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H. C. POULTER

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SLOW-WAVE GUIDE FOR TRAVELING WAVE TUBES

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FIG. 1

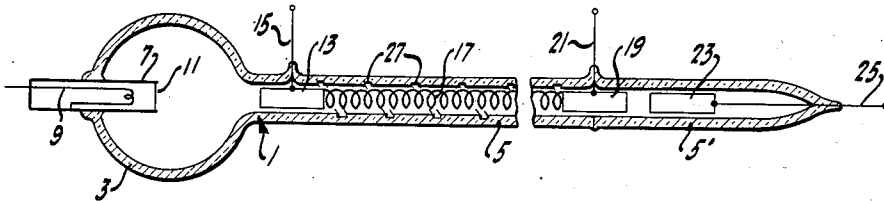


FIG. 2

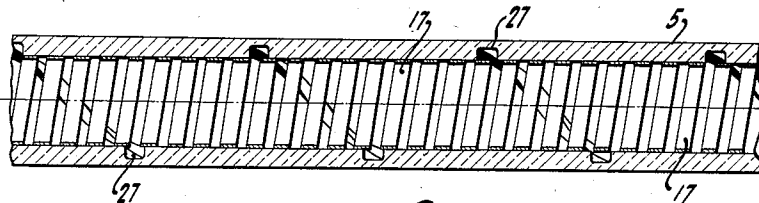
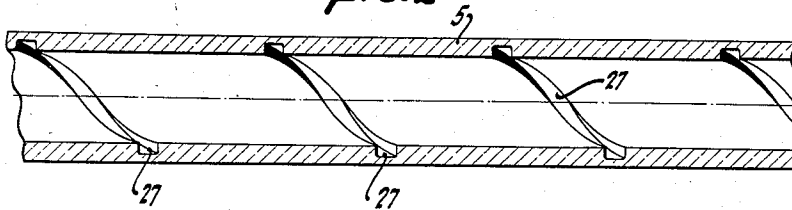


FIG. 3

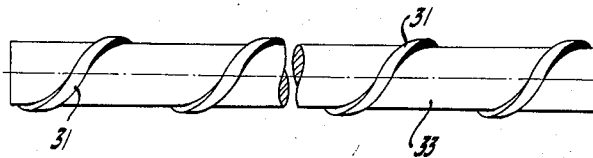


FIG. 4

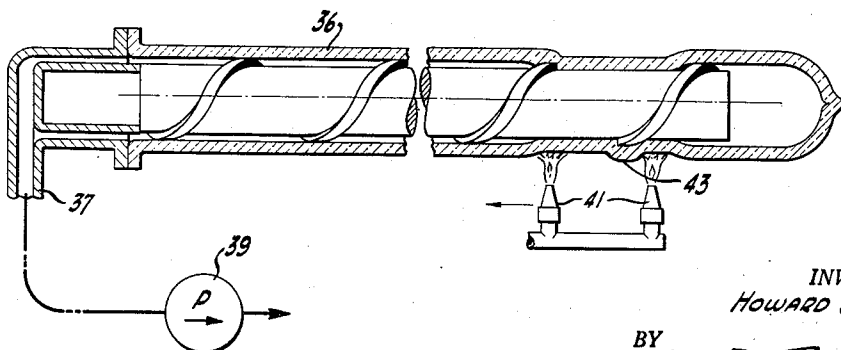


FIG. 5

INVENTOR.
HOWARD C. POULTER

BY
Lippincott & Smith

ATTORNEYS

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SLOW-WAVE GUIDE FOR TRAVELING WAVE TUBES

Howard C. Poulter, Palo Alto, Calif., assignor to Research Corporation, New York, N. Y., a corporation of New York

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5 Claims. (Cl. 315—3.5)

This invention relates to traveling wave tubes, such as are particularly adapted for amplification of wide bands of ultra-high or microwave frequencies. Particularly it relates to constructions suitable for forming the slow-wave guides which form an integral and essential portion of such tubes, so as to impart to such guides characteristics which will contribute to the stability of the tubes when operated as amplifiers.

Traveling wave tubes of the type to which the present invention is applicable comprise an electron gun, adapted to generate a narrow beam of electrons. The gun is mounted at one end of an elongated tubular envelope through which the beam is axially directed by the electron gun. A collector-anode is mounted at the opposite end of the envelope, and between the two and surrounding the path of the electron beam there is positioned a slow-wave guide which, in the form to which the present invention particularly relates, comprises a long, slender helix or solenoid, having terminals at the input or electron gun end for supplying the high frequency signal which is to be amplified by the tube, and, at the output end, terminals connecting to a load.

A radio frequency wave, introduced at the input end of the slow-wave guide, travels longitudinally of the guide at a velocity, considered along the axis, which is a function of the inductance and capacitance of the guide conductor. To a first approximation the velocity of the wave along the conductor forming the wire is equal to the velocity of light in free space. This being the case it is at once evident that because of the helical form of the conductor forming the guide, the velocity of the wave as referred to the axis of the helix will be much less than the velocity of light.

The potential differences applied between the cathode and anode of the electron gun are so selected that the electron velocities and the velocity of the waves propagated along the guide are substantially equal throughout the band of frequencies for which the apparatus is designed. When this condition is met, there is an interaction between the fields established by the radio frequency waves and those of the electrons themselves. The electrons of the beam tend to "bunch" in their path through the helix, and, in so doing, they build up the amplitude of the traveling wave so that there is an increase in the power delivered at the output end of the slow-wave guide over that introduced at its input terminal. The bunching of the electrons in the beam also represents a radio frequency wave which carries power which may also be utilized under certain conditions.

The same structure which functions as a traveling wave amplifier in the manner thus briefly described, can, under certain conditions, also act as a "backward wave amplifier," i. e., certain modes are possible wherein radio frequency energy will build up and be propagated along the guide in the opposite direction to that in which the electron beam is traveling. In this case the radio frequency power available at the electron gun end of the

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tube may exceed that available at the collector or output end.

The conditions for backward wave operation are much more critical than those for normal or traveling wave operation. Backward wave operation is a narrow-band phenomenon, as distinct from the broad-band characteristics which give the traveling wave tube its greatest value. It is possible, or even probable, that the conditions for backward wave operation occur within the wide-band at which operation is desired. Where this occurs instability is extremely likely to develop, the apparatus going into oscillation on the frequency at which backward wave operation can occur.

Instability of this character may be prevented by so designing the slow-wave guide that it has a narrow attenuating or stop-band at the frequency or frequencies where backward wave operation is likely to occur, and the broad purpose of the present invention is to provide a traveling wave tube wherein the slow-wave guide has a stop-band or bands of the type described. To this end, among the objects of the invention are to provide a slow-wave guide wherein stop characteristics are provided by the support for the helical conductor, the latter being of the simple and readily constructed simple solenoidal form; to provide a slow-wave guide wherein the helical conductor is supported by the envelope of the tube, as in the case of more conventional traveling wave tubes; to provide means and methods for constructing the helix support which is applicable either to a support which is integral with the envelope or may be separately supplied; to provide a type of stop-band, slow-wave guide, wherein the position of the stop-band with relation to the broad, traveling wave band which the device is intended to amplify may be varied through a wide range at the discretion of the designer; to provide an inherently stable traveling wave amplifier; and to provide a traveling wave tube having the above stated characteristics which is of utmost simplicity of design and of manufacture and which can be constructed at only a very slight increase in expense over the cost of a simple traveling wave tube having no stop-band characteristic.

The helical conductor which forms the slow-wave guide in a conventional traveling wave tube is formed of fine wire or strip, wound, usually, with many turns to the inch. The over-all length of the helix may be somewhere in the neighborhood of a foot. A solenoid of this type is obviously extremely flexible and requires support throughout its entire length to maintain it in alignment with the path of the electron beam, so that the latter can pass axially through it. Normally such support is provided by the tube envelope itself, the latter having a bore or lumen which is substantially equal to the outer diameter of the helix. A tube within the envelope, the sole purpose of which is to support the helix, can, of course, be provided, but this would ordinarily be merely an expensive and useless complication, although the possibility of such use cannot be ignored.

In accordance with the present invention the helical conductor constituting the slow-wave guide is held in position by a tubular insulating support which may be and preferably is part of the envelope of the tube itself. This support, however, differs from that customarily used in that it is rifled; i. e., one or more grooves are formed internally of its wall, so that contact between the conductor and the supporting wall is interrupted for uniform intervals, uniformly spaced along the conductor, these spaces being substantially equal to one-half wavelength, along the conductor itself, of the desired stop-band frequency. In general, the rifling will, itself, be helical and uniform throughout the length of the conductor helix which it covers, and the location of the stop band is de-

terminated by the relation between the pitch of the conductor helix and the pitch of the groove. If one-half wavelength along the conductor at the desired stop-band frequency is less than the length of one turn of the conductor helix, the pitch of the groove will be in the opposite direction or in opposite sense from that of the conductor helix; if the half wavelength is greater than the length of one turn of the conductor the pitch of both helices will be in the same direction, while if the half wavelength is equal to the length of one conductor turn the pitch of the helical groove becomes infinite, the helix degenerating into a straight line. Obviously the pitch of the rifling and that of the conductor must be different, either in magnitude or in sense, since if rifling and conductor had equal pitches in the same sense there would be no interruption in the support of conductor and no non-uniformities in conductor capacity introduced at regular intervals to produce a stop-band.

In the formation of a rifled support tube in accordance with the invention a mandrel is constructed whose diameter is the external diameter of the conductor helix. On this mandrel there is formed one or more projecting helical threads which may be similar in cross-section to an ordinary screw thread, although a square or trapezoidal form is preferred as being mechanically stronger and less likely to breakage. Preferably this thread is formed by fitting a helix wound of metal tape, or wire of the desired cross-section, onto the mandrel. The mandrel is then inserted in a vitreous tube, of large enough internal diameter to slip over the mandrel and its thread, and the tube is then heated to a plastic condition and shrunk down over the mandrel, preferably by sealing the end of the tube and exhausting it. The mandrel, being of metal, has a higher coefficient of thermal expansion than the glass or quartz of the tube and shrinks away from the latter so that it can be unscrewed after the glass has cooled. This construction will leave a ridge on the rifled tube; if desired this ridge can be ground off, on a centerless grinder or on a suitable mandrel, or it may be left to project if desired. Because, in tubes of this character, the electron beam is ordinarily confined to its axial path by means of a longitudinal magnetic field developed by a solenoid surrounding the envelope, the grinding procedure is usually preferred.

In the detailed description of a preferred embodiment of the invention which follows, reference will be made to the accompanying drawings, wherein:

Fig. 1 is a schematic diagram of a traveling wave tube embodying the instant invention;

Fig. 2 is an axial cross-sectional view of a portion of the envelope of the tube of Fig. 1, illustrating the rifling within the envelope;

Fig. 3 is a view similar to Fig. 2 showing the position of the conducting helix within the rifled envelope;

Fig. 4 shows a portion of the mandrel upon which the envelope shown in Figs. 2 and 3 is formed;

Fig. 5 is a longitudinal cross-sectional view illustrating the shrinking operation.

Since, with the single exception of the wave guide and its support, the traveling wave tube of the present invention may be nearly identical with substantially any other form of traveling wave device, one of the simplest of such forms has been chosen to illustrate symbolically the inventive idea. Such a tube is shown in Fig. 1, wherein the envelope, generally designated by the reference character 1 comprises a somewhat enlarged or bulbous base portion 3 and elongated tubular portion or barrel 5. Within the base portion is mounted a cathode 7, enclosing a heater element 9, and having an electron emissive surface 11. Electrons from this surface are attracted to a tubular anode 13, the combination of cathode and anode forming an electron gun for directing a beam of electrons axially through the elongated barrel of the apparatus. In operation the barrel

will normally be enclosed in a solenoidal coil (not shown) for maintaining the beam in a compact conformation in its progress through the tube.

Biassing potential for the anode may be applied through a sealed-in connection 15, and this connection may be used to introduce the radio-frequency signals to be amplified. Such signals can also be introduced through a coupling cavity from a wave guide or by other well known coupling means, but since the particular method of introduction of the energy into the tube has no relation to the present invention, such refinements are not shown.

The anode 13 connects to the slow-wave guide 17, illustrated by a symbolically shown helix which terminates in a tubular output electrode 19 which may be coupled, in any of the ways mentioned for the input anode 13, with an output or load circuit, but is shown as so connected through a sealed-in lead 21. Spaced slightly along the tubular portion of the envelope from the output electrode 19 is a collector-anode 23, which connects to an energizing circuit through a sealed-in lead 25. Positive biasing potential for the anode is applied through the lead 25, and, as in the case of the conventional traveling wave tube, this lead also may couple to a load circuit.

The tube as thus described differs from a conventional traveling wave tube only in the construction of the barrel 5, the inner surface of which is provided with a groove 27, extending through the major portion of its length which is occupied by the helix 17.

This groove or rifling is shown much more clearly in the enlarged sectional views of Figs. 2 and 3. Fig. 2 is a cross-sectional view of a short length of the envelope of an actual tube design, drawn on a considerably enlarged scale. In this particular design the internal diameter is 0.225 inch. The helical groove 27, constituting the rifling, is 0.050 inch wide and 0.030 inch deep, the rifling having a left-hand pitch of one and one-half turns per inch.

The slow-wave guide 17 is introduced within the barrel thus formed and is supported thereby as is shown in Fig. 3. In this case the conducting helix is formed of thin metal tape, about 50 mils wide and a few mils thick, wound with a right-hand pitch of 14 turns per inch. Such a helix may be introduced into the barrel of the tube tightly wound on a mandrel of such size that it clears the barrel very slightly, and then allowed to expand through its own resiliency into contact with the supporting barrel, after which the mandrel can be withdrawn.

Since the rifling groove helix has a left-hand pitch of one and a half turns per inch and the conductor helix has a right-hand pitch of fourteen turns per inch, there will be fifteen and one-half cross-overs per inch between the two helices measured along the axis of the tube, or very nearly nine-tenths of a turn of the conductor between cross-overs.

The velocity of wave propagation along the helix is inversely proportional to $\sqrt{LC}$, where L is the inductance per unit length and C is the capacitance per unit length. This velocity will be materially less than the velocity of propagation of a wave along a straight conductor in free space, approaching the speed of light, because L is increased by the coupling between adjacent turns of the helix and C is increased because of the close juxtaposition of the conductor and the glass throughout the major portion of the length of the conductor. The removal of this contact where the cross-overs take place does not affect the inductance, but it does affect the capacitance. Accordingly slight perturbations or non-uniformities in the constants of the conductor, considered as a line, occur every nine-tenths of a turn along its length; that is, at intervals of 0.647 inch or 1.62 centimeters.

It is well known that any departure from uniformity

in the characteristic impedance of a line causes a certain amount of reflection of energy back toward the source from the point at which irregularity occurs. Where these reflections occur at uniform intervals of one-half wavelength they become cumulative, the reflected waves reinforce, and the repeating structure becomes a band-elimination filter. The result is an attenuation of waves at or closely adjacent to the half-wavelength frequency. At frequencies materially different from the center of the stop band the reflections are not cumulative and the attenuation falls off very rapidly. With the structure here disclosed the number of perturbations is very large, the wave guide corresponds to a filter of from 100 to 200 sections. Even a small attenuation per section is therefore very effective, despite the relatively small attenuation per section.

If the pitch of the groove helix is in the same direction as that of the conductor the number of perturbations per axial inch becomes equal to the difference of the lineal pitches instead of their sum. There is then more than a single turn of the conductor between perturbations. It follows, of course, that if the pitch of the rifling is identical with the pitch of the conductor no perturbations are introduced, whereas as if one perturbation per turn is desired the helix of the rifling has a pitch approaching or equal to infinity and the helix degenerates to a single straight groove. Where the pitches of the two helices are in the same direction the number of perturbations for a slow-waveguide of a given length is, of course, reduced, and the effectiveness of the construction as a filter drops off materially before equality of pitch is reached. In practice, however, a stop band which would necessitate any such arrangement will not normally be required.

Since the conductor helix is, in effect, supported by a helical strip of insulation in close proximity to it (defining "helical" to include helices of infinite pitch) it would obviously be possible to form such a helical strip of insulating material separately from the envelope of the tube and insert it into the tube barrel, the result being the equivalent of forming a groove in the barrel itself. One of the advantages of the present invention, however, is its simplicity and the possibility of rifling the barrel itself easily and economically.

The means of accomplishing this are illustrated in Figs. 4 and 5. A mandrel is first constructed of cylindrical form having a diameter substantially equal to the desired external diameter of the conductor helix. A helical thread is formed thereon, the dimensions of the thread, as regards cross-section and pitch, being equivalent to the dimensions desired of the groove to be formed within the barrel. The cross-sectional shape of the thread is not particularly important, since the effect of the contacting insulator upon the capacitance of the conductor falls off with great rapidity as the distance between the conductor and its insulating support increases, and hence the difference between a thread of triangular, square, trapezoidal or semi-circular cross-section is very small indeed. A triangular, V-shaped thread has the disadvantage that its sharp corner may unduly weaken the envelope, owing the concentration of stress at the apex of the V. Such a thread could, of course, be formed integrally with the mandrel by conventional screw-cutting technique. It is much simpler and more economical, however, to wind a tape or strand of metal of the desired cross-section on the mandrel to form the thread, and since the rectangular shape is as effective as any other and tape of rectangular cross-section is both easiest to handle and commercially available it will ordinarily be chosen for the purpose.

The winding can be done on an ordinary screw-cutting lathe, geared to advance the carriage at the proper rate to give the winding the desired pitch. The tape is wound under heavy tension to make the helix cling tightly to the mandrel. The tape may first be wound on a smaller mandrel. Then it can be slipped over the proper size

mandrel and will cling tightly to this mandrel. The resultant structure is illustrated in Fig. 4.

Preferably the coefficient of thermal expansion of the mandrel should exceed that of the tape, so that the tension on the latter will be increased when the structure is heated and the tape will cling more closely to the mandrel. This is especially important if the pitch of the "winding" is infinite, and the tape is stretched parallel to the axis of the mandrel. While this latter arrangement is entirely feasible it is preferable for purely mechanical reasons so to design the structure that a finite pitch will give the proper stop-band.

There are many combinations of metals or alloys which meet the requirements as to differential coefficients of expansion. For example, a nickel-iron alloy of low coefficient may be used for the tape and a mild steel for the mandrel, if the barrel is to be made of glass. If fused quartz is to be used for the tube barrel higher melting point materials will be preferred, such as a molybdenum mandrel and a tungsten tape.

The vitreous tubing 36 which is to form the rifled barrel is of sufficient size to slip over both mandrel and tape. One end is sealed vacuum tight, the mandrel is inserted, and the other end is connected to an exhaust line 37 leading to a vacuum pump 39, as shown schematically in Fig. 5, and the structure is evacuated. The portion of the tubing 36 which is to form the tube barrel 5 is then heated to the flow-point, as by the gas torches 41, whereupon the tubing collapses under atmospheric pressure, shrinking to conform tightly to the threaded mandrel. The shrinking can be done progressively, from the sealed end toward the exhaust end, the flames being moved ahead gradually as the tubing shrinks.

The whole is preferably allowed to cool before the vacuum is broken, especially if quartz tubing is used, to prevent oxidation of the mandrel and tape. After cooling the sealed end of the now rifled tubing is cut off and the mandrel is simply screwed out of the barrel.

Ordinarily the next step in the formation of the envelope would be to anneal the rifled tube, although with quartz or some types of glass this may be an unnecessary refinement. The barrel may be used in the form in which the shrinking has left it. Under these circumstances it will have a projecting helix 43 corresponding generally to the helical rifling within it. If desired, however, this external helix may be removed by grinding, as was done in the case of the tube illustrated in the Figs. 2 and 3. With a helix of finite pitch this will be most readily accomplished in a centerless grinder; where the helix is degenerated into a single straight groove more uniform results can be obtained by grinding between centers; it can be done by mounting the tube on a mandrel similar to or identical with that on which the shrinking was done.

Once formed, the barrel can be fused to the bulbous base end 3, either directly or through a length of unrifled tubing. The collector anode may similarly be inserted directly into the rifled portion of the barrel or additional length of tubing may be added. In the latter case the seal through which the lead 21 is brought out may be conveniently formed at the junction between the rifled and unrifled tubings. Such a junction is indicated schematically in Fig. 1, where the sealed-on, unrifled portion of the barrel is shown at 5'.

Such a splicing-on procedure offers one method of introducing two stop bands in the same traveling wave tube, in case there may be two critical frequencies at which oscillation might occur. Two pieces of tubing, rifled with grooves of different pitch, may be spliced together. In this case neither stop band will give the same degree of attenuation that would be offered by a single band, but it may be that sufficient attenuation may be thus introduced to prevent the instability of operation. Whether or not this will prove to be the case depends upon the operating parameters of the tube. Another method of introducing two stop bands is to provide a mandrel which

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is separable into two parts, the thread formed on one part being different from that formed on the other. A piece of glass tubing is shrunk onto the composite mandrel in the same fashion as before, and after the glass and mandrels have cooled the two halves of the mandrel are screwed out of the tubing from opposite ends.

As will be apparent to those skilled in the art, the present invention provides not only a means of extreme theoretical simplicity for solving a problem which has heretofore required complex and expensive equipment, but also a ready and relatively inexpensive method of constructing the apparatus to apply the theory. It is, accordingly, applicable to apparatus which differs greatly in details from that shown. The detailed descriptions herein are therefore not intended to be limiting, all intended limitations being specifically expressed in the following claims.

What is claimed is:

1. A traveling wave tube comprising an electron gun for generating a beam of electrons, an anode positioned to receive the electrons of said beam, and a slow-wave guide interposed between said electron gun and said anode and surrounding the path of said beam and comprising a helically wound conductor, and a tube of insulating material surrounding and supporting said conductor, the wall of said tube having a single internal generally longitudinal groove formed therein to interrupt its contact with the conductor for regularly spaced and substantially uniform intervals along the length thereof.

2. A traveling wave tube comprising an electron gun for generating a beam of electrons, an anode positioned to receive the electrons of said beam, and a slow-wave guide interposed between said electron gun and between said electron gun and said anode and surrounding the path of said beam and comprising a helically wound conductor, and a tube of insulating material surrounding and

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supporting said conductor, the wall of said tube having a single internal groove extending longitudinally there-through to interrupt the contact between said wall and said conductor for substantially uniform and equally spaced distances along the length of said conductor, the major portion of said conductor being in contact with said wall.

3. A traveling wave tube as defined in claim 2 wherein said groove describes a helix of substantially uniform pitch differing from the pitch of the conductor helix.

4. A traveling wave tube comprising an evacuated envelope enclosing an electron gun for developing a beam of electrons, a collector anode positioned to receive said beam, a slow-wave guide interposed between said cathode and anode comprising a helix of conducting material, and a support for said helix comprising a helix of insulating material substantially surrounding the conducting helix and of different pitch whereby contact between said conducting helix and said support is interrupted for substantially uniform equally spaced intervals therealong.

5. A traveling wave tube as defined in claim 4 wherein said support is integral with said evacuated envelope.

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