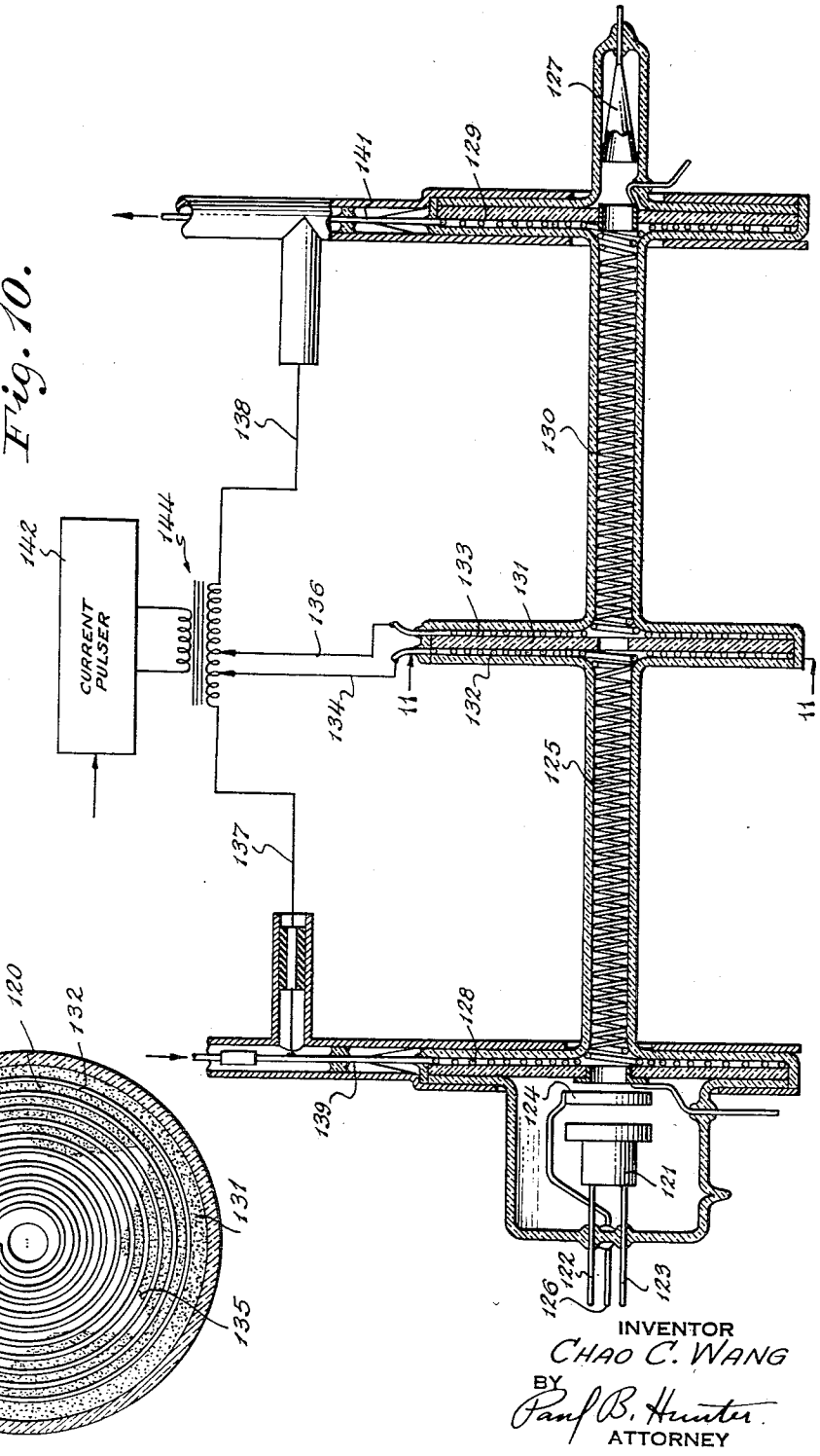


Fig. 11.

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HIGH FREQUENCY APPARATUS

Chao C. Wang, Bayside, N. Y., assignor to Sperry Rand Corporation, a corporation of Delaware

Application November 25, 1950, Serial No. 197,535

12 Claims. (Cl. 315—3.5)

This invention relates to slow wave propagating electron discharge devices and, more particularly, to means for pulsing such devices.

Electron discharge devices including slow electromagnetic wave energy propagating structures or travelling wave tubes are becoming increasingly important in microwave transmission systems. Travelling wave tubes have satisfactory efficiencies and gain properties compared to other microwave tubes and, in addition, are characterized by noise figures which are superior to other microwave devices. More important, however, at the present time is the extremely superior bandwidth characteristics of travelling wave devices as compared to other microwave tubes.

In many microwave transmission systems it is desirable to employ electromagnetic energy of an intermittent or pulsed variety. According to one form of the present invention, means are provided for pulsing slow wave propagating devices. According to another form of the present invention in connection with a slow wave propagating structure means are provided for pulsing an electron beam focusing means in synchronism with an electron beam producing means.

In another aspect the present invention provides for the elimination of any external electron beam focusing means, such as a solenoid coupled to the electron beam. This may take the form of introducing direct current into the ends of the slow wave propagating structure, such as a helix, whereby such current is effective for maintaining a suitable magnetic focusing field. In this arrangement, the magnetic focusing field may be established only substantially during the time that electrons are traversing the axis of the device. Such a device is extremely compact, lightweight and characterized by reduced power requirements. There is additionally provided an improved radio frequency coupling member, which cooperates with the magnetic focusing means. The coupling member, to effect the desired purpose, may be provided with a longitudinal slot.

Accordingly, it is an object of the present invention to provide an improved slow wave propagating electron discharge device.

Another object of the present invention is to provide a compact and lightweight high-power slow wave propagating device.

Another object of the present invention is to provide in an electron discharge device means for utilizing the slow wave propagating structure for providing a magnetic focusing field.

A still further object is to provide in connection with a pulsed high power slow wave propagating electron discharge device having a suitable electron beam trajectory, means for eliminating the necessity of any external electron beam field control means.

A further object is to provide in a slow wave propagating device periodic electron beam focusing field means.

A further object lies in the provision of an improved

radio frequency coupling member for cooperation with magnetic focusing means.

Other objects and advantages of this invention will become apparent from the specification, taken in connection with the accompanying drawings, wherein the invention is embodied in concrete form, and in which

Fig. 1 is a longitudinal view, mainly in cross section, of a preferred form of the present invention;

Fig. 2 is a diagrammatical representation, useful in explaining the operation of, for instance, the device of Fig. 1;

Fig. 3 is an enlarged cross-sectional view of a portion of the structure of the device of Fig. 1;

Fig. 4 is a block diagram of a modulator, which may be used in conjunction with, for example, the device of Fig. 1;

Fig. 5 is a circuit diagram of the magnetizing pulse generator of a part of the modulator of Fig. 4;

Fig. 6 is a graphic representation, useful for explaining the principles of operation of the circuit of Fig. 5;

Fig. 7 is a longitudinal view, mainly in cross section of a modification of the device of Fig. 1;

Fig. 8 is a fragmentary view, showing a further modification of the device of Fig. 1;

Fig. 9 is a longitudinal view, mainly in cross section, of an alternate embodiment of the present invention;

Fig. 10 is a longitudinal view, mainly in cross section, of a further embodiment of the present invention; and

Fig. 11 is a cross-sectioned view of the device of Fig. 10 taken along lines **11—11** thereof.

Similar characters of reference are used in all of the above figures to indicate corresponding parts.

In Fig. 1 there is provided means, including for example electron emitter or cathode button **16**, for producing an electron beam, with the cathode button **16** aligned along the longitudinal axis **17** of the electron discharge device. Positioned to receive the electron beam in energy-exchanging relation is a means defining a slow wave propagating structure, such as cylindrical helix **18**. Adjacent one end of the helix **18** is a radio frequency input means, such as rectangular wave guide **19**, which has an impedance-matching plunger **21** arranged at one end thereof. For providing translatory movement of the plunger **21** along the axis of the wave guide **19**, activating member **22** may be rigidly secured to the plunger **21**. At the radio frequency entrance end of the helix **18** there is disposed a radio frequency coupling member, such as tube **23**, which is electrically connected for transmission of radio frequency or microwave energy to the helix **18**. At the output end of the helix **18** there is provided a means for abstracting radio frequency energy from the helix **18**, which means may include output wave guide **27**.

Throughout the major portion of the helix **18**, the pitch may be uniform; however, at the electromagnetic energy input and output regions of the helix **18**, which are electrically coupled for radio frequency energy to the tubes **23**, **30**, the pitch may be greater, becoming progressively smaller to match the uniform pitch of the helix **18** approximately in the region between the points **24**, **25**, which uniform pitch portion may be designated **35**.

If desired, a coil **26** may be employed in the vicinity of the tube **23**, which upon energization is effective for providing a trimmer magnetic field for focusing the electron beam, as will be explained more fully hereinbelow.

The previously-referred-to cathode button **16** is provided with its active surface suitably oxide coated and substantially spherically concave in cross section about the longitudinal axis **17**. The edge of the aperture of the apertured cup **28**, which is supported by sleeve **29**, provides a first line conductor or edge **31** positioned outwardly of and along the longitudinal axis **17** in a direc-

tion away from the cathode button **16**. Accordingly, it will be noted that the diameter of the aperture of cup **28** is larger than the diameter of the cathode button **16**.

The end of the sleeve **29** in a direction toward the main body of the electron discharge device provides a second line conductor or edge **32**, with the second edge **32** being located outwardly of the cathode button **16** to a greater extent than the first edge **31**. The second edge **32** is, in addition, disposed along the longitudinal axis **17** in a direction away from the cathode button **16** to a greater extent than the first edge **31**. The first and second line conductors or edges **31**, **32** constitute an electrostatic field forming means or focusing electrode **33**, which is similar to that disclosed and claimed in applicant's co-pending application S. N. 81,480, entitled Charged Particle Beam Forming Apparatus, filed March 15, 1949, now U. S. Patent 2,564,743, dated August 21, 1951.

For accelerating and directing electrons emanating from the outward button **16** toward the main body of the electron discharge device, an accelerating electrode or anode **34** is provided, which anode **34** is suitably energized by an external potential source, as discussed hereinbelow. The cathode button **16**, focusing electrode **33** and the anode **34** comprise an electron gun for forming a high density electron beam in which the individual electrons thereof traverse substantially rectilinear trajectories and travel toward a point.

To preserve the internal vacuum of the device the cylindrical helix **18** is coaxially disposed within a vitreous envelope **36** which is joined at one end to anode **34** by means of annular member **37** and apertured disc **38**, with all of the connections being effected in a vacuum tight manner. At the other end of the helix **18** a similar vacuum-tight connection of the envelope **36** is effected to the cylindrical member **39** by means of annular member **41**. If desired, a coil **26'** may be employed in the vicinity of the coupling tube **30**.

For the collection of electrons an electron collector **42** is positioned to receive electrons after their exchange of energy with the helix **18**. The collector **42** is formed of an apertured tubular member **43**, which is joined to coaxially-disposed tubes **44**, **46**. Between the tubes **44**, **46** is a fluid conducting pipe **47**, by means of which heat developed in collector **42** may be removed from the discharge device. The cylindrical member **39**, which partially surrounds the collector **42** is joined to a further cylindrical member **48** in a vaccum tight manner by means of a vitreous tubular seal **49**. Closing the end of the further cylindrical member **48** is a disc **51**, with the connection therebetween effected in a manner suitable to preserve the internal vacuum of the discharge device. To the same end, the fluid conducting pipe **47** is similarly joined to the disc **51**.

In the device of Fig. 1 there is additionally provided means for confining electrons to desired trajectories, which means may include the previously-mentioned helix **18**. The helix **18** is suitable for conveying direct current for establishing a magnetic focusing field, the helix comprising means for passage of said direct current along a helical path about the axis of the tube. Pulsed operation of the device of Fig. 1 may be obtained by periodically injecting or introducing an electron beam into the helix **18**. In addition, the previously-referred-to magnetic focusing field, emanating from the helix **18**, may be of a pulsed character and may be substantially established in synchronism with the pulsed electron beam. In Fig. 2 there is shown a diagrammatic representation of a pulsed electron beam, as represented by curve **52**. The pulse of magnetizing current, which is introduced into the helix **18**, may be represented by curve **53**, with curve **53** having a substantially flat portion or constant-amplitude portion during the time that the pulse **52** is operative. Moreover, the arrangement provides for the establishment of the magnetic focusing field of sufficient magnitude prior to the injection of electrons into the helix **18**, as represented by curve **52**.

As shown more clearly in Fig. 3, the helix **18** extends through the tubes **23**, **30**. For convenience, the part of the helix **18** extending from the opposed ends **54**, **56** of the tubes **23** and **30** may be designated helix portion **57**. By reason of this arrangement, a suitable magnetic focusing field may be maintained in the region, for instance, between the anode **34** and the end **54** of coupling tube **23**, with the helix portion **58** contained within the tube **23** being insulated therefrom by means of tubular insulator **59**. To prevent the tube **23** from acting as a short-circuited secondary of a transformer, a longitudinal slot **60** is provided therein. Helix portion **57**, which is electrically coupled for microwave frequency energy to the end **54** of tube **23**, is effective for radio frequency interaction with an electron beam. By maintaining the pitch of the helix portion **58** similar to that of the pitch of the helix portion **35**, that is, that part between the points **24**, **25**, these regions of the helix **18** are suitable for providing a magnetic focusing field of substantially the same strength.

To this end, the cross-sectional configuration of the helix portion **58** may be rectangular so that its internal diameter is substantially the same as that of the helix portion **35**. Moreover, the cross-sectional area of the helix portions **35**, **58** may be substantially the same, thereby insuring substantially equal current carrying capacities for the portions **35**, **58**. By reason of this arrangement helix portions **57**, **58** may be effective for providing magnetic focusing fields of substantially the same strength.

In order to provide an input connection for focusing current to helix portion **58**, which is electrically continuous with helix portion **57**, the end of helix portion **58** may be formed in a lead **61**, which may be for electrical conduction secured, as by soldering, to the annular member **37**. It will be understood that a further helix portion, similar to helix portion **57**, may be contained within coupling tube **30**.

Viewed somewhat differently, it may be said that a slow wave propagating structure or helix is provided by helix portion **57** and that additional helices are provided substantially surrounded by coupling tubes **23**, **30**, which may be connected to and integral with the aforementioned helix, for the passage of a magnetic-focusing current.

In Fig. 4 a pulse generator or modulator is illustrated, which is suitable for energizing the device of Fig. 1. A control pulse emanating from synchronizer **62** is effective for controlling a magnetizing pulse generator **63** having output leads **64**, **66** which may be connected to annular members **37**, **41** respectively of the device of Fig. 1. The control pulse emanating from the synchronizer **62** is further coupled to the power supply **67** by way of a delay circuit **68**, with the power supply **67** having output leads **69**, **71**, which may be connected to the cathode button **16** and the anode **34** respectively. It will be understood that these connections, if desired, may be made through suitable input leads at the base of the discharge device of Fig. 1. The output pulses emanating from the magnetizing pulse generator **63** and the power supply **67** may have the same waveform and relative time relation as the curves **53**, **52**, respectively, of Fig. 2.

If desired the synchronizer pulse emanating from the delay circuit **68** may be employed to control a radio frequency driver **72** having an ouput coupling means **73**, which may be electrically coupled to wave guide **19**.

In operation, electrons emanating from the cathode button **16**, under the influence of the focusing electrode **33** and the anode **34** are formed into an electron beam, in which the individual electrons thereof traverse substantially rectilinear trajectories and travel toward a point located in the vicinity of the aperture of the anode **34**. Thus, it will be noted that the electron beam is formed

substantially through electrostatic focusing means with the magnetic field substantially excluded from the cathode region, including for instance the cathode button **16**.

To insure that substantially none of the magnetic lines of force thread the cathode region, anode **34** may be formed of magnetic material and formed with a skirt **70**. However, in view of the pulsed nature of the magnetic focusing field, if desired, anode **34** may be formed of a highly conductive material, such as copper. Such an arrangement insures the exclusion of the magnetic field from the cathode region by reason of eddy currents flowing in such a copper member under the influence of a pulsed magnetic field.

Radio frequency energy, may be coupled to the helix portion **57** by introduction through wave guide **19**. Upon leaving the tube **23** the electron beam traverses the length thereof in energy exchanging relationship. More specifically, the electron beam initially abstracts energy from the electromagnetic energy passing through the turns of the helix portion **57**. Subsequent thereto the electron beam, which has become density modulated in the process, is effective for delivering radio frequency energy to the helix portion **57**. Such electromagnetic energy may be abstracted from the helix portion **57** at its output end by means of wave guide **27**.

Simultaneously with the radio frequency energy interchange between the electron beam and the helix portion **57**, a magnetic focusing field, which is established by introducing direct current into the helix **18**, is effective for focusing the electron beam throughout its traverse of the helix portion **57**. Furthermore, with additional helices, such as helix portion **58**, included within the tubes **23**, **30**, the magnetic focusing field extends along the entire length of the helix **18**. As a result, a magnetic focusing field is established by current passing through helix **18**, which field is effective for confining electrons to desired trajectories substantially from the time they leave the anode **34** until they enter the collector **42**.

Thus, the electron beam throughout its transit of the entire helix **18** is subjected to a magnetic focusing field emanating from the helix **18**. By reason of the uniform pitch of the helix portions **58** and uniform pitch helix portion **57** the magnetic field established thereby has a substantially axially symmetrical configuration. In the region of the helix **18** between the ends **54**, **56** of the tubes **23**, **30** and points **24**, **25** where the pitch is variable, the helix **18** may not be effective for providing a symmetrical axially-directed magnetic field. To compensate for this nonuniformity, an additional magnetic flux, provided by coils **26**, **26'** may be useful.

If desired, the pitch of the helix **18** may be made uniform throughout its length, including those helix portions adjacent coupling tubes **23**, **30**. This arrangement has the advantage of obtaining a symmetrical axially-directed magnetic field emanating from the helix **18** for the control of the trajectories of the electrons of the beam. It will be noted that the opposed ends of the coupling tubes **23** and **30** extend linearly and are formed at approximately 45° angles with respect to the axis **17**. With the proposed uniform pitch for the helix **18** the aforementioned ends of the tubes **23** may be formed with curved shapes or other complex configurations.

If desired, coils **26**, **26'** may be replaced by coils of a few turns connected in series with the helix **18**.

In Fig. 5 means are provided for pulsing a load having a relatively large reactive component. Before discussing the circuit of Fig. 5 it is useful to consider other types of pulsing circuits, including the hard tube modulator and the artificial line modulator. The hard tube modulator is characterized by high vacuum electron discharge devices, which inherently are limited as to current carrying capacity. To avoid such difficulty, the artificial line modulator has been provided, which is characterized by its high current handling capacity and customarily includes gaseous electron discharge devices, such as thyratrons. In the design of such a line modulator, an attempt is made to operate with a pure resistance load, in order to avoid excessive dissipation of power. More particularly, there is an attempt to match the characteristic impedance of the artificial or delay line to the impedance of the load. It is apparent that with a load constituted of a large inductance, it is necessary to introduce a large series resistance therewith to preserve the waveform. In such case, the losses involved in the circuit would become prohibitive, thereby relegating against the use of a line modulator.

It also appears that where energy storage circuits, including for instance a delay line or a condenser, have been employed, the power which is released from such storage circuits is dissipated. According to the present invention, means are provided for circulating energy from one storage circuit to another in a substantially lossless manner. By this arrangement, there is considerable saving in the drive power required in view of the fact that only a small amount of power is dissipated in the switching device and other small circuit resistances.

In Fig. 5 a pulse forming circuit is provided, which includes energy storage means, such as condenser **74**, connected in a first loop I through a current controlling means, such as thyratron **76**, to terminals **77**, **78**. Connected in series with terminals **77**, **78**, is a further energy storage circuit, which may be constituted by a means defining a slow wave propagating structure, and represented in Fig. 5 by its electrical equivalents, that is inductor **79** having an internal resistance **81**. By periodically releasing energy from the condenser **74** by activation of the current control grid **82** of the thyratron **76**, the inductor **79** may be periodically pulsed so as to set up an axially-directed magnetic field, which field may be useful for controlling the trajectories of electrons.

Condenser **74** is also connected in loop II to an additional energy storage circuit, such as inductor **83** having an internal resistance **84**. Also included in loop II is a variable source of potential, such as battery **86** and means for controlling the direction of current flow, such as holding or blocking diode **87**. On the assumption of an initial condition of a positive charge being present on the upper plate **88** of condenser **74** and the activation of current flow in loop I by means of the firing of thyratron **76**, the polarity of the condenser **74** will reverse so that the lower plate **89** of the condenser **74** will become positively charged. Loop II is effective in restoring the original charge of the condenser **74**, that is, a positive charge associated with the upper plate **88**. The circuit of Fig. 5 achieves the circulation of energy back and forth through the inductor **79** without involving any sizeable dissipation of power. The only drive power required for the operation of the circuit of Fig. 5 is that arising from losses in the thyratron **76**, diode **87** and other small circuit resistances, such as resistances **81**, **84**.

In a steady operation of a simple inductance-capacitance circuit, the maximum voltage across the condenser is maintained in quadrature relationship with respect to the maximum current. By permitting the capacitor of such a circuit to reverse the polarity of its voltage from a positive maximum to a negative minimum, the current increases from zero to a maximum and decreases to zero again. In other words, while the capacitor voltage undergoes the aforementioned variation, the current experiences a half-cycle pulse.

More particularly, in Fig. 5, it may be assumed that the upper plate **88** of the condenser **74** is at a positive potential at the start of a cycle having a period T. By activating the control grid **82** of the thyratron **76**, the condenser **74** may be permitted to discharge through the inductor **79** and resistance **81**. Under these circumstances, as shown more clearly in the graphical representation of Fig. 6, the voltage of the condenser **74**, as represented by curve **91**, reverses its polarity, so

that the lower plate 89 thereof at the end of current flow in the loop II, as represented by curve 92, has a positive polarity.

In connection with the thyratron 76 it may be pointed out that assuming the voltage thereacross is suitable for the conduction of current, the grid 82 is effective for controlling the firing or conduction of current therethrough provided that the thyratron 76 is deionized. Further mention will be made of the importance of the deionization of the thyratron 76 subsequent to the discussion of the operation of loop II of the circuit of Fig. 5.

The inductor 83 receives current therethrough as shown more clearly in Fig. 6, with the battery 86 suitable for providing the aforementioned small dissipation of power associated with the circuit resistance. Thus, during the time that current is passing in loop II, the polarity of the condenser 74 is restored to its initial condition. The holding diode 87 included in loop II is effective during the passage of current in loop I for preventing the flow of current through loop II.

By defining the pulse period and the duty cycle T and α, respectively, αT indicates the time during which the pulse, represented by curve 92, is operating. Similarly, the duty cycle associated with the loop II may be indicated by β, with current flow therethrough represented by curve 93. Preferably, the inductor, in loop II is of considerably larger magnitude than the inductor 79 of loop I so that the charging period βT is of sufficiently long duration to maintain the voltage of the condenser 74 negative during the time that the thyratron 76 deionizes. The current flow through loop II has a half sine waveform similar to the current waveform of loop I, with the exception that it is longer in duration and smaller in amplitude.

The voltage across the thyratron 76 immediately prior to conduction of current therethrough is of a magnitude equal to the voltage across the condenser 74. Upon the firing of the thyratron 76, the voltage thereacross drops to a small magnitude and remains substantially constant throughout the time that current is conducted in loop I. More particularly, the voltage across the thyratron 76 will have during the time αT a small amplitude, which could be represented by a horizontal line spaced a small distance above the zero axis of Fig. 6. At the end of current conduction in loop I, the voltage across the thyratron 76 decreases to that of the voltage across the condenser 74 and follows the voltage of the condenser 74 during the remainder of the time T, that is, until the start of the next pulse cycle. It is apparent that the voltage across the inductor 79 and resistance 81 may be determined by taking the difference of the voltages across the condenser 74 and thyratron 76.

The geographical representations of Fig. 6 indicate slightly idealized conditions, which however, appear to be amply justified by the operation of the circuit of Fig. 5. Owing to the fact that during the latter half of the time αT or during conduction of current in loop I, the polarity of the condenser 74 is such as to tend to cause current flow in loop II. More particularly, the lower plate 89 of the condenser 74 assumes a positive potential, which is favorable for the flow of current through loop II. However, the magnitude of such current flow is negligible and may be disregarded in the present analysis.

As previously indicated, the thyratron 76 may pass current if it is not in a deionized condition. During the time βT, from Fig. 6, it will be noted that the voltage of the condenser 74, as represented by curve 91, changes from a negative maximum to a positive maximum, passing through zero. In the event that this voltage were to change its magnitude from the aforementioned negative maximum to a small positive value relative to zero axis in a time less than that required for the thyratron 76 to deionize, current would again start flowing in loop I. By selecting essentially the magnitudes of the inductors 79, 83, this difficulty may be avoided. With the time during the βT portion of the cycle during which the condenser 74 changes its polarity from a negative maximum to substantially zero voltage at a value greater than the deionization time of the thyratron 76, spurious current flow in loop I may be substantially eliminated.

If desired, a current step-up transformer may be associated with loop I of the circuit of Fig. 5. In such case, a coil 94 may be inductively coupled to inductor 79, with inductor 79 and coil 94 forming the primary and secondary of the transformer 96, respectively. The coil 94 is provided with terminals 97, 98 which may be connected to annular members 37, 41, respectively, that is, to the helix 18 of the device of Fig. 1. Thus, this arrangement is particularly useful where it is desired to employ a relatively large magnitude of magnetic focusing current in the helix 18, thereby permitting a substantially smaller magnitude of current to be conducted in loop I of the circuit of Fig. 5.

If desired, in the circuit of Fig. 5 the condenser 74 and the thyratron 76 may be interchanged. This arrangement permits the cathode of thyratron 76 to be maintained at ground potential. It will be noted that in this proposed modification energy is circulated from one energy storage circuit to another, without involving any substantial dissipation of power.

If desired, the thyratron 76 in the circuit of Fig. 5 may be replaced by a high vacuum electron discharge device. This modification makes possible the formation of pulses having a length unrelated to the deionization time of gaseous electron discharge devices, such as thyratron 76. As previously discussed, the time for the grid 82 of the thyratron 76 to regain control thereof is an important consideration. However, by reason of the currently proposed modification any difficulties associated therewith may be avoided. It will, of course, be understood that a step-up transformer, such as transformer 96, may be useful for providing the desired magnitude of current.

As thus far described, the circuit of Fig. 5 has been shown to be effective for producing pulses of current. It will be understood that it is also useful for the production of voltage pulses. For example, a negative voltage pulse appears across the condenser 74, as shown by curve 91 of Fig. 6. Such a voltage pulse may be useful in connection with an accelerating electrode or anode for the production of an electron beam.

By way of example, in the device of Fig. 1 a capacitance is present between the cathode button 16 and the anode 34, which may correspond to the condenser 74 of the circuit of Fig. 5. In this arrangement, the holding diode 87 may be replaced by a gaseous discharge device, such as a thyratron, the firing of which may be useful for controlling the flow of current in loop II. Accordingly, this arrangement permits the formation of a flat-topped voltage pulse. In addition, if desired the thyratron 76 may be replaced by a high vacuum electron discharge device, in the event that it is desired to produce a pulse having a length substantially less than the deionization time of a gas tube, such as thyratron 76.

The circuit of Fig. 5 may be further modified for the production of voltage pulses, by replacing the condenser 74 with a coil forming the primary of a transformer. The secondary of this transformer may then be coupled to the capacitance formed by a cathode and its accelerating electrode, such as cathode button 16 and anode 34 of the device of Fig. 1. For operation at a high voltage and low current, the thyratron 76 may be replaced by a high vacuum electron discharge device.

If desired, an additional accelerating electrode may be employed in the device of Fig. 1. Such additional electrode may be insulated from and maintained at a substantially lower potential than anode 34. Under such circumstances, such additional accelerating electrode may

be pulsed at a substantially lower voltage, such as a tenth of the voltage maintained between the cathode button **16** and the anode **34**. This arrangement permits the pulsing of the electron beam at a lower voltage level, and is somewhat analogous to the action occurring in a triode tube, wherein the grid is effective for controlling the passage of current.

While the possible modifications of the current of Fig. 5 relating to the production of voltage pulses are useful in connection with slow wave propagating structures, such as the device of Fig. 1, it will be understood that such modifications are equally applicable to other types of electron discharge devices, such as klystrons. By way of illustration in this connection reference may be had to a velocity modulation electron discharge device, suitable for utilizing the proposed circuit modifications. More particularly, the capacitance of the condenser **74** could be replaced by the capacitance between the cathode button and the anode of the discharge devices shown in application S. N. 117,187, entitled High Frequency Beam Tube Device, in the name of Charles E. Rich et al., filed September 22, 1949, and assigned to the same assignee as the present application, now U. S. Patent 2,687,490, dated August 24, 1954. If desired, an additional accelerating electrode could be employed or the accelerating electrode shown therein could be insulated from the main body of the tube and maintained at a lower potential.

In Fig. 7 there is shown a modification of the device of Fig. 1 in which the coil **26** is replaced by an electromagnet **90** having aperture **95** to accommodate input and output wave guides **19, 27**, respectively. The electromagnet **90** may be constituted of magnetic frame **99** energized by coil **100**. If desired, by omitting coil **100**, the structure may take the form of a permanent magnet.

As previously discussed, owing to the non-uniformity of pitch in portions of the helix **18** the magnetic field established by the introduction of current therein may not be completely axially symmetrical. Thus, in the region of, for instance, the end **54** of coupling tube **23** the magnetic field emanating from the helix **18** may have components which are directed out of the paper of the drawing. The electromagnet **90** is effective for providing additional focusing in such regions.

In addition, by varying the position of the electromagnet **90** or other magnetic structure, such as coil **26** of the device of Fig. 1, the lack of uniformity in the magnetic field established by the helix **18** in the region of the end **54** of the coupling tube **23** may be compensated for, thereby maintaining a substantially axially-directed magnetic field throughout the length of the helix **18**. Under such circumstances, the control of the trajectories of the electrons of the beam may be more readily achieved.

In Fig. 8 a further modification of the device of Fig. 1 is shown, in which a transition section is employed, which is generally similar to that shown in application S. N. 97,070, entitled High Frequency Coupling Device, in the name of Calvin F. Quate, filed June 3, 1949, and assigned to Leland Stanford University, now abandoned. The transition section **101** is formed of a tubular conductor **102**, which is provided with a slot **103**, the pitch of which changes continuously and smoothly throughout the length of the conductor **102**. At the end of the transition section **101** remote from the anode **34** the conductor **102** joins a helix **104**, which has a uniform pitch and generally corresponds to helix portion **57** of the device of Fig. 1. At the end of the conductor **102** facing the anode **34**, the slot **103** is substantially parallel to the axis **17**, that is, the pitch has an infinite value.

The width of the slot **103** may be made approximately the same as the space between adjacent turns of the helix **104**. The pitch of the slot **103** decreases toward the end of the conductor **102**, where it joins the helix **104**. At the point where the conductor **102** and helix **104** join, the pitch of the slot **103** may be substantially the same as that of the helix **104**, and the width of the conductor between adjacent convolutions of the slot **103** may be substantially equal to the width or the diameter of the conductor forming the helix **104**.

To couple magnetization current to the conductor **102**, which is electrically connected to the helix **104**, lead **105** is provided, which is joined to annular member **37**. The transition section **101** is effective for coupling electromagnetic energy to the helix **104**. Surrounding a portion of the conductor **102** is a metallic band **106** which is electrically connected to the inner conductor **107** of an input coaxial line **108**, which has its outer conductor **109** joined to tubular member **111**.

In operation, electromagnetic energy is coupled to the device by way of coaxial transmission line **108**. Within tubular member **111** in the vicinity of the band **106**, electromagnetic energy exists in the principal or TEM mode, with the velocity of wave propagation substantially the same as in free space. More particularly, the electric field is radially directed and the magnetic field lines are disposed in concentric circles around the conductor **102**.

In the required mode of operation in the helix **104**, the electric field lines curve from one turn to another, both inside and outside the helix **104**. The resultant electric field inside the helix **104** extends substantially axially, being directed oppositely at half-wavelength intervals. Since the velocity of axial propagation is relatively low, these intervals are considerably shorter than half-wavelengths in free space. The transition section **101** is effective for accomplishing the desired result.

By introducing magnetic focusing current through lead **105** into the conductor **102**, which in turn is electrically coupled to helix portion **104**, a magnetic focusing field may be established substantially in synchronism with an electron beam, in the same manner as that previously described in connection with the device of Fig. 1. The modulator of Fig. 4 may be employed, if desired.

In Fig. 9 there is shown a further modification of the device of Fig. 1, wherein a magnetic focusing field is provided by an external solenoid **112**. In this arrangement, the helix **113** extending from the opposed ends **114, 116** of the radio frequency coupling tubes **117**, is generally similar to that portion of the helix **18** extending between the ends **54, 56** of the coupling tubes **23, 30** or, stated differently, helix portion **57** of Fig. 1. In Fig. 9 the coupling tubes **117** are formed without a longitudinal slot and are substantially hollow, that is, they are formed without a helix portion **58** (Fig. 3). Thus, in Fig. 9 the helix **113** is effective solely in connection with the interchange of radio frequency energy with the electron beam and is not instrumental in establishing a magnetic focusing field.

For the energization of the device of Fig. 9 the circuit of Fig. 4 may be employed, with leads **64, 66** thereof coupled to leads **118, 119** of coil **112**. In addition, leads **69, 71** may extend to the cathode (now shown) and the anode **34** of the device of Fig. 9. By reason of this arrangement the focusing field, provided by coil **112**, may be established substantially in synchronism with a pulsed electron beam.

Except for the changes introduced by reason of the structural differences the operation of the device of Fig. 9 is essentially similar to that of the device of Fig. 1.

By means of the pulse operation of the device of Fig. 9, which includes the pulsed control of the solenoid **112** in synchronism with the electron beam, a compact lightweight electron discharge device characterized by small power consumption is provided. An appreciation of these and related properties of the device may be gained by considering the weight and heat dissipation properties of the components, such as for example solenoid **112**.

At the outset, it may be noted that the heat dissipation can be reduced by increasing the weight of components, such as solenoid **112**. Several factors may be taken

into consideration, including the weight of the components, such as solenoid **112**, the weight and the capacity of the power supply such as parts of the circuit of Fig. 5, means for cooling, and so forth.

The solenoid **112** may have a length l, an internal diameter $2x$, an average diameter d, and a thickness c. The cylindrical helix may have a diameter $2b$. The ratio of the thickness c to the average diameter d of the solenoid **112** may be defined as q. Thus, the average diameter d of the solenoid **112** may be stated to be

$$\frac{2x}{1-q} \tag{2}$$

The ratio of the total area occupied by the conductor to that of the gross area in connection with the solenoid **112** is the space factor s. Further with regard to the solenoid **112** the gross volume may be designated U, the heat loss P, the resistivity ρ, and the total ampere turns NI. It follows that

$$\frac{U}{l}=\frac{4\pi x^2 q}{(1-q)^2} \tag{3}$$

$$\frac{P}{l}=\left(\frac{NI}{l}\right)^2\frac{\rho\pi}{sq} \tag{4}$$

The power density P_d equals

$$\frac{P}{sU}=\rho\left(\frac{NI}{scl}\right)^2 \tag{5}$$

It follows that

$$\sqrt{\frac{P_d}{\rho}}=\frac{NI}{sl}\cdot\frac{1-q}{2xq} \tag{6}$$

A new parameter η may be defined as equal to

$$\frac{NI}{2xsl}\sqrt{\frac{\rho}{P_d}}=\frac{q}{1-q} \tag{7}$$

It follows that

$$q=\frac{\eta}{1+\eta}=\frac{1}{1+\frac{1}{\eta}} \tag{8}$$

$$\frac{U}{l}=4\pi x^2\cdot\eta(1+\eta) \tag{9}$$

$$\frac{P}{l}=4\pi x^2\eta(1+\eta)P_d s \tag{10}$$

The inductance L and resistance R of a solenoid **112** where $l/c>>1$, $l/d>>1$, that is, for a long coil, is

$$L=\frac{N^2d^2}{l}[0.025-0.0162q]\times 10^{-6} \tag{11}$$

$$R=\frac{N^2\pi d}{scl}\rho=\frac{N^2\pi}{ql}\rho \tag{12}$$

Accordingly,

$$\frac{L}{R}=\frac{sU/l}{\pi^2\rho}(0.025-0.0162q) \tag{13}$$

In Equations 11, 12 and 13 unit length is in inches, R in ohms, L in henries, and current in amperes.

The significance of Equations 2 to 13 may be explained as follows. d is the average diameter of the solenoid **112**, q is the geometrical factor which is the ratio of the thickness of the solenoid **112** to the mean diameter d of the solenoid **112**, and x is the inner radius of the solenoid **112**. In order for the solenoid **112** to be maintained free from electrical interaction with the radio frequency field of the helix **113**, x must be large compared to b, the radius of the helix **113**. When x and q are selected, the volume occupied by the solenoid **112** may be determined by Equation 3. After it is decided how many ampere turns per unit length are to be provided by the solenoid **112**, and the resistivity ρ of the material and the space factor s of the solenoid **112** is known, Equation 4 may be used to determine the power consumption or I^2R loss of the solenoid **112** per unit length. Equations 3 and 4 give the

volume and hence the weight of the solenoid **112**, and the power consumption when the geometric factor q, the inner radius x, the magnetizing force required NI/l, resistivity ρ, and the space factor s are known.

When the coil thickness c is a small fraction of the average diameter d of the solenoid, q is a small quantity and approaches unity when the solenoid **112** is so large that the center aperture is but a small fraction of the outside diameter of the solenoid **112**.

Generally speaking, the value of q must be selected in terms of the power density which may be associated with the particular material. By way of illustration, a coil, such as solenoid **112**, formed of formax copper wire with free air circulation may be employed on the basis of 600 circular mils for every ampere the wire carries. On the other hand, if the wire is formed of copper tubing with cooling water circulation, the allowable power and current density can be materially higher. Therefore, the highest permissible power density sets a lower limit for q. The power density P_d, as set forth in Equation 5, may be used as a design parameter. This together with the given constants, NI/l, ρ, $2x$, s, may be grouped together into one normalization constant η, as defined in Equation 7.

When the power density P_d is fixed, as set forth in Equation 8, q is defined. When the magnitudes of the power density P_d is small, η is large and q approaches unity. When the magnitude of the power density P_d is increased η is small and q approaches η. The volume and power consumption of the solenoid **112** may be redefined in terms of η, as in Equations 9 and 10.

As previously discussed, the device of Fig. 9 may be energized by the modulator of Fig. 4, including the circuit of Fig. 5. It is deemed useful to discuss the inductor **83** together with its resistance **84**, with the inductance and resistance thereof, for convenience, designated L_2 and R_2, respectively. In general, we may employ subscripts **1** and **2** in connection with the solenoid **112** and inductor **83**, respectively.

We may first consider the weight and heat dissipation of the inductor **83** included in loop II of the circuit of Fig. 5. It can be shown that the maximum energy storage in inductor **83** must be the same as the peak energy storage in inductor **79** included in loop I. In order to minimize power dissipation in the combination of inductor **83** and resistance **84**, it is desirable to employ a coil having a high ratio of inductance to resistance. For convenience, such a coil may be designated inductor **83**, it being understood that the resistance **84** is associated therewith. The inductor **83** may have an average radius y, and a thickness and length equal substantially to $\frac{2}{3}$ y. The inductance L_2 and R_2 of such an inductor **83** may be stated, as follows:

$$L_2=0.035\times 10^{-6}N_2y_2 \text{ henries} \tag{14}$$

$$R_2=\rho_2 N_2^2\frac{(2\pi y_2)^2}{s_2U_2} \tag{15}$$

where ρ_2 is the resistivity, s_2 is the space factor, and U_2 is the volume of the inductor **83**.

The ratio of L_2/R_2 is

$$\frac{0.035\times 10^{-6}}{\rho_2}\frac{s_2U_2}{(2\pi)2_{v_2}} \tag{16}$$

The interrelationship of the solenoid **112** and the inductor **83** may be considered. It appears that

$$\frac{I_1^2L_1}{I_1^2R_1}=\frac{s_1U_1l_1}{\pi 2\rho_1}(0.025-0.0162q)\times 10^{-6} \tag{17}$$

$$\frac{I_2^2L_2}{I_2^2R_2}=\frac{S_2U_2}{(2\pi)2_{v_2}\rho_2}(0.035\times 10^{-6}) \tag{18}$$

It can be shown that the ratio of the average power $\overline{P_2}$ to the peak P_1 is

$$\frac{1.6q_1d_1^2\beta}{y_2^2}(1-0.648q_1)\frac{S_1P_2}{S_2P_1} \tag{19}$$

From Equation 19 it appears that the power dissipation in the inductor **83** may be greatly reduced below that of the peak power dissipation of the solenoid **112**, if the radius y_2 is selected as large in comparison with radius x, and if the duty cycle β of loop I of the circuit of Fig. 5 is made low.

In this connection it will be recalled that the terminals **77, 78** of Fig. 5 may be connected to the opposite ends of the helix **18** of the device of Fig. 1. The foregoing analysis is equally applicable to such an arrangement with the quantities suitably adjusted. This may be conveniently, for example, accomplished by considering the helix **18** of Fig. 1 as the solenoid **112** of Fig. 9, that is, the inner diameter of the helix **18** may be taken as $2x$, the average diameter of the helix **18** as d, the diameter of the helix **18** as c, and the length of the helix **18** as l. It may be pointed out that where the helix **18** is arranged to produce the magnetic field, the spacing factor may be shown to be

$$\frac{(0.06)^2\pi/4}{0.06(1/6)}=0.283 \qquad (20)$$

In Figs. 10 and 11 there is shown an electron discharge device of the slow wave propagating variety, which is similar to the device of Fig. 1 in that the slow wave propagating structure is useful for establishing both a radio frequency field and a magnetic focusing field. Means are provided defining a slow wave propagating structure, such as cylindrical helices **125, 130**, the opposed ends of which are substantially abutting. By reason of the arrangement both helices **125, 130** are effective in connection with the interchange of radio frequency energy with an electron beam.

A cathode button **121**, energizable by means of leads **122, 123**, is effective in conjunction with an accelerating electrode or anode **124**, for producing an electron beam with the anode **124** maintained at a suitable potential by means of lead **126**. The electron beam after its traverse of helix **130** may be collected by electron collector **127**. Radio frequency energy may be introduced into and abstracted from the electron discharge device by means of input flat spiral **128** and output flat spiral **129**, respectively.

At the opposed ends of the helices **125, 130**, means are provided for interrupting the slow wave propagating structure, such as helices **125, 130**, which means may include an apertured disc **131**. The disc **131** may be formed of an insulating material, such as fused quartz, and a dissipative coating may be provided by painting the disc **131** with a carbon suspension, such as the substance commonly known as "Aquadag." The coating is preferably distributed over both sides of the disc **131** in approximately sectoral areas **120**, as shown more clearly in Fig. 11, with a generally star-shaped portion **135** of the disc **131** uncoated. Surrounding the disc **131** are additional flat spirals **132, 133**, which are connected to leads **134, 136**, respectively. The inner ends of flat spirals **132, 133**, as well as inner ends of flat spirals **128, 129** may be coupled to or made continuous with the helices **118, 119**. The outer ends of spirals **128, 129** may be connected to leads **137, 138** through inner conductors **139, 141**, respectively.

To establish a magnetic focusing field, magnetic focusing current may be introduced into the helices **125, 130** by use of current pulser **142** and transformer **144**.

In operation, electrons emanating from the cathode button **121** under the influence of the accelerating electrode **124** are formed into an electron beam, which traverses in succession the helices **125, 130**. Radio frequency energy coupled to the input end of helix **125** by means of flat spiral **128** is amplified by reason of the interaction of the electron beam with the radio frequency field associated with helices **125, 130** in a manner similar to that described, for instance, in connection with the device of Fig. 1. At the output end of helix **130**, electromagnetic energy may be coupled to an external load (not shown) by means of flat spiral **129**.

By employing plural sections for a cylindrical helix, such as helix **118** of the device of Fig. 1, different magnitudes of magnetic focusing current may be employed in connection with the aforementioned plural sections. Such plural sections may be constituted of helices **125, 130** as illustrated in the device of Fig. 10. If desired, the arrangement permits the accurate control of the trajectory of an electron beam in terms of the equilibrium radius, that is, the distance at which the space charge repulsion forces balance the magnetic field forces. A discussion of this type of electron beam control is presented in applicant's co-pending application S. N. 186,730, entitled High Frequency Apparatus, filed September 26, 1950, now U. S. Patent 2,741,718, dated April 10, 1956. In addition, if desired, the device of Fig. 1, or any of its modifications may be operated according to such principles.

In the device of Fig. 10, the magnetic focusing current introduced into the helix **125** by means of leads **134, 137** may be of a different magnitude than that introduced into helix **130** by means of leads **136, 138**. In this manner, it is possible to achieve an improved control of the electron beam trajectory. By way of illustration it will be recalled that the electron beam in traversing the helices **125, 130** undergoes density modulation so that, owing to the increased space charge repulsion forces, it may be desirable to employ a magnetic focusing field of greater intensity in connection with helix **130**.

Where it is contemplated to employ a pulsed electron beam, the magnetic field may be established in synchronism with such a beam by means of the current pulser **142**. In this connection, the modulator of Fig. 4, together with the magnetizing pulse generator of Fig. 5 may be useful. More particularly, leads **69, 71** of the power supply **67** may be connected to leads **122, 126** of the device of Fig. 10. In addition, the current transformer **144** of the device of Fig. 10 may be generally similar to the current transformer **96** of the circuit of Fig. 5.

Thus, the electron discharge device provides a means for separately energizing various portions of a slow wave propagating structure, which structure is useful for establishing a magnetic focusing field. Other details of the discharge device of Figs. 10 and 11 are discussed in co-pending application S. N. 171,479, entitled Travelling Wave Tubes, filed June 30, 1950, in the name of Lester M. Field, and assigned to Leland Stanford University, now U. S. Patent 2,712,614, dated July 5, 1955.

While the device of Fig. 10 is particularly useful in connection with the pulsed operation of a slow wave propagating electron discharge device, it will be understood that, if desired, continuous wave operation may be employed. In this connection, the device provides for the establishing of the magnetic focusing field by means of helices **125, 130** in such a manner that different magnitudes of magnetic focusing fields may be employed in conjunction with different portions of an electron beam.

The device of Fig. 10, may include, if desired, the synchronous pulsing of the radio frequency energy introduced therein, by means of flat spiral **128**, together with the electron beam and magnetic focusing field. In addition, if desired the cathode structure, including the cathode button **16**, focusing electrode **33** and the anode **34**, of, for example, Fig. 1, may be employed in substitution in part or in whole for the cathode button **121** and anode **124**. Moreover, if desired external magnetic focusing coils, such as solenoid **112** of Fig. 9 may be employed to produce magnetic fields of different strength along the axis of the electron beam, thereby providing for a more accurate control of the trajectories of the electrons thereof.

It is apparent that many changes could be made in the construction of the device discussed hereinabove and that many apparently different embodiments of the invention could be made without departing from the scope thereof. For example, many of the structural arrangements, while particularly suitable for pulsed operation, are also suitable for continuous wave operation. Accordingly, it is

intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. An ultra high frequency apparatus comprising means for producing an electron stream directed along a predetermined axis, a slow wave propagating structure associated with the stream producing means and extending along said axis, a source of radio frequency energy, radio frequency input means coupling energy from said source to the slow wave propagating structure for transmitting ultra high frequency energy along the slow wave propagating structure in the direction of travel of the electron stream, electromagnetic focusing means extending along said axis, and pulse generating means electrically connected to the electromagnetic focusing means for supplying pulsed excitation current to the electromagnetic focusing means, said pulse generating means being coupled to the electron stream producing means and said source for synchronously pulsing the energy output of the electron stream producing means and ultra high frequency source with the pulsing of the electromagnetic focusing means.

2. An ultra high frequency apparatus as defined in claim 1 wherein the slow wave propagating structure and electromagnetic focusing means include a common helical conductor.

3. An ultra high frequency apparatus as defined in claim 1 wherein the pulse generating means include means for exciting said focusing means a longer pulse time duration than the stream producing means and the ultra high frequency source means.

4. An ultra high frequency apparatus comprising means for producing an electron stream directed along a predetermined axis, a slow wave propagating structure associated with the stream producing means and extending along said axis, electromagnetic focusing means extending along said axis, and means coupled to said electron stream producing means and said focusing means for synchronously pulsing the electron stream producing means and the electromagnetic focusing means.

5. High frequency travelling wave tube apparatus, comprising electron gun means for producing and directing an electron beam having a boundary of predetermined configuration along a linear axis, a collector longitudinally spaced along said axis from said gun for receiving said electron beam, highly conductive helix means comprising a slow wave propagating structure for high frequency electromagnetic waves extending along said axis between said collector and said electron gun means and positioned for interaction of electromagnetic waves propagated along said helix means with said beam, envelope-defining means about said axis for maintaining said beam and said helix means in a vacuum, conductor means electrically connected to opposite ends of said helix means, said conductor means having supply terminals externally of said envelope means for receiving a magnetizing current for passage by said helix means along a helical path to produce an axial magnetic focussing field of sufficient flux density for controlling said electron beam for maintaining the boundary of said beam at a substantially constant diameter along said helix means.

6. High frequency travelling wave tube apparatus as set forth in claim 5, wherein said conductor means comprises first and second tubular conductors in coaxial relationship with said helix means at opposite ends thereof, said tubular conductors having substantially the same diameter as said helix means with the helix end of each tubular conductor terminating on a bias angle with respect to said predetermined axis, longitudinal slot means in each of said tubular conductors, and first and second hollow wave guides each having a pair of apertures through opposite wave guide walls for receiving said helix means and tubular conductors with the helix end portions of said first and second tubular conductors being in the interiors of said first and second wave guides, respectively, for coupling of electromagnetic energy between said wave guides and said helix means.

7. Ultra high frequency apparatus comprising means for producing an electron stream directed along a predetermined axis, a tubular conductive member having a variable pitch helical slot, a helix of conductive material connected to one end of the tubular member, the helix and tubular member being axially aligned with the electron stream producing means along said predetermined axis for passage of the electron stream successively through the tubular conductor and helix, means electrically connected across the tubular conductive member and helix for passing a current therethrough to provide a magnetic field along the electron stream, and means for synchronously pulsing the electron stream producing means and said last-named means for passing current through the helix.

8. High frequency apparatus comprising means for producing an electron stream directed along a predetermined axis, two coaxially-disposed cylindrical helices aligned along said axis and having their opposed ends substantially abutting, energizing means connected across said helices for introducing different magnitudes of current into each of said helices, whereby said helices provide magnetic focusing fields of different strength, and means for synchronously pulsing the electron stream producing means and said energizing means.

9. High frequency travelling wave tube apparatus, comprising a vacuum envelope having a linear axis, a highly conductive helix having a region of substantially constant diameter extending along the axis of said envelope, said helix comprising means for propagating slow wave electromagnetic energy, electron gun means at one end of said helix for producing and directing an electron beam for travel along said axis within said envelope for interaction with electromagnetic energy propagated along said helix, collector means at the other end of said helix for receiving said beam, means including a source of pulsed unidirectional voltage coupled to said helix for producing a magnetizing current pulses for passage by said helix along a helical path for providing an axial magnetic beam controlling field for maintaining the diameter of said electron beam substantially constant along said helix, and means coupled to beam producing means for pulsing said beam in synchronism with said magnetizing current pulses.

10. High frequency apparatus comprising an elongated vacuum tube having a longitudinal axis, coil means extending along said axis, means for generating a stream of electrons directed along the axis of the tube and through said coil means, the coil means when energized producing a magnetic field extending substantially parallel to the electron stream in the region of the stream, pulse generating means electrically connected to the coil means for passing pulsed unidirectional current through the coil means, and means operatively associated with the electron stream generating means for interrupting the electron stream, the stream interrupting means being synchronized with the pulse generating means whereby the stream of electrons flows only during the time the coil means is energized.

11. High frequency apparatus comprising an elongated vacuum tube having a longitudinal axis, a helix of conductive material extending along the axis of the tube, means for generating a stream of electrons directed along the axis of the tube and through said helix, pulse generating means electrically connected to the helix for passing pulsed unidirectional current through the helix, the helix when energized producing a magnetic field extending substantially parallel to the electron stream in the region of the stream, means for coupling ultra high frequency energy to the helix for propagation therealong in the direction of the electron stream, and means operatively

associated with the electron stream generating means for interrupting the electron stream, the stream interrupting means being synchronized with the pulse generating means whereby the stream of electrons flows only during the time the helix is pulsed with unidirectional current.

12. High frequency travelling wave tube apparatus as set forth in claim 5, further including means coupled to said electron gun means for pulsing said electron beam, means coupled to said supply terminals external of said envelope defining means for supplying a pulsating unidirectional current to said helix means for providing a pulsed magnetic focusing field, and means coupled to said last two-named means for substantially synchronizing the pulsing of the electron beam and the magnetic focusing field.

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