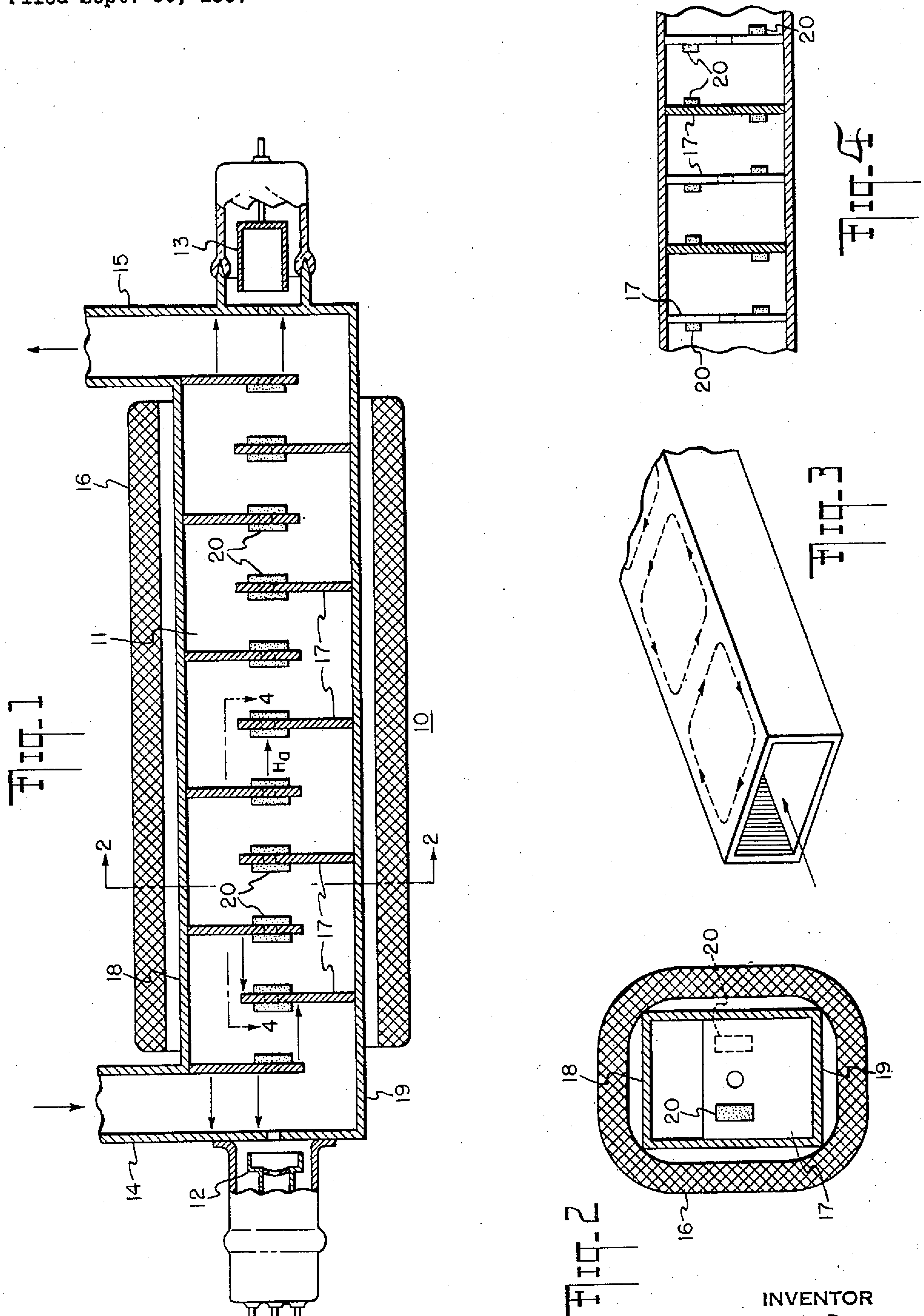
Sept. 20, 1960 B. J. DUNCAN 2,953,708

TRAVELING-WAVE TUBE ATTENUATOR

Filed Sept. 30, 1957

2 Sheets-Sheet 1



INVENTOR
BOBBY J. DUNCAN
BY
ATTORNEY

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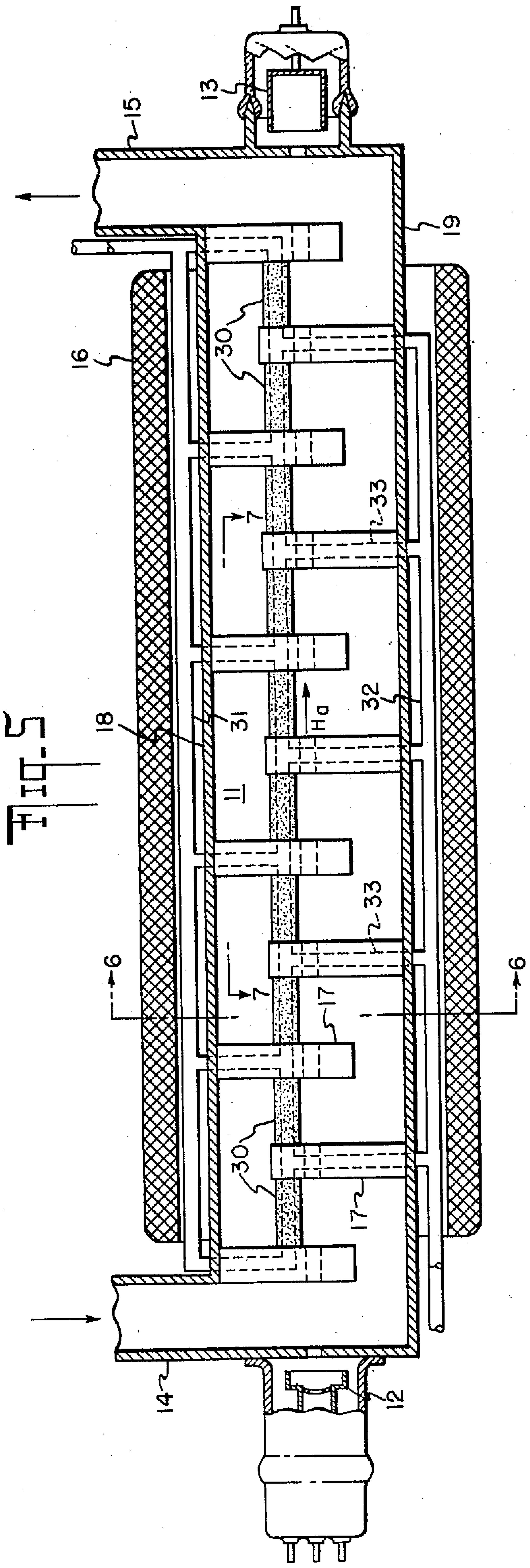
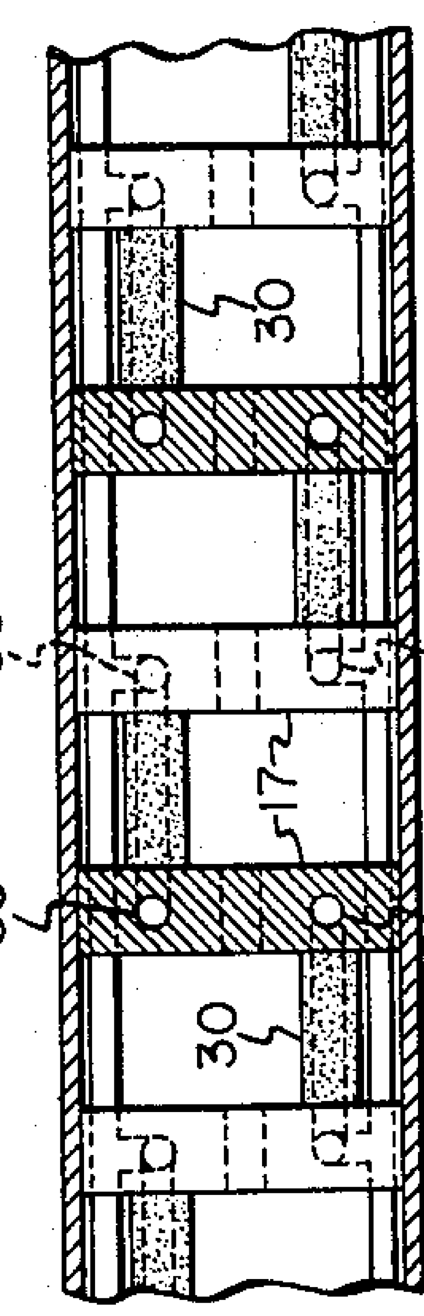


FIG. 5

FIG. 7



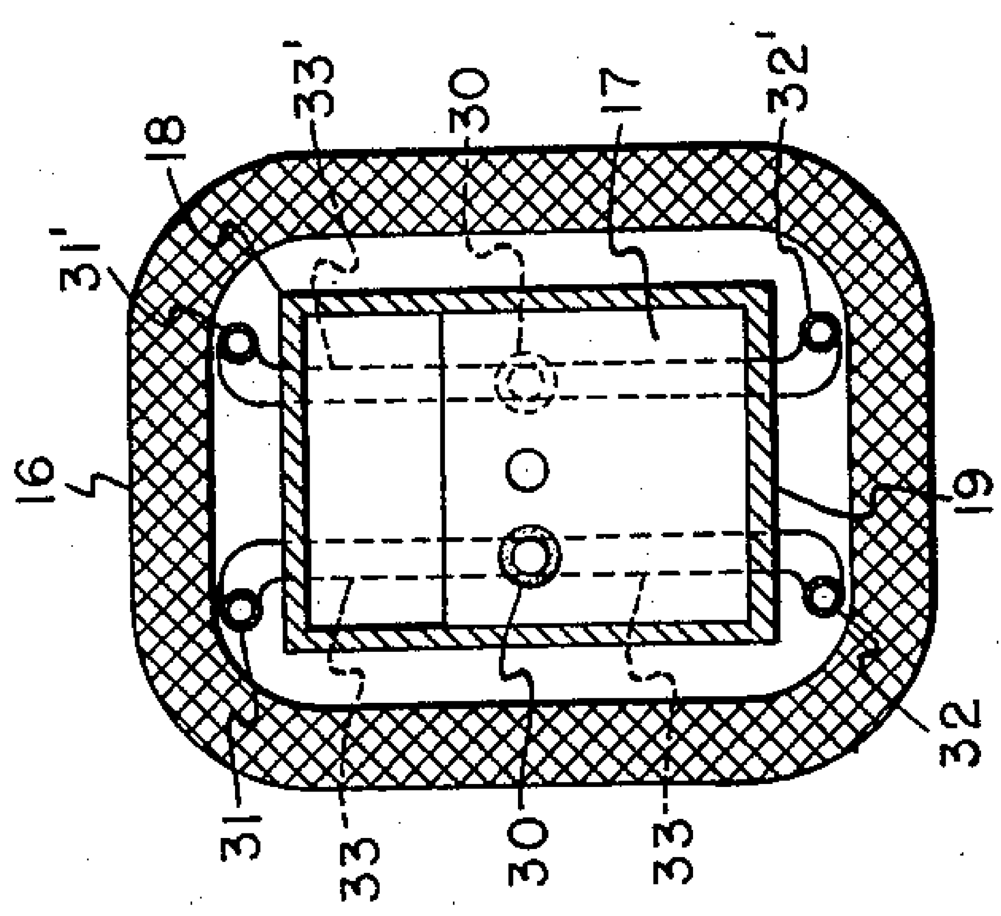


FIG. 6

INVENTOR
Bobby J. Duncan
BY
L. V. Braddock
ATTORNEY

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TRAVELING-WAVE TUBE ATTENUATOR

Bobby J. Duncan, Clearwater, Fla., assignor to Sperry Rand Corporation, a corporation of Delaware

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2 Claims. (Cl. 315—3.5)

This invention relates to traveling-wave tubes and more particularly to novel means for attenuating reflected waves in such tubes employing folded-waveguide slow-wave propagating structures.

A problem that has long existed in traveling-wave tube amplifiers is that reflections of the forward propagating waves are created by mismatches in the microwave circuit of the tube. These reflected waves, if of sufficient amplitude, will cause the tube to oscillate, thus destroying its use as an amplifier. In order to reduce the amplitude of the reflected waves and to prevent the tube from oscillating, it has been the practice in the past to introduce a lossy material into the microwave circuit of the tube. This method has been successful to prevent the tube from oscillating. However, because the lossy material is a bilateral attenuator, that is, it attenuates waves traveling in the forward direction as well as in the reverse direction, the gain of the traveling-wave amplifier is reduced.

It is therefore an object of this invention to provide a traveling-wave tube in which reflected waves are substantially eliminated.

It is another object of this invention to provide a traveling-wave tube in which the forward propagating waves are amplified in their passage through the tube and waves propagating in the reverse direction are greatly attenuated.

It is a further object of this invention to provide in a traveling-wave tube employing a folded-waveguide slow-wave propagating structure novel means for preventing oscillations caused by reflected waves in the microwave circuit of the tube.

These and other objects which will become more apparent as the description proceeds are achieved by providing a traveling-wave tube comprising a hollow rectangular chamber having conductive walls and a plurality of conductive plates extending alternately from opposite parallel walls of said chamber. The conductive plates form top and bottom walls of a plurality of connecting waveguide sections which are oriented transversely to the longitudinal axis of the chamber and form a folded-waveguide structure. Input and output waveguide means are coupled to the ends of the structure and couple electromagnetic waves into and out of said structure. An electron gun and a collector electrode are positioned at opposite ends of said structure and establish a beam of electrons along its longitudinal axis. Means are provided for establishing a unidirectional magnetic field along the longitudinal axis of the structure to focus the beam of electrons. Ferrite members are positioned on the faces of the conductive plates and are located in regions where the electromagnetic waves are circularly polarized. The ferrite members are immersed in a unidirectional magnetic field and may be magnetically biased to either gyromagnetic resonance or to zero permeability.

Under such conditions incident waves propagate through the tube and are amplified without being affected by the ferrite members, while reflected waves propagating in the reverse direction are attenuated by the ferrite members.

The invention will be described in connection with the following drawings, wherein:

Fig. 1 is a cross-sectional view of one embodiment of a traveling-wave tube constructed in accordance with this invention;

Fig. 2 is a transverse sectional view taken along line 2—2 of Fig. 1;

Fig. 3 is a diagrammatic representation of a magnetic field in a rectangular waveguide and is used to explain the theory of operation of the device of this invention;

Fig. 4 is a partial longitudinal sectional view taken along line 4—4 of the tube of Fig. 1;

Fig. 5 is a cross sectional view of another embodiment of this invention;

Fig. 6 is a transverse sectional view taken along line 6—6 of Fig. 5, and;

Fig. 7 is a partial longitudinal view taken at line 7—7 of Fig. 5.

It is known that ferrite materials immersed in a steady magnetic field may be employed to construct microwave attenuators and isolators by locating the ferrite material in a region of circular polarization of the electromagnetic wave and by magnetizing the ferrite member in a direction perpendicular to a component of the circularly polarized R.F. magnetic field. It is possible to operate such devices with the ferrite material magnetically biased to either gyromagnetic resonance or to zero permeability.

The present invention may be practiced with the ferrite material biased to either of these conditions. For a detailed explanation of the phenomenon of gyromagnetic resonance in a ferrite, reference is made to applicant's patent application 579,421, filed April 16, 1956, assigned to applicant's present assignee. For a description of the ferrite zero permeability phenomenon reference is made to an article by B. J. Duncan and L. Swern entitled "Effects of Zero Ferrite Permeability on Circularly Polarized Waves," proceedings of the IRE, May 1957, p 647.

The ferrite unilateral attenuating devices proposed in the past have been constructed in straight sections of waveguide or around helical transmission lines wherein the direction of propagation of the electromagnetic waves is directly along the longitudinal axis of the waveguide or the helix. In these transmission lines the region where the magnetic field of the R.F. electromagnetic waves is circularly polarized in a given sense is located in a certain position with respect to a transverse section of the waveguide or helix, and this position remains fixed throughout the length of the transmission line. It is therefore a simple matter to place the ferrite in this fixed region and direct a steady magnetic field either perpendicular to the broad wall of a rectangular waveguide or along the longitudinal axis of a circular waveguide or a helical transmission line, and thus achieve differential action between the ferrite and the R.F. electromagnetic waves.

In a traveling-wave tube employing a folded-wave guide slow-wave propagating structure, however, the propagation path of the electromagnetic waves constantly reverses back and forth as the waves propagate along the tube. Because extraneous magnetic fields in the traveling wave tube will have a deleterious effect on the focusing of the electron beam it is desirable to employ the electron beam magnetic focusing field to magnetically bias the ferrite. In the folded-waveguide section of a traveling-wave tube the path of the propagating waves constantly reverses with respect to the direction of this magnetic field. For this reason the regions where R.F. waves are circularly polarized in a given sense are not located in the same relative position throughout the length of the propagating section, but alternate from one side of the structure to the other along the propagating path. This presents an entirely different situation than is present in the prior ferrite devices, and for this reason none of these devices are applicable for use in a traveling-wave tube employing a folded-waveguide slow-wave propagating structure.

Additionally, because of the available space for inserting components in a traveling-wave tube employing a folded-waveguide structure is restricted, and because the propagating mode of the wave is somewhat distorted as it passes around the 180° bends, means for constructing non-reciprocal ferrite attenuators in such a tube have been unknown in the past.

Refering now to Fig. 1, the traveling-wave tube of this invention is comprised of a slow-wave propagating section **11**, and input and output waveguide terminals **14** and **15** for coupling electromagnetic energy into and out of section **11**. Electron gun **12** and collector electrode **13** are located at opposite ends of section **11** and establish a stream of electrons which traverse section **11**. Electromagnet **16** surrounding section **11** is energized by a source of direct current (not shown) and provides a unidirectional, or steady, magnetic field H_a directed parallel to the longitudinal axis of the tube and focuses the electrons emitted by electron gun **12** into a concentrated beam. It is to be understood that a permanent magnet may be employed in place of electromagnet **16** if so desired.

Slow-wave propagating section **11** is comprised of a hollow rectangular chamber (Fig. 2) having conductive plates **17** extending alternately from opposite conductive walls **18** and **19** of the chamber. The width of plates **17** is equal to the width of walls **18** and **19**. The arrangement thus comprises a folded-waveguide section having a plurality of connecting waveguide sections oriented transversely to the longitudinal axis of the chamber. The individual waveguide sections have a height determined by the spacing between conductive plates **17** and have a width determined by the width of walls **18** and **19**. Conductive plates **17** are apertured as shown to permit the free passage of the electron beam produced by electron gun **12**.

Waveguides **14** and **15** are oriented with their narrow walls parallel to the longitudinal axis of the slow-wave propagating section and couple electromagnetic waves into and out of the section.

Positioned on the faces of conductive plates **17** are ferrite members **20** which are shown as thin slabs, although other geometrical forms may be employed as well. In adjacent transverse sections of the folded-waveguide structure the ferrite members are displaced on opposite sides of a vertical plane through the longitudinal axis of the structure so that they lie in regions where the magnetic field of the electromagnetic waves is circularly polarized in the same sense, as will be explained. Ferrite members **20** are immersed in the longitudinal steady magnetic field H_a which is provided by electromagnet **16**.

Electromagnetic waves in the TE_{10} mode couple from input waveguide **14** into the folded-waveguide section **11** and it may be assumed that the waves continue to propagate in this mode in the transverse sections of the folded-waveguide structure. This assumption is particularly justified in the regions where conductive plates **17** are coextensive.

It is well known that the magnetic field of an R.F. electromagnetic wave propagating in the TE_{10} mode is circularly polarized in two regions across the broad dimension of the waveguide. This may be illustrated by referring to Fig. 3 wherein the magnetic field is shown in the form of closed loops parallel to the broad walls of the waveguide. Considering that propagation is from front to rear in the waveguide section, to an observer looking down on the waveguide on the left side of the centerline of the waveguide, the vectors representing the magnetic field will appear to rotate in a counterclockwise direction, and to an observer looking down on the right side of the waveguide the vectors will appear to rotate in a clockwise direction. When the direction of propagation is reversed the direction of rotation of the vectors on the two sides will also reverse. Thus the wave is circularly polarized in two regions which lie on either side of the centerline of the waveguide. The position of these regions will vary with frequency.

In the trasverse waveguide sections of Fig. 1, these two regions will appear on opposite sides of a vertical plane through the longitudinal axis of the slow-wave section.

As pointed out in application 579,421, when a magnetized ferrite is placed in a waveguide propagating circularly polarized waves, the direction of the magnetization of the ferrite will determine the sense of circular polarization (positive or negative) which the R.F. wave presents to the ferrite.

It will be seen from Fig. 1 that the direction of the electric field of the electromagnetic waves, represented by vectors in the waveguides, reverses with respect to the steady magnetic field H_a as the waves propagate in adjacent transverse sections of the folded-waveguide structure. Therefore in adjacent waveguide sections the regions of circular polarization on one given side of the sections will be of opposite senses since the R.F. magnetic field will be rotating in opposite directions with respect to the steady magnetic field H_a. For ferrite members in adjacent transverse sections to see the same sense of R.F. magnetic field circular polarization they must be located on opposite sides of the sections.

The location of a ferrite member in the section of waveguide taken at line 2—2 is shown in Fig. 2. In adjacent sections the ferrite members will be located on opposite sides of the faces of plates **17**. For example, the location of the ferrite member in the next transverse section adjacent to the section taken at line 2—2 is shown in broken lines in Fig. 2. The location of the ferrite members **20** will alternate in this manner in successive sections throughout the length of the slow-wave structure. This is illustrated by Fig. 4 which is a partial longitudinal view taken at line 4—4 of Fig. 1.

With the direction of propagation shown in Fig. 1, and with the steady magnetic field H_a in the direction shown, ferrite members **20** are positioned in regions where the R.F. magnetic field of forward propagating waves will be circularly polarized in a negative sense and reflected waves will be circularly polarized in a positive sense. Thus the conditions required for operation of a unilateral ferrite gyromagnetic resonance attenuator are present.

In the operation of the device of Fig. 1, the velocity of the electron beam provided by electron gun **12** and the velocity of the electromagnetic waves propagating through the slow-wave propagating section **11** are proportioned so that there is an interchange of energy between the beam and the wave, and the wave is amplified as it propagates through the slow-wave section **11**, in the well known manner.

The ferrite material saturation magnetization, the shape of the ferrite members, and the strength of the steady magnetic field are proportioned so that the ferrite members **20** are magnetically biased to gyromagnetic resonance.

Because the forward propagating waves in section **11** appear as negative circularly polarized waves, the forward wave will not be attenuated by ferrite members **20**. The reflected waves are circularly polarized in a positive sense, however, and will be greatly attenuated by the ferrite members. In this manner oscillations caused by reflected waves are prevented from occurring in traveling-wave tube **10**.

For operation of the device of Fig. 1 with the ferrite members **20** magnetically biased to zero permeability, the members will be located on opposite sides of the faces of plates **17** so as to be located in regions of circular polarization which are of opposite sense to the regions employed for operation at gyromagnetic resonance. In addition the shape and composition of the ferrite members and the strength of the magnetic field will be proportioned so that the members are biased to zero permeability. Under such circumstances the ferrite members **20** will be located in regions where the forward propagating waves are circularly polarized in a positive sense and the waves will be excluded from the ferrite members and will not be attenuated by them. Reflected waves will have a negative sense of circular polarization in the regions occupied by the members and will propagate through the members and will be attenuated thereby. In such an embodiment ferrite members **20** may be made of a dielectrically lossy material, or may be made of a substantially lossless ferrite material and a dielectrically lossy material may be inserted within the ferrite member, as taught in the above-cited article by Duncan and Swern. Thus the traveling-wave tube amplifier will operate substantially as described above in connection with Fig. 1.

An alternative embodiment of a device constructed in accordance with this invention which is particularly adapted for high power operation is illustrated in Fig. 5. This embodiment of the traveling-wave tube is similar to the tube of Fig. 1 except for the construction of ferrite members **30** and conductive plates **17**. Ferrite members **30** are hollow rods which extend between the faces of conductive plates **17**, and in adjacent transverse waveguide sectoins are located on alternate sides of a vertical plane through the longitudinal axis of the slow-wave section **11** in the same manner as ferrite members **20** of Fig. 1. Conductive plates **17** are provided with fluid passages **33** which connect at one end to the hollow interior of ferrite members **30** and at their opposite ends are connected alternately to manifolds **31** and **32** located adjacent conductive walls **18** and **19** respectively. A fluid coolant introduced into manifold **32**, for example, will flow through the passages **33** in the plates **17** located on bottom wall **19**, through the interior of ferrite members **30**, and through the passages **33** in the plates **17** on top wall **18**, and then into manifold **31**, where it may then be carried to a heat exchanger (not shown) and recirculated back to manifold **32**.

A cross-sectional view of the tube taken at line **6—6** is represented in Fig. 6. Manifolds **31′**, **32′**, and passages **33′** comprise part of the cooling system for ferrite members located in the adjacent transverse waveguide section. A longitudinal sectional view of the tube taken at line **7—7** is shown in Fig. 7. Thus, in the manner described the heat which is generated in ferrite members **30** as a result of the absorption of microwave energy is transferred to the fluid coolant and carried away therein. The cooling system provided by the tube of Fig. 5 is particularly adapted for high-power traveling-wave tubes and will maintain the temperature of ferrite members **30** within operating limits.

The electrical operation of the tube of Fig. 5 is substantially the same as the operation of the tube illustrated in Fig. 1.

When ferrite members **30** are magnetically biased to zero permeability the ferrite material may be a dielectrically lossless material and a lossy liquid coolant may be circulated through the members. In such an embodiment the positive circularly polarized waves will not propagate in the ferrite members and will not encounter the lossy coolant, while the negative circularly polarized waves will propagate through the ferrite members and

will be attenuated by the lossy coolant therein. Water will adequately serve as the lossy coolant in such an embodiment.

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. A traveling-wave tube comprising a hollow rectangular chamber having conductive walls, a plurality of spaced conductive plates extending alternately from the top and bottom walls of said chamber, said conductive plates having a height substantially less than the separation of said top and bottom walls, whereby a folded-waveguide slow-wave structure is formed, the folded sections of said slow-wave structure extending transversely to the longitudinal axis of said chamber and said plates forming the broad walls of said folded sections, means adjacent one end of said hollow chamber for establishing an electron beam which is directed parallel to the longitudinal axis of said chamber, collector electrode means adjacent the other end of said chamber for terminating said beam, input and output waveguide means coupled to the respective ends of said chamber for transferring electromagnetic waves at a predetermined frequency into and out of said folded-waveguide section, a plurality of hollow ferrite rods extending between pairs of said plates along the length of said slow-wave section, the rods in adjacent transverse waveguide sections being positioned on opposite sides of a vertical plane through said axis, means for establishing a steady magnetic field parallel to said axis for maintaining said electron beam and for magnetizing said ferrite rods to attenuate said waves propagating through said slow-wave structure, said conductive plates being provided with fluid passages connecting with the hollow portions of said rods, and means for circulating a fluid coolant through said passages and said rods to cool said ferrite rods.

2. The combination as claimed in claim 1 wherein said fluid coolant is dielectrically lossy and wherein the strength of said magnetic field, the shape and composition of said ferrite rods are proportioned to magnetize said ferrite rods to zero permeability to waves at said predetermined frequency propagating in a first direction through said slow-wave structure, whereby the waves propagating in said first direction propagate past said ferrite rods substantially unattenuated while waves propagating in an opposite direction through said slow-wave structure propagate through said ferrite rods and are attenuated by the lossy coolant therein.

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