April 27, 1965 S. SENSIPER 3,181,024

TRAVELING-WAVE TUBE WITH OSCILLATION PREVENTION MEANS

Filed May 23, 1962 2 Sheets-Sheet 1

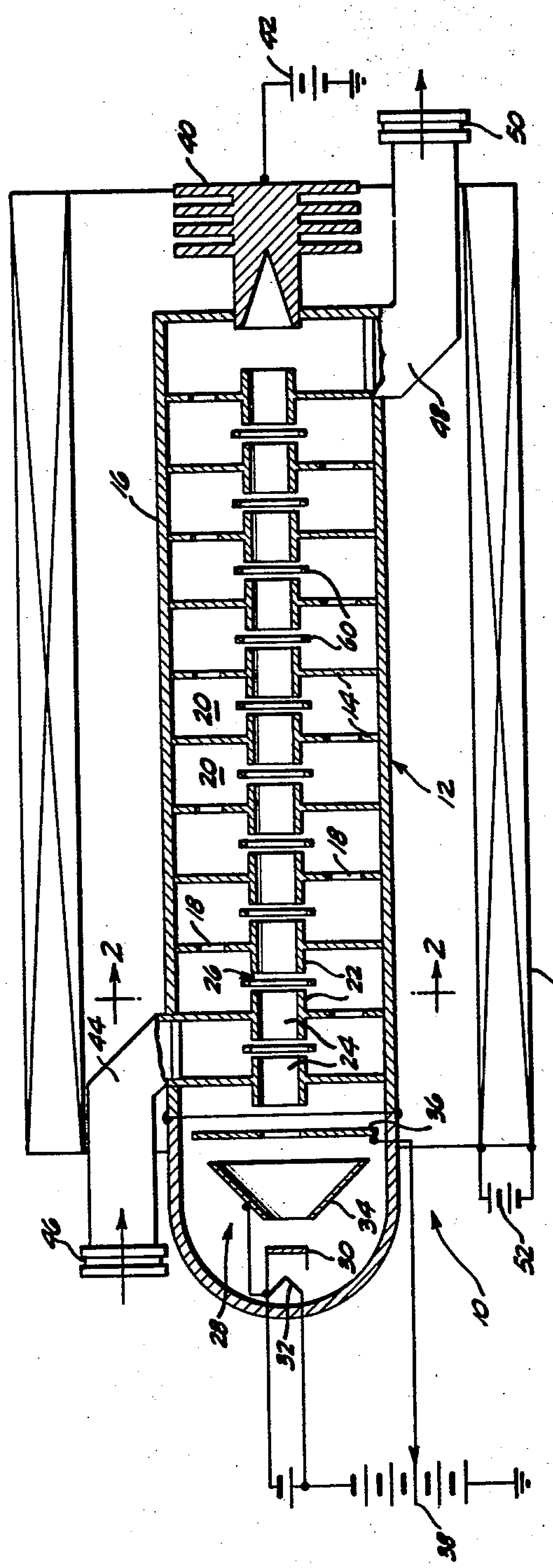

FIG. 1.

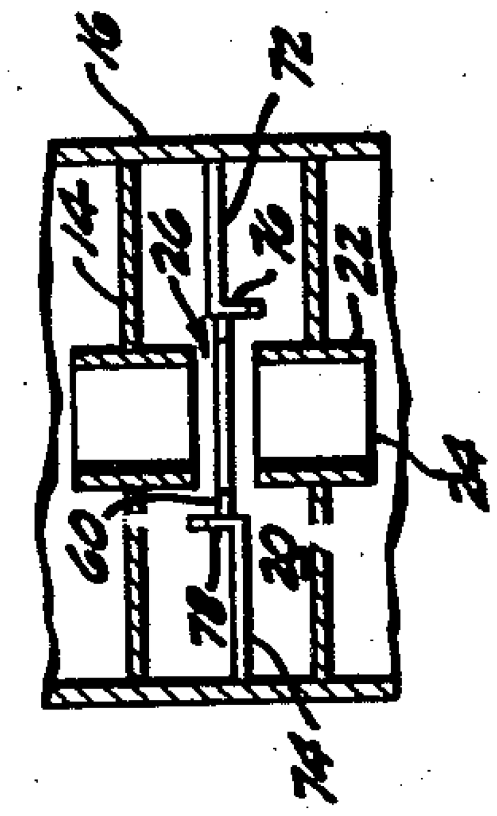

FIG. 4.

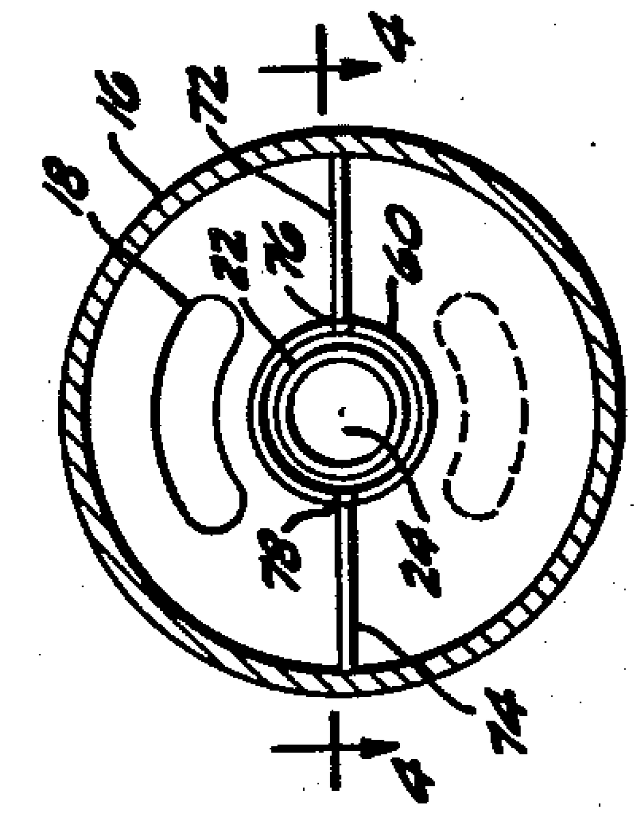

FIG. 3.

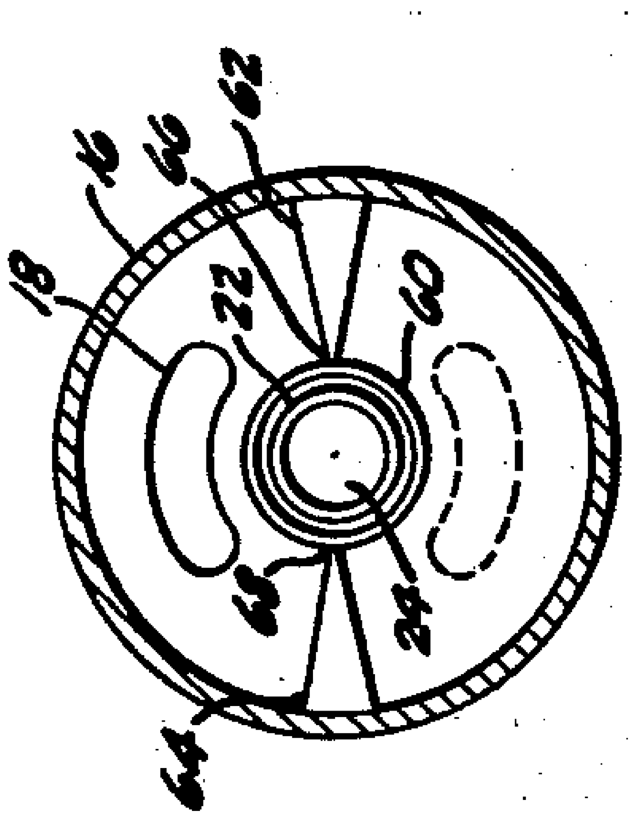

FIG. 2.

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TRAVELING-WAVE TUBE WITH OSCILLATION PREVENTION MEANS

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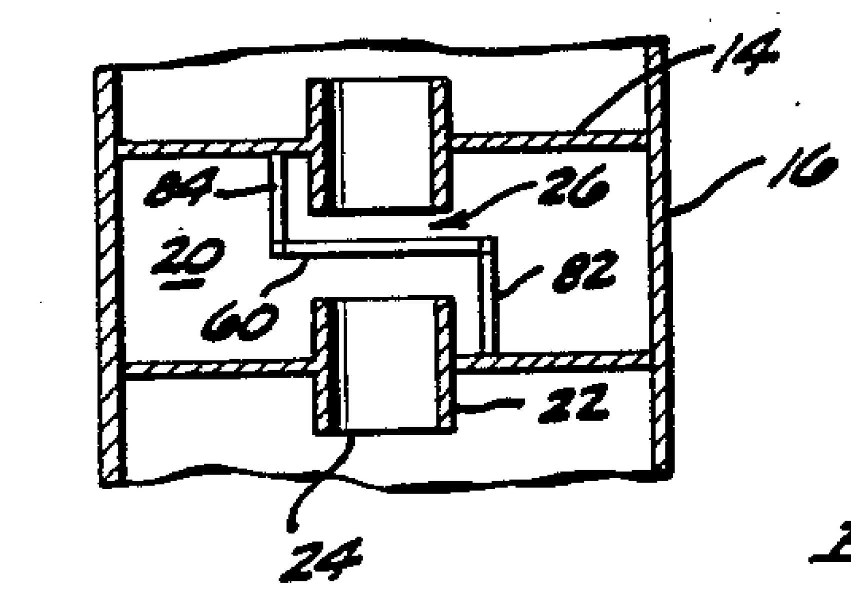

FIG. 5

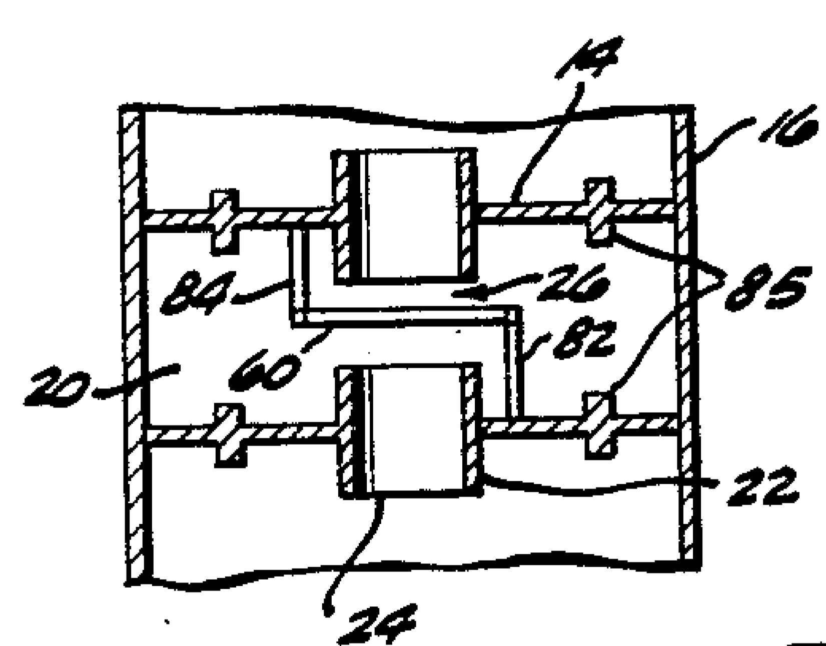

FIG. 6.

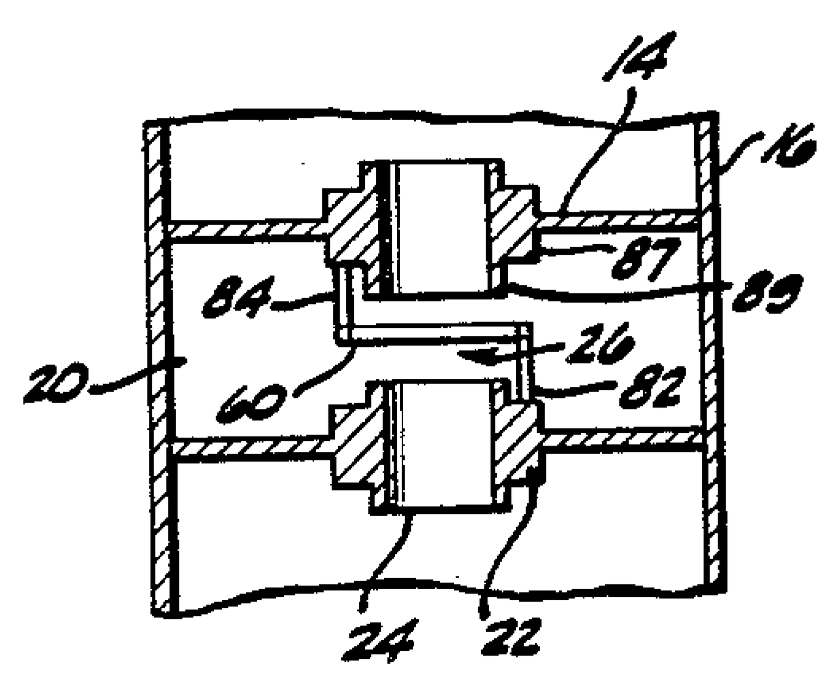

FIG. 7.

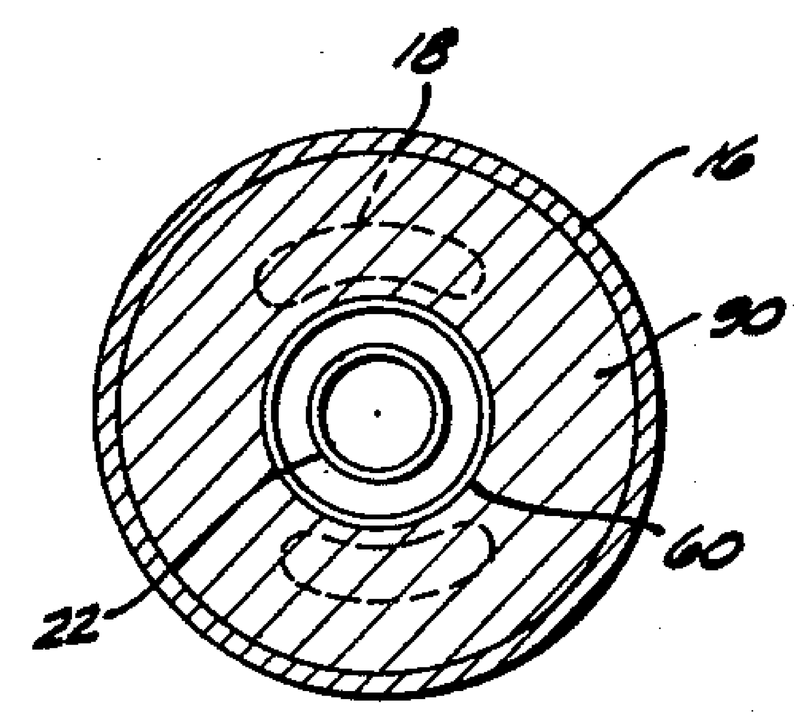

FIG. 8.

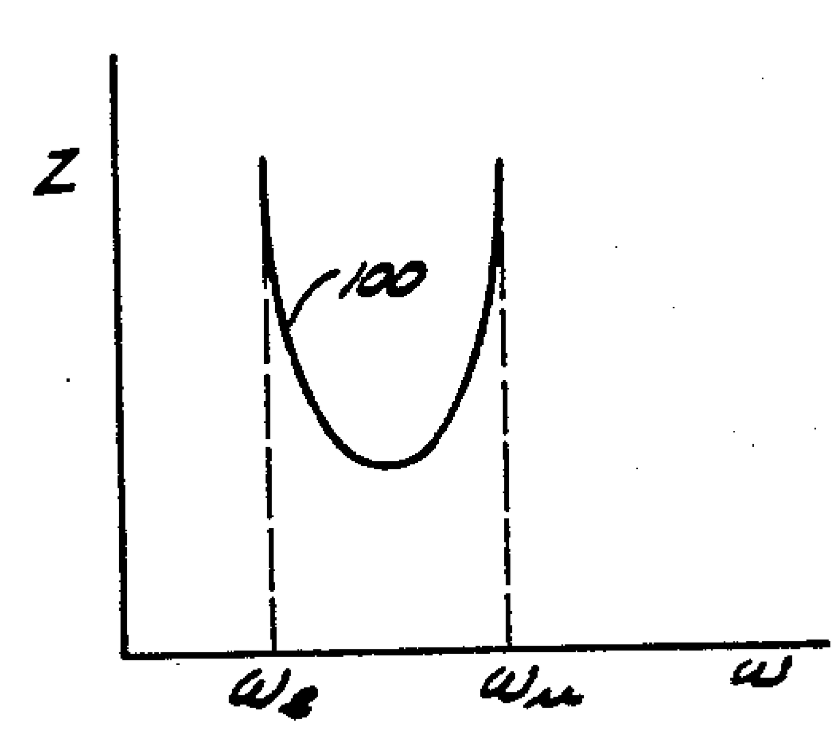

FIG. 9(a)

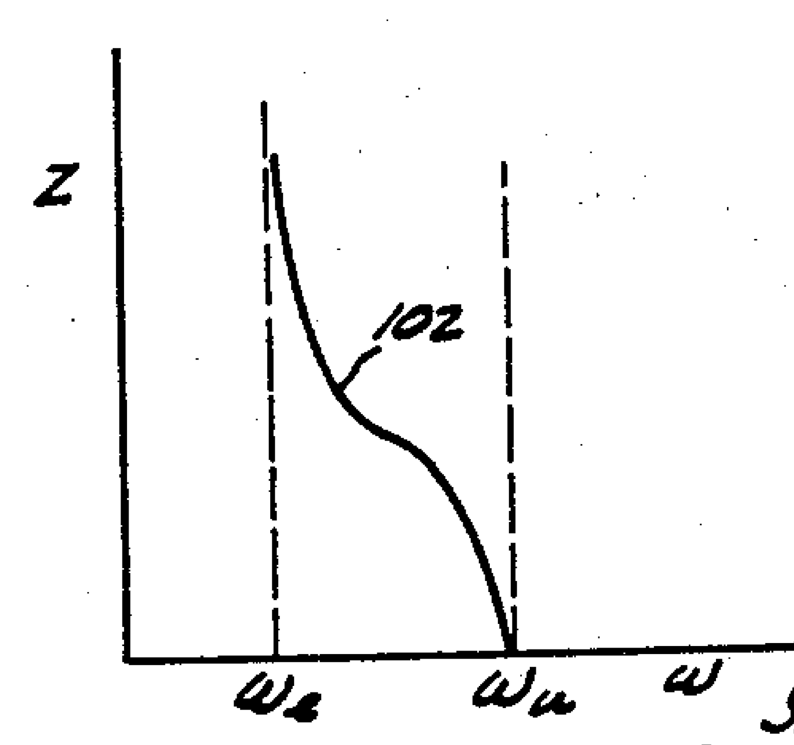

FIG. 9.(b).

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TRAVELING-WAVE TUBE WITH OSCILLATION PREVENTION MEANS

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Filed May 23, 1962, Ser. No. 196,938
18 Claims. (Cl. 315—3.5)

This invention relates generally to microwave devices, and more particularly relates to traveling-wave tubes having means for substantially eliminating oscillations in the vicinity of a predetermined frequency, such as the upper cutoff frequency of the tube passband.

In traveling-wave tubes a stream of electrons is caused to interact with a propagating electromagnetic wave in a manner which amplifies the electromagnetic energy. In order to achieve such interaction, the electromagnetic wave is propagated along a slow-wave structure, such as a conductive helix wound about the path of the electron stream or a folded waveguide type of structure in which a waveguide is effectively wound back and forth across the path of the electrons. The slow-wave structure provides a path of propagation for the electromagnetic wave which is considerably longer than the axial length of the structure, and hence, the traveling-wave may be made to effectively propagate at nearly the velocity of the electron stream. The interactions between the electrons in the stream and the traveling-wave cause velocity modulations and bunching of electrons in the stream. The net result may then be a transfer of energy from the electron beam to the wave traveling along the slow-wave structure.

The present invention is primarily concerned with traveling-wave tubes utilizing slow-wave structures of the folded waveguide type, which structures are also known as the coupled cavity, or interconnected cell type. In this type of slow-wave structure a series of interaction cells, or cavities, are disposed adjacent to each other sequentially along the axis of the tube. The electron stream passes through each interaction cell, and electromagnetic coupling is provided between each cell and the electron stream. Each interaction cell is also coupled to an adjacent cell by means of a coupling hole at the end wall defining the cell. Generally, the coupling holes between adjacent cells are alternately disposed on opposite sides of the axis of the tube, although various other arrangements for staggering the coupling holes are possible and have been employed. When the coupling holes are so arranged, a folded waveguide type of energy propagation results, with the traveling-wave energy traversing the length of the tube by entering each interaction cell from one side, crossing the electron stream, and then leaving the cell from the other side, thus traveling a sinuous, or serpentine, extended path.

One of the problems encountered in traveling-wave tubes of the coupled cavity variety, and especially high power tubes of this type, is a tendency for the tube to oscillate at frequencies near the upper cutoff frequency of the tube passband. This problem arises from the fact that for wideband operation, the phase velocity of the slow-wave circuit wave and the velocity of the electron beam should be essentially synchronized over as large a range of frequencies as possible; hence, these velocities are also close to synchronism near the upper cutoff frequency. Since the interaction impedance is high and the circuit-to-transmission line match is poor at and in the vicinity of the upper cutoff frequency, the loop gain for the tube, or even for a section of the tube, may be sufficiently large for oscillations to start.

It is, therefore, an object of the present invention to provide a coupled cavity traveling-wave tube in which any tendency for the tube to oscillate in the vicinity of the upper cutoff frequency of the frequency passband of the tube is substantially eliminated.

In accordance with the objective stated above, the traveling-wave tube of the present invention includes means for launching a stream of electrons along a predetermined path of fixed length and a coupled-cavity slow-wave structure disposed along and about the electron stream path for propagating an electromagnetic wave in such manner as to provide energy exchange between the electron stream and the electromagnetic wave. Electric field modifying means, preferably in the form of an electrically conductive ring concentrically disposed about the electron stream in a plane perpendicular to the electron stream path, is provided in the interaction gap of each slow-wave structure cavity. The electric field modifying means is made resonant at a preselected frequency, preferably the upper cutoff frequency of the tube passband. This reduces the electric field along the electron stream path in the interaction gap at the preselected frequency, which in turn reduces the interaction impedance at that frequency, thereby substantially eliminating any tendency for the tube to oscillate in the vicinity of the preselected frequency.

The exact nature of the invention as well as other objects and advantages thereof will be readily apparent from consideration of the following specification describing preferred embodiments of the invention as illustrated in the accompanying drawings in which:

FIG. 1 is a schematic view, primarily in longitudinal section, of a traveling-wave tube constructed in accordance with the present invention;

FIG. 2 is a cross-sectional view taken along line 2—2 of FIG. 1;

FIG. 3 is a cross-sectional view, similar to FIG. 2, illustrating an alternate embodiment of the present invention;

FIG. 4 is a longitudinal sectional view taken along line 4—4 of FIG. 3;

FIGS. 5, 6 and 7, respectively, are longitudinal views, similar to FIG. 4, illustrating further embodiments of the present invention;

FIG. 8 is a cross-sectional view, similar to FIG. 2, illustrating a still further embodiment of the present invention; and

FIGS. 9(*a*)–(*b*) are graphs of interaction impedance as a function of frequency which are used in explaining the theory of the present invention.

Referring with more particularity to the drawings, in FIG. 1 there is shown a traveling-wave tube **10** in which a coupled cavity slow-wave structure **12** is utilized for propagating microwave energy in a serpentine path about an electron beam traveling along the longitudinal axis of the tube **10**. The slow-wave structure **12** comprises a series of circular vane members, or plates, **14** which are disposed perpendicular to the longitudinal axis of the tube **10** and are mounted in a cylindrical waveguide **16** which serves as an envelope for the slow-wave structure **12**. The vane members **14**, as well as the envelope **16**, are composed of a nonmagnetic electrically conductive material, such as copper or brass. The vanes **14** are disposed at spaced points along the envelope **16** to provide a series of interaction cells, or cavities, **20**. Each cavity **20** is defined by the walls of the two adjacent vanes **14** and that portion of the inner surface of the waveguide **16** located between these two vanes. Adjacent cavities **20** are interconnected by means of an off-center coupling hole **18** provided through the intermediate vane **14** to permit the transfer of microwave energy from cell to cell along the slow-wave structure **12**. As is illustrated, the coupling holes **18** may be substantially kidney-shaped and may be alternately disposed 180° apart with respect to the longitudinal axis of the tube, although the coupling holes **18** may be of other shapes and may be staggered in other arrangements well known in the art.

Each vane **14** defines a drift tube, or ferrule, **22** in its central region. The drift tube **22** is in the form of a cylindrical extension, or lip, protruding axially along the path of the electron stream from both surfaces of the vane **14**, i.e., in both directions normal to the plane of the vane **14**. The drift tubes **22** are provided with centrally and axially aligned apertures **24** to provide a passage for the flow of the electron beam. Adjacent ones of the drift tubes **22** are separated by an interaction gap **26** in which energy exchange between the electron stream and microwave energy traversing the slow-wave structure occurs.

At one end of the slow-wave structure **12** there is disposed a conventional electron gun **28** which may include an electron emitting cathode **30** and filamentary heater **32**. The emitted electrons are shaped and focused into a beam by a focusing electrode **34** and are accelerated to a high velocity by accelerating anode **36**. A voltage source **38** is tapped at appropriate potentials, as shown, to provide operating voltages for the electrodes **30**, **34** and **36**.

A collector electrode **40** is disposed at the opposite end of the slow-wave structure **12** to intercept the stream of electrons and dissipate their kinetic energy. A source of potential **42** is connected to the collector **40** to bias the collector **40** positive to prevent secondarily emitted electrons from the slow-wave structure **12** from returning to the interaction region, thereby reducing noise and other interference.

An input waveguide **44** is connected to the input end of the slow-wave structure **12** which, although illustrated as the electron gun end in FIG. 1, may alternately be the collector end if a backward wave device is desired. The waveguide **44** is connected to external circuitry (not shown) by a coupling flange **46**, which may include a microwave window to enable a pressure differential to exist between the exterior and the evacuated interior of the traveling-wave tube **10**. Similarly, an output waveguide **48** is connected to the opposite end of the slow-wave structure **12**. A coupling flange **50**, which may be similar to the flange **46** described above, is provided at the end of the waveguide **48** for coupling to external circuitry (not shown). A solenoid **54**, energized by a source of potential **52**, is disposed concentrically about and substantially coextensive with the low wave structure **12** for providing a longitudinal focusing magnetic field which constrains the electron beam to flow along an axial path toward the collector electrode **40**.

In order to minimize any tendency for the tube to oscillate in the vicinity of the upper cutoff frequency, electric field modifying means is provided in each interaction gap **26** to reduce the interaction impedance in the gap for the traveling wave and the electron beam at the upper cutoff frequency of the tube, while leaving the interaction impedance substantially unaffected for the remaining frequencies in the tube passband. For this purpose, an electrically conductive ring **60** is concentrically mounted in each interaction gap **26** in a plane perpendicular to the electron beam path. The rings **60** are made resonant at a predetermined frequency, preferably the upper cutoff frequency of the tube passband, by making the circumference of each ring **60** equal to one wavelength corresponding to the desired resonant frequency. For typical traveling-wave tube frequencies this results in the rings **60** having a circumference slightly greater than that of the drift tubes **22**.

As is shown in FIG. 2, each ring **60** is supported at diametrically opposite points **66** and **68** by a pair of electrically conductive webs **62** and **64**, which webs are connected to and project inwardly from the envelope **16**. The support webs **62** and **64** are substantially sector-shaped, with the sector angle being selected experimentally for optimum results. The mounting points **66** and **68** act as nodes for the ring **60** when energized at its resonant frequency.

The theory of operation of the resonant ring structure will now be explained with reference to FIG. 9. In this figure there are illustrated graphs of the interaction impedance Z in a gap **26** and on the tube axis plotted as a function of the frequency of the interacting microwaves. The curve **100** in FIG. 9(*a*) shows the interaction impedance for a coupled-cavity traveling-wave tube of the type shown in FIG. 1 but without the inclusion of the resonant rings **60**. It will be observed that the interaction impedance is a maximum (theoretically approaching infinity) at both the upper and lower cutoff frequencies ω_u and ω_1, respectively.

According to the accepted definition the interaction impedance is given by the relation $Z=E_{zn}^2/2\beta_n^2Wv_g$, where E_{zn} is the axial electric field of the *n*th space harmonic in the interaction gap, β_n is the propagation constant of the *n*th space harmonic of the traveling microwave, W is the stored energy per unit length, and v_g is the group velocity of the microwave. Normally at the upper cutoff frequency ω_u the group velocity v_g becomes zero, and hence the interaction impedance theoretically approaches infinity, as illustrated in FIG. 9(*a*). However, with the inclusion of the resonant ring structure, the axial electric field across the gap **26** at the resonant frequency ω_u is drawn outwardly to the ring **60**, thus reducing to essentially zero the electric field in the center of the gap, i.e., at the location of the electron beam. Since the interaction impedance varies directly as the square of the electric field E and inversely as the group velocity v_g, the interaction impedance goes to zero when the electric field goes to zero, even though the group velocity also approaches zero. Thus, as is illustrated by the curve **102** in FIG. 9(*b*), the resonant rings cause the interaction impedance Z to be minimum (theoretically approach zero) at the upper cutoff frequency ω_u. By reducing the interaction impedance in the vicinity of the upper cutoff frequency, while maintaining it essentially at its normal value throughout substantially the remainder of the tube passband, any tendency for the tube to oscillate at the upper cutoff frequency is substantially eliminated.

In order to extend the frequency range of influence of the resonant rings, a coating of lossy material, for example kanthal, may be applied to either the rings **60**, the supporting webs **62** and **64**, or both, in order to reduce the Q of the resonance and thereby broaden the range of frequencies affected.

A modified form of the resonant ring structure of the present invention is illustrated in FIGS. 3 and 4. In this embodiment the resonant ring **60** is supported by a pair of electrically conductive rods **72** and **74** projecting inwardly from the envelope **16**. Coupling probes **76** and **78**, disposed parallel to the longitudinal axis of the tube, are provided at the inner ends of the rods **72** and **74**, respectively, adjacent the ring **60**. As illustrated in FIG. 4, the coupling probes **76** and **78** extend in opposite directions along the axis of the tube from the plane containing the ring **60**. The coupling probes ensure maximum current flow on the ring at resonance in order to achieve maximum excitation of the ring at ω_u.

In the embodiment shown in FIG. 5, the resonant ring **60** is mounted on a pair of longitudinally extending rods **82** and **84**. The rods **82** and **84** are disposed parallel to the tube axis and extend from opposite faces of the ring **60** to the vane members **14** defining the cavity **20** in which the ring **60** is located, the rods **82** and **84** being located on opposite sides of the axis of the tube. The rods **84** perform the dual function of supporting the resonant ring **60** and also serving as coupling probes to ensure maximum excitation of the ring at its resonant frequency.

Although the introduction of the resonant ring structure advantageously serves to reduce the interaction impedance at the upper cutoff frequency, there may also be a slight narrowing of the passband of the fundamental mode due to a lowering of the upper cutoff frequency. One way to maintain the upper cutoff frequency ω_u of the tube at the desired value is to make the resonant frequency ω_u' of the ring 60 occur at a value slightly higher than ω_u.

Alternately, additional capacitance may be added to the slow-wave circuit by the structure of FIG. 6. For this purpose annular ridges 85 are provided on the vanes 14, which ridges project into the cavities 20 at points radially outwardly of the ring support rods 82 and 84.

Another way of introducing the additional capacitance necessary to maintain the desired upper cutoff frequency of the tube passband is illustrated in FIG. 7. In this embodiment drift tubes 22 are constructed with first tubular steps 87 of increased outer circumference and second tubular steps 89 of the same inner circumference but a smaller outer circumference than the steps 87 projecting beyond the steps 87 into the gaps 26. The rods 82 and 84 which support the resonant ring 60 are connected to the inner steps 87 of the drift tubes 22.

A further embodiment of the present invention is illustrated in FIG. 8. The resonant ring 60 is supported in the gap 26 by an annular disk 90 of dielectric material which extends from the inner circumference of the envelope 16 to the outer circumference of ring 60.

It should be understood, of course, that the foregoing disclosure relates only to preferred embodiments of the invention, and that numerous modifications or alterations may be made therein without departing from the spirit and scope of the invention as set forth in the appended claims.

I claim:

1. A traveling-wave tube comprising: means for providing a stream of electrons along a predetermined path, slow-wave structure means disposed along and about said path for propagating electromagnetic wave energy within a predetermined frequency range in such manner as to provide energy exchange between said electron stream and said electromagnetic wave energy in energy exchange regions along said path, and resonant electrically conductive means disposed in proximity to said stream and adjacent at least one of said energy exchange regions for modifying the electric field in said one region of electromagnetic wave energy within a small portion of said predetermined frequency range without substantially affecting the electric field of electromagnetic wave energy within the remainder of said predetermined frequency range.

2. A traveling-wave tube comprising: means for providing a stream of electrons along a predetermined path, slow-wave structure means disposed along and about said path for propagating electromagnetic wave energy within a predetermined frequency range in such manner as to provide energy exchange between said electron stream and said electromagnetic wave energy in energy exchange regions along said path, and resonant electrically conductive means disposed in proximity of said stream and adjacent at least one of said energy exchange rgeions for reducing the interaction impedance of said electron stream with electromagnetic wave energy within a small portion of said predetermined frequency range without substantially affecting the interaction impedance of said electron stream with electromagnetic wave energy within the remainder of said predetermined frequency range.

3. A traveling-wave tube comprising: means for providing a stream of electrons along a predetermined path, slow-wave structure means defining a plurality of intercoupled cavities disposed sequentially along and about said path for propagating electromagnetic wave energy within a predetermined frequency range in such manner as to provide energy exchange between said electron stream and said electromagnetic wave energy, and electrically conductive means disposed in at least one of said cavities in proximity to said stream and resonant at a preselected frequency within substantially said predetermined frequency range for reducing the electric field along said path in said one cavity of electromagnetic wave energy within a small portion of said predetermined frequency range encompassing said preselected frequency without substantially affecting the electric field of electromagnetic wave energy within the remainder of said predetermined frequency range.

4. A traveling-wave tube comprising: means for providing a stream of electrons along a predetermined path, slow-wave structure means defining a plurality of intercoupled cavities disposed sequentially along and about said path for propagating electromagnetic wave energy within a predetermined frequency range in such manner as to provide energy exchange between said electron stream and said electromagnetic wave energy, and an element of electrically conductive material mounted in at least one of said cavities adjacent said predetermined path, said element being resonant at a preselected frequency within substantially predetermined frequency range.

5. A traveling-wave tube according to claim 4 wherein said element is coated with a lossy material.

6. A traveling-wave tube comprising: means for providing a stream of electrons along a predetermined path, slow-wave structure means defining a plurality of intercoupled cavities disposed sequentially along and about said path for propagating electromagnetic wave energy within a predetermined frequency range in such manner as to provide energy exchange between said electron stream and said electromagnetic wave energy, and an electrically conductive ring mounted in at least one of said cavities and being concentrically disposed about said electron stream in a plane perpendicular to said predetermined path, said ring being resonant at a preselected frequency within substantially said predetermined frequency range.

7. A traveling-wave tube comprising: means for providing a stream of electrons along a predetermined path, slow-wave structure means defining a plurality of intercoupled cavities disposed sequentially along and about said path for propagating electromagnetic wave energy within a predetermined frequency range in such manner as to provide energy exchange between said electron stream and said electromagnetic wave energy, and an element of electrically conductive material mounted in selected ones of said cavities adjacent said predetermined path, each said element being resonant at a frequency in the vicinity of the upper cutoff frequency of said predetermined frequency range.

8. A traveling-wave tube comprising: means for providing a stream of electrons along a predetermined path, slow-wave structure means defining a plurality of intercoupled cavities disposed sequentially along and about said path for propagating electromagnetic wave energy within a predetermined frequency range in such manner as to provide energy exchange between said electron stream and said electromagnetic wave energy, a pair of electrically conductive support elements affixed to said slow-wave structure means and projecting therefrom into at least one of said cavities on opposite sides of said electron stream, and an electrically conductive ring mounted on the ends of said support elements remote from said slow-wave structure means, said ring being concentrically disposed about said electron stream in a plane perpendicular to said predetermined path and having a circumference equal to a preselected wavelength corresponding to a frequency within substantially said predetermined frequency range.

9. A traveling-wave tube according to claim 8 wherein said support elements are coated with a lossy material.

10. A traveling-wave tube comprising: an envelope, means disposed adjacent one end of said envelope for

launching a stream of electrons along a predetermined path within said envelope, means disposed within said envelope and cooperating therewith to define a plurality of intercoupled cavities disposed sequentially along and about said path for propagating electromagnetic wave energy within a predetermined frequency range in such manner as to provide energy exchange between said electron stream and said electromagnetic wave energy, a pair of electrically conductive support elements affixed to said envelope and projecting inwardly therefrom on opposite sides of said electron stream in at least one of said cavities, and an electrically conductive ring mounted on the inner ends of said support elements, said ring being concentrically disposed about said electron stream in a plane perpendicular to said predetermined path and having a circumference equal to a preselected wave-length corresponding to a frequency within substantially said predetermined frequency range.

11. A traveling-wave tube according to claim 10 wherein said support elements are substantially sector-shaped webs of a predetermined sector angle.

12. A traveling-wave tube according to claim 10 wherein said support elements are parallel rods disposed perpendicular to said predetermined path.

13. A traveling-wave tube according to claim 10 wherein conductive probes are disposed parallel to said electron stream path at said inner ends of said support elements.

14. A traveling-wave tube comprising: an envelope, means disposed adjacent one end of said envelope for launching a stream of electrons along a predetermined path within said envelope, means disposed within said envelope and cooperating therewith to define a plurality of intercoupled cavities disposed sequentially along and about said path for propagating electromagnetic wave energy within a predetermined frequency range in such manner as to provide energy exchange between said electron stream and said electromagnetic wave energy, a dielectric plate defining a central circular aperture affixed to said envelope and projecting inwardly therefrom in at least one of said cavities, and an electrically conductive ring mounted in said aperture and being concentrically disposed about said electron stream in a plane perpendicular to said predetermined path, said ring having a circumference equal to a preselected wave-length corresponding to a frequency within substantially said predetermined frequency range.

15. A traveling-wave tube comprising: means for providing a stream of electrons along a predetermined path, an electrically conductive envelope disposed about and axially aligned with said path, a plurality of electrically conductive plates mounted perpendicular to said path at spaced points along said envelope to define therewith a plurality of cavities, said plates defining aligned apertures in their central regions to provide a passage for said electron stream and further defining coupling apertures in regions radially outwardly of said central regions for interconnecting adjacent cavities whereby a propagation path is provided for electromagnetic wave energy within a predetermined frequency range in a manner to provide energy exchange between said electron stream and said electromagnetic wave energy, at least a pair of electrically conductive support elements respectively affixed to a pair of adjacent plates and projecting therefrom on opposite sides of said electron stream into the cavity bounded by said pair of plates, and an electrically conductive ring mounted on the ends of said support elements remote from said pair of plates, said ring being concentrically disposed about said electron stream in a plane perpendicular to said electron stream path and having a circumference equal to a preselected wavelength corresponding to a frequency within substantially said predetermined frequency range.

16. A traveling-wave tube comprising: means for providing a stream of electrons along a predetermined path,

an electrically conductive envelope disposed about and axially aligned with said path, a plurality of electrically conductive plates mounted perpendicular to said path at spaced points along said envelope to define therewith a plurality of cavities, said plates defining aligned apertures in their central regions to provide a passage for said electron stream and further defining coupling apertures in regions radially outwardly of said central regions for interconnecting adjacent cavities whereby a propagation path is provided for electromagnetic wave energy within a predetermined frequency range in a manner to provide energy exchange between said electron stream and said electromagnetic wave energy, each of said plates defining a tubular portion adjacent its central aperture which projects beyond the remainder of said plate on at least one side thereof in a direction along said electron stream path whereby an interaction region is provided in the cavity into which said tubular portion projects of an axial length less than the axial length of said cavity, and a ring of electrically conductive material concentrically mounted about said electron stream in said interaction region and in a plane perpendicular to said electron stream path, the circumference of said ring being equal to a preselected wavelength corresponding to a frequency within substantially said predetermined frequency range and being slightly greater than the circumference of said tubular portion.

17. A traveling-wave tube comprising: means for providing a stream of electrons along a predetermined path, an electrically conductive envelope disposed about and axially aligned with said path, a plurality of electrically conductive plates mounted perpendicular to said path at spaced points along said envelope to define therewith a plurality of cavities, said plates defining aligned apertures in their central regions to provide a passage for said electron stream and further defining coupling apertures in regions radially outwardly of said central regions for interconnecting adjacent cavities whereby a propagation path is provided for electromagnetic wave energy within a predetermined frequency range in a manner to provide energy exchange between said electron stream and said electromagnetic wave energy, each of said plates defining a tubular portion adjacent its central aperture which projects beyond the remainder of said plate on at least one side thereof in a direction along said electron stream path whereby an interaction region is provided in the cavity into which said tubular portion projects of an axial length less than the axial length of said cavity, at least a pair of electrically conductive support elements respectively affixed to a pair of adjacent plates at points radially outwardly of said tubular portions thereof, said support elements projecting from said pair of plates on opposite sides of said electron stream into the cavity bounded by said pair of plates, each plate of said pair of plates further defining an annular ridge portion concentrically disposed about said tubular portion thereof and projecting from said plate in the direction in which said support element affixed to said plate projects, and an electrically conductive ring mounted on the ends of said support elements remote from said pair of plates, said ring being concentrically disposed about said electron stream in a plane perpendicular to said electron stream path and having a circumference equal to a preselected wavelength corresponding to a frequency within substantially said predetermined frequency range.

18. A traveling-wave tube comprising: means for providing a stream of electrons along a predetermined path, an electrically conductive envelope disposed about and axially aligned with said path, a plurality of electrically conductive plates mounted perpendicular to said path at spaced points along said envelope to define therewith a plurality of cavities, said plates defining aligned apertures in their central regions to provide a passage for said electron stream and further defining coupling apertures in regions radially outwardly of said central regions for interconnecting adjacent cavities whereby a propagation

path is provided for electromagnetic wave energy within a predetermined frequency range in a manner to provide energy exchange between said electron stream and said electromagnetic wave energy, each of said plates defining a first tubular portion adjacent its central aperture which projects beyond the remainder of said plate on at least one side thereof in a direction along said electron stream path and a second tubular portion of the same inner circumference and smaller outer circumference than said first tubular portion projecting beyond said first tubular portion in said direction whereby an interaction region is provided in the cavity into which said first and second tubular portions project of an axial length less than the axial length of said cavity, at least a pair of electrically conductive support elements respectively affixed to the first tubular portions of the plates defining said cavity, said support elements projecting from said first tubular portions on opposite sides of said electron stream

into said cavity, and an electrically conductive ring mounted on the ends of said support elements remote from said first tubular portions, said ring being concentrically disposed about said electron stream in a plane perpendicular to said electron stream path and having a circumference equal to a preselected wavelength corresponding to a frequency within substantially said predetermined frequency range.

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GEORGE N. WESTBY, *Primary Examiner.*

ARTHUR GAUSS, *Examiner.*

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,181,024

April 27, 1965

Samuel Sensiper

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 3, line 48, for "low wave" read -- slow-wave --; column 5, line 60, for "of" read -- to --; column 6, line 22, after "substantially" insert -- said --.

Signed and sealed this 12th day of October 1965.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents