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2,679,019

HIGH-FREQUENCY ELECTRON DISCHARGE DEVICE

Filed Dec. 2, 1947

2 Sheets-Sheet 1

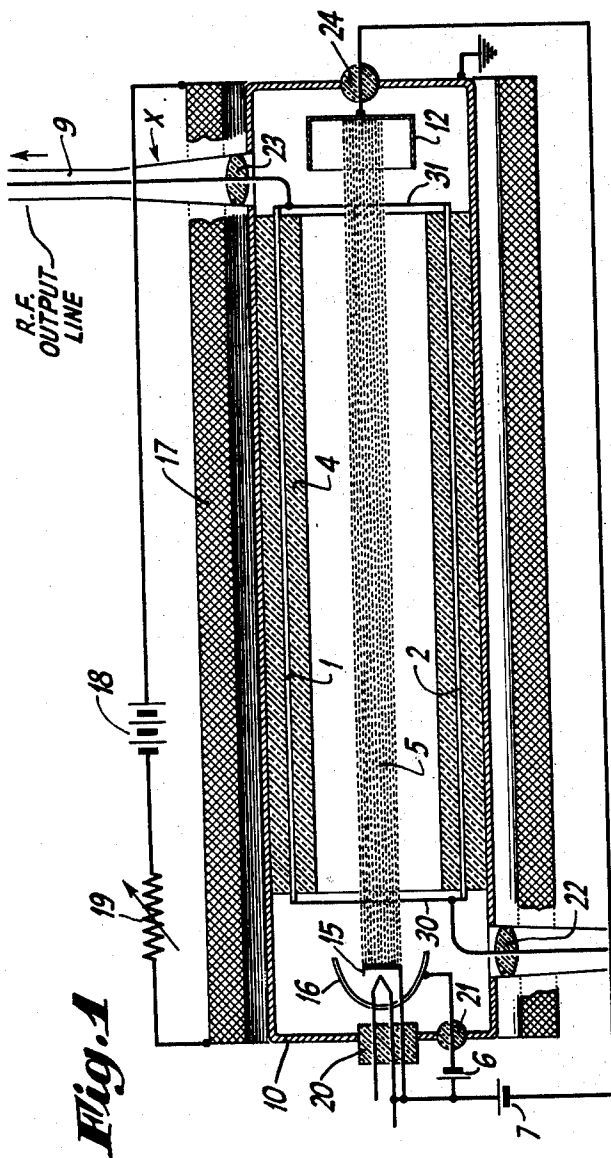


Fig. 1

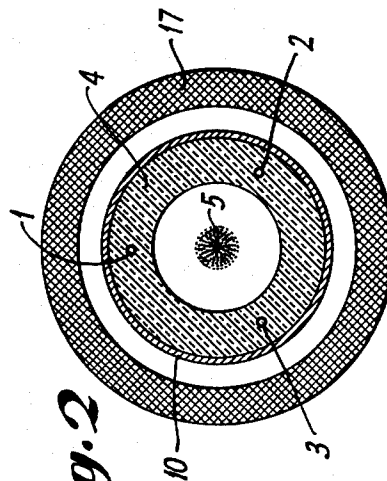


Fig. 2

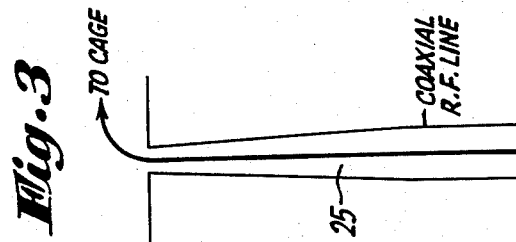


Fig. 3

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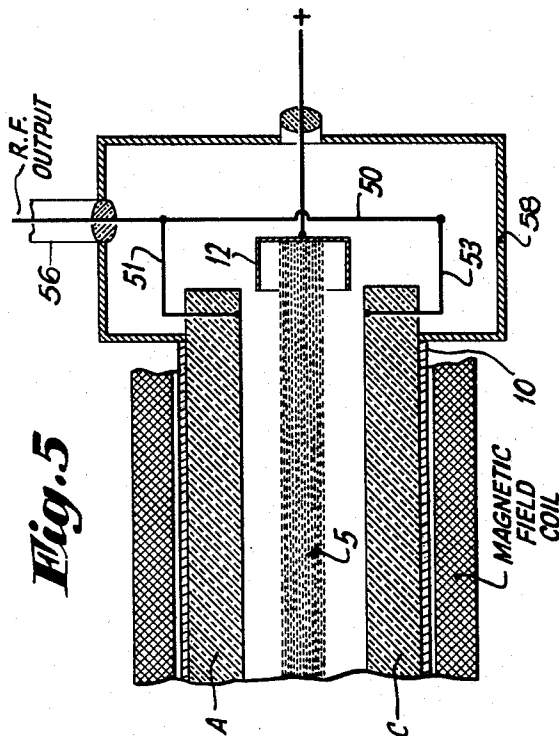


Fig. 5

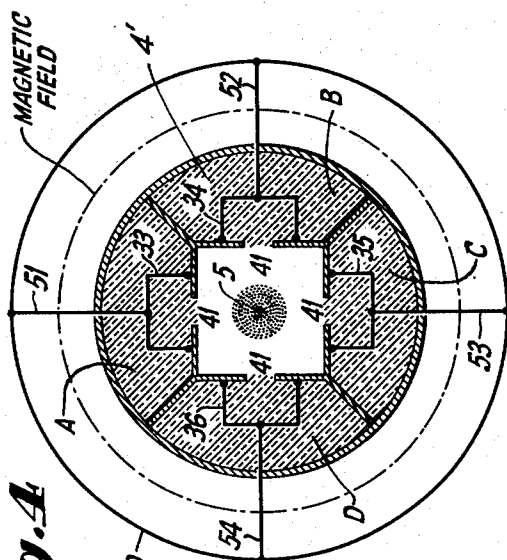


Fig. 4

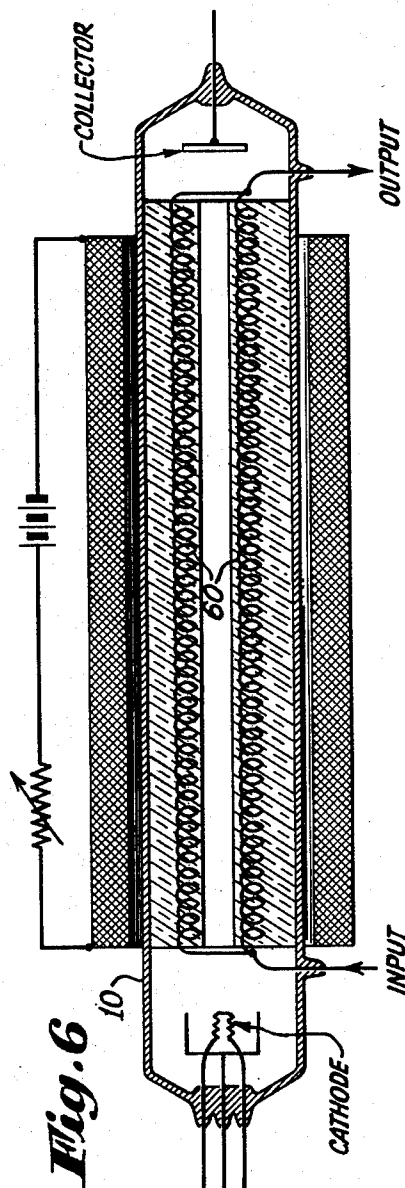


Fig. 6

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UNITED STATES PATENT OFFICE

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HIGH-FREQUENCY ELECTRON DISCHARGE
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23 Claims. (Cl. 315-3)

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This invention relates to electron discharge devices and circuit therefor, especially adapted for use at very high frequencies of the order of 600 megacycles ranging into many thousands of megacycles, and particularly to an electron discharge device capable of operating over a wide band of frequencies such as would be required in a radio relay system.

An object of the present invention is to provide an improved growing wave (sometimes called a traveling wave) type of tube in which a wave travels along a conductor arranged adjacent, parallel, and in energy coupling relation to a stream of electrons.

Another object is to provide an improved electron discharge device amplifier capable of amplifying a wide band of high frequencies and which does not depend upon resonance phenomenon in the output circuit.

It has been suggested in growing wave types of tubes to surround an electron stream with a helical conductor which extends along an appreciable portion of the length of the electron stream and to substantially match the velocity of the wave traveling along this helical conductor to the velocity of the electron stream. The helical conductor in this case would be so constructed and arranged that its projected axial velocity would be different from but substantially or nearly equal to that of the electron stream in order to assure energy transfer therebetween in the proper direction; viz, from the helical line to the electron stream or vice versa. For a general description of the broad principles involved in these growing wave tubes, reference is herein made to my U. S. Patent 2,300,052, granted October 27, 1942, and to my copending applications Serial Numbers 724,330, filed January 25, 1947, and 756,851, filed June 25, 1947, now Patent No. 2,578,434, dated December 11, 1951.

The growing wave tube of the present invention, in accordance with one embodiment, achieves the desired velocity relation between the wave traveling in the conductor adjacent the electron stream and the electron stream by embedding the conductor in a suitable solid medium of such dielectric and/or magnetic properties that the velocity of the wave traveling along the embedded conductor or line has a value which assures the proper transfer of energy between the conductor (line) and electron stream without coiling or spiraling the conductor. The conductor or line may consist simply of one or a plurality of straight wires arranged parallel to the electron stream; as for example, in the form of

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a cage around the stream. This cage should not possess the properties of a perfect shield, such as are possessed by a cylindrical-shaped electron impermeable metallic tube. This cage form of construction of the invention offers certain manufacturing advantages, among others.

It will be understood that one or more straight wires in air or vacuum would propagate waves therealong at very high velocity, approaching the velocity of light. Therefore, the straight wires are embedded in a solid dielectric or magnetic medium to slow down the waves therealong to practical electron velocities.

It should, of course, be understood that if such dielectric and/or magnetic material, having the required high constants for the use of linear lines is not readily available, the use of dielectric and/or magnetic materials with lesser constants will permit the use of coiled lines embedded therein having greater pitch than would otherwise be possible. This means that mutual turn affects, would be reduced and that such lines could be constructed having lower characteristic impedance.

Another embodiment of growing wave tube of the invention involves the use of a waveguide positioned adjacent and parallel to the electron stream and filled with a suitable solid medium having such dielectric and/or magnetic properties that the desired velocity relation between electron stream and the wave traveling through the wave guide is obtained. In this embodiment, however, the velocity variations which take place in the waveguide with changes in frequency should be such as not to handicap the operation of the system.

Still another embodiment of the invention utilizes a plurality of coiled but spaced lines of very small circumference arranged parallel to the electron stream and lying in vacuo or embedded in a solid medium of suitable dielectric and/or magnetic properties to obtain the desired wave velocity relation. The diameter of each coiled line is made so small that the circumference formed by one turn is only a small fraction of a half wave. In this way the variable mutual effects formed between adjacent turns from wave distributional effects is avoided. In other words two wave crests of equal or opposite polarities cannot exist adjacent to each other in the coiled line. These coiled lines may be arranged to form a cage.

A more detailed description of the invention follows in conjunction with drawings, wherein: Fig. 1 illustrates a longitudinal cross-section

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of the preferred embodiment of a growing wave tube constructed in accordance with the principles of the invention;

Fig. 2 is a transverse sectional view through the center of Fig. 1;

Fig. 3 is a detail, showing a tapered transmission line which can be connected to the input or output end of the tube of Fig. 1;

Fig. 4 is a transverse cross-section of another growing wave tube embodiment of the invention, using waveguides;

Fig. 5 is a longitudinal section view of the output end of the growing wave tube embodiment of Fig. 4; and

Fig. 6 illustrates a longitudinal sectional view of another embodiment of the invention which utilizes a cage formed from a plurality of small diameter interconnected coiled lines.

Referring to Figs. 1 and 2, the growing wave tube of the invention, which is especially suitable as an amplifier of very high frequency waves over a very wide band of frequencies, comprises a non-magnetic metallic envelope 10 which surrounds a hollow cage of three wave carrying elements in the form of straight parallel wires 1, 2 and 3, the cage, in turn surrounding and being in energy transfer relation to an electron stream 5 passing along the longitudinal axis of the tube. The wires 1, 2 and 3 are each embedded in and completely surrounded by a suitable annular solid medium 4 having dielectric and/or magnetic properties such as to produce the desired velocity relation between a wave traveling down the wires and the velocity of the electron stream. The wires 1, 2 and 3 are connected together at both ends of the cage by a wire ring or connecting leads 30 and 31. A suitable cathode 15 backed up with a negatively charged electron repeller electrode 16 is provided at one end of the tube for furnishing a heavy concentrated stream of electrons which pass through the center of the cage of wires 1, 2 and 3, for the collection by a collector electrode 12 at the other end of the end. The repeller electrode 16 is maintained at a negative potential relative to the cathode by means of battery 6. The collector electrode 12 is maintained at a slight positive (or if desired at a slight negative potential) relative to the cathode by means of a battery 7). The cathode is shown by way of illustration only, and in practice may take other forms. A magnetic field coil 17 surrounds the tube and is energized by a D. C. source 18 in series with the variable resistor 19. This coil 17 is so arranged that the lines of flux produced thereby extend parallel to the longitudinal axis of the tube in order to focus the beam of electrons along the center of the tube, and prevent the electrons from impinging on the medium 4.

The metallic envelope 10 is at ground potential. A coaxial input line 8 supplies radio frequency input current to that end of the cage of wires 1, 2, 3 which is nearest the cathode, while the amplified current is abstracted from the other end of the cage by an output coaxial line 9. In order to assure a vacuumtight shell or envelope 10, glass beads 22 and 23 are provided in the input and output coaxial lines at a location near shell 10. Other glass beads 20, 21 and 24 are also provided at those locations where leads enter the interior of the envelope 10.

The cage of wires 1, 2 and 3 has a length which is a plurality of wavelengths long, for example 15 to 40 wavelengths long at the mean operating frequency, and provides a velocity for waves

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traveling over the wires which is determined by the dielectric and/or magnetic material in which they are embedded. If desired, the wires 1, 2 and 3 may be given such D. C. potentials as may be required by particular circuit designs.

If a predominantly dielectric medium 4 is employed, it is necessary, in order that conventional electron accelerating voltages may be used, for the material to have a high dielectric constant. One such material which may be used is titanium dioxide. If a predominantly magnetic medium is employed for material 4, this medium may comprise extremely fine powder of a suitable iron alloy or a powder comprising an iron oxide. This powder should be dispersed in and bound together by a suitable dielectric binder preferably one that can be molded. Suitable proportions of dielectric and magnetic materials may be used in a mixture to obtain a medium which will give a desired propagation velocity for the waves traveling along the embedded wires 1, 2 and 3.

Because the characteristic impedance of the cage 1, 2, 3 is different from that of the coaxial input and output R. F. lines 8 and 9, it is necessary to match the impedance of these coaxial lines to the characteristic impedance of the cage. Where the cage has a higher characteristic impedance than the coaxial lines, it may be advisable to insert a tapering impedance X as a transmission line link or impedance transformer between the coaxial lines and the terminals of the cage. This link X is inserted externally of the electron discharge device between the cage terminal and the coaxial line, as shown. It should be noted that the diameter of the tapering link X decreases from a point near the cage to the point where the link joins the coaxial lines 8 or 9. These coaxial lines may have an impedance of 50 ohms, for example, while the cage may have a considerably higher characteristic impedance. Where the reverse conditions exist, that is, where the cage has a characteristic impedance less than that of the coaxial lines, then there may be used a tapering impedance transmission line link or impedance transformer 25 as shown in Fig. 3, where the diameter of the link 25 increases from a point near the cage to the point where the link joins the coaxial input or output line.

If the medium 4 is predominantly magnetic, the cage of wires 1, 2, 3 is apt to possess a high characteristic impedance Z_0 . If the medium 4 is predominantly dielectric, then the cage of wires 1, 2, 3 is apt to possess a low characteristic impedance Z_0 .

Fig. 4 shows a construction of growing wave tube in which a plurality of wave carrying elements in the form of similar and coextensive waveguides A, B, C and D are symmetrically arranged around the longitudinally projected electron stream 5. Each wave guide comprises a metal enclosure having a slot 41 extending down the length thereof. This slot is arranged parallel to and in proximity to the electron stream 5. Each waveguide is filled with a suitable solid medium 4', possessing dielectric or magnetic properties or a mixture of both, as outlined above in connection with medium 4 of Figs. 1 and 2. The wave velocity along the waveguides A, B, C and D in air or vacuum, without the solid medium, would be relatively high as compared to practical electron velocities. At both ends of the tube, the slots in the waveguides are bridged by wire connections 33, 34, 35 and 36. The wire connections 33 to 36 are respectively

connected at both ends of the waveguides to wire rings 50 by means of leads 51, 52, 53 and 54. The input coaxial line, not shown, supplies radio frequency current to the ring 50 at the end of the tube nearest the cathode (not shown), while the amplified output currents are taken off from the ring 50 at that end of the tube nearest the collector 12, and supplied to the R. F. output coaxial line 56 (note Fig. 5). A metallic cover or shield 58 is provided at the output end of the tube, and a similar shield may be provided at the input end of the tube.

Although three embedded wires 1, 2 and 3 have been shown for the cage of Figs. 1 and 2, and four waveguides A, B, C and D have been shown for the tubes of Figs. 4 and 5, it should be understood that these are only for purpose of illustration and that fewer or a greater number of these elements may be employed in practicing the invention. Even a single embedded wire or a single waveguide may be used in the tube of the invention.

Fig. 6 illustrates another embodiment of the invention employing a cage composed of a plurality of wave carrying elements in the form of coiled lines 60 each of which has relatively large pitch and a diameter so small that the circumference formed by one turn is only a small fraction of a half wave of the operating radio frequency energy. The ends of the coiled lines are connected together as shown, in a manner somewhat similar to that shown in Fig. 1, in order to form a cage. Although only two such lines are shown, in practice, three or more such lines may be used, properly spaced apart. The coiled lines may be embedded in and completely surrounded by a suitable solid material 61 having desired dielectric and/or magnetic properties, or used in vacuo merely by arranging them within the evacuated envelope 19 suitably spaced from electron stream projected by the cathode toward the collector electrode. It will be understood that where the coiled lines 60 are embedded in a wave retarding solid medium the pitch of the helix can be made as great as desired. In Fig. 6, the electron beam will pass down the center of the cage and be internal relative to the coiled lines. If desired, the electron beam can be a hollow stream passing adjacent to but external of the cage. Only the essential components of the traveling wave tube have been shown diagrammatically in Fig. 6, in order not to unnecessarily complicate the drawing. The input radio frequency means and the output radio frequency means may comprise coaxial lines connected to the cage in the same manner as shown in Fig. 1.

The arrangements of the cage of Figs. 1, 2 and 6, and of the waveguides of Figs. 4 and 5 are such that the input waves travel longitudinally down the cage or waveguides at the portion of the tube nearest the cathode at a velocity slightly greater than the velocity of the electron stream in order to impart energy to the electrons and bunch them, while this velocity relation is reversed along the central portion and opposite end of the tube in order to abstract energy from the stream.

It should be understood that the line elements 1, 2, 3 of the cage of Figs. 1 and 2 need not necessarily be similar in dimensions as long as they are similar in velocity characteristics for waves traveling thereover, and in distribution. It is preferred, however, that the linear wires of the

cage have identical dimensions and characteristics.

What is claimed is:

1. An electron discharge device including means for projecting a stream of charged particles, a radio frequency wave carrying element positioned parallel to the path of said stream and adapted to be in energy coupling relation to said stream, said element being embedded in a solid medium having a dielectric constant causing the velocity of the waves traveling along the length of said element to match approximately the velocity of said stream of charged particles, said element being completely surrounded by said medium.

2. An electron discharge device including means for projecting a stream of charged particles, a radio frequency wave carrying element positioned parallel to the path of said stream and adapted to be in energy coupling relation to said stream, said element being embedded in a solid medium having dielectric and magnetic properties causing the velocity of the waves traveling along the length of said element to match approximately the velocity of said stream of charged particles, said element being completely surrounded by said medium.

3. An electron discharge device including means for projecting a stream of charged particles, a conductor positioned parallel to the path of said stream and adapted to be in energy coupling relation to said stream, said conductor being embedded in a solid medium having a high dielectric constant to reduce the velocity of waves traveling along said conductor, said conductor being completely surrounded by said medium, means for producing a magnetic field having flux lines running parallel to said stream of charged particles, and a radio frequency terminal means coupled to said conductor near one end thereof.

4. An electron discharge device including means for projecting a stream of charged particles, a straight conductor positioned parallel to the path of said stream and adapted to be in energy coupling relation to said stream, said conductor being embedded in a solid medium having a high dielectric constant to reduce the velocity of waves traveling along said conductor, said conductor being completely surrounded by said medium, means for producing a magnetic field having flux lines running parallel to said stream of charged particles, and a radio frequency terminal means coupled to said conductor near one end thereof.

5. An electron discharge device including means for projecting a stream of charged particles, a straight conductor positioned parallel to the path of said stream and adapted to be in energy coupling relation to said stream, said conductor being embedded in a solid medium having a high dielectric constant to reduce the velocity of waves traveling along said conductor, said conductor being completely surrounded by said medium, a radio frequency input terminal means coupled to one end of said conductor, and a radio frequency output terminal means coupled to the other end of said conductor.

6. An electron discharge device including means for projecting a stream of charged particles along an axis of said device, a plurality of straight conductors spaced from one another and positioned parallel to the path of said stream and forming a cage around said stream, means for producing lines of magnetic flux in a direction parallel to the path of said stream for causing

said stream to travel along said axis, said conductors being embedded in a solid medium having a high dielectric constant to reduce the velocity of waves traveling along said conductors, at least a portion of said medium being outside said cage, connections between said conductors at both ends thereof, a radio frequency input terminal means coupled to that end of said conductors nearest the source of charged particles, and a radio frequency output terminal means coupled to the other end of said conductors.

7. An electron discharge device including means for projecting a stream of charged particles, a plurality of straight conductors spaced from one another and symmetrically disposed to form a cage around the path of said stream and arranged parallel to the path of said stream, said conductors being adapted to be in energy transfer relation to said stream by virtue of the space therebetween, a hollow annulus of solid material surrounding said stream and embedding said conductors therein, said annulus having dielectric and magnetic properties causing a wave traveling along said conductors to have a velocity which approximates the velocity of said stream of charged particles, at least a portion of said medium being outside said cage, means for focusing said stream to follow a path parallel to the lengths of said conductors, connections between said conductors at both ends of said annulus, and input and output radio frequency terminal means coupled to opposite ends of said conductors.

8. An electron discharge device including within an evacuated envelope means for projecting a stream of electrons along an axis of said device, a plurality of coextensive and similar straight waveguides extending parallel to but spaced from said axis and forming a cage around said stream, each of said waveguides having a slot adjacent said stream and extending along the length of said guide, said guides having in their interiors a solid medium having dielectric and magnetic properties causing the velocity of the waves traveling along the guides to approximate the velocity of said stream, connections between said guides at both ends thereof, a radio frequency input terminal means coupled to said connections at that end nearest the source of electrons, and a radio frequency output terminal means coupled to said connections at the other end thereof.

9. An electron discharge device as defined in claim 1, characterized in this, that said element is a coiled line of relatively large pitch.

10. An electron discharge device including means for projecting a stream of charged particles, a plurality of physically spaced wave carrying elements positioned parallel to the path of said stream and forming a cage around said stream, said elements being embedded in a solid medium having dielectric properties causing the velocity of waves traveling along said elements to approximate the velocity of said stream, electrical connections between correspondingly positioned ends of said elements, a radio frequency input terminal means coupled to the connections at one end of said elements, and an output terminal means coupled to the connections at the other end of said elements, each of said elements comprising a coiled line whose pitch is relatively large and whose diameter is so small that the circumference formed by one turn is only a small fraction of a half wave of the operating frequency.

11. An electron discharge device according to claim 2 wherein the magnetic properties of said

medium predominate over the dielectric properties.

12. An electron discharge device including means for projecting a stream of charged particles, a radio frequency wave carrying element positioned parallel to the path of said stream and adapted to be in energy coupling relation to said stream, said element being embedded in a solid dielectric material having dispersed therein comminuted particles of magnetic material, the properties of said dielectric material and particles of magnetic material causing the velocity of the waves traveling along the length of said element to match approximately the velocity of the stream of charged particles, said element being completely surrounded by said medium.

13. An electron discharge device including means for projecting a stream of charged particles, a plurality of radio frequency wave carrying elements spaced from one another and positioned parallel to the path of said stream and forming a cage around said stream, said elements being embedded in a solid medium comprising powdered magnetic material whose characteristics cause the velocity of the waves traveling along the length of said elements to match approximately the velocity of the stream of charged particles.

14. An electron discharge device including a plurality of spaced, parallel radio-frequency wave-carrying elements forming a cage, means for reducing the velocity of waves traveling along said elements to a predetermined wave velocity comprising a solid dielectric medium in which said elements are embedded, and means for projecting a stream of charged particles coaxially of said cage and parallel to said elements at a velocity approximately matching said predetermined wave velocity.

15. An electron discharge device including means for projecting a stream of charged particles, a plurality of spaced wave carrying elements positioned parallel to the path of said stream and forming a cage around said stream, said elements being embedded in a solid medium having dielectric properties causing the velocity of waves traveling along said elements to approximate the velocity of said stream, connections between correspondingly positioned ends of said elements, a radio frequency input terminal means coupled to the connections at one end of said elements, and an output terminal means coupled to the connections at the other end of said elements.

16. A traveling wave tube including a radio frequency wave carrying line having a structure determining a relatively high in vacuo wave velocity therealong, means for reducing the velocity of waves along said line to a substantially lower wave velocity than said in vacuo velocity comprising a solid medium in which said line is embedded, said line being completely surrounded by said medium, means for projecting a stream of electrons parallel to and in energy-coupling relation to said line at a velocity substantially matching said lower wave velocity, and input and output transmission lines coupled to the input and output ends, respectively, of said first named line.

17. A traveling wave tube as in claim 16, wherein said medium is predominantly dielectric.

18. A traveling wave tube as in claim 16, wherein said medium is predominantly magnetic.

19. A traveling wave tube as in claim 16,

wherein said first named line comprises a straight wire.

20. A traveling wave tube as in claim 16, wherein said first named line comprises a coiled line of relatively large pitch.

21. A traveling wave tube as in claim 16, wherein said first named line comprises a plurality of elongated conductors parallel to and forming a cage about said stream.

22. An electron discharge device including means for projecting a stream of charged particles along an axis of said device, a plurality of wave carrying elements extending parallel to but spaced from said axis and forming a cage around said stream, and means causing the velocity of waves traveling along said elements to approximate the velocity of said stream comprising a solid medium adjacent to at least a portion of the surface of each of said elements.

23. An electron discharge device as defined in claim 22, further including connections between said elements at both ends thereof, a radio fre-

quency input terminal means coupled to said connections at that end nearest the source of charged particles, and a radio frequency output terminal means coupled to said connections at the other end thereof.

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