Nov. 21, 1961 J. E. NEVINS, JR 3,010,048

TRAVELING WAVE TUBE WAVEGUIDE SYSTEM

Filed April 2, 1959 4 Sheets-Sheet 1

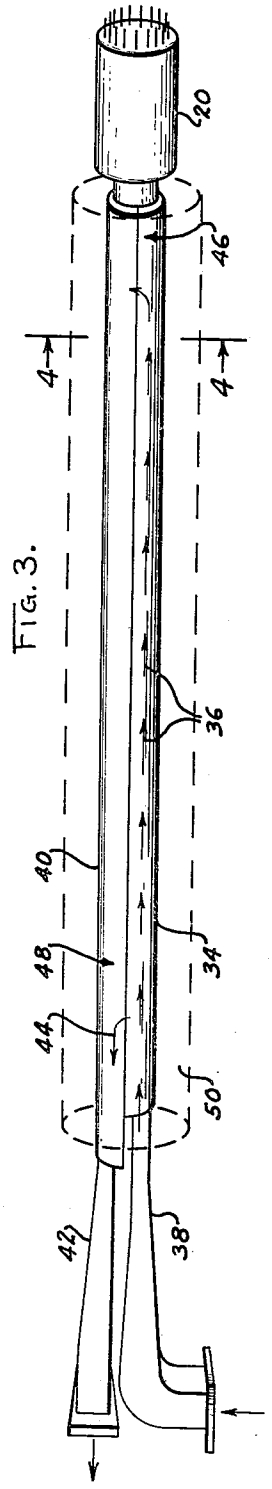



FIG. 3.

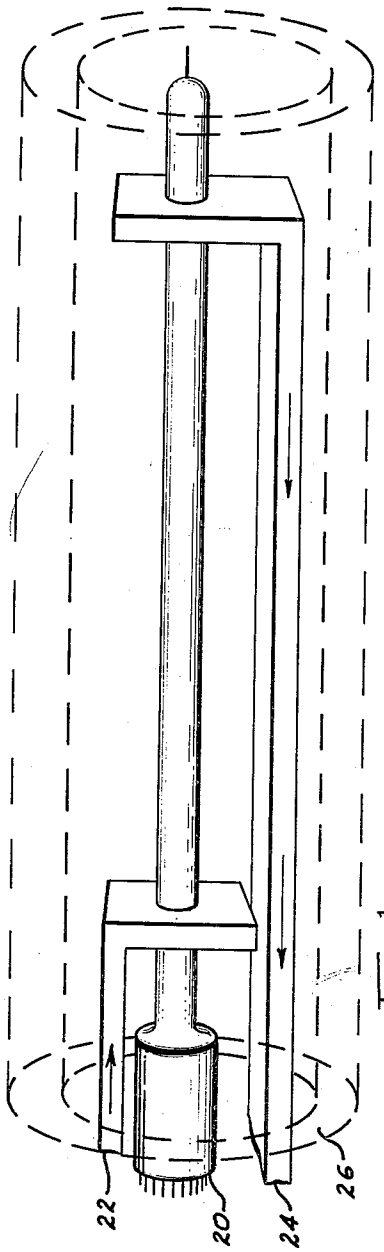



FIG. 1.

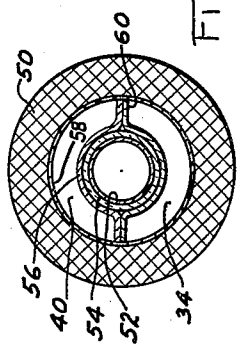



FIG. 4.

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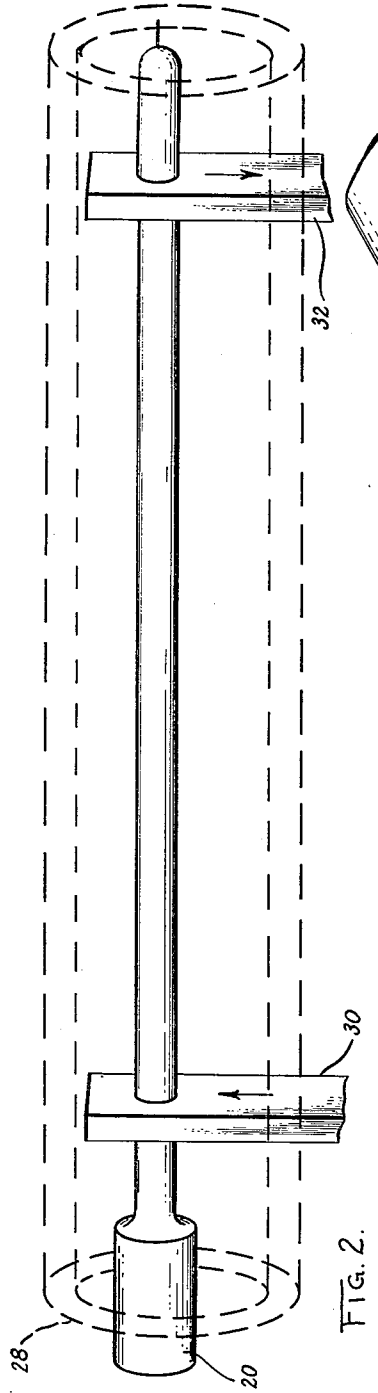



FIG. 2.

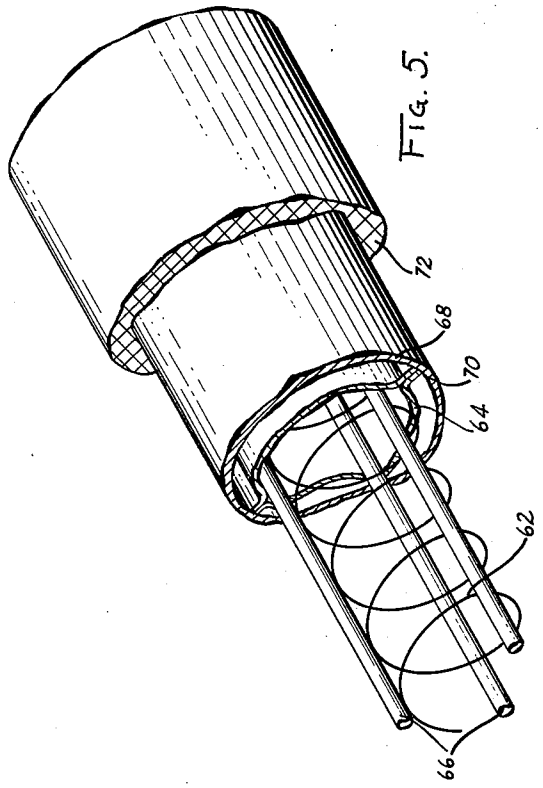


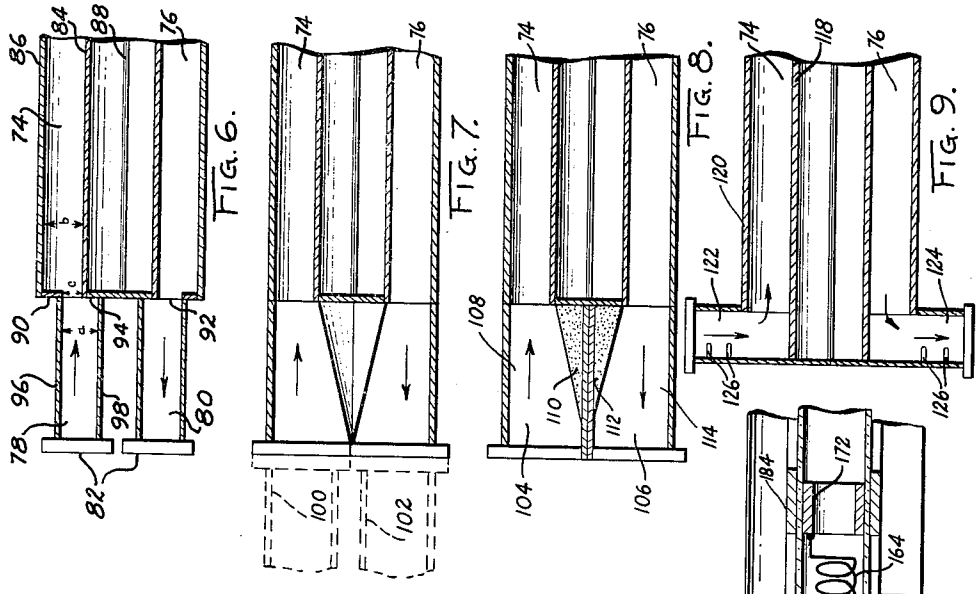

FIG. 5.

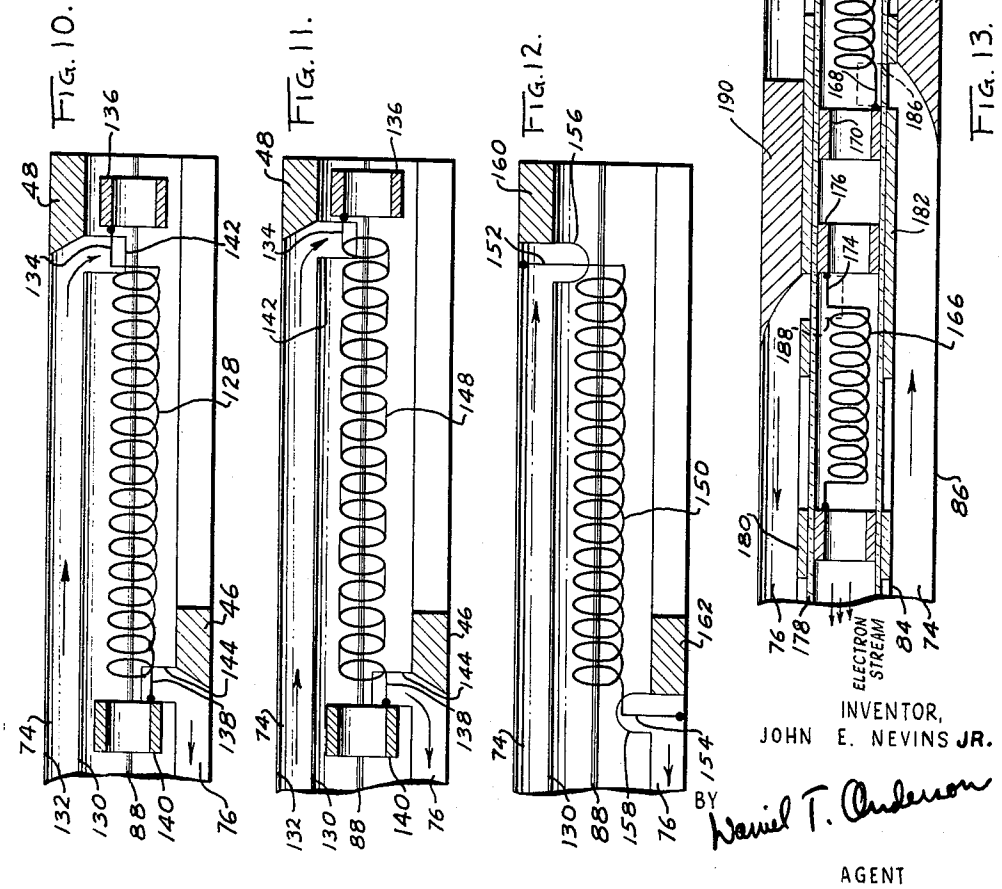
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TRAVELING WAVE TUBE WAVEGUIDE SYSTEM

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FIG. 14.

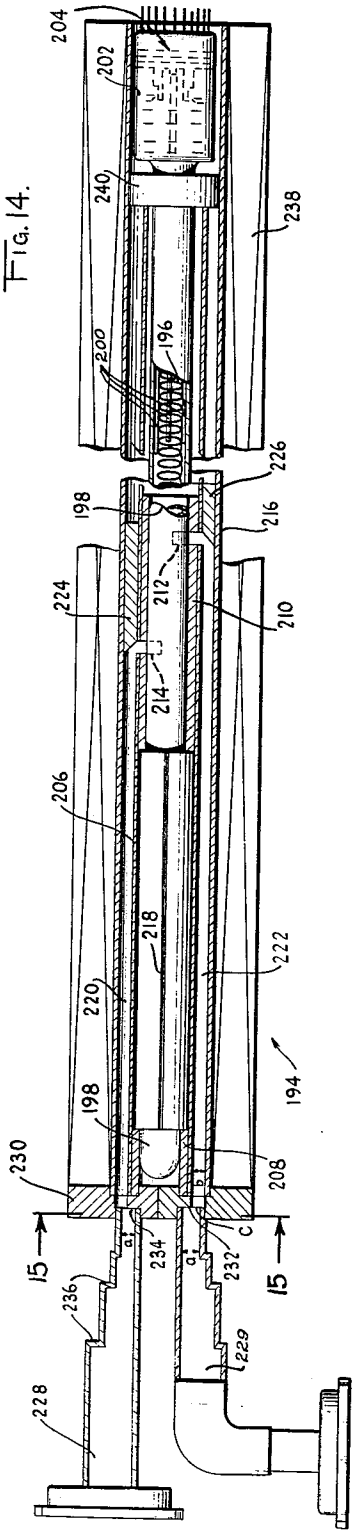
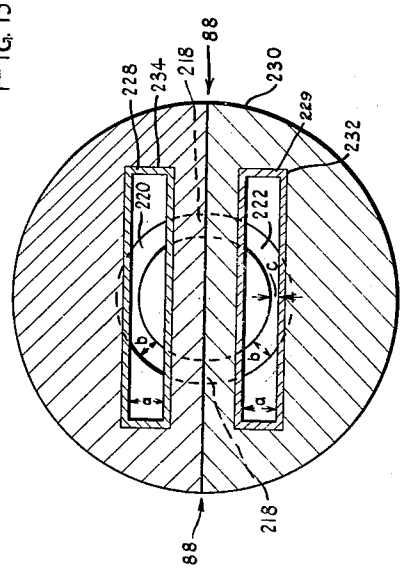



FIG. 15.




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United States Patent Office 3,010,048 Patented Nov. 21, 1961



3,010,048

# TRAVELING WAVE TUBE WAVEGUIDE SYSTEM

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Filed Apr. 2, 1959, Ser. No. 803,803
6 Claims. (Cl. 315—3.6)

This invention relates to waveguide systems in general and more particularly to waveguides having a semiannular cross-sectional configuration.

This invention finds particularly valuable application in connection with traveling-wave tubes wherein it is usually desirable to be able to insert the elongated traveling-wave tube into and withdraw it from a magnetic focusing system which provides an axial magnetic field for focusing the electron stream of the traveling-wave tube.

In one typical form of the prior art a traveling-wave tube with its necessary connecting waveguide system requires a large magnet to surround the traveling-wave tube and the waveguides with their right angle bends. Since the volume circumscribed by the focusing magnet must be so large in diameter, obviously the magnet must be quite large and heavy and, if electrical, must also require a large magnitude of power in order to provide a given strength of focusing magnetic field along the axis of the tube. If the magnet could be made smaller, for example, by the elimination of the rectangular waveguides, clearly, the magnet could be much smaller in diameter and thereby require less magnetic energy in order to provide the given required focusing effect. It is well known in the case of a solenoid, for example, that for a given axial field and constant electrical power, the weight of the solenoid varies as the square of its inner diameter.

An alternative system commonly practiced in the prior art uses rectangular waveguides which extend radially outwardly from the traveling-wave tube and which pass through apertures in the focusing magnet. The magnet here may be somewhat smaller than that noted above; however, the apertures or discontinuities in the focusing magnet will distort or cause perturbations in the focusing of the electron stream unless extra magnetic energy is provided to compensate for the discontinuities. Therefore, although the magnet may be somewhat smaller than in the previously noted case, it still represents an inefficiency in providing a given overall focusing effect from the magnet.

The present invention therefore includes among its objects the following:

To provide a bidirectional waveguide system within a minimum circumscribed cylindrical volume;

To provide a bidirectional waveguide system about an elongated slow-wave structure within a minimum circumscribed cylindrical volume;

To provide a semiannular waveguide system about a slow-wave structure and within a minimum circumscribed cylindrical volume;

To provide a transition from such a semiannular waveguide system to a rectangular waveguide system;

To provide a magnetically focused traveling-wave tube which may be inserted into and withdrawn from a focusing magnet having exceptionally low requirements of size, weight and power;

To provide a low noise backward-wave amplifier traveling-wave tube having an especially strong focusing magnetic field which may be inserted into and effectively focused by an especially small and light magnet.

Briefly, these and other objects are achieved by the present invention in the following manner:

A pair of waveguides, semiannular in cross-section, are provided which may be separately coupled to different feed points of a slow-wave structure inserted coaxially within and between the semiannular waveguides. The entire system may then be inserted into a solenoid or other focusing magnet having a minimum inner diameter due to the overall cylindrical geometry of the traveling-wave tube and pair of semiannular waveguides. The semiannular waveguides may be transformed to conventional rectangular waveguide circuitry at a point axially beyond the focusing magnet so that the focusing magnet need only be large enough and long enough to encompass the semiannular waveguides and the necessary length of traveling-wave-tube and need not circumscribe any rectangular waveguide components. Means are shown herein for providing such a transition which readily provides a voltage standing wave ratio of the order of 1.05.



The novel features of this invention, as well as the invention itself, both as to its organization and method of operation, will best be understood from the following description, taken in conjunction with the accompanying drawings in which like reference numerals refer to like parts, and in which:

FIG. 1 is a schematic view of a prior art traveling-wave tube and associated waveguide system useful in discussing the features of the present invention;

FIG. 2 is a schematic view of an alternative prior art configuration, also useful for purposes of description;

FIG. 3 is a simplified schematic view of an exemplification of the present invention as utilized in conjunction with a traveling-wave device indicated partially in dotted lines;

FIG. 4 is a sectional view taken along the lines 4—4 through the structure shown in FIG. 3;

FIG. 5 is an enlarged partially cut-away view of a segment of the structure shown in FIG. 3;

FIGS. 6 through 9 are longitudinal sectional views of alternative waveguide transition systems, from semiannular to rectangular, constructed in accordance with the present invention;

FIG. 10 is a longitudinal sectional view of a structure in accordance with the present invention which utilizes a helix terminated by coupling leads and matching ferrules and coupled to semiannular waveguides;

FIG. 11 is a longitudinal sectional view of a traveling-wave tube arrangement in accordance with the present invention utilizing an interconnected ring or ring-bar type of slow-wave structure terminated by coupling leads and matching ferrules and coupled to semiannular waveguides;

FIG. 12 is a longitudinal sectional view of a traveling-wave tube utilizing a helical slow-wave structure which is terminated by probes coupling directly into the feed-in semiannular waveguides in accordance with the present invention;

FIG. 13 is a longitudinal sectional view of a backward-wave amplifier embodiment of the present invention utilizing cascaded helices terminated by coupling leads and matching ferrules and coupled to semiannular waveguides;

FIG. 14 is a more detailed view, partly in section and partly broken away, of a practical backward-wave amplifier traveling-wave tube constructed in accordance with the present invention; and

FIG. 15 is a cross-sectional view taken along the lines 15—15 of the structure depicted by FIG. 14.

Referring now with more particularity to the figures, in FIG. 1 there is shown a typical prior art traveling-wave tube 20 which, with its input waveguide 22 and its output waveguide 24, may be inserted coaxially within an encompassing cylindrical magnet or solenoid 26 (shown by dotted lines only). As is readily apparent from the dotted lines, the magnet 26 is very large in comparison to the electron stream of the tube 20 which it is designed to focus; however, the cost in weight, power and material has been readily paid by practitioners in the prior art because of the value in being able to insert and withdraw

the traveling-wave tube 20 for purposes of replacement, repair or experimentation. As pointed out above, however, the size and weight could be drastically reduced but for the necessity of the rectangular waveguides 22 and 24. As may realistically be deduced from the drawing, the inner diameter of the magnet 26 is many times larger than the outer diameter of the glass envelope of the tube 20.

Referring to FIG. 2, there is shown a common alternative practiced in the prior art in which the traveling-wave tube 20 is inserted into a focusing magnet 28 which is apertured along its length to permit the radial passage of an input waveguide 30 and an output waveguide 32. This arrangement has certain advantages in the total size and weight of the magnet required but it has the disadvantage of lack of versatility since the traveling-wave tube 20 cannot be removed from the magnet without removing it also from its waveguide couplings. Thus the critical alignment of traveling-wave tube and waveguides may not be accomplished in the open but must be done within the confines of the focusing magnet 28. A further disadvantage is that the apertures for the waveguides 30 and 32 cause perturbations and a decrease in the otherwise available focusing effect of the magnet 28. The magnet must therefore be made larger and heavier in order to minimize the consequences of the perturbations to a practical magnitude. As a result, and as again may be deduced realistically from the drawing, the size of the magnet 28 is many times larger than it inherently would have to be in order to focus the electron stream within the traveling-wave tube 20.

Referring to FIG. 3, it is seen that a traveling-wave tube 20 may be fed by a system of semiannular waveguides in a manner in accordance with the present invention. The term "semiannular" refers to the cross-section, in conformity with the general use of cross-sectional shapes to denote waveguide types. The lower semiannular waveguide designated 34 is the input waveguide, as indicated by the arrows 36 showing the direction of microwave energy flow for a forward traveling-wave type amplifier. A transition section 38 couples the input semiannular waveguide 34 to external waveguide circuitry, not shown. The upper semiannular waveguide 40 is the output waveguide and couples energy from the traveling-wave tube 20 and carries it to a second transition section 42 from whence it propagates to external waveguide circuitry, not shown. A portion of each of the semiannular waveguides 34 and 40 toward the gun end from the arrows 36 and output arrows 44, respectively, are not utilized and are accordingly physically blocked by conductive plugs 46 and 48, respectively, in the regions indicated by arrows. See FIGS. 10 and 11 for more detail as to these plugs. Also, as will be shown in more detail below, coupling slots are provided in the inner circular walls of the semiannular waveguides 34 and 40 for coupling these waveguides to the slow-wave structure of the traveling-wave tube 20. The terms "upper" and "lower" are used for establishing a frame of reference with respect to the figures, it being understood that the attitude of the structure can be inverted or placed in any other position desired.

The system of semiannular waveguides 34 and 40 and the traveling-wave tube therewithin are inserted within a focusing magnet 50, the outer diameter of which is shown in the figure by dotted lines. Here, the focusing magnet 50 may fit snugly about the semiannular waveguides and may be only slightly larger in diameter than the envelope of the traveling-wave tube 20.

In operation, briefly, the input rectangular waveguide 38 is excited in a conventional mode of propagation such as the $TE_{10}$ mode. This energy passes through the transition section and excites in the $TE_{11}$ the lower or input semiannular waveguide 34 which in turn propagates the energy to the input end of the slow-wave structure of the tube 20. The microwave energy at that point launches a traveling wave upon the slow-wave structure. The traveling wave is caused to interact with the electron stream and is amplified thereby. At the output end of the slow-wave structure, the amplified wave is transmitted into and excites a $TE_{11}$ mode of propagation in the upper, output, semiannular waveguide 40 which in turn excites the output rectangular waveguide 42 in a conventional $TE_{10}$ mode of propagation. Thus, microwave energy is taken from rectangular waveguide, amplified in a traveling-wave tube, and transmitted again into a rectangular waveguide.

FIG. 4 is a slightly enlarged cross-scetional view taken as indicated through the structure of FIG. 3. The inner cylinder 52 illustrates the slow-wave structure within the traveling-wave tube 20. The next outer cylinder illustrates the glass wall 54 of the elongated portion of the envelope for the tube 20. The next outer cylinder indicates the inner conductive nonmagnetic cylinder 56 which forms the inner circular cylindrical surface of the semiannular waveguides 34 and 40. The next outer cylinder depicts the outer circular cylindrical conductive nonmagnetic wall 58 of the semiannular waveguides 34 and 40. The outer, cross-hatched cylinder illustrates the magnet 50. Dividing the annular space between the inner conductive wall 56 and the outer conductive wall 58 are a pair of coplanar conductive vanes 60 which conductively join the two concentric cylinders and divide the annular space into semiannular microwave passages, viz, the input and output waveguides 34 and 40. The conductive vanes 60 lie in an axial diametrical plane, as shown.

Referring to FIG. 5, there is presented a more pictorial and detailed fragmentary view of a structure similar to that of FIGS. 3 and 4. Here, a slow-wave structure or helix 62 is supported and separated from an inner conductive cylinder 64 by a set of dielectric rods 66. A glass envleope may or may not be situated between the rods 66 and the cylinder 64, depending upon the particular configuration chosen by a practitioner. In the structure of FIG. 5 a glass envelope is not shown. An outer conductive cylinder 68 is secured to the inner cylinder 64, again by a pair of mutually coplanar conductive vanes 70, disposed in a diametrical plane passing through the axis of the helix 62. The conductive material of cylinders 64 and 68 and the vanes 70 is generally nonmagnetic in order that the encompassing focusing magnet 72 is not magnetically isolated from the electron stream within the helix 62. The slow-wave structure, illustrated here as a wire helix 62, may be instead a ribbon helix or a ring-bar type of slow-wave structure and may be glazed to the dielectric rod 66 in order to provide a rigid slow-wave structure.

Refer now to FIG. 6, which shows the transition from a pair of semiannular waveguides 74 and 76 to rectangular waveguides 78 and 80. The upper semiannular waveguide is coupled to the input rectangular waveguide 78 and the lower semiannular waveguide 76 is coupled to the output rectangular waveguide 80. Flanges 82 are illustrated as a practical means for coupling the rectangular waveguide, which in this example is a reduced height waveguide, to external rectangular waveguide of conventional height. The semiannular waveguide system is shown without an accompanying inner traveling-wave tube or outer focusing magnet for purposes of simplifying the illustration.

The semiannular waveguides are formed by an inner conductive cylinder 84 and an outer conductive circular cylinder 86. A pair of planar conductive vanes 88 support the cylinders 84 and 86 in concentric alignment and divide the annular space between them into a pair of semiannular waveguide passages. The lefthand ends (as seen in FIG. 6) of the semiannular waveguides 74, 76 are in part closed off by an end planar conductor 90. The planar conductor 90 has two parallel rectangular openings 92 and 94 therein for receiving the righthand ends (again as seen in FIG. 6) of the rectangular waveguide

sections 78 and 80. Referring to the upper or input rectangular waveguide 78, its upper surface is determined by a plane 96 parallel to the diametrical plane indicated at 88 and spaced apart therefrom by a distance intermediate to the different radii of the cylinders 84 and 86. The lower surface of the rectangular waveguide 78 is determined by a plane 98 which is also parallel to the diametrical plane and is separated therefrom by a distance less than the radius of the inner conductive cylinder 84. The waveguide height, *a*, of the rectangular waveguide 78 is approximately equal to the height, *b*, of the semiannular waveguide section 74 which is defined as the difference between the inner radius of the outer cylinder 86 and the outer radius of the inner cylinder 84. The plane 96 is separated from the outer surface of inner cylinder 84 by a distance, *c*, at the point of their closest approach to each other. In practice, the dimension *c*, has proven to be fairly critical and will be discussed in more detail below in connection with the description of FIGS. 14 and 15.

The portion of FIG. 6 below the diametrical plane indicated at 88 is geometrically similar to the upper portion above described and a detailed description is accordingly omitted.

Referring to FIG. 7, an alternative transition is shown for matching an upper semiannular waveguide section 74 and a lower section 76 to rectangular waveguide sections 100 and 102, shown in dotted lines. The transition is a completely smooth one from the semiannular waveguide on the right to a conventional standard height rectangular waveguide on the left.

Referring to FIG. 8, another alternative transition is shown from semiannular waveguide sections 74 and 76 to standard height rectangular waveguide sections 104 and 106. The rectangular waveguide section are simply butted against the cylindrical form of the pair of semiannular waveguides 74 and 76. In order to properly match the geometrically dissimilar form of waveguides 104 and 106 to waveguide sections 74 and 76, dielectric fillets 108, 110, 112 and 114 are placed in the rectangular waveguide sections and are shaped in an appropriate manner to provide a smooth transition from rectangular to semiannular cross-section. For example, the shape of the dielectric fillet 110 is that of a straight line at the lefthand end and a semicircle at the righthand end.

Referring to FIG. 9, another transition from semiannular to rectangular waveguide is shown. In this embodiment the semiannular waveguides 74 and 76 are formed by an inner conductive cylinder 118 and an outer conductive cylinder 120. The inner conductive cylinder 118 extends axially to the left beyond the end of the outer cylinder 120 by a distance which is approximately equal to the waveguide height of a pair of rectangular waveguide sections 122 and 124. The waveguide height of the rectangular waveguides 122 and 124 is approximately equal to the waveguide height of the semiannular waveguides 74 and 76 as defined in connection with FIG. 6. It has been found that one or more matching pins 126 improve the impedance matches between the rectangular waveguides 122 and 124 and the semiannular waveguides 74 and 76, the rectangular waveguides being disposed orthogonally to the axis of the semiannular waveguides 74, 76.

Referring to FIG. 10, there is shown in simplified schematic form means for coupling microwave energy from a pair of semiannular waveguides 74 and 76 to the ends of a traveling-wave tube helix 128. The waveguides are formed by inner and outer cylinders 130 and 132, respectively, which for the sake of a simplified presentation are shown as lines without wall thickness. The helix and the two encompassing conductive cylinders are all concentrically aligned. Adjacent the axial positions of the ends of the helix 128 and coupled thereto are respectively an input coupling lead 134 and matching ferrule 136 and an output coupling lead 138 and matching ferrule 140.

At the axial positions of the coupling leads 134 and 138 are provided coupling slots 142 and 144 through the inner cylinder 130, only, for permitting a coupling communication between a coupling lead and its respective waveguide 74 or 76. To the right of each of the coupling slots 142 and 144 are provided, as indicated in connection with FIG. 3, individual conductive plugs 46 and 48, each of which is semiannular in cross-section and substantially fills the waveguide at the position indicated. The coupling slots 142 and 144 may be rectangularly arcuate in shape extending through any portion of the 180° arc on eitheir side of the diametrical plane indicated at 88.

Referring to FIG. 11, a coupling scheme similar to that depicted in FIG. 10 is illustrated, except that a ring-bar type of slow-wave structure 148 is utilized in the traveling-wave tube instead of the helix 128.

FIG. 12 depicts a similar system for coupling microwave energy from a pair of semiannular waveguides 74 and 76 wherein, however, the helix 150 is terminated at each of its ends by a radially extending coupling lead 152 and 154. The input coupling lead 152 extends radially outwardly through a coupling slot 156 through the inner circular wall of the semiannular waveguide 74 and is electrically connected to the outer cylindrical wall of the waveguide 74 at a point opposite the coupling slot 156. The output end of the helix 150 is in like manner coupled by means of the lead 154 through a coupling slot 158 to the outer wall of the output semiannular waveguide 76. Again, conductive blocks 160 and 162 plug and electrically short the waveguide openings to the right of each of the coupling slots.

Referring to FIG. 13, a backward-wave amplifier arrangement in accordance with the present invention is shown in a simplified schematic view. An input semiannular waveguide 74 and an output semiannular waveguide 76 again are made up of an inner conductive cylinder 84 and an outer conductive cylinder 86 is arranged concentrically about a slow-wave structure system of the backward-wave amplifier which comprises an input helix 164 and an output helix 166.

At its lefthand end (as seen in FIG. 13) the input helix 164 is terminated by a coupling lead 168 and a matching ferrule 170. At the opposite or righthand end, the helix 164 is terminated by a ferrule 172. A resistive termination at this end may be provided by applying a lossy substance, such as aquadag, to the last few turns of the helix 164 and the ferrule 172.

The output helix 166 is similarly terminated at each end by a coupling lead 174 and a matching ferrule 176 at its righthand end, and a resistive termination applied to its lefthand end as described concerning the input helix 164. The helices and ferrules in this example are supported within a glass envelope 178 which is in turn supported within the semiannular waveguide system by a series of spacing cylinders 180, 182 and 184. An input coupling slot 186 at the axial position of the input coupling lead 168 is provided through both the inner conductive wall 84 and the supporting cylinder 182 to provide electromagnetic coupling communication between input waveguide section 74 and the input helix 164. Similarly, a coupling slot 188 is provided through the inner wall 84 and the supporting cylinder 182 at the axial position of the coupling lead 174. Again, the semiannular waveguides 74, 76 are blocked and shorted to the right of the coupling slots by conductive plugs 190 and 192.

The electron stream in this cascaded helix backward-wave amplifier example traverses the tube from right to left in the figure, as shown.

Input microwave energy propagated through the waveguide section 74 is impressed upon the input helix 164 and the electron stream is modulated in a backward-wave mode. The stream thus modulated passes through an

output helix 166 and produces thereon an amplified signal corresponding to the original stream modulation. The backward-wave energy thus amplified is coupled by means of the lead 174 into the output semiannular waveguide 76.

Not shown in the simplified views of FIGS. 10 through 13 are other necessary traveling-wave tube components, e.g., the annular encompassing focusing magnets. The use of these and other elements have been omitted to clarify the description, but will be understood by those skilled in the art.

Referring to FIG. 14, there is shown, partly in section and partly broken-away, a practical embodiment of a backward-wave amplifier constructed in accordance with the present invention and embodying structure similar to that schematically shown in FIG. 13. A pair of cascaded helices are included in the slow-wave structure system of the traveling-wave tube 194. Only the input helix 196 is visible in the drawing. An output helix is disposed toward the opposite or lefthand end of the tube 194. The helix 196 is supported concentrically within a glass envelope 198 and separated therefrom by three dielectric rods 200. Attached to the righthand end of the glass envelope 198, forming an extension of the same vacuum envelope, is an enlarged glass envelope 202 which encompasses and supports a low noise electron gun 204. The electron gun utilized in this particular example is constructed generally along the lines of the low noise electron gun discussed in the following co-pending application and patent assigned to the assignee of the present invention: Low Noise Traveling-Wave Tube, Serial No. 631,129, filed December 28, 1956, now Patent No. 2,936,393, by M. R. Currie and D. C. Forster, and Patent No. 2,869,021, issued January 13, 1959, entitled Low Noise Traveling-Wave Tube by M. R. Currie. Such low noise electron guns readily make possible traveling-wave tubes having noise figures of the order of 3 decibels.

Such low noise guns are usually immersed in an exceptionally strong focusing magnetic field which aids in the mechanisms of achieving noise reduction. This requirement of an exceptionally strong magnetic field would cause a conventional focusing system to be exceptionally large and heavy in order to provide the required field. However, in accordance with the present invention whereby the focusing magnet may be substantially immediately adjacently about the electron gun, the magnet may be vastly reduced in size and weight and power as compared to that which would otherwise be required.

The portion of the traveling-wave tube system enclosed by the glass envelopes 198 and 204 may be freely inserted and withdrawn from the semiannular waveguide system and focusing magnet which is constructed generally in accordance with the schematic figures previously described. Spaced radially outwardly from the glass envelope 198 is an inner, nonmagnetic circular conductive cylinder 206. Secured to the inner surface of the cylinder 206 are supporting cylinders 208 and 210. These cylinders substantially fill the annular space between the envelope 198 and the conductive cylinder 206 so as to maintain concentricity between the glass envelope and the cylinder 206. The supporting cylinder 210 and the inner cylinder 206 are relieved to provide a pair of coupling slots 212 and 214 at the axial position of coupling leads on the ends of the helices, for example, helix 196. Disposed radially outwardly and concentric with the inner cylinder 206 is shown an outer, nonmagnetic conductive cylinder 216. The annular space between cylinders 206 and 216 is divided into semiannular cylindrical microwave passages 220 and 222 by a pair of conductive vanes 218 lying coplanarly in a diametrical axial plane. Because of the view taken, only one of the vanes, 218, appears in the drawing.

To the right of each of coupling slots 212 and 214 is disposed a conductive shorting plug 224 and 226. These plugs are semiannular in cross-section and substantially fill semiannular waveguide passages 220 and 222, respectively, so that microwave energy may only traverse in the passage from the left up to the associated coupling slot 212 or 214. The lefthand end of each of plugs 224 and 226 is conically tapered to aid in the coupling between slot and waveguide.

At the lefthand end of the tube 194 each of the semiannular waveguides 220 and 222 are coupled to a segment of rectangular waveguides 228 and 229, respectively. The semiannular waveguides are effectively continued for a short distance beyond the lefthand end of cylinders 216 and 206 by a pole piece 230 having semiannular passages therethrough substantially matching and aligned with the semiannular passages of waveguides 220 and 22. Recessed into the lefthand face of the pole piece 230 are rectangular openings 232 and 234 adapted to receive snugly the reduced height righthand end of each of rectangular waveguides 229 and 228. The reduced height of the rectangular waveguides 228, 229 is made approximately equal to the height, *b*, of the semiannular waveguide 220 or 222, as discussed in connection with FIG. 6. The minimum clearance at the juncture of the two forms of waveguide is again designated as "*c*." A series of waveguide steps 236 are provided to form an impedance transformer between the reduced height, *a*, and the conventional rectangular waveguide height at the lefthand end of waveguides 228 and 229.

Immediately surrounding the outer cylinder 216 is the focusing magnet 238 which extends from the pole piece 230 to axially beyond and over the electron gun 204. An additional pole piece may be supplied at the righthand end of the magnet 238, if desired. It has been found expedient for purposes of ease in assembling to form the pole piece 230 from a pair of matched halves. The same has been found regarding the fabrication of some of the other elements of the structure, for example, the elongated inner and outer cylinders and the supporting cylinder 208. Thus, these cylindrical parts may be stamped from flat sheet stock and then built up into their finished forms.

It has been found desirable to provide a transverse component of the axial magnetic field near the collector end of the tube 194 in order to defocus the electron stream and spread its energy over a larger portion of the surface of the collector electrode. To this end, the individual halves of the cylinder 208 may be of magnetically different materials. For example, the upper half may be copper and the bottom half iron. In similar manner, the pole piece 230 may also be constructed to provide an angular asymmetry in the focusing field near the collector.

About the righthand end of the elongated envelope 198 is a supporting collar 240 which has an inner diameter approximately equal to the outer diameter of the envelope 198, and has an outer diameter equal to the inner diameter of the outer cylinder 216. The collar 240 is secured to the outer cylinder 216 and to the inner cylinder 206 which it physically terminates.

In a particular example of the invention designed to operate at X-band and constructed generally in accordance with the structure depicted in FIG. 14, as discussed above, and FIG. 15, discussed below, the height, *a*, of the rectangular waveguide was made .090 inch and the height, *b*, of the semiannular waveguide was .095 inch. The clearance, *c*, was .009 inch. The voltage standing wave ratio in the waveguide was approximately 1.05 and the gain of the tube was approximately 30 decibels over an appreciable fraction of the X-band frequency range. The noise figure was less than four decibels and the magnet weight was approximately one-third of that which is otherwise required to achieve like results.

Referring to FIG. 15, some of the details of the transition from rectangular to semiannular waveguide at the lefthand end of the tube 194 of FIG. 14 are represented from a cross-sectional view for additional clarity. The semiannular waveguides 220 and 222 are shown end-on

and in part by dotted lines due to the opaqueness of the pole piece 230. The longitudinal conductive dividing vanes 218 are shown lying in the axial diametrical plane indicated at 88. The reduced height ends of the waveguides 228 and 229 are shown in place, inserted into the rectangular recesses 234 and 232 in the pole piece 230. The height of the semiannular waveguides is indicated by "*b*" and is defined as the differential between the inner radius of the outer cylinder 216 and the outer radius of the cylinder 206. The reduced height of the rectangular waveguide is again indicated by "*a*." "*c*" again designates the slight minimum vertical clearance between the plane of the lower surface of the upper portion of the waveguide 228 and the upper surface of the inner cylinder 206. The letter "*c*" in the lower half of FIG. 15 indicates the geometrically similar quantity regarding the waveguides 222 and 229.

There have thus been described a number of embodiments of semiannular waveguide structure which are capable of providing two waveguide passages about an inner cylindrical structure such as a traveling-wave tube slow-wave structure and electron gun within a minimum circumscribed circle about which an encompassing focusing magnet may be placed. Such a configuration provides a given required focusing effect from a minimum weight or power of focusing magnet. The overall package may thus be lighter in weight considering both the magnet and its power supply, if electrical, by a factor of 2 to 4. Thus, the arrangement makes practical the use of traveling-wave tubes in airborne, otherwise mobile, or miniaturized equipment where the size and weight required for focusing magnets and/or focusing magnet power supplies would heretofore have rendered such traveling-wave tubes impractical.

What is claimed is:

1. A traveling-wave tube including: a waveguide system for propagating microwave energy in a predetermined frequency range in both directions along the axis of and exterior to an elongated circular cylindrical volume having a predetermined radius, said waveguide system including a pair of substantially semiannular waveguides comprising an inner conductive circular cylinder having substantially said predetermined radius, an outer conductive substantially circular cylinder disposed coaxially with said inner cylinder and at least two longitudinally disposed conductive planar vane members conductively secured between said cylinders dividing the annular space therebetween into said semiannular waveguides, the radius of said outer cylinder being of a magnitude to provide said waveguide system about said elongated cylindrical volume within a circumscribed cylinder of minimum radius, and transition means from one of said semiannular waveguides to a rectangular waveguide comprising a rectangular waveguide impedance step transformer varying in waveguide height from the conventional dimension of approximately half the width of the waveguide to a substantially lesser height approximately equal to the annular differential radius of said semiannular waveguides, said impedance transformer being disposed at the end of said one of said semiannular waveguides with its longitudinal dimension parallel to the axis of said semiannular waveguides and with the lower height end thereof being partially in register with said one of said semiannular waveguides; and a cylindrical focusing magnet system having an inner diameter substantially equal to that of said outer conductive cylinder and being disposed adjacently thereabout.

2. A traveling-wave tube including: a waveguide system for propagating microwave energy between a rectangular waveguide and a slow-wave structure within a minimum circular cylindrical volume comprising an inner cylindrical conductive tube disposed about and coaxially with said slow-wave structure; an outer cylindrical conductive tube disposed coaxially about said inner cylindrical tube, two coplanar conductive vanes lying in an axial diametrical plane conductively joining said inner and outer cylinders and dividing the annular space therebetween into a pair of semiannular waveguides; a length of rectangular waveguide whose broad walls lie respectively in first and second planes parallel to said diametrical plane and abutting one of said semiannular waveguides in partial optical register and in electromagnetic communication therewith, said first plane lying apart from said diametrical plane by a distance less than the radius of said inner cylinder, said second plane lying apart from said diametrical plane by a distance intermediate the radii of said inner and outer cylinders; and a cylindrical focusing magnet system having an inner diameter substantially equal to that of said outer conductive tube and being disposed adjacently thereabout.

3. A traveling-wave tube including: a waveguide system for propagating microwave energy between a rectangular waveguide and a slow-wave structure within a minimum circular cylindrical volume comprising an inner cylindrical conductive tube disposed about and coaxially with said slow-wave structure, an outer cylindrical conductive tube disposed coaxially about said inner cylindrical tube, two coplanar conductive vanes lying in an axial diametrical plane conductively joining said inner and outer cylinders and dividing the annular space therebetween into a pair of semiannular waveguides; a length of rectangular waveguide whose broad walls lie respectively in first and second planes parallel to said diametrical plane and abutting one of said semiannular waveguides in partial optical register and in electromagnetic communication therewith, said first plane lying apart from said diametrical plane by a distance less than the radius of said inner cylinder, said second plane lying apart from said diametrical plane by a distance intermediate the radii of said inner and outer cylinders, the height of said semiannular waveguides being equal to the differential radius of the annulus and being substantially equal to the height of said rectangular waveguide, the width of said rectangular waveguide being of the order of the outer diameter of said annulus; and a cylindrical focusing magnet system having an inner diameter substantially equal to the outer diameter of said annulus and being disposed adjacently thereabout.

4. A traveling-wave tube comprising: an electron gun for projecting an electron stream along the axis of said tube; a slow-wave structure system for propagating microwave energy in electromagnetic interaction relationship with said stream; a first elongated conductive cylinder coaxial with said tube and disposed closely about said slow-wave structure system; a second coaxial conductive cylinder disposed externally to said first cylinder providing an annular cylindrical space therebetween; a pair of conductive planar vanes lying in a diametrical plane and disposed along and dividing said annular space into a pair of semiannular waveguides, each of said semiannular waveguides being coupled through apertures in said inner conductive cylinder to said slow-wave structure system; a focusing magnet system disposed closely about said outer cylindrical conductor along at least a portion of the length thereof for focusing said electron stream.

5. A traveling-wave tube amplifier system which may readily be inserted into and withdrawn from an annular focusing magnet of relatively small radial dimensions and small weight comprising: an electron gun for projecting an elongated electron stream in a given direction along a predetermined path; a helical slow-wave structure system disposed about said electron stream in electromagnetic energy exchange relationship therewith; a pair of semiannular waveguides disposed about said helical system and adapted to fit inside said focusing magnet, said semiannular waveguides surrounding said helical system thereby supporting said helical system in coaxial alignment with said magnet when inserted therein; waveguide transition means axially displaced from said magnet when

said waveguides are inserted therein for matching said semiannular waveguides to rectangular waveguides external to said magnet, said helical slow-wave structure system having along its length at a predetermined axial point at least one signal coupling means, one of said semiannular waveguides being apertured through its inner wall at said axial point to provide coupling between the particular semiannular waveguide and said helical system, and means in the apertured semiannular waveguide for shorting said waveguide in one direction from said predetermined axial point.

6. A low noise backward-wave amplifier traveling-wave tube system comprising: an elongated glass envelope in a major portion of the length thereof being of a first predetermined radius and one end of said envelope being somewhat enlarged for encompassing and supporting a low noise electron gun for projecting a hollow stream of electrons along the common axis of said elongated envelope; said enlarged end portion having a second predetermined radius; a pair of helices disposed along said major portion of the length of said envelope and supported thereby coaxially about said stream, the ends of said helices toward each other being terminated by a coupling lead and a matching ferrule, said matching leads being respectively at a first and a second axial position along the length of said envelope; a first conductive nonmagnetic cylinder disposed over substantially all of said major portion of the length of said envelope; a second nonmagnetic conductive cylinder having an inner radius substantially equal to said second predetermined radius extending over substantially the entire



length of said envelope and coaxially about said first conductive cylinder; a pair of nonmagnetic conductive vanes disposed in the annular space between said first and second conductive cylinders lying coplanarly in an axial diametrical plane of said tube for dividing said annular space into a pair of substantially isolated semiannular waveguides, each of said semiannular waveguides, including a pair of arcuate coupling slots, one of said arcuate slots being at said first predetermined axial position for coupling one of said semiannular waveguides to one of said helices, the other of said arcuate slots being at said second predetermined axial position for coupling the other of said helices to the other semiannular waveguide; an annular focusing magnet having an inner radius substantially equal to the outer radius of said second conductive cylinder and extending thereover for substantially the entire length of said envelope, said semiannular waveguides extending at least to the end of said focusing magnet at the end thereof opposite to said electron gun; and transition means for matching each of said semiannular waveguides to rectangular waveguides externally to said magnet, said semiannular waveguides being shorted and blocked at axial points adjacent to said arcuate slots in each guide toward the electron gun end of said tube.

**References Cited** in the file of this patent

UNITED STATES PATENTS

| | | |
|---|---|---|
| 2,281,552 | Barrow | May 5, 1942 |
| 2,306,282 | Samuel | Dec. 22, 1942 |
| 2,653,270 | Kompfner | Sept. 2, 1953 |
| 2,868,978 | Kearney et al. | Jan. 13, 1959 |