

May 7, 1957

M. S. GLASS

2,791,718

MAGNETIC STRUCTURE FOR TRAVELING WAVE TUBES

Filed April 23, 1956

2 Sheets-Sheet 1

FIG. 1

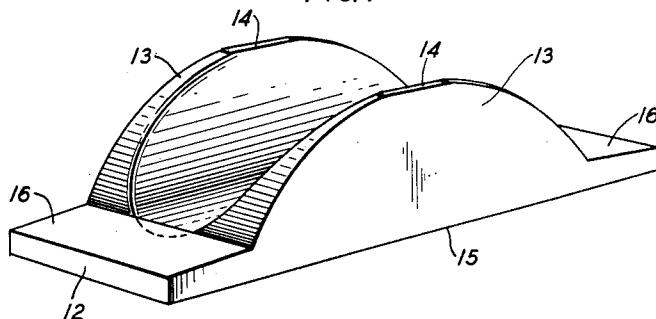


FIG. 2

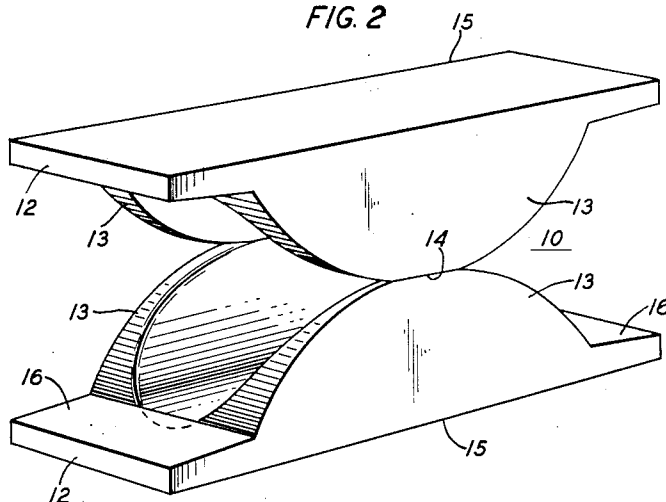
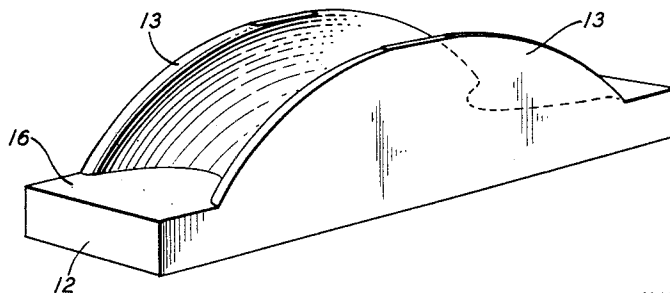


FIG. 3



INVENTOR
M. S. GLASS

BY

James F. Felt

ATTORNEY

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M. S. GLASS

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FIG. 4

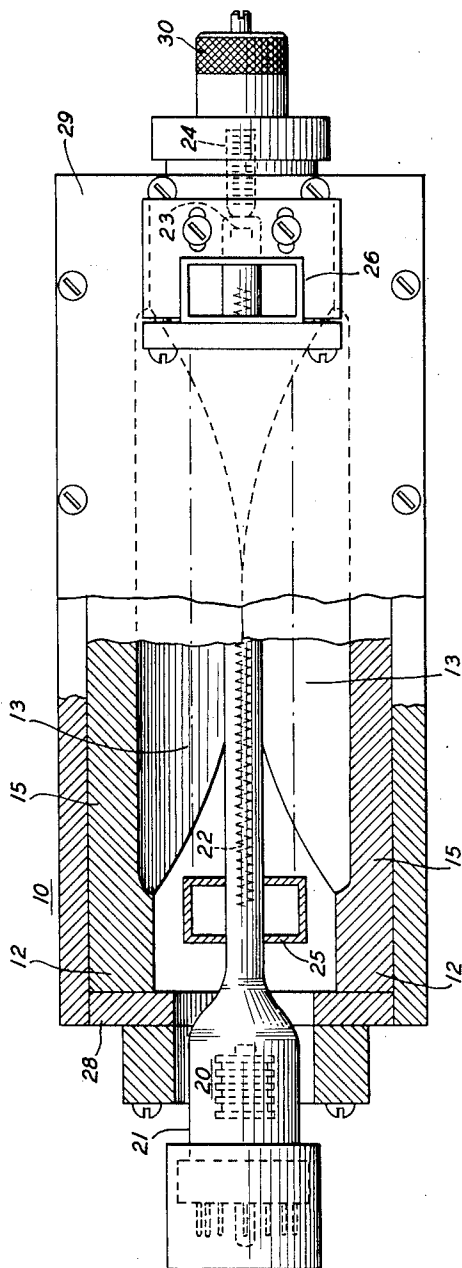
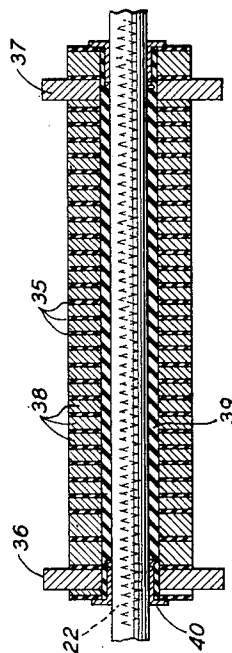


FIG. 5



INVENTOR
M. S. GLASS
BY *James W. Felt*
ATTORNEY

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2,791,718

MAGNETIC STRUCTURE FOR TRAVELING WAVE TUBES

Myron S. Glass, West Orange, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

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15 Claims. (Cl. 315—3.5)

This invention relates to apparatus including magnetic structures, and more particularly to such apparatus including traveling wave tubes wherein an electron beam is focused by a magnetic field along a relatively long path.

In certain electron discharge devices, such as traveling wave tubes, an electron stream is projected into an interaction space generally defined by a helix, where it is made to interact with an electromagnet wave traveling along the helix. Optimum operation is achieved when the electron stream is confined to a substantially cylindrical form having electrons at its radial extremities close to but not impinging the helix throughout the interaction space. It has been the practice to establish a longitudinal magnetic field along the path of electron flow to confine the beam as desired.

It is an object of this invention to improve magnetic focusing of electron beams in electron discharge devices such as traveling wave tubes.

More specifically, it is an object of this invention to provide a magnetic field which will focus an electron stream over a relatively long path, confining the stream to a uniform shape within narrow limits.

Another object of this invention is to provide a uniform straight magnetic field of sufficient strength to achieve the desired focusing of an electron beam while reducing the size and weight of the focusing equipment.

In electron discharge devices employing high density electron beams, such as traveling wave tubes, a longitudinal field is encountered in a drift space of the device, and electrons entering this field attain an angular velocity proportional to the difference in magnetic flux encountered in going from a shielded electron gun region into the field region. The inward or focusing force per charge is proportional to the product of the angular velocity and the longitudinal magnetic field or effectively the square of the magnetic field. This inward force is adjusted to counterbalance exactly the sum of outward mutually repulsive forces of the electrons, generally described as space charge forces, and the outward centrifugal force of the spiraling electrons.

In the past, in order to provide a uniform straight longitudinal magnetic field of sufficient strength to offset the large space charge forces existing in an electron stream of high density over a relatively long electron path, the permanent magnets required were many times the weight and size of the device employing my invention. From the standpoints of expense, compactness and portability, among others, it is desirable to reduce the size and weight of the focusing equipment.

In order to attain the precise degree of focusing desired without the need for employing large and cumbersome magnets, there has been suggested a system of periodic focusing to overcome the difficulties encountered in straight field focusing. In such a system, a series of pole pieces having successively opposite polarity is deployed along the path of electron flow to establish a succession of axially symmetric regions of longitudinal magnetic field. Concentration of the field in such a succession of relatively short regions rather than a uniform field over a relatively long region, as in conventional straight field permanent magnets, permits a reduction in total magnet size and weight while maintain-

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ing the desired field distribution. An example of such a system is disclosed in an article "Electron Beam Focusing with Periodic Permanent Magnet Fields" by J. T. Mendel, C. F. Quate and W. H. Yocom, Proceedings of the I. R. E., volume 42, pages 800-810, May 1954.

A proposal by P. P. Cioffi, described in his application Serial No. 543,235, filed October 27, 1955, suggests employment of a single permanent magnet extending over the length of the interaction space of the traveling wave tube and having an axial cylindrical hole through the magnetic material concentric with the longitudinal axis of the magnet, in which axial hole the helical conductor of the traveling wave tube is positioned. The required volume of uniform air gap field can be developed within this hole. It is customary in traveling wave tube applications to provide coaxial or wave guide entrance and exit points to the interaction space. A small hole adjacent each end of the permanent magnet penetrating to the axial interaction space allows for coaxial fittings without disrupting the continuity of the magnetic circuit. Larger openings in the magnetic material are required for wave guide fittings, however, and resultant discontinuities may affect the magnetic circuit appreciably.

The straight field air gap volume may be reduced in dimensions, in accordance with my invention, to those obtainable with periodic field structures for particular focusing requirements and the straight field magnet weight and volume made comparable to that of the periodic field structure. This is accomplished with adequate provision for wave guide coupling and presents a rugged, easily supported assembly. Thus the benefits of a straight and substantially uniform magnetic field can be achieved in wave guide coupled traveling wave tube applications without the encumbering weight and volume of prior straight magnetic field devices.

In addition, a marked reduction in undesirable transverse magnetic field components and adequate shielding against external fields is realized so as to permit the use of field straightening apparatus known in the art, with optimum results.

My invention accomplishes these results by employing a pair of permanent magnets extending over the length of the interaction space of the traveling wave tube and positioned on opposite sides thereof. Each of the magnets comprises a flat bed portion having a pair of projections, protuberances, or ears, one extending from each side of the bed portion in a plane normal to the plane of the bed portion and tapered from an apex in the mid-section toward the ends of the bed portion and toward the median of its width. The apex area advantageously may be flattened to provide a good contact surface to meet the corresponding extension of the other bed portion. When properly positioned the magnets substantially enclose the interaction space, the projections from the flat bed portions of each magnet meeting the corresponding projections from the other magnet at the mid-section. The taper in the projections provides areas of access at the sides of the structure adjacent the ends to accommodate wave guide couplings.

I have found that the desired axial field distribution may be obtained if the magnetic material cross-sectional area at the ends of the interaction space of the traveling wave tube is about 60 percent of that in the midsection. The tapered magnetic structure of the specific illustrative embodiment of this invention satisfies this requirement of distribution of cross-sectional area of magnetic material to obtain the desired field. In traveling wave tube applications employing wave guide couplings, it may be desirable to attain a uniform magnetic field intensity of 500 oersteds, for example. A suitable permanent magnet material for straight magnetic fields of 500 oersteds is Alnico V, an iron alloy containing aluminum, nickel, cobalt,

copper and titanium, since it develops its optimum energy product at a point having coordinates of flux density and field intensity of 8600 gauss and 500 oersteds, respectively. I have found that in the specific illustrative embodiment of this invention wherein the permanent magnet is Alnico V and is given the tapered configuration described hereinbefore, for a magnet length of 5.75 inches along the axis of the conductor and an inside diameter at the median section is 1.6 inches, the resultant volume of magnetic material to produce the desired straight magnetic field in the interaction space is comparable to the total required volume of periodic field magnetic materials. The weight, of course, is reduced proportionately.

It is a feature of this invention that traveling wave tube apparatus comprise a pair of flat permanent magnet members positioned on opposite sides of the tube's interaction space, each member having projections or ears extending from its sides to meet the projections from the opposite member and increasing in length and width away from the areas of contact with each other and toward the flat members.

It is another feature of this invention that the decrease of the projections or ears at distances successively greater from the center of the magnetic structure is so proportioned as to give a suitable taper in cross section area of magnetic material to attain a uniform or flat magnetic field distribution along the axis of the magnetic structure. Thus in accordance with this feature of the invention the magnets are shaped so as to avoid any abrupt discontinuities or changes in the cross section area of the magnetic materials while still allowing for a change in the distribution or cross-sectional area of the material. Such abrupt discontinuities give rise to sharp changes in field strength on the axis and frequently to undesired "cross-fields."

It is a further feature of this invention that the protuberances or ears extending from the flat or bed portions of the magnetic members at the middle close the gap at the sides of the magnet and provide effective shielding against disturbances from other magnets or magnetic materials in the vicinity. Further shielding, in accordance with an aspect of this invention, may be provided by field straighteners around the traveling wave tube itself within the magnetic structure.

It is still a further feature of this invention that the ears be so tapered and dimensioned as to provide adequate clearance for the microwave input and output circuits at the ends of the magnetic structure.

A complete understanding of this invention and of the various features thereof may be gained from consideration of the following detailed description and the accompanying drawing, in which:

Fig. 1 is a perspective view of one section of a permanent magnet structure utilized in one specific embodiment of this invention;

Fig. 2 is a perspective view of a complete assembly utilizing sections as shown in Fig. 1;

Fig. 3 is a perspective view of one section of a variation of the permanent magnet structure of Fig. 1;

Fig. 4 is a side view partly in section of apparatus utilized in one specific illustrative embodiment of this invention employing the magnet structure of Fig. 1; and

Fig. 5 is a side view in section showing additional apparatus in accordance with another specific embodiment of this invention.

The specific illustrative embodiment of this invention as depicted in Fig. 4 comprises a permanent magnet assembly 10 best seen in the perspective views of Figs. 1 and 2. As seen in Fig. 2 the permanent magnet assembly 10 comprises a lower section 15 having a bed portion 12 of substantially parallelepiped configuration and tapered protuberances or ears 13 extending from sides of the bed portion 12 in a plane normal to the plane of the flat inner surface 16 of the bed portion. The area of greatest extension of the ears 13 from the bed portion 12 is at the

median of the bed length, and each ear 13 has a flattened reference surface 14 in this area. The ears 13 taper from this reference surface toward each end of the bed portion 12 and also toward the median of the bed width and join the opposing ear 13 below the inner surface 16 of the bed portion 12. An upper section 15 of the magnet assembly 10 is of the same configuration as the lower section 15. When the two sections 15 are joined at the reference surfaces 14, a unitary assembly is presented providing an aperture therethrough which affords adequate space for a traveling wave tube assembly and sufficient openings in the tapered sides for insertion of wave guide couplings for such an assembly.

I have found that tapering the ears 13 toward the median of the bed width so as to meet the median below the plane of the inner surface 16 of the bed portions 12, as in Figs. 1 and 2, affords optimum results, with a minimum weight, although acceptable results are also obtained by employing tapered sides of the ears 13 meeting the median of the bed width at or above the plane of the bed portion inner surface 16, as in Fig. 3.

The traveling wave tube 20, which may be of any type known in the art, is inserted into the space between the upper and lower sections 11 and 15 of the permanent magnet assembly 10 and extends over the length of the assembly 10. The traveling wave tube essentially comprises an electron gun assembly 21, a helix transmission circuit 22, and an electron collector assembly 23.

Input and output wave guides 25 and 26 are positioned within the end sections of the magnet assembly 10 transverse to the axis of the traveling wave tube 20 in energy coupling relation with the input and output ends of the helix transmission circuit 22. The taper of the extension ears 13 toward each end of the magnet assembly 10 affords ready access for the wave guides 25 and 26.

The helix 22 extends within the magnet assembly 10 from the input wave guide 25 to the output wave guide 26. Pole pieces 28 and 29 advantageously abut directly against the ends of the magnet bed portions 12 of magnet assembly 10 and enclose the space between the ends of the upper and lower bed portions 12. The pole piece 28 has an aperture therethrough of sufficient size to accommodate the enlarged portion of the envelope of the traveling wave tube 20, which enlarged portion encompasses the electron gun 21. Similarly, the pole piece 29 adjacent the output wave guide 26 has an aperture therethrough to accommodate the heat radiator portion 24 of the traveling wave tube 20 adjacent the electron collector 23.

In the specific illustrative embodiment of my invention depicted in Fig. 4, an eccentric unit assembly 30 is mounted coaxially on the exit end of the traveling wave tube 20 adjacent the heat radiator portion 24 and provides for alignment of the tube axis with the magnetic axis. Trimming screws around the pole pieces 28 and 29 provide for additional correction, if necessary. I have found that uniformity of the magnetic field in the interaction space is assured by shaping of the magnet assembly 10 to the configuration shown in Fig. 2, so that flux guides, required in other configurations to provide the requisite uniformity, are not required here. The tapered extension ears 13 also provide a shield for the interaction space against stray external magnetic fields.

In homogeneities in the material of the permanent magnet assembly 10 and its close proximity to the magnetic field axis may cause slight field components transverse to the axis which disturb the uniform straight longitudinal field set up in the interaction space. Such transverse fields may be offset by additional magnetic shielding. The shielding means referred to in this instance as field straighteners, may comprise spaced apart coaxial rings or discs 35, Fig. 5, of high permeability material located between the interaction space and the magnetic walls defining the interaction space. Such shielding means is well known in the art. The discs 35 would be supported

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by supports 36 and 37 and spacer discs 38 of nonmagnetic material in such a manner as not to be in contact with each other, with the pole pieces 28 and 29, or with the magnetic walls defining the interaction space. A hollow mandrel 39 of an insulating material may be inserted between the shielding discs 35 and the interaction space through which the tube 22 extends to provide adjustable support for the discs 35 and to permit accurate alignment to promote optimum shielding. The discs used in this instance act to align the transverse fields normal to the magnetic axis so as not to disrupt the uniformity of the main field. Adequate shielding against external magnetic fields is supplied by the magnet assembly 10.

The open sections of the magnet assembly 10 adjacent each end thereof, due to the taper of the extension ears 13, are necessary to accommodate the wave guide coupling arrangement for the traveling wave tube 20. These open or bridging sections of the magnet assembly 10 are effective to extend the magnetic field of the magnet assembly 10 to include the area occupied by the wave guides 25 and 26, the tapered ears 13 providing the necessary field uniformity and distribution in these areas. This peculiar shaping of the magnetic material is sufficient without flux guides to realize the desired field uniformity in the coupling areas, thus permitting a material saving in materials, fabrication, size and weight.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of this invention.

What is claimed is:

1. An electron discharge device comprising an electrical conductor defining an elongated electromagnetic wave transmission system, an input and an output coupling means for said transmission system, said coupling means being spaced apart from each other along said conductor, electron gun means adjacent one end of said conductor for projecting an electron stream lengthwise of and in coupling relation to said conductor and means applying a magnetic field along said conductor to focus said electron stream, said last-mentioned means comprising a pair of flat permanent magnet members positioned on opposite sides of said conductor, each of said members having a pair of projecting ears extending from the sides of said members, the ears of said members being contiguous to each other and said ears increasing both in length and in width away from the point of contact with each other and toward said flat members, and said coupling means extending between said flat members adjacent the ends of said projecting ears.

2. An electron discharge device comprising means defining an electromagnetic wave transmission system, electron gun means adjacent one end of said system for projecting an electron stream lengthwise of and in coupled relationship thereto, electron receiving means adjacent the other end of said system and means applying a magnetic field along said system to focus said electron stream, said last-mentioned means comprising a permanent magnet member having a first and a second bed portion, a first pair of protuberances from said first bed portion, a second pair of protuberances from said second bed portion, said member arranged such that each of said first protuberances is contiguous to a corresponding one of said second protuberances, said protuberances increasing in cross section away from the point of contact with each other and toward said bed portions.

3. An electron discharge device in accordance with claim 2 wherein said protuberances extend from opposite sides of said bed portions and regularly increase in length away from said point of contact and toward opposite ends of said bed portions and increase in thickness away from said point of contact and toward the centerline between said opposite sides of said bed portions.

4. An electron discharge device in accordance with

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claim 2 wherein said protuberances on opposite sides of one of said first and second bed portions are joined below the surface of said one of said bed portions.

5. An electron discharge device in accordance with claim 2 wherein said protuberances on opposite sides of one of said first and second bed portions are joined above the surface of said one of said bed portions.

6. An electron discharge device comprising an electrical conductor defining an elongated electromagnetic wave transmission system, an input and an output coupling means for said transmission system, said coupling means being spaced apart from each other along said conductor, electron gun means adjacent one end of said conductor for projecting an electron stream lengthwise of and in coupling relation to said conductor and means applying a magnetic field along said conductor to focus said electron stream, said last-mentioned means comprising a permanent magnet member having first and second bed portions of substantially parallelepiped configuration positioned on opposite sides of said conductor, a first pair of projections from opposite sides of said first bed portion substantially in parallel planes normal to the plane of said first bed portion, a second pair of projections from opposite sides of said second bed portion substantially in parallel planes normal to the plane of said second bed portion and arranged such that each of said first extensions is contiguous at its apex to a corresponding one of said second extensions at its apex, each of said extensions increasing both in length and in width away from its apex and toward said bed portions, and said coupling means extending between said flat members adjacent the ends of said projecting ears.

7. An electron discharge device in accordance with claim 6 wherein said projections from opposite sides of one of said first and second bed portions are joined below the surface of said one of said bed portions.

8. An electron discharge device in accordance with claim 6 wherein said projections from opposite sides of one of said first and second bed portions are joined above the surface of said one of said bed portions.

9. An electron discharge device in accordance with claim 6 and further comprising means for aligning the axis of said magnet members with the axis of said conductor.

10. An electron discharge device in accordance with claim 9 and further comprising shielding means positioned between said magnet member and said conductor and substantially encompassing said conductor.

11. An electron discharge device in accordance with claim 10 wherein said shielding means comprises a plurality of spaced-apart magnetic discs disposed along the axis of said magnet member.

12. Traveling wave tube apparatus comprising a permanent magnet member having first and second flat sections spaced apart by extensions from opposite sides of each section, pairs of said extensions being contiguous at an apex and each extension sloping downwardly from the apex toward the ends of said flat sections and toward the median of the sides of said flat sections, an elongated helical conductor extending between said flat sections, and means for projecting a stream of electrons lengthwise of and in coupled relationship to said conductor.

13. An electron discharge device in accordance with claim 12 and further comprising means for aligning the axis of said magnet members with the axis of said conductor.

14. An electron discharge device in accordance with claim 12 and further comprising shielding means positioned between said magnet member and said conductor and substantially encompassing said conductor.

15. An electron discharge device in accordance with claim 14 wherein said shielding means comprises a plurality of spaced-apart magnetic discs disposed along the axis of said magnet member.