June 28, 1966 B. MINAKOVIC 3,258,640

TRAVELLING WAVE TUBES HAVING MULTIPLE SLOW WAVE STRUCTURES

Filed March 8, 1961 3 Sheets-Sheet 1

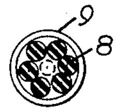

FIG. 2.

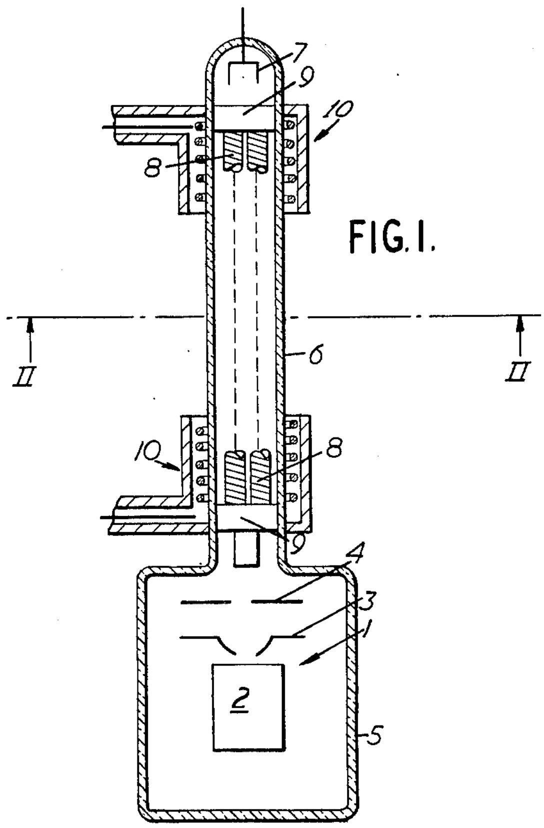

FIG. 1.

FIG. 3.

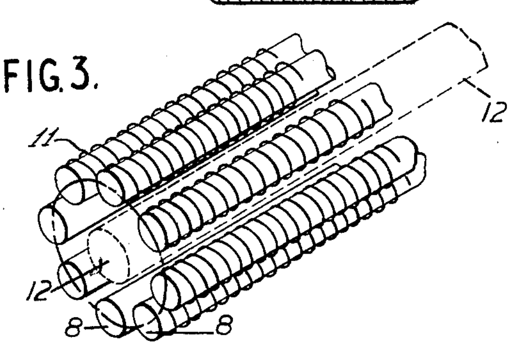

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FIG.4.

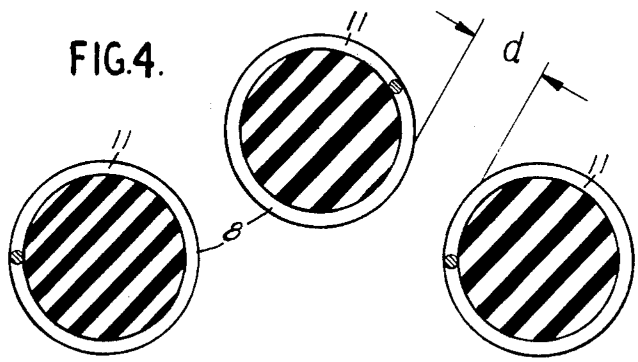

FIG.5.

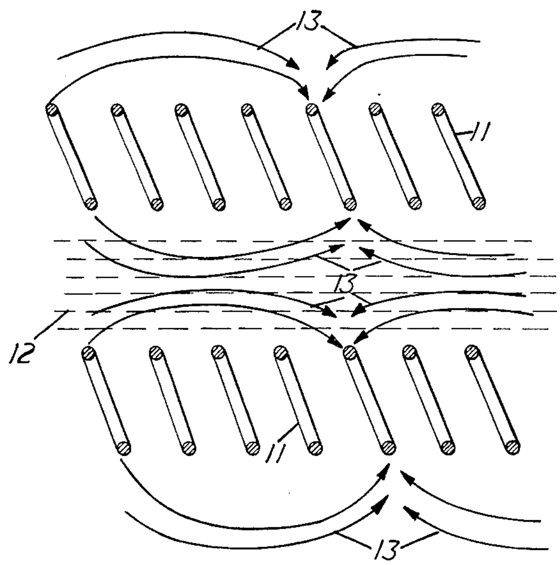

FIG.8.

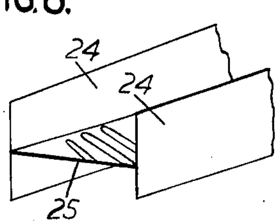

FIG.9.

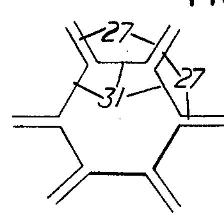

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FIG. 6.

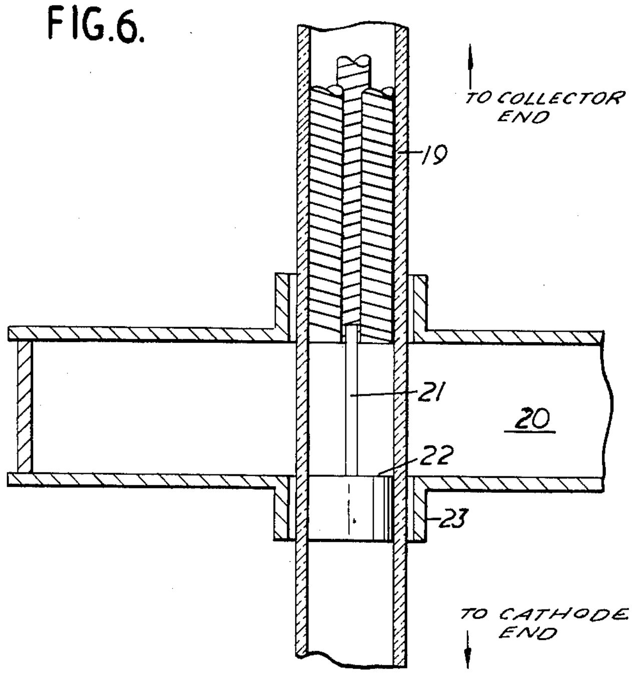
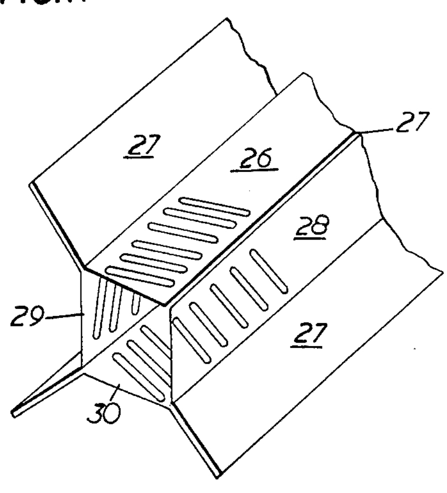


FIG. 7.



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TRAVELLING WAVE TUBES HAVING MULTIPLE SLOW WAVE STRUCTURES

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10 Claims. (Cl. 315—3.6)

The present invention relates to travelling wave tubes and is particularly concerned with the construction of slow wave structures therefor. The term "travelling wave tube" includes backward wave oscillator or amplifier tubes in which the energy of wave propagation along the slow wave structure is oppositely directed to the electron stream.

In the most commonly used travelling wave tubes an electron beam is projected from an electron gun along the axis of a wire helix to an electron collector electrode. The dimensions of the helix are chosen to provide slow wave propagation along the axis of the helix with a phase velocity approximately the same as that of the electrons of the beam. These dimensions, therefore, depend, inter alia, upon the desired frequency of operation of the travelling wave tube and also upon the accelerating voltage applied to the electrons of the beam. Thus, in tubes for operation in the 4–6 kmc./s. band with a beam voltage of 3,000 volts the helix is typically made of wire 0.010" diameter, wound at 30 turns per inch with the helix having a mean diameter of 0.090". Such a helix is conveniently and conventionally supported between three parallel dielectric rods extending between the electron gun and electron collector electrode. If it were desired to operate a travelling wave tube at a comparatively low beam accelerating voltage—say, 100 volts—even at much lower frequencies, the helix would have to be wound of very fine wire at many turns per unit axial length. Difficulties would then arise in supporting the helix and avoiding distortion to its geometry; the conventional three rod support becomes impracticable.

At very high frequencies, say in the millimetre wave range, irrespective of beam voltage considerations, the helix slow wave structure becomes extremely difficult to support. For this and other reasons recourse is made to devices such as ladder types of slow wave structure, examples of which will be discussed below.

In the present invention a slow wave structure is used which has an arrangement surrounding the electron beam of a set of slow wave structures whose fields couple to one another and to the electron beam in such a manner as to provide along the electron beam path a means for the propagation of electro-magnetic waves in a slow mode in which the electric vector is predominantly longitudinal. Each of the structures, of which there are at least three, is of the same class of slow wave structure. Thus, the structures may all be helices or they may all be ladder type structures of similar form. The structures are arranged parallel to one another, side-by-side, symmetrically around the electron beam axis and should not overlap in planes transverse to that axis—i.e. in the case of helices, for example, the turns of one helix should neither touch nor overlap those of its neighbour.

In embodiments of the invention using a set of helices around the electron beam to provide the composite slow wave structure it becomes practicable to wind the helices of very fine wire on dielectric rods which, in the assembled tube, remain as the supports for the respective helices, thus overcoming the difficulties mentioned above in connection with low voltage travelling wave tubes. For use at very high frequencies it is possible to provide a set of several ladder type structures arranged parallel to one another and to flood the whole assembly with an electron beam. In the present invention the ladder type structures can be arranged around the beam so that interception of the beam electrons is largely avoided.

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Embodiments of this invention will be described, with reference to the accompanying drawings, in which:

FIG. 1 is a diagrammatic illustration of a travelling wave tube according to the invention employing a set of helices for the slow wave structure;

FIG. 2 is a cross section through the plane II—II of FIG. 1;

FIGS. 3 and 4 illustrate the general arrangement of the individual helices in embodiments such as that of FIGS. 1 and 2;

FIG. 5 illustrates the electric field configuration produced in the arrangement of FIGS. 3 and 4;

FIG. 6 illustrates an alternative form of h.f. feed for the slow wave structure; and

FIGS. 7 to 9 relate to ladder type slow wave structures, FIGS. 7 and 9 showing respective arrangements according to the invention of structures derived from the basic ladder structure of FIG. 8.

In the embodiments of FIGS. 1 and 2 an electron gun **1** having a cathode **2** focusing electrode **3** and anode **4** is mounted within an envelope portion **5**, from which projects an elongated envelope portion **6** of smaller diameter surrounding the electron beam path and the composite slow wave structure and which at its far end carries an electron collector electrode **7**. The composite slow wave structure comprises a set of helices each wound upon a dielectric rod **8** the rods being parallel to the electron beam axis and symmetrically arranged about that axis as shown in FIG. 2. The dielectric rods are supported at their ends in a pair of metal sleeves **9**. Input and output couplings for the composite slow wave structure are provided by externally contra-wound helical couplers illustrated at **10**.

The general arrangement of the composite slow wave structure is illustrated in FIGS. 3 and 4. In FIG. 3, eight similar helices **11** are shown, each wound upon its own support rod **8**. In any plane transverse the electron beam axis the centres of the rods lie upon a circle whose centre is the electron beam axis and are spaced from one another by a distance d as indicated in FIG. 4. The electron beam indicated in FIG. 3 at **12** passes close to the helices so that the beam electrons interact with the external fields of the helices. A simple transmission line theory shows that irrespective of whether all the helices are wound in the same direction, or, in the case of an even number, alternate ones are contrawound, two modes of slow wave propagation are possible. The faster of these modes has a predominantly longitudinal electric field as illustrated in FIG. 5. The lines of electric force **13** flow from node to node along the length of each helix so that the electric vector is predominantly longitudinal. In the other mode of propagation lines of electric force tend to be directed transversely from on helix to its adjacent neighbour so that any electric field near the axis is predominantly transverse. In the present invention the mode illustrated in FIG. 5—the in-phase mode—is utilised. The propagation constant of the composite slow wave structure may be expressed in terms of the propagation constants of the individual helices, together with terms involving the distance d. For maximum band width and freedom from unwanted Hartree harmonics we prefer to dimension the individual helices so that γa for each helix is approximately 1.5, γ being the radial phase constant of propagation and a the radius of the helix. These terms are taken from the known Hartree equation, a discussion and derivation of which is found on pages **72**, **73** and **76** of the text entitled "Travelling Wave

Tubes" by J. R. Pierce, 1950 edition. For a six helix structure with each helix dimensioned so that $\gamma a=1.5$ the simple transmission line theory predicts that the interaction impedance of the composite slow wave structure with the electron beam should be about 0.45 of the single helix interaction impedance. The effect of the dielectric of the support rods on which the individual helices are wound is to reduce the interaction impedance still further. On the other hand, since the in-phase mode is the faster of the two slow modes of propagation, the interaction impedance for the composite structure will be higher than that given by the simple theory, so that a compensating effect is obtained. The six helix structure is more dispersive than a single helix, and this is, in general, true for any member of slow wave structures whether of the helix class or otherwise. The dispersion can be increased when using the helix class by contrawinding alternate helices or adjacent groups of helices, the symmetry of the arrangement still being preserved. The dispersion may also be varied by choice of the spacing d.

If a small number of slow wave structures is used to form the composite slow wave structure, interaction with the electron beam will be relatively inefficient, while if a large number is used the field on the axis tends to fall off because of the greater distance of the individual slow wave structures from the common axis, hence the use of a large number of slow wave structures is suitable for a hollow electron beam. For a solid electron beam, considerations of dispersion and interaction lead to a choice of six helices as being the optimum number. If the spacing d between individual helices approaches the diameter of a helix the interaction with the electron beam becomes very inefficient. As d is decreased the dispersion of the composite structure increases with consequent loss of band width.

In a practical embodiment of the invention a six helix structure was used, all helices being wound in the same direction. The helix was wound with 0.002 inch diameter tungsten wire at 250 turns per inch on ceramic rods each of diameter 0.075 inch. The length of each helix was 4½ inches with a beam 0.083 inch in diameter carrying a current of 2 ma. with a beam voltage centered on 100 v. The beam diameter was chosen as in conventional single helix travelling wave tubes to occupy about 0.8 of the available spacing. A maximum gain of 20 db was obtained at 760 mc./s. and 118 volts on the beam. The amplifier was voltage-tuned by varying the beam voltage over the range 86–125 volts, the average gain in the frequency range 1020–710 mc./s. being about 10 db.

In the arrangement illustrated in FIG. 1, coupling to the slow wave structure is indicated as by means of contra-wound helix couplers **10**. If P_1 be the pitch of the individual helices of the slow wave structure and P_2 be the pitch of the outer coupling helix then, approximately

$$P_2=P_1D/D-S$$

where D is the mean diameter of coupling helix and S is the mean distance between coupling helix and inner helix.

As in the case of a conventional helical coupler the power is transferred to the structure by a spatial heating process. The coupling length of the outer helix can be found very approximately from the usual helical coupler theory. This value, however, will be shorter than actually required because the spacing between inner helices tends to reduce the coupling to the outer helix.

In the alternative feeder arrangement illustrated in FIG. 6 waveguide coupling is used. The individual helices are closely surrounded by a glass envelope **19**, which projects in an analogous manner to the conventional travelling wave tube through a waveguide **20**. The ends of the helices terminate flush with the inner wall of the waveguide. A metal drift tube **21**, held in between the helices of the slow wave structure and surrounding the electron beam, projects transversely across the waveguide and is joined to a choke sleeve **22**, which co-operates with a flange **23**, projecting from the waveguide wall to form a conventional waveguide choke for passage of the envelope **19**.

Besides the two arrangements described above for coupling power into or out of a slow wave structure according to the invention, various other methods may be adopted. Thus, in the case of an even number of helices, alternate ones of which are contrawound and which are closely spaced so as to provide strong coupling between adjacent helices, it is sufficient to couple a waveguide or coaxial feeder to only one of them, using waveguide probe or other forms of coupler such as conventionally used in travelling wave tubes. It is not necessary, in any case, that there be direct D.C. coupling between the several helices unless it be for beam focusing reasons.

Turning now to the use of other types of slow wave structure, FIG. 7 illustrates an arrangement of four juxtaposed ladder type slow wave structures, together forming a composite slow wave structure for use in high frequency embodiments of the invention. Each component slow wave structure of FIG. 7 can be regarded as derived from the ladder structure of FIG. 8 which is made up of a pair of side plates **24**, between which stretches a transverse grating **25** of parallel resonators, here shown as slots, but which could be bars, inclined to the normal between the side plates **24** so as to produce an assymmetry in the electric field distribution and enable it to propagate over a finite band of frequencies. In FIG. 7 the slotted grating **26** corresponds to the grating **25** of FIG. 8 and the vanes **27**, which are now turned each outwards through an angle of 45°, correspond to the upper parts of the side plates **24**. The lower skirts of the side plates **24** are replaced by the adjacent slotted gratings **28** and **29**. Similarly the adjacent slow wave structure has the grating **28** corresponding to the grating **25**, the vanes **27** corresponding to the upper portions of the skirts **24** and the adjacent gratings **26** and **30** corresponding to the lower skirts of the side walls **24**.

FIG. 9 shows diagrammatically an end view of an arrangement of six slow wave structures of the ladder type assembled together in an analogous manner to the four structures of FIG. 7 and comprises webs **27** and similar gratings **31**. The gratings **31** can take other forms than those illustrated in FIG. 8 such for example, as an intersecting structure of conductors forming a mesh such as disclosed in U.S. Patent No. 3,090,886, issued May 21, 1963, and assigned to the same assignee as the instant application.

In embodiments using the arrangements of FIGS. 7 and 9, the electron beam is projected along the axis of the composite slow wave structure, as in the case of the multiple helix embodiments. Coupling to input and output feeders may be effected in various ways known to those skilled in the art; one method of coupling would be to mount the composite slow wave structure between input and output waveguides normal to the axis of the electron beam, as in many conventional travelling wave tubes, and to have extensions of the individual grating projecting into the respective waveguides through slots cut in the waveguide walls.

While the principles of the invention have been described above in connection with specific embodiments, and particular modifications thereof, it is to be clearly understood that this description is made only by way of example and not as a limitation on the scope of the invention.

What I claim is:

1. A travelling wave tube including an envelope means for projecting an electron beam along a given axis of said envelope and at least three slow wave structures of the same form positioned radially and symmetrically about said beam with the axes of propagation of said structures parallel to said given axis and the electric field having a predominantly longitudinal mode, each said structure being electromagnetically coupled to and spaced apart from the electron beam and the adjacent structure, and signal coupling means around said envelope adjacent and spaced from the ends of said slow wave structure for electromagnetically coupling power into and out of respective said ends.

2. A travelling wave tube according to claim **1** in which the slow wave structures are helices whose pitch circles are spaced apart from one another and from said beams.

3. A travelling wave tube according to claim **1** in which each slow wave structure is formed by a uni-planar grating of parallel conductors arranged in a mesh formation between a pair of side walls.

4. A travelling wave tube according to claim **2** wherein said helices are each wound in the same direction.

5. A travelling wave tube according to claim **2** wherein adjacent said helices are wound alternately in opposite directions.

6. A travelling wave tube including an envelope, an electron gun beam forming structure, a slow wave structure and an electron collector electrode aligned along a given axis of said envelope, in which the slow wave structure is formed by a set of at least three similar helices each wound upon a dielectric support rod, and signal coupling means around said envelope adjacent and spaced from the ends of said helices for electromagnetically coupling power into and out of respective said ends the travelling wave tube further including means mounting the helices and rods symmetrically surrounding and parallel to the given axis and beam in an electromagnetically coupled spaced relationship with the electron beam and with one another, and the electric field

within said tube having a predominantly longitudinal mode.

7. A travelling wave tube according to claim **6** in which the set contains six helices.

8. A travelling wave tube according to claim **7** in which the ends of each rod are mounted in a metal sleeve and each helix is joined at its respective ends to the adjacent sleeve.

9. A travelling wave tube according to claim **7** wherein said signal coupling means includes a waveguide feeder and means for coupling the slow wave structure thereto, said coupling means for said waveguide feeder comprising a drift tube having one end inserted between the helices of the slow wave structure and surrounding the electron beam, said drift tube extending transversely through said waveguide feeder, and a choke at the other end sleeve mounted on the far end of the drift tube continuous with the opposite waveguide wall.

10. Apparatus including a travelling wave tube according to claim **7** wherein said signal coupling means includes a contrawound helix coupler surrounding the travelling wave tube about one end of the slow wave structure.

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