May 19, 1959 W. D. McBEE 2,887,608

TRAVELLING WAVE TUBE

Original Filed June 9, 1954

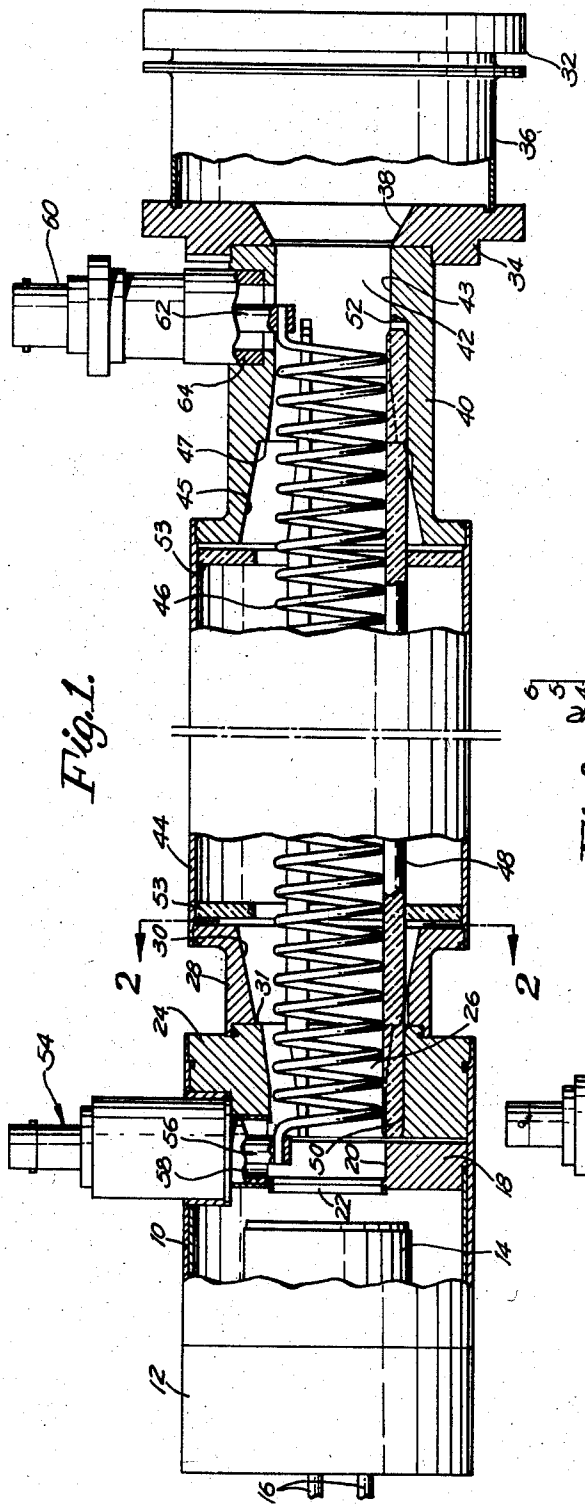


Fig. 1.

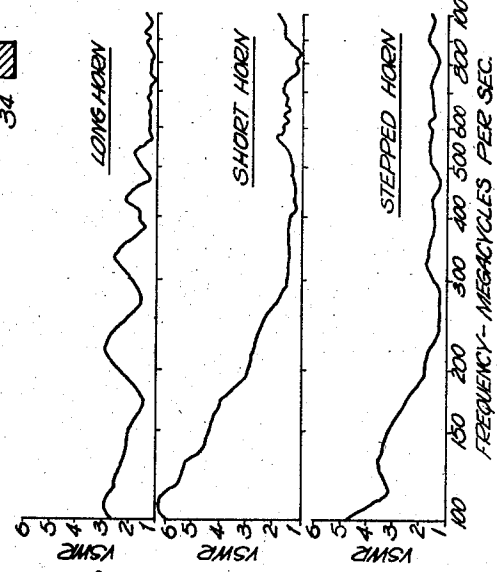


Fig. 3a.

Fig. 3b.

Fig. 3c.

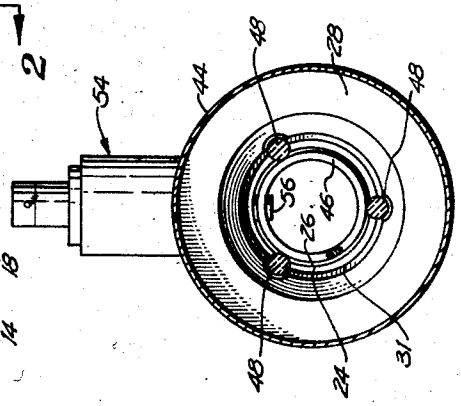


Fig. 2

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TRAVELLING WAVE TUBE

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Continuation of application Serial No. 435,453, June 9, 1954. This application October 24, 1956, Serial No. 618,153

6 Claims. (Cl. 315—3.5)

This invention relates to travelling wave tubes, and more particularly, is concerned with improved means for coupling of radio frequency energy into and out of the helix of a travelling wave tube. This application is a continuation of copending application Serial No. 435,453, filed June 9, 1954, in the name of the present inventor, now abandoned.

As pointed out in the copending application Serial No. 426,362 filed April 29, 1954, in the name of Seymour B. Cohn by the assignee of the present invention, to achieve a smooth transition between a helix and coaxial line in a travelling wave tube for example, a tapered horn member may be utilized which surrounds the end of the helix. The tapered horn smoothly converts the helix mode of propagation to a TEM mode of propagation by gradually introducing a ground plane adjacent the helix wire. By proper spacing between the helix wire and the ground plane, the characteristic impedance of the transmission line in the region where the TEM mode of propagation is effected may be made equal to the characteristic impedance of the coaxial line coupled to the end of the helix, so that a good match may be obtained over a substantial frequency band.

The transition section between the tapered horn and the helix, at least in the region where an appreciable amount of the energy is propagated in the TEM mode, functions in the manner of a linearly tapered section of coaxial line. As is well known (see Microwave Transmission Design, by T. Moreno, McGraw-Hill, 1948, pages 53–55), the VSWR of such a tapered section varies at a given frequency as a function of the length of the taper in a periodic fashion, with voltage minimums occurring when the length of the taper is a half wavelength or integral multiple thereof. A similar periodic variation of VSWR exists with change in frequency for a given length of taper, the voltage minimums occurrings where the frequency is such that the length of the tapered section is a half wavelength or integral multiple thereof. As the frequency increases, i.e., as the length of the taper in terms of wavelengths increases, the successive maximums of VSWR decrease in magnitude. This indicates that to operate within a certain maximum VSWR, at lower frequencies the length of the taper must be increased.

However, it is desirable that the horn in a travelling wave tube be made as short as possible. The reason is that the portion of the helix within the horn does not interact with the electron stream, so that the effective portion of the helix is only that part between the horns. Thus the longer the horns are, the longer must be the helix and the travelling wave tube to have the same effective length for interaction with the beam. The longer the tube, however, the more expensive it becomes and the greater the beam focusing problem becomes.

It is the general object of this invention therefore to provide an improved travelling wave tube amplifier in

which the useful bandwidth is appreciably extended in the direction of lower operating frequencies.

Another object of this invention is to provide a matching structure between the helix of a travelling wave tube and the input and output coaxial lines which for a given bandwidth of operation is more compact and results in a less expensive tube.

These and other objects of the invention which will become apparent as the description proceeds are achieved by the provision of a travelling wave tube having a helical conductor and means for directing a stream of electrons along the longitudinal axis of the helical conductor. A first horn member and a second horn member encircle the respective ends of the helix and are coaxial therewith, the horn members having throat portions of inner diameter slightly larger than the diameter of the helix and flaring portions directed toward each other. The flaring portion of each of the horn members has two sections, the second section having a greater flaring taper than the first section and being larger in diameter where the two sections are joined. Thus, each of the horn members is provided with a step formed in the inner surface thereof between the two sections. Input and output coaxial lines couple the R.F. signal into and out of the helix at the ends thereof within the throat portions of the horn members.

For a better understanding of the invention, reference should be had to the accompanying drawing, wherein:

Fig. 1 is a longitudinal view of a travelling wave tube showing the features of the present invention;

Fig. 2 is a cross-sectional view taken substantially on the line 2—2 of Fig. 1; and

Fig. 3 is a series of graphs used in explaining the theory of operation of the invention.

Referring to Fig. 1, the travelling wave tube as there illustrated includes at one end a cylindrical shell **10** forming part of the evacuated envelope. The input end of the tube includes a base **12** to which is mounted a cathode assembly **14**. Connections to the cathode and heater (not shown) are made through suitable pin connections indicated at **16** projecting from the base **12**. An accelerating anode **18** is positioned within the shell **10** adjacent the cathode assembly **14**, the anode **18** having a central opening **20** therein provided with a grid assembly **22** to form in combination with the cathode **14** an electron gun assembly for directing a stream of electrons along the longitudinal axis of the tube.

Also mounted within the cylindrical shell **10** is a magnetic pole piece **24** adjacent the anode **18**. The pole piece **24** has an opening **26** aligned with the opening **20** in the anode **18** along the longitudinal axis of the tube. The opening **26** is tapered over a portion of its extent in a manner and for a purpose which will hereinafter be more fully described. Forming part of the vacuum envelope and secured to the pole piece **24** is a metallic transition member **28** having a tapered opening **30** therethrough which is axially aligned with the openings **20** and **26**. The anode **18** with its opening **20**, the pole piece **24** with its opening **26**, and the transition member **28** with its opening **30** define an input horn member having a throat portion and flaring portion. The flaring portion is in two sections, the first section being formed by the flared part of the opening **26** in the pole piece **24** and the second section being formed by the opening **30** in the transition member **28**. A step **31** is provided between the two sections. This step is a significant feature of the present invention, as will become apparent.

The output end of the tube includes a collector electrode **32** and a magnetic pole piece **34**, the collector electrode **32** being joined to the pole piece **34** by means

of a cylindrical shell 36 forming part of the evacuated envelope of the tube. The pole piece 34 has an opening 38 therethrough for passage of the electron stream directed towards the collector from the cathode 14. Mounted adjacent the pole piece 34 is a metallic horn member 40 forming part of the envelope of the tube, the horn member 40 having an opening 42 therethrough extending along the longitudinal axis of the travelling wave tube. As at the input end, the member 40 with its opening 42 defines an output horn member having a throat portion 43 and flaring portion 45 in two sections with a step 47 between the two sections. The first section of the flaring portion 45 extends from throat portion 43 to the step 47, the second section extending from step 47 towards the input horn member.

The input end and the output end of the tube are joined by an elongated cylindrical metallic shell 44 extending between the transition member 28 and the horn member 40. Extending along the longitudinal axis of the tube with a portion thereof being within shell 44 and coaxial therewith, is a helical conductor 46. The conductor 46 is supported by a plurality of ceramic rods 48, the shell 44 having a diameter of sufficient magnitude so that it has substantially no effect on the fields of energy travelling along conductor 46 over the desired frequency band of operation for the device. The rods 48 are preferably three in number. These rods extend between and are supported by the pole piece 24 at the input end of the tube and the horn member 40 at the output end of the tube, the ends of the rod 48 being positioned in holes or bores 50 and 52 in the pole piece 24 and the horn member 40 respectively. Thus, the helix conductor 46 is coaxially positioned within the openings 26 and 30 at the input end of the tube and the opening 42 at the output end of the tube. Ceramic spacer members 53 may be positioned along the helix to give support to the rods and helix.

An input coaxial line, indicated at 54, having an inner conductor 56 and an outer conductor 58, is provided for coupling ultra-high frequency energy into the traveling wave tube. To this end, the outer conductor 58 passes through the shell 10 and terminates in a T-junction with the anode 18 and pole piece 24. The inner conductor 56 extends into the opening 20 in the anode 18 and is joined to the end of the helix 46.

Similarly, an output coaxial line section, indicated at 60, having an inner conductor 62 and an outer conductor 64, extends at right angles to the horn member 40, the outer conductor 64 forming a T-junction with the horn member 40 and the inner conductor 62 extending into the longitudinal opening 42 where it joins the end of the helical conductor 46 for coupling energy out of the helix. Both the input and output coaxial line sections preferably have a standard characteristic impedance of 50 ohms, the impedance between the helix 46 and throat portion of each of the input and output horn members being substantially the same as that of the aforementioned coaxial line sections. The impedance of the section of helix 46 between the horn members is many times larger than that of the coaxial line sections at the lower frequencies within a desired frequency band of operation from 200–1000 megacycles, and becomes decreasingly less as the frequency increases toward the upper end of said frequency band.

Suitable magnetic means (not shown) may be provided in conventional manner to establish a magnetic focussing field between the pole pieces 24 and 34. The aforementioned focussing field is provided for maintaining the electron beam produced by cathode 14 and anode 22 for passage through helix 46 to collector 32 at a substantially constant diameter as the beam progresses through the helix.

Within certain design limitations to be described further below, the best dimensions for the stepped horn over a particular frequency band are generally developed empirically. A suitable horn and helix design which gives a VSWR of less than 2 over a 5:1 band and going down to 200 megacycles at the low end is as follows:

First taper	6°40′
Second taper	10°40′
Smallest dia. of first section	1.012″
Axial length of first section	9/16″
Smallest dia. of second section	1.254″
Axial length of second section	27/32″
Helix outer dia.	0.980″
Helix turns per inch	5

By making the tapered portion of each horn of the present invention of two sections with a step discontinuity between rather than a straight horn of the same length without a step, it is possible to extend the bandwidth of operation at the lower frequency end of the band without intolerably increasing the length of the horn and still operate well below a VSWR (voltage standing wave ratio) design limit of 2.0 at all frequencies within a frequency band of about 200–1000 megacycles. Why this is so may be better understood by referring to the graphs of Fig. 3 illustrating the VSWR vs. frequency curves of performance for various tapered horn helical transmission line matching sections.

Fig. 3*a* is illustrative of a typical frequency response curve of a straight tapered horn helix matching structure without a step, not illustrated, for operation over a desired frequency range from 200–1000 megacycles. Such a horn is approximately that which would result from an extension in length of the first tapered section of the stepped horn illustrated in Fig. 1, whose design characteristics are given above, to approximately 4 inches along a similar helix. This straight horn extends along its axis for about one-half wavelength of microwave energy along the helix at a frequency corresponding to the first VSWR minimum to the right of the ordinate in Fig. 3*a*.

The VSWR behavior of a horn and helix producing the results observed in Fig. 3*a* is periodic with frequency up to about 575 megacycles, each VSWR minimum corresponding to a frequency at which the horn is approximately an integral number of half wavelengths long. Above 575 megacycles, the curve in Fig. 3*a* smooths out. This is because at frequencies below about 575 megacycles, reflection takes place from both ends of the horn producing a typical interference pattern between the two reflected waves. Above the foregoing frequency, little or no reflection takes place at the larger end of the horn since its dimensions were such that its larger end was too far removed from the helix; i.e., the helix electric field at the larger end of the horn is negligible for the higher frequencies. If the straight tapered horn were made even longer than that described above, the points of maximum VSWR would decrease in magnitude. However, increasing the length of the horn is undesirable for reasons already described.

A shorter, straight tapered horn than that described with reference to Fig. 3*a* may also be used. The VSWR vs. frequency curve for the shorter horn is illustrated in Fig. 3*b*, in which case the horn is about one-eighth as long as that producing the results shown in Fig. 3*a* with a similar helix. The shorter horn gives good performance in a middle range of frequencies, but its performance is not as good as the long horn in the upper half of the desired frequency band of operation. The VSWR for the short horn at lower frequencies below approximately 275 megacycles is far above a desired minimum of 2. This is due to the fact that at lower frequencies, both ends of the taper of the short horn present large discontinuities to the field and are spaced much less than one-half wavelength apart so that one reflected wave does not cancel the other. An attempt to decrease the VSWR at lower frequencies by increasing the horn length leads to a characteristic such as that in Fig. 3*a*. Horns of various lengths between the 0.5 inch horn producing the results shown in Fig. 3*b* and the 4 inch horn producing the results in

Fig. 3*a* have been tested with the VSWR being well above 2 at various points in the desired frequency band from 200–1000 megacycles.

In the present invention, advantage is taken of the differences in radial variation of the field at high and low frequencies by the two stage horn shown in Fig. 1 as above described to extend the range of frequencies for which the VSWR is less than 2 to a lower frequency limit, and to keep the VSWR considerably less than 2 from this frequency limit all the way up the band of frequencies including the highest frequencies of operation. The VSWR vs. frequency performance curve of the stepped horn and helix shown in Fig. 1 having design dimensions as given above is shown in Fig. 3*c*, the stepped horn showing good performance from 200 megacycles on up the frequency band.

The first tapered section or stage of each stepped horn in Fig. 1 adjacent the throat thereof is designed so that the radius of its smaller end corresponds to that of the throat portion. The first tapered section extends along the axis of the tube for one half wavelength of microwave energy carried by the helix within the horn at a frequency in the upper half of a desired frequency band. This frequency corresponds to approximately 680 megacycles per second for a horn design for operation over a frequency band from approximately 200–1000 megacycles per second producing the results shown in Fig. 3*c*, for example. The radius of the larger end of the aforementioned first tapered section of each horn is chosen so that the inner horn wall at the larger end of the first section is just beyond the effective radial extent of the helix fields at a predetermined frequency slightly lower than that at which the first tapered horn section would become three quarters of a wavelength long. The foregoing predetermined frequency corresponds to approximately 1000 megacycles per second for a stepped horn providing a performance curve over the frequency band shown in Fig. 3*c*.

The smaller end of the second tapered section of each horn is slightly larger than the adjacent end of the first tapered section so that a step discontinuity exists between the sections. The extents of both the first and second tapered sections of each horn along the axis of the tube is chosen so that their total is approximately one-half wavelength of the microwaves carried by the helix within the horn at a frequency within the lower half of the design frequency range for the device. In the example shown in Fig. 3*c*, the foregoing frequency corresponds to about 290 megacycles per second, for example. The largest end of the second tapered section has a radius so that the inner wall of the large end of the horn is just beyond the effective radial extent of the helix fields at a predetermined frequency slightly lower than that at which the total lengths of both horn sections would become three quarters of a helix wavelength long.

The taper of the second section of each horn is greater than the taper of the first tapered section thereof, the size of the step between the tapered sections being chosen so that it is just sufficient for insuring that the second section of horn including the smaller end of said second section has substantially no effect upon the operation of the device for frequencies higher than the frequency at which the first tapered section is one-half wavelength long. If the step between the tapered sections is too large, the impedance match provided by the horn is adversely affected at the low frequency end of the frequency band. If the step is made too small, an interference peak shows up at the middle frequencies. The size of the step must be designed within the foregoing limitations.

When it is stated above that a portion of the horn has a certain radius so that the inner horn wall thereat is just larger than the effective radial extent of the helix field at a certain frequency, it is meant that E^2 of the helix electric field E at such an extent is negligible; i.e., has a strength which is at least 10 db less than the strength of the E^2 of the electric field at the helix.

For purposes of calculating the length of the horn sections for the device of Fig. 1 in accordance with the above described design procedure, the phase velocity around the turns of the helix can be assumed to be that resulting from a velocity of propagation along the helix wire at approximately the velocity of light. The axial phase velocity of the waves is

$$V_p=\frac{(P)(C)}{2\pi r}$$

where P is the distance between turns of the helix, C is the velocity of light, r is the radius of the helix and π is 3.1416. The length of the waves λ_g along the helix is

$$\lambda_g=\frac{V_p}{f}$$

where f represents the operating frequency. It should be kept in mind, however, that the velocity of propagation around the turns of the helix becomes decreasing less than the velocity of light as the frequency decreases since the horn has more effect on the velocity of the helix waves at lower frequencies, especially in the lower half of the desired operating frequency band.

From the above description, it will be seen that the various objects of the invention have been achieved by the provision of an improved transition between a helix and a coaxial line for use in a travelling wave tube. By providing a horn of two tapered sections with a step between, the length of the horn transition section has been materially reduced over that required to achieve similar matching qualities at the same frequencies with a smoothly tapered horn. In fact the length of a straight horn achieving an equivalent match to that of the present invention is many times that of the stepped horn described herein.

While the invention has been described in its preferred embodiments, it is to be understood that the words which have been used are words of description rather than of limitation and that changes within the purview of the appended claims may be made without departing from the true scope and spirit of the invention in its broader aspects.

What is claimed is:

1. In combination, a conductive helix for guiding travelling electromagnetic wave energy over a predetermined frequency band, transmission line means coupled to one end of said helix, said transmission line means having an appreciably different value of impedance from that of said helix over said frequency band, and tapered horn means extending coaxially along and surrounding a portion of said helix beginning near said one helix end for providing an efficient transfer of energy between said transmission line means and helix over said frequency band, said horn means extending axially of said helix for substantially one half wavelength of helix wave energy at a given frequency within said band, the end of said tapered horn means of largest radius being furthest from said one end of said helix with said radius being just larger than the effective radial extent of travelling wave energy along said helix at a higher frequency than said given frequency within said band at which said horn means extends axially of said helix for approximately three quarters of a wavelength of helix wave energy.

2. In combination, a conductive helix for guiding travelling electromagnetic wave energy over a predetermined frequency band, transmission line means of different impedance from said helix for electromagnetic energy within said frequency band being coupled to one end of said helix, and tapered horn means extending coaxially along and surrounding a portion of said helix beginning near said one helix end for providing an efficient transfer of energy between said transmission line means and helix, said horn means having first and second tapered sections

whose sum total of axial extent along the axis of said helix is substantially one half wavelength of helix wave energy at a first frequency at the lower end of said band, the radius of the end of said horn means farthest from said one helix end being just larger than the effective radial extent of helix wave energy at a second frequency within said band at which said horn means extends axially of said helix for three quarters of a wavelength of helix wave energy, the first section of said horn means extending axially of said helix for substantially one half wavelength of helix wave energy at a third frequency within said frequency band higher than said first and second frequencies, the radii of the adjacent ends of said first and second horn sections being larger than the effective radial extent of a helix wave energy at a fourth frequency within said band at which said first section of horn means extends axially of said helix three quarters of a wavelength of helix wave energy.

3. The combination as set forth in claim 2, wherein the smaller end of said second section of said horn means has a larger radius than the radius of the larger end of said first section of horn means and is effectively beyond the effective radial extent of helix wave energy at said third frequency for which said first section extends axially of said helix for substantially one half wavelength of helix wave energy, the radius of the larger end of said first section of horn being less than the effective radial extent of helix wave energy at said third frequency.

4. A travelling wave tube for operation over a wide microwave frequency band between predetermined frequency limits, comprising conductive helix means extending along a predetermined axis, first and second means located at opposite ends of said helix means for coupling microwave energy over said frequency band to and from said helix means, respectively, means for producing and directing a stream of electrons along said axis for interaction with microwave energy propagated by said helix means between said first and second coupling means, and first and second conductive tapered horn members adjacent respective ones of said coupling means in coaxial relationship with said helix means and encircling opposite end regions of said helix means between said coupling means; each of said horn members having a flared portion divided into first and second sections by a step between the larger end of said first section and the smaller end of said second section, the radius of the smaller end of said first section being slightly larger than the radius of said helix means with the impedance between said helix means and horn member at the smaller end of said first section being substantially the same as that of the coupling means adjacent thereto for microwave energy within said frequency band, the sum of the axial lengths of both sections of each horn being one half wavelength at a first frequency within the lower half of said frequency range, the radius of the larger end of said second section of each horn being just larger than the effective

radial extent of a helix field at a second frequency slightly lower than that which the total axial extent of said first and second sections of each horn is three quarters of a wavelength, the axial length of said first section of each horn being approximately one half of a helix means wavelength at a third frequency in the upper half of said frequency band, the radius of the larger end of said first section of each horn being just larger than the effective radial extent of the helix field at a fourth frequency slightly lower than that at which said first section of horn is approximately three-quarters of a helix wavelength long, said second section of horn being outside the effective radial extent of helix fields at said third frequency at which said first section of each horn is one-half wavelength long.

5. A travelling wave tube device, comprising a conductive helix, means for coupling R.F. energy over a predetermined frequency band into and out of the helix at respective ends thereof, means for producing and directing a stream of electrons along said helix for interaction with helix R.F. energy, first and second horn members encircling opposite ends of said helix and coaxial therewith for enhancing the transfer of energy between said helix and said R.F. coupling means, each of said horn members having first and second tapered sections of increasingly larger diameter extending along the axis of said helix with the radii of adjacent ends of said tapered sections being different, the axial extent of said first tapered sections of each horn being one half wavelength at a predetermined operating frequency within said frequency band, the walls of the second section of each horn being beyond the effective radial extents of helix fields at said predetermined frequency and above while being within the effective radial extent of helix fields at lower frequencies.

6. A travelling wave tube as set forth in claim 5, wherein the tapered section of each horn member most remote from the smaller end of the horn has a larger taper than the other tapered section thereof, the sum total of the axial extents of both tapered sections of each horn being one half wavelength for R.F. helix energy at a lower frequency within said frequency band than said predetermined frequency, the radius of each horn member at its largest end being just larger than the effective radial extent of R.F. helix energy at a frequency within said frequency band at which each horn member is approximately three quarters of a wavelength long for R.F. helix energy.

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