Nov. 5, 1957 J. S. COOK ET AL 2,812,470

PERIODIC FOCUSING IN TRAVELING WAVE TUBES

Filed Oct. 22, 1954

FIG. 1

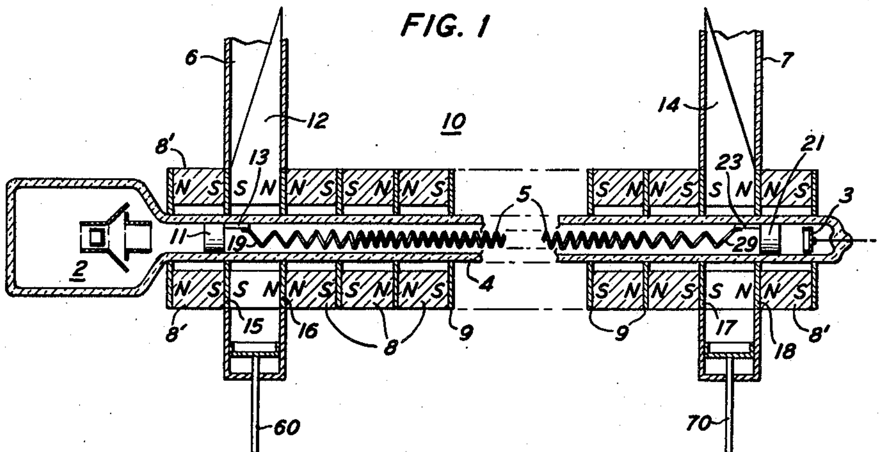


FIG. 2

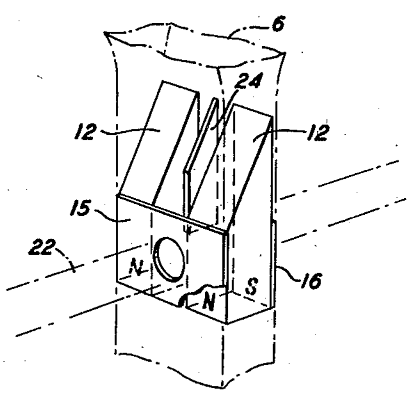


FIG. 3

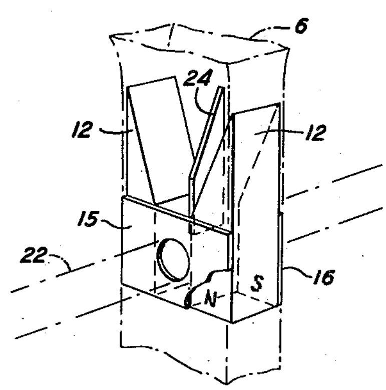


FIG. 5

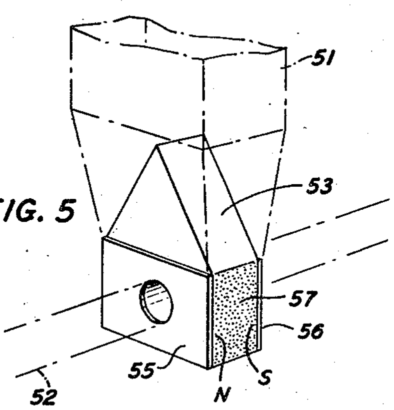
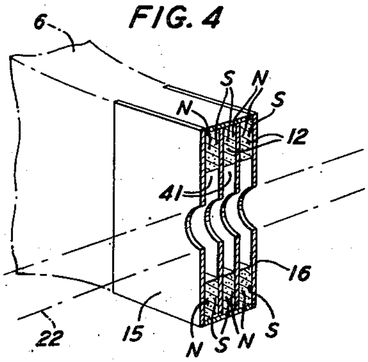


FIG. 4



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PERIODIC FOCUSING IN TRAVELING WAVE TUBES

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16 Claims. (Cl. 315—3.5)

This invention relates to apparatus for focusing an electron beam in a traveling wave tube, and more particularly in traveling wave tubes provided with hollow wave guide coupling elements for coupling microwave energy thereto.

In a traveling wave tube, an electron stream is projected in coupling proximity with an electromagnetic wave propagating along a slow wave interaction circuit. For the most efficient operation, it is important to maintain the electron flow cylindrical (i. e., neither convergent nor divergent) to avoid having electrons strike the slow wave circuit and to direct the cylindrical electron flow in close proximity to the slow wave circuit for maximum coupling. To this end, it is necessary to provide effective focusing along the entire length of the interaction circuit of the traveling wave tube. In order to obtain effective focusing throughout this region it is generally desirable that the electrons be focused into a beam from the onset of their emission from the electron gun and maintained in this beam until they have passed through the interaction circuit.

Various focusing arrangements have been proposed employing the recently developed technique of periodic focusing. This technique of focusing utilizes a succession of longitudinal fields periodically spaced in a linear array. Each of the fields are symmetrical about a common axis and the polarity of adjacent fields in the succession is reversed to form, in effect, a time-constant spatially alternating field along this axis. This spatially alternating field provides effective focusing for an electron beam projected along the axis. Some of the advantages of this type of focusing are discussed in an article entitled "Electron Beam Focusing With Periodic Permanent Magnet Fields" by J. T. Mendel, C. F. Quate, and W. H. Yocum, Proceedings of the I. R. E., vol. 42, No. 5, May 1954, pages 800–810. A very important practical advantage enjoyed by these focusing arrangements is a sharp reduction in weight over focusing arrangements utilizing a uniform longitudinal magnetic field. A shortcoming, however, of the periodic focusing structures proposed heretofore has been that a discontinuity in the periodic focusing field is ordinarily occasioned by the coupling connectors positioned to couple microwave energy into, and out of, the traveling wave tube. This shortcoming is manifest most strikingly in the case of hollow wave guide coupling elements since the wave guide, being positioned to couple energy in close proximity to the electron beam, interrupts the longitudinal array of magnetic elements arranged for producing a periodic field for focusing the beam. The comparatively large size of the wave guide elements effects a rather large gap in the otherwise continuous periodic focusing field. If the magnetic elements are positioned on either side of the wave guide coupling elements and this spacing is maintained along the length of the interaction circuit, a periodic spatially alternating field will be established but the length of the period will be too great ordinarily to afford satisfactory focusing.

Proposed arrangements for bridging these coupling elements so as to maintain one or more periods of the spatially alternating field in the region of the elements have resulted in the use of rather large bridging magnets thereby lessening the advantage of employing this type of operation.

A principal object of the present invention is to adapt the principles of continuous periodic focusing to traveling wave tubes which employ hollow wave guide coupling connections to the interaction circuit.

A related object is to permit the use of hollow wave guide coupling connections to the interaction circuit of a traveling wave tube without disturbing the periodicity of the spatially alternating magnetic field used for focusing.

To this end a feature of the present invention is a focusing structure comprising a succession of magnetic elements and including elements properly designed and inserted in the interior of the hollow wave guide coupling connections for maintaining continuous periodic focusing in this region.

In an illustrative embodiment of the present invention a traveling wave tube having input and output wave guide coupling connections is provided with a periodic focusing arrangement which comprises a succession of ferroxdure permanent magnets positioned along the path of electron flow forming a succession of longitudinal magnetic fields. The sense of adjacent magnets is reversed thereby reversing the direction of the longitudinal magnetic fields along the path of flow. A pair of the ferroxdure magnets is positioned within each of the wave guide connections to the traveling wave tube, on opposite sides of the central axis of the wave guide. The magnets are preferably tapered in a direction parallel to the central axis of the wave guide and away from the traveling wave tube and the wave guide is ridged for a distance along its central portion for concentrating the propagated wave energy in the region of the ridge away from the magnets.

The composition and properties of ferroxdure are set forth in an article entitled "Ferroxdure, a Class of New Permanent Magnet Materials" by J. J. Went, G. W. Ratheman, E. W. Gorter and G. W. van Oosterhout in the January 1952 issue of the Philips Technical Review (vol. 13, No. 7, pages 194 to 208). As used herein ferroxdure refers to the oxide $BaFe_{12}^{III}O_{19}$ which has a hexagonal crystal structure and has one axis of easy magnetization parallel to the hexagonal axis.

The above and other features and objects of the invention will become apparent by referring to the following description taken in connection with the accompanying drawings, in which:

Fig. 1 shows, in a traveling wave tube, a continuous periodic focusing structure in accordance with the present invention;

Fig. 2 shows an enlarged perspective view of the wave guide couplers of Fig. 1, having a portion cut away for purposes of illustration;

Fig. 3 shows a modified form of wave guide couplers for use in Fig. 1, having a portion of the guide cut away;

Fig. 4 is a perspective view of a modification of the wave guide couplers shown in Figs. 2 and 3, and

Fig. 5 is perspective view of an alternative form of wave guide coupler shown in coupling connection with a traveling wave tube, in accordance with the present invention.

Referring now more particularly to the drawings, Fig. 1 shows an illustrative periodic focusing arrangement embodied in a traveling wave tube **10**. In this tube electron gun **2** and target **3** are positioned within an evacuated envelope **4** and maintained at suitable operating voltages by lead-in conductors not shown. This establishes an electron beam along the length of the envelope between these electrodes. The electrodes are shown schematically for purposes of simplification. Helix **5** is positioned around the electron path for propagating an electromagnetic wave in coupling proximity thereto and in operation is maintained at a suitable accelerating potential. Wave guides **6** and **7** are positioned in wave energy transfer relationship with helical slow wave circuit **5**, in the manner described in Patent 2,575,383, issued November 20, 1951, to L. M. Field. These wave guides are tapered inwardly in a direction toward the traveling wave tube from the dimensions of a standard hollow wave guide to suitable smaller dimensions for coupling to the relatively small diameter tube. The wave guides may be terminated by metallic plungers **60, 70** or other suitable means for minimizing reflections.

There is provided at the one end of the helix a hollow cylindrical non-magnetic metallic section **11** which supports a coupling strip **13** and at the other end of the helix a similar cylindrical section **21** which supports coupling strip **23**. These coupling strip support sections are maintained in spaced relation with the electron gun and target by ceramic spacing elements not shown. The helix **5** is joined to the coupling strips **13** and **23** by the impedance matching sections **19** and **29**, respectively. These matching sections are simply extensions of the helix in which the spacing between turns is increased in the direction toward the coupling strips. They serve to provide a wave transmission path of uniformly changing impedance from the relatively high impedance at the end of the coupling strip to the relatively low impedance of the central portion of the helix.

When operating as a forward wave amplifier wave guide **6** serves at the input wave guide and is coupled to a source of signal energy so as to produce a mode of wave propagation having an electric field vector parallel to coupling strip **13**. A corresponding wave is thus generated along the coupling strip and imparted to the helix through the impedance matching section **19**. This matching section acts as a tapered transmission line and transfers the wave from the relatively high impedance at the coupling strip to the relatively low impedance of the helix with a minimum reflection of energy back to the signal source. The wave energy is amplified in passing along the helix in the direction of electron flow by the now well-known process of energy interchange between the electrons in motion and the electromagnetic field of the propagated wave. The amplified wave then traverses the second impedance matching section **29** and is transferred to wave guide **7** by means of coupling strip **23** and passes along this wave guide to utilization means.

A focusing arrangement which is the subject matter of this invention, is spaced along the major portion of the length of envelope **4** for focusing the electron beam passing longitudinally within this envelope. This focusing arrangement includes a plurality of ferroxdure annular magnets interposed along the tube between wave guide terminals **6** and **7**. The magnets are arranged so that the sense of successive magnets is reversed for reversing the direction of their longitudinal magnetic fields along the path of flow whereby a time-constant spatially alternating field is produced along the path of electron flow. Adjacent magnets are spaced by annular sections **9** of a high permeability material, such as permalloy, which serve as pole pieces for concentrating the magnetic fields produced by the array of magnets **8**. The pole pieces also help to insure that the successive fields produced along the path of electron flow will be uniform in nature. The spacing between adjacent pole pieces is maintained uniform along the length of the tube for establishing a periodic field as described in the above-mentioned publication.

In accordance with the present invention, ferroxdure magnets **12** and **14** are positioned within wave guides **6** and **7**, respectively, for focusing the electron stream through the region of these coupling elements. The structural aspects of these coupling elements will be discussed in more detail hereinafter in connection with Figs. 2 through 5. Sections **15**, **16**, **17**, and **18** of the wave guide walls which lie in a plane perpendicular to the axis of the traveling wave tube are made of a high permeability material and serve as pole pieces in the same manner as pole pieces **9** and serve to maintain the periodicity of the fields established by the array of pole pieces positioned between these wave guides. Since there exists no discontinuity, in the periodic focusing field, caused by the presence of wave guides **6** and **7**, the spatially alternating magnetic field can be extended to provide effective focusing along the entire length of the electron path by positioning annular magnets outside of the region between these guides. Magnets **8′** are shown positioned in this manner at each end of the tube and separated by pole pieces for concentrating the lines of magnetic force as described above.

Although the focusing arrangement has been discussed with reference to its use in a forward wave amplifier it is understood that this arrangement is also applicable for backward wave amplifiers and backward wave oscillators. In these latter devices the wire helix slow wave circuit **5** is advantageously replaced by a ribbon helix. Other changes necessary for operation as a backward wave amplifier or oscillator will be apparent to one skilled in the art.

The arrangement of the ferroxdure magnets can be seen more readily by referring to Fig. 2. Wave guide **6** is shown in perspective as positioned substantially perpendicular to the axis of traveling wave tube **22** and tapered in a direction away from this tube. Ferroxdure sections **12** are positioned within wave guide **6** in the region of the traveling wave tube. Because of the lossless character of ferroxdure it has been found that permanent magnets of this material can be inserted within a hollow wave guide without severely attenuating the wave energy passing therethrough. This material, however, is characterized by a high dielectric constant which affects the impedance and low frequency cutoff of the wave guide. The impedance change in the wave guide results in the reflection of wave energy incident upon the surface of the magnets. This effect can be minimized as shown in Fig. 2 by positioning the ferroxdure sections **12** in the region of the wave guide where the electric field is a minimum, that is, away from the central axis of the wave guide. Moreover, advantageously a ridge **24** is provided along the central portion of wave guide **6** for concentrating the electric field along this ridge away from the ferroxdure sections. Both the magnets **12** and ridge **24** are tapered in a direction parallel to the central axis of the wave guide to minimize reflections further. The presence of ferroxdure sections **12** also functions to extend the operating frequency range of wave guide **6** by lowering the low-frequency cut-off of wave guide **6** in the region of traveling wave tube **22**. The effect of the ferroxdure to lower the cut-off frequency in this region offsets the effect of the reduced dimensions of the wave guide in this region to raise its low cut-off frequency. Thus the ferroxdure sections help to maintain broad band operation which would otherwise be lost as a result of the reduced size of the wave guide necessary for coupling to tube **22**. The magnetic pole pieces **15** and **16** form the top and bottom of wave guide **6** in the region surrounding traveling wave tube **22**. These pole pieces are preferably coated with a thin layer of copper for minimizing the loss they introduce.

An alternative arrangement of the magnet sections is shown in Fig. 3. In this arrangement the magnets **12** are tapered in a direction parallel to the central axis of the guide but the tapered sections thereof are terminated in an edge proximate to the narrow wall of wave guide **6**. Ridge **24** and pole pieces **15** and **16** are provided as explained with respect to Fig. 2.

A modification of the arrangement of Figs. 2 and 3 is shown in Fig. 4. In this figure wave guide **6** serves to couple energy to traveling wave tube **22** as explained with reference to Fig. 1. A plurality of ferroxdure magnets preferably tapered, as shown in Fig. 2, are positioned within the wave guide in the region of tube **22**. The sense of alternate sections of ferroxdure is reversed and pole pieces **41** are positioned within adjacent ferroxdure sections, for advantageously providing a spatially alternating field having a relatively small period. It is understood that this period will be maintained by the suitable spacing of pole pieces positioned outside of the wave guide, as shown in Fig. 1. The presence of pole pieces **41** will not severely interfere with the wave propagating along wave guide **6** since these pole pieces are positioned in planes perpendicular to the electric field of the propagating wave. Sections **15** and **16** of the walls of wave guide **6** also serve as pole pieces as explained above.

An alternate form of the present invention is shown in Fig. 5. In this figure wave guide **51** serves to couple microwave energy into, or out of, traveling wave tube **52**. The tube as shown schematically in Fig. 5 passes through the terminal portion of wave guide **51**. In this embodiment the high dielectric constant of the ferroxdure is more fully utilized to extend the operating frequency range of the amplifying arrangement by increasing the frequency band of the coupling connection thereto. By substantially filling wave guide **51**, with permanent magnet ferroxdure material **53** in the region where the cross section of the guide is reduced for coupling to the traveling wave tube **52**, the low frequency cut-off of the reduced section can be lowered and made equal to the low frequency cut-off of guide **51** in the region of its larger cross section. This effectively reduces the low frequency cut-off of the system thereby extending the operating frequency range of the amplifier. Both the wide and narrow dimension walls of wave guide **51** are tapered outwardly in a direction away from tube **52** for minimizing reflections resulting from the transition in guide cross-sectional size. The ferroxdure permanent magnet material **53** is tapered inwardly in a direction away from tube **52** for further minimizing reflections and for keeping the low frequency cut-off constant along the length of the wave guide. The magnetic axis of the ferroxdure **53** is perpendicular to the axis of the tube **52** and pole pieces **55** and **56** are positioned on either side of the ferroxdure for concentrating the magnetic lines of force as explained with reference to Fig. 1.

In another aspect the non-reciprocal properties of the ferroxdure material **53** in Fig. 5 can be utilized by inserting resistance material **57** along one side of wave guide **51** in the region where the ferroxdure material is located and positioning the traveling wave tube **52** to the side of the wave guide central axis away from the resistance **57**. These non-reciprocal properties, however, are present in ferroxdure only at very high frequencies, in the order of 100 kmc, or in the presence of extremely high fields at lower frequencies. These properties are described in an article entitled "Faraday Effect in Magnetic Materials With Travelling and Standing Waves" by H. G. Beljers in Phillips Research Report, vol. 9, No. 2, pages 131–139, April, 1954. The technique of adding resistive material along wave guide **51** in the region of the magnetically biased ferrite material included within a wave guide is discussed in a copending application S. N. 362,193, filed June 17, 1953, by S. E. Miller. By the inclusion of resistance material **57** in Fig. 5 there may be provided a simple structure for focusing having both broadband and non-reciprocal properties. In operation, briefly, the non-reciprocal properties of the ferroxdure material at very high frequencies will present a low impedance path along one side of the wave guide central axis to a circularly polarized wave propagating along wave guide **51** in one direction, and will present a low impedance path on the other side of the central axis to a circularly polarized wave propagating in the other direction. Hence, a wave propagating along wave guide **51** in a direction toward the traveling wave tube will be con-

fined to the side of the wave guide away from resistance **57** and coupled to the tube **52**, whereas any reflections from the termination of wave guide **51** will pass along the side where the resistance material is located and therefore will be attenuated.

It is understood that the above-described arrangements are merely illustrative of the application of the general principles of the invention. In particular, other ferrite material exhibiting permanent magnet characteristics may be substituted for ferroxdure. Moreover, the ferroxdure magnets positioned outside of the wave guide coupling elements may be replaced by properly designed metallic magnets. Various other arrangements may be devised by one skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In a device which utilizes the interaction between an electromagnetic wave and an electron stream, means for producing an electron stream along an extended path, a slow wave interaction circuit for propagating wave energy in coupling relation with said electron stream, a hollow wave guide in coupling relation with said slow wave circuit for coupling wave energy between said wave guide and said circuit, and a succession of magnets positioned along the path of electron flow for forming a succession of longitudinal magnetic fields, the sense of adjacent magnets being reversed for reversing the direction of said longitudinal magnetic fields along the path of flow, and at least one of the magnets of said succession of magnets being of ferroxdure and positioned within the wave guide for focusing the electron beam in the region of the wave guide.

2. In a device which utilizes the interaction between an electromagnetic wave and an electron stream, means for producing an electron stream along an extended path, a slow wave interaction circuit for propagating wave energy in coupling relation with said electron stream, a hollow wave guide coupling element intersecting the slow wave circuit, said wave guide tapered from an extended straight section having predetermined cross-sectional dimensions to a section having smaller cross-sectional dimensions for coupling electromagnetic wave energy to the slow wave circuit, a succession of magnets positioned along the path of electron flow for forming a succession of longitudinal magnetic fields, the sense of adjacent magnets being reversed for reversing the direction of said longitudinal magnetic fields along the path of flow and at least one of the magnets of said succession of magnets being of ferrite material and positioned within the wave guide in the region of its smaller cross-sectional dimensions for focusing the electron beam in the region of the coupling element and for decreasing the cut-off frequency of this region of wave guide.

3. In a traveling wave tube, an evacuated envelope, an electron gun and target within said envelope and spaced apart for establishing a flow of electrons therebetween, a slow wave interaction circuit for propagating wave energy in coupling relation with said electron flow, a hollow wave guide intersecting said envelope and in coupling relation with said slow wave circuit for coupling wave energy between the wave guide and said circuit, a succession of magnets external to the envelope and positioned along the path of electron flow for forming a succession of longitudinal magnetic fields, the sense of adjacent magnets being reversed for reversing the direction of adjacent longitudinal magnetic fields along the path of flow and two permanent magnets of ferrite material positioned within, and co-extensive along, the hollow wave guide in the region of the intersection of the wave guide and envelope, said magnets being positioned away from the central axis of said wave guide.

4. In a traveling wave tube, an evacuated envelope, an electron gun and target within said envelope and spaced apart for establishing a flow of electrons therebetween, a slow wave interaction circuit for propagating

wave energy in coupling relation with said electron flow, a hollow wave guide intersecting said envelope and in coupling relation with said slow wave circuit for coupling wave energy between the wave guide and said circuit, a succession of magnets positioned along the path of electron flow for forming a succession of longitudinal magnetic fields, the sense of adjacent magnets being reversed for reversing the direction of adjacent longitudinal magnetic fields along the path of flow and two permanent magnets of ferrite material positioned within, and co-extensive along, the wave guide in the region of the intersection of the wave guide and envelope, said magnets being positioned away from the central axis of the wave guide and the wave guide being ridged along its central axis for concentrating the propagated electromagnetic wave energy in the region of said ridge.

5. In combination, a traveling wave tube having means forming an electron beam and a slow wave interaction circuit for propagating wave energy in coupling proximity to said beam, a hollow wave guide coupling connection to said interaction circuit for coupling wave energy between said wave guide and said circuit, and means including a permanent magnet of ferrite material located within said wave guide for focusing the electron beam in the region of the coupling connection.

6. In combination, a traveling wave tube having means forming an electron beam and a slow wave interaction circuit for propagating wave energy in coupling proximity to said beam, a hollow conductively-bounded wave guide in coupling relation with the slow wave circuit for coupling said guide and said circuit in energy exchange relation, said wave guide being tapered from an extended straight section of predetermined cross-sectional dimensions to a section having smaller cross-sectional dimensions, and means including a permanent magnet of ferrite material within the wave guide in the region of its smaller cross-sectional dimensions for focusing the electron beam in this region and for decreasing the low cutoff frequency of this section of wave guide.

7. In combination, a traveling wave tube having a slow wave interaction circuit and means forming a beam of charged particles, a tapered wave guide coupled to one end of said interaction circuit, and a permanent magnet of ferrite material in said wave guide in the region of the traveling wave tube for focusing the charged particle beam past said wave guide.

8. In combination, a traveling wave tube having an electron gun and target for forming therebetween an electron beam, and a slow wave interaction circuit; a wave guide intersecting said traveling wave tube in coupling relation with the slow wave circuit for coupling microwave energy to said circuit, two permanent magnets of ferrite material within, and coextensive along, the wave guide in the region of the intersection of said wave guide and the traveling wave tube for focusing the electron beam in the region of the wave guide, said permanent magnets being positioned on opposite sides of the central axis of the wave guide and having the magnetic axis of each substantially perpendicular to the electron beam.

9. In combination, a traveling wave tube having an electron gun and target for forming a flow of electrons therebetween and a slow wave interaction circuit, a hollow wave guide in coupling relation with the slow wave circuit for coupling microwave energy to said circuit, the wave guide being ridged along its central portion in the region of slow wave circuit for concentrating the propagating wave energy along said ridge, and two permanent magnets of ferrite material positioned within, and coextensive along, said wave guide in the region of the ridge for focusing the electron beam past said wave guide, said permanent magnets being positioned away from the central portion of the wave guide on opposite sides of said ridge.

10. In a device which utilizes the interaction between an electromagnetic wave and an electron stream, means for producing an electron stream along an extended path, a slow wave interaction circuit for propagating wave energy in coupling relation with said electron stream, a hollow wave guide in coupling relation with the slow wave circuit for coupling said guide and said circuit in energy exchange relation, said wave guide being tapered from an extended straight section having predetermined cross-sectional dimensions to a section having smaller cross-sectional dimensions, a succession of magnets positioned along the path of electron flow for forming a succession of longitudinal magnetic fields, the sense of adjacent magnets being reversed for reversing the direction of said longitudinal magnetic fields along the path of flow and one of the magnets of said succession of magnets being of ferrite material and positioned in the wave guide in the region of its smaller dimensions, a portion of said magnet being tapered and extending into the tapered section of said wave guide for maintaining substantially a constant low frequency cut-off along the length of the wave guide.

11. In combination, a traveling wave tube having an electron gun and target for forming therebetween an electron beam and a slow wave interaction circuit, a wave guide intersecting said traveling wave tube in coupling relation with the slow wave circuit for coupling microwave energy to said circuit, two permanent magnets of ferrite material within, and coextensive along, the wave guide in the region of the intersection of said wave guide and the traveling wave tube for focusing the electron beam past said wave guide, said permanent magnets being positioned on opposite sides on the central axis of the wave guide and being tapered in a direction away from the intersection, and two sides of the wave guide acting as pole pieces to concentrate the field produced by said magnets.

12. In combination, a traveling wave tube having an electron gun and target for forming therebetween an electron beam, and a slow wave interaction circuit, a hollow wave guide intersecting said traveling wave tube in coupling relation with the slow wave circuit for coupling microwave energy to said circuit, a plurality of magnets within the wave guide in the region of the intersection of said wave guide and the traveling wave tube, said plurality being arranged in a first and second row on opposite sides of the central axis of the guide, and the sense of adjacent magnets in each row being reversed, and a succession of pole pieces, each pole piece extending between a pair of adjacent magnets of the first row and a pair of adjacent magnets of the second row.

13. In a device which utilizes the interaction between an electromagnetic wave and an electron stream, means for producing an electron stream along an extended path, a slow wave interaction circuit for propagating wave energy in coupling relation with said electron stream, a hollow wave guide in coupling relation with the slow wave circuit for coupling said guide and said circuit in energy exchange relation, said wave guide being tapered from an extended straight section having predetermined cross-sectional dimensions to a section having smaller cross-sectional dimensions, a succession of magnets positioned along the path of electron flow for forming a succession for longitudinal magnetic fields, the sense of adjacent magnets being reversed for reversing the direction of said longitudinal magnetic fields along the path of flow and at least one of the magnets of said succession of magnets being of ferrite material and positioned within the hollow wave guide in the region of its smaller cross-sectional dimensions, two of the walls of said wave guide serving as pole pieces for concentrating the magnetic flux, and additional pole pieces positioned between adjacent magnets along the succession of magnets.

14. Apparatus for focusing an electron beam along a predetermined path comprising means athwart the beam path providing a wave propagating path which intersects the beam path, a succession of magnets positioned along

the beam path for forming a succession of longitudinal magnetic fields therealong, the sense of adjacent magnets being reversed for reversing the direction of said longitudinal fields along said beam path and at least one of said magnets being transparent to electromagnetic wave energy and extending into the wave propagating path.

15. In combination, means for projecting charged particles along a predetermined path, means athwart the charged particle path forming a wave propagating path which intersects the charged particle path, and means for controlling the flow of charged particles along said charged particle path including a magnetic element which is transparent to electromagnetic wave energy positioned

within said wave propagating path in the region of its intersection with the charged particle path for producing a magnetic field adjacent said region of intersection.

16. In combination, means for projecting electrons along a predetermined path, means including a hollow wave guide athwart the electron path providing a wave propagating path which intersects the electron path, and means for focusing said electrons including a magnetic element which is transparent to electromagnetic wave energy and is positioned within said hollow wave guide and surrounding the electron path.

No references cited.