Nov. 21, 1967 W. HANT 3,354,347

TRAVELING-WAVE TUBE HAVING LOSSY MATERIAL WALLS SEPARATING ADJACENT OSCILLATION SUPPRESSION RESONANT CAVITIES COUPLED TO SLOW-WAVE STRUCTURE INTERACTION CELLS

Filed Oct. 28, 1964 3 Sheets-Sheet 1

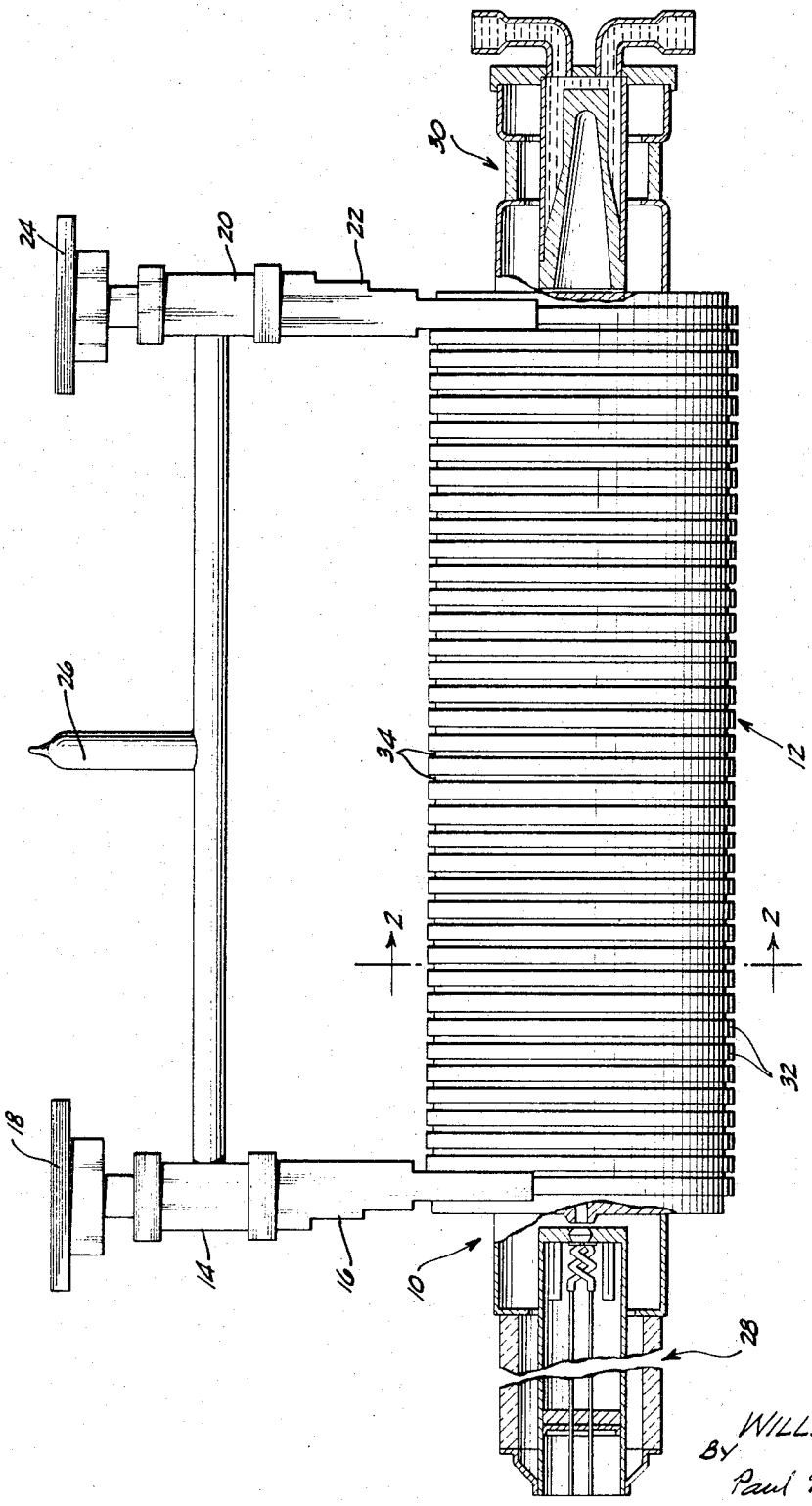


FIG. 1.

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Filed Oct. 28, 1964 3 Sheets-Sheet 2

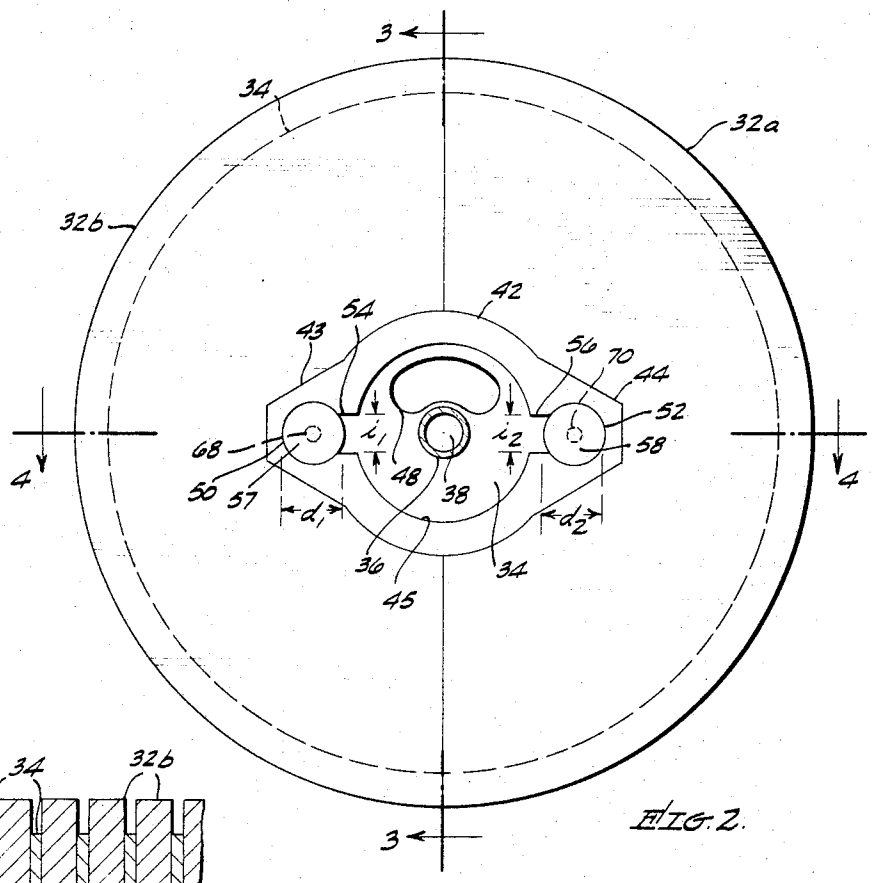


FIG. 2.

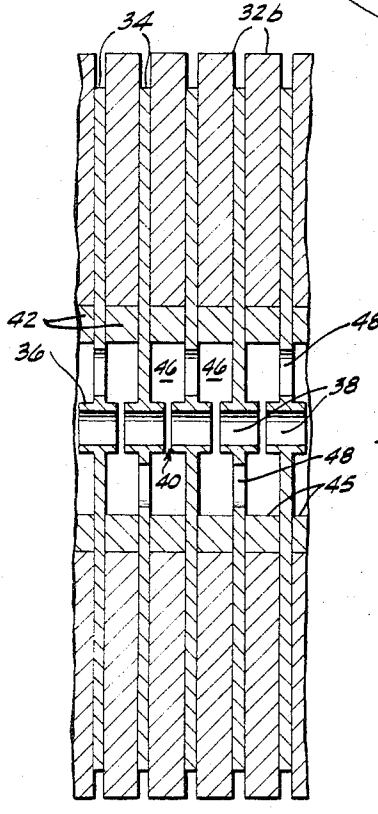


FIG. 3.

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Filed Oct. 28, 1964 3 Sheets-Sheet 3

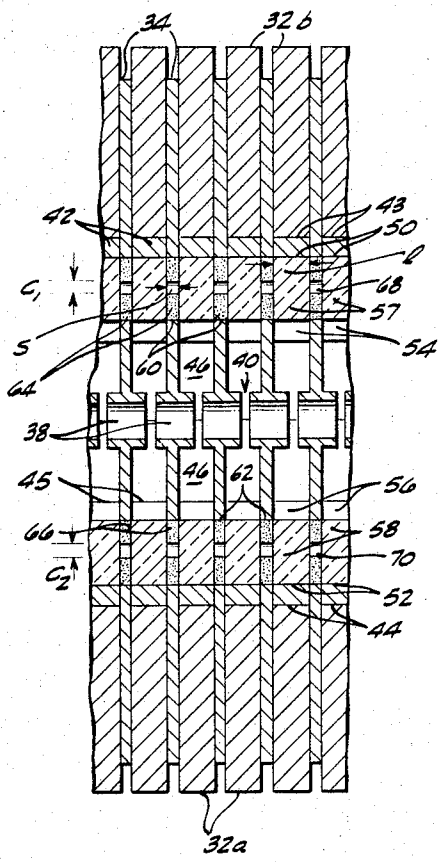


FIG. 4.

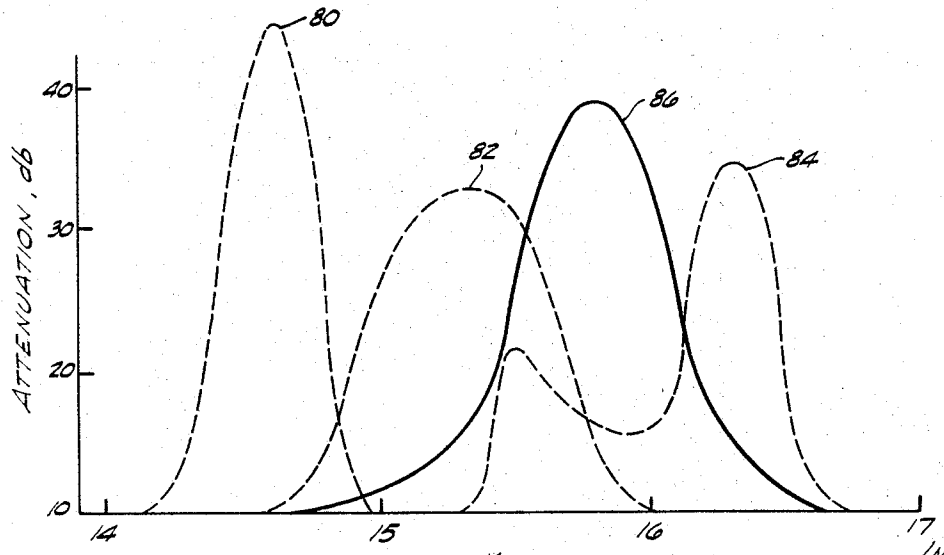


FIG. 5.

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TRAVELING-WAVE TUBE HAVING LOSSY MATERIAL WALLS SEPARATING ADJACENT OSCILLATION SUPPRESSION RESONANT CAVITIES COUPLED TO SLOW-WAVE STRUCTURE INTERACTION CELLS

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9 Claims. (Cl. 315—3.5)

This invention relates generally to microwave devices, and more particularly relates to traveling-wave tubes having novel and improved means for substantially eliminating oscillations at desired frequencies, such as those at the edges of the frequency passband of the tube.

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 the 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, although not necessarily, concerned with traveling-wave tubes utilizing slow-wave structures of 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 edges of the tube passband. This problem arises from the fact that for wide band 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 and lower cutoff frequencies of the tube. Since the interaction impedance is high and the circuit-to-transmission line match is poor at and in the vicinity of the cutoff frequencies, the loop gain for the tube, or even for a section of the tube, may be sufficiently large for oscillations to start.

One technique which has been used to solve this oscillation problem involves coupling to the slow-wave structure interaction cells specially designed cavities which are sharply resonant at a frequency in the vicinity of a cutoff frequency of the slow-wave structure and providing lossy ceramic buttons in these special cavities to attenuate energy at the resonant frequency of the cavity. In order to afford a greater loss-bandwidth product and otherwise improve the loss vs. frequency characteristics, a further resonant loss arrangement has been employed for oscillation suppression in which a coupling aperture is provided in each wall separating a pair of axially adjacent resonant cavities to provide capacitive coupling directly between the pair of cavities.

As traveling-wave tubes are designed for operation with higher average power ratings, over wider bandwidths, and throughout larger temperature ranges, it is necessary to employ oscillation suppression devices which operate reliably under these new and more stringent requirements. In view of the success of lossy resonant cavity arrangements for oscillation suppression, it is desired that new and improved resonant loss schemes be developed which are better able to meet the above operating requirements.

Accordingly, it is an object of the present invention to provide a traveling-wave tube which is capable of operating at higher temperatures, with higher power levels, and over wider bandwidths than has heretofore been possible while insuring that undesired oscillations will not develop.

It is a further object of the present invention to provide a resonant loss type of oscillation suppression arrangement for a traveling-wave tube which affords an attenuation vs. frequency characteristic having a greater amplitude of maximum attenuation and a higher attenuation-bandwidth product than comparable prior art arrangements of this type, and which characteristic is also less sensitive to temperature changes than in the prior art.

It is a still further object of the present invention to provide a traveling-wave tube which employs a resonant loss arrangement to attenuate energy at frequencies at the edges of the slow-wave circuit frequency passband, and which arrangement is less likely to introduce spurious attenuation into the slow-wave circuit passband than in the prior art.

It is still another object of the present invention to provide a resonant loss oscillation suppression arrangement for a traveling-wave tube which may be manufactured with greater reliability and less expense than comparable prior art arrangements.

In accordance with the foregoing objects, the traveling-wave tube of the present invention includes means for providing a stream of electrons along a predetermined path and a slow-wave structure having a plurality of intercoupled interaction cells disposed sequentially along and about the electron stream path for propagating electromagnetic wave energy in such manner that it interacts wih the stream of electrons. A plurality of cavities are sequentially disposed along a direction parallel to the electron stream path, with each cavity being electromagnetically coupled to one of the interaction cells. Each cavity is made resonant at a preselected frequency and contains a substantially lossless dielectric material, with at least a portion of the cavity walls being of lossy material. Axially adjacent ones of the resonant cavities are separated by wall means which defines an aperture for providing capacitive coupling directly between the adjacent cavities. In a preferred embodiment of the invention kanthal is used as the lossy material, while alumina is employed as the substantially lossless dielectric material.

The foregoing, as well as other objects, advantages, and characteristic features of the present invention will become more readily apparent from the following detailed description of a preferred embodiment of the invention when considered in conjunction with the accompanying drawings in which:

FIG. 1 is an overall view, partly in longitudinal section and partly broken away, 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 longitudinal sectional view taken along line 3—3 of FIG. 2;

FIG. 4 is a longitudinal sectional view taken along line 4—4 of FIG. 2; and

FIG. 5 is a series of graphs illustrating the attenuation as a function of frequency for various traveling-wave tube lossy resonant attenuating arrangements including an arrangement according to the present invention.

Referring to the drawings with more particularity, in FIG. 1 the reference numeral **10** designates generally a traveling-wave tube which includes an arrangement **12** of magnets, pole pieces and spacer elements which will be described in detail later. At this point it should suffice to state that the spacer elements and interior portions of the pole pieces function as a slow-wave structure, while the magnets and pole pieces constitute a periodic focusing device for the electron beam traversing the length of the slow-wave structure.

Coupled to the input of the arrangement **12** is an input waveguide transducer **14** which includes an impedance step transformer **16**. A flange **18** is provided for coupling the assembled traveling-wave tube **10** to an external waveguide or other microwave transmission line (not shown). The construction of the flange **18** may include a microwave window (not shown) transparent to microwave energy but capable of maintaining a vacuum within the traveling-wave tube **10**. At the output end of the arrangement **12** an output transducer **20** is provided which is substantially similar to the input transducer **14** and which includes an impedance step transformer **22** and a coupling flange **24**, which elements are similar to the elements **16** and **18**, respectively, of the input transducer **14**. For vacuum pumping or out-gassing the traveling-wave tube **10** during manufacture, a double-ended pumping tube **26** is connected to both of the input and output waveguide transducers **14** and **20**.

An electron gun **28** is disposed at one end of the traveling-wave tube **10** which, although illustrated as the input end in FIG. 1, may alternatively be the output end if a backward wave device is desired. The electron gun **28** functions to protect a stream of electrons along the axis of the tube **10** and may be of any conventional construction well known in the art. For details as to the construction of the gun **28** reference is made to Patent No. 2,985,791, entitled "Periodically Focused Severed Traveling-Wave Tube," issued May 23, 1961 to D. J. Bates et al. and assigned to the assignee of the present invention and to Patent No. 2,936,393, entitled "Low Noise Traveling-Wave Tube," issued May 10, 1960 to M. R. Currie et al. and assigned to the assignee of the present invention.

At the output end of the traveling-wave tube **10** there is provided a cooled collector structure **30** for collecting the electrons in the stream. The collector is conventional and may be of any form well known in the art. For details as to the construction of the collector, reference is made to the aforesaid Patent No. 2,985,791 and to Patent No. 2,860,277, entitled "Traveling-Wave Tube Collector Electrode" issued November 11, 1958 to A. H. Iversen and assigned to the assignee of the present invention.

The construction of the slow-wave structure and magnetic focusing system for the traveling-wave tube **10** are illustrated in more detail in FIGS. 2–4. A plurality of essentially annular disk-shaped focusing magnets **32** are

interposed between a plurality of ferromagnetic pole pieces **34**. As is illustrated in FIG. 2, the magnets **32** may be diametrically split into two sections **32***a* and **32***b* for convenience during assembly of the tube. The ferromagnetic pole pieces **34** extend radially inwardly of the magnets **32** to approximately the perimeter of the region adapted to contain the axial electron stream. The individual pole pieces are constructed in such a manner that a short drift tube, or ferrule, **36** is provided at the inner extremity of each pole piece. The drift tube **36** is in the form of a cylindrical extension, or lip, protruding axially along the path of the electron stream from both surfaces of the pole piece **34**, i.e., in both directions normal to the plane of the pole piece **34**. The drift tubes **36** are provided with central and axially aligned apertures **38** to provide a passage for the flow of the electron beam. Adjacent ones of the drift tubes **36** are separated by a gap **40** which functions as a magnetic gap to provide a focusing lens for the electron means and also as an interaction gap in which energy exchange between the electron beam and traveling-wave energy traversing the slow-wave structure occurs.

Disposed radially within each of the magnets **32** is a slow-wave circuit spacer element **42** of a conductive nonmagnetic material such as copper. Each spacer element **42** has an annular portion of an outer diameter essentially equal to the inner diameter of the magnets **32** and a pair of oppositely disposed ear portions **43** and **44** projecting outwardly from the annular portion. Each spacer element also defines a central cylindrical aperture **45** to provide space for a microwave interaction cell, or cavity, **46** which is defined by the inner lateral surface of the spacer **42** and the walls of the two adjacent pole pieces **34** projecting inwardly of the spacer element **42**. The inner diameter of the spacer **42** determines the radial extent of the interaction cell **46**, while the axial length of the spacer **42** determines the axial length of the cell **46**.

For interconnecting adjacent interaction cavities **46** an off-center coupling hole **48** is provided through each of the pole pieces **34** to permit the transfer of electromagnetic wave energy from cell to cell. As is illustrated, the coupling holes **48** may be substantially kidney-shaped and may be alternately disposed 180° apart with respect to the drift tubes **36**. It should be pointed out, however, that the coupling holes **48** may be of other shapes and may be staggered in various other arrangements, such as those disclosed in Patent No. 3,010,047, entitled "Traveling-Wave Tube," issued November 21, 1961 to D. J. Bates and assigned to the assignee of the present invention. In any event, it will be apparent that the spacer elements **42** and the portions of the pole pieces **34** projecting inwardly of the spacers **42** not only form an envelope for the tube, but also constitute a slow-wave structure for propagating traveling-wave energy in a serpentine path along the axially traveling electron stream so as to support energy exchange between the electrons of the stream and the traveling-wave.

The axial length of the magnets **32**, hence that of the spacers **42**, is equal to the spacing between adjacent pole pieces **34**, and the radial extent of the magnets **32** is approximately equal to or, as shown, slightly greater than that of the pole pieces **34**. To provide focusing lenses in the gaps **40**, the magnets **32** are stacked with alternating polarity along the axis of the tube, thus causing a reversal of the magnetic field at each magnetic lens and thereby providing a periodic focusing device. It should be pointed out, however, that although the lengths of the spacers **42** may be substantially constant, they may also be varied slightly with respect to each other so that the effective axial length of the cavities **46** is varied as a function of distance along the tube to ensure that the desired interaction between the electron stream and the traveling waves will continue to a maxi-

mum degree even though the electrons are decelerated toward the collector end of the tube.

In order to minimize any tendency for the traveling-wave tube to oscillate at frequencies near the edges of the slow-wave circuit passband, frequency selective attenuation is provided to substantially decrease the gain at these frequencies and, thereby, suppress the oscillations. This attenuation takes the form of resonant cavities which are coupled to the slow-wave circuit interaction cells and the end walls of which contain a lossy material. Thus, as is shown in FIGS. 2 and 4, a slow-wave circuit spacer element **42** may define a pair of cylindrical cavities **50** and **52** which are respectively disposed in the projecting ear portions **43** and **44** of the spacer element **42**. The cavity **50** has a diameter d_1 and is coupled to the central aperture **45** in the spacer **42** by means of a coupling hole, or iris, **54** of width i_1. Similarly, the cavity **52** has a diameter d_2 and is coupled to the spacer aperture **45** via a coupling iris **56** of width i_2. The diameters d_1 and d_2 for the respective cavities **50** and **52** may either have the same or a different value, and similarly, the iris widths i_1 and i_2 may or may not be equal. As may be seen from FIG. 4, the cavities **50** and **52** have a length l equal to the thickness of the slow-wave circuit spacer element **42**.

The cavities **50** and **52** are designed to resonate in the TM_{010} mode at a frequency at which loss is to be introduced into the circuit. Although the cavity resonant frequency is preferably at or near either the upper or lower cutoff frequency of the slow-wave circuit, it should be understood that the resonant frequency may be any preselected frequency. Cylindrical button-like elements **57** and **58** of a dielectric material are disposed in the respective cavities **50** and **52**. Although the dielectric material comprising the elements **57** and **58** is preferably alumina, other materials which could be used for forsterite, beryllia, and talc.

In accordance with the principles of the present invention the desired attenuation is introduced by providing lossy end walls for the resonant cavities **50** and **52**. Each pole piece **34** disposed between a pair of axially adjacent resonant cavities **50** defines a cylindrical aperture **60** of a diameter d_1 which is coaxially aligned with the adjacent cylindrical cavities **50**. Similarly, each pole piece **34** disposed between a pair of axially adjacent resonant cavities **52** defines a cylindrical aperture **62** of a diameter d_2 which is coaxially aligned with the adjacent cavities **52**. A disk-like ring **64** of a lossy material is disposed in each pole piece aperture **60**, while a similar lossy ring **66** resides in each pole piece aperture **62**. Although in a preferred embodiment of the present invention the lossy material comprising the rings **64** and **66** is kanthal, silicon carbide may be used instead. The outer diameters of the rings **64** and **66**, respectively, are essentially equal to the respective diameters d_1 and d_2 of the pole piece apertures **60** and **62**.

Each lossy ring **64** defines a cylindrical coupling aperture **68** of a diameter c_1 which is coaxially aligned with the cylindrical cavities **50** and the pole piece apertures **60**. Similarly, each ring **66** is provided with a cylindrical coupling aperture **70** having a diameter c_2 which is coaxially aligned with the cavities **52** and the pole piece apertures **62**. The apertures **68** provide capacitive coupling directly between axially adjacent resonant cavities **50**, while the apertures **70** capacitively couple axially adjacent resonant cavities **52**. Preferably, the diameters c_1 and c_2 of the respective coupling holes **68** and **70**, which may or may not be equal, vary from essentially between 0.2 and 0.7 of the diameters d_1 and d_2 of the resonant cavities **50** and **52**. The length of the coupling apertures **68** and **70**, which is equal to the thickness of the respective rings **64** and **66** defining the apertures, is denoted by s in FIG. 4.

The manner in which the resonant loss arrangement of the present invention affects the attenuation vs. frequency characteristics of the slow-wave structure is illustrated in FIG. 5. In this figure the dashed curve **80** depicts the attenuation as a function of frequency for a scheme in which no pole piece apertures **60** and **62** and rings **64** and **66** are provided, with the ferromagnetic pole pieces **34** completely filling the space occupied by the rings **64** and **66** and the capacitive coupling apertures **68** and **70**. In the exemplary arrangement from which data for the curve **80** was taken the diameters d_1 and d_2 of the resonant cavities **50** and **52** were both .150 inch, the coupling iris widths i_1 and i_2 were both .130 inch, the cavity length l was .096 inch, the pole piece thickness s was .040 inch, the diameters of the apertures **60**, **62**, **68** and **70** were all zero, and the resonant cavities **50** and **52** were filled with alumina. For this arrangement it may be observed that an attenuation vs. frequency characteristic is provided having a high Q and a large amplitude of maximum attenuation.

The attenuation vs. frequency characteristic for a further resonant loss arrangement in which capacitive coupling apertures but no lossy rings **64** and **66** are provided, i.e., with the pole pieces **34** extending all the way to the perimeters of the capacitive coupling apertures **68** and **70**, is illustrated by the dashed curve **82** of FIG. 5. The curve **82** was made from a slow-wave circuit-resonant loss arrangement having parameters identical to those set forth above with respect to the curve **80**, except that cylindrical coupling apertures **68** and **70** were provided in the pole pieces **34** between axially adjacent pairs of cavities **50** and **52**, respectively, the diameters c_1 and c_2 for the respective coupling apertures **68** and **60** each being .075 inch. It may be observed from FIG. 5 that as the coupling aperture diameter is increased the center frequency and the bandwidth of the attenuation band increases, while the amplitude of the maximum attenuation decreases.

As the diameter of the coupling apertures is increased further, a critical diameter is reached at which the attenuation vs. frequency characteristic degenerates into a double-humped curve such as shown by the dashed curve **84** of FIG. 5. The curve **84** was made from an arrangement identical to that from which the curve **82** was plotted, except with a coupling aperture diameter $c_1=c_2=.090$ inch.

The attenuation vs. frequency characteristic for a resonant loss arrangement in accordance with the present invention is illustrated by the solid curve **86** of FIG. 5. The curve **86** was made from a slow-wave circuit-resonant loss arrangement having parameters identical to those set forth above with respect to the curve **84**, except that cylindrical apertures **60** and **62** (each of a diameter of .150 inch) were provided in the pole pieces **34**, and kanthal rings **64** and **66** were disposed in the respective apertures **60** and **62**, the rings **64** and **66** defining respective coupling apertures **68** and **70** (each of a diameter of .090 inch).

From the inspection of FIG. 5 it will be apparent that the resonant loss arrangement of the present invention increases the amplitude of maximum attenuation and the attenuation-bandwidth product of the attenuation vs. frequency characteristic. In addition, on account of the low loss characteristics of the material filling the resonant cavities and the high loss properties of the cavity end walls, most of the loss in the system occurs as conductor wall loss and not as dielectric loss. Therefore, a traveling-wave tube provided with an oscillation suppression arrangement in accordance with the present invention is able to operate at higher temperatures, with higher average power levels, and over wider bandwidths than is possible when using prior art oscillation suppression schemes. It has also been found that the loss vs. frequency characteristics of an attenuating device according to the present invention is more stable as a function of temperature and introduces less spurious attenuation into the slow-wave circuit passband than in the prior art. Moreover, since critical mixing of lossy and dielectric

materials in the fabrication of loss buttons is eliminated, component parts for the arrangement of the present invention may be manufactured more readily and with more repeatable characteristics than component parts for prior art oscillation suppression arrangements, thereby decreasing manufacturing time and complexity, and hence, reducing the cost of the traveling-wave tube.

In the preferred embodiment of the present invention illustrated and described herein the cavity end walls only are composed of lossy material. It should be understood, however, that within the principles of the invention either the end walls of the cavities, or the lateral walls, or both, may contain lossy material. Thus although the present invention has been shown and described with reference to a particular embodiment, nevertheless, various changes and modifications obvious to a person skilled in the art to which the invention pertains are deemed to be within the spirit, scope and contemplation of the invention as set forth in the appended claims.

What is claimed is:

1. 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 interaction cells disposed sequentially along and about said predetermined path for propagating electromagnetic wave energy in such manner that it interacts with said stream of electrons, means defining a plurality of cavities sequentially disposed along a direction parallel to said predetermined path, each of said cavities being electromagnetically coupled to one of said interaction cells and being resonant at a preselected frequency, said cavity defining means including wall means at least a portion of which is of lossy material, said wall means defining an aperture for providing electromagnetic coupling directly between said adjacent ones of said cavities, and substantially lossless dielectric material disposed in each of said cavities.

2. A traveling-wave tube according to claim 1 wherein said lossy material is kanthal and said substantially lossless dielectric material is alumina.

3. A traveling-wave tube according to claim 1 wherein each of said cavities is resonant in the TM_{010} mode.

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 interaction cells disposed sequentially along and about said predetermined path for propagating electromagnetic wave energy in such manner that it interacts with said stream of electrons, means defining a plurality of cavities sequentially disposed along a direction parallel to said predetermined path, each of said cavities being electromagnetically coupled to one of said interaction cells and being resonant at a preselected frequency, said cavity defining means including lossy wall means separating adjacent ones of said cavities, said wall means defining an aperture for providing electromagnetic coupling directly between said adjacent ones of said cavities, and substantially lossless dielectric material disposed in each of said cavities.

5. 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 interaction cells disposed sequentially along and about said predetermined path for propagating electromagnetic wave energy in such manner that it interacts with said stream of electrons, means defining a plurality of sequentially disposed cylindrical cavities aligned with one another along a direction parallel to said predetermined path, each of said cavities being electromagnetically coupled to one of said interaction cells and being resonant at a preselected frequency, said cavity defining means including wall means of a lossy material separating adjacent ones of said cavities, said wall means defining a cylindrical aperture coaxially aligned with said cylindrical cavities for providing electromagnetic coupling between said adjacent ones of said cavities, and a cylindrical element of substantially lossless dielectric material substantially filling each of said cavities.

6. A traveling-wave tube comprising: means for providing a stream of electrons along a predetermined path, a plurality of axially aligned essentially annular electrically conductive spacer elements sequentially disposed along and encompassing said predetermined path, a plurality of electrically conductive plates each mounted between a pair of adjacent spacer elements to define in conjunction with said spacer elements a plurality of interaction cells, said plates defining aligned apertures in their central regions to provide a passage for said electron stream and further defining coupling holes in regions radially outwardly of said central regions for interconnecting adjacent interaction cells whereby a propagation path is provided for an electromagnetic wave in a manner to provide interaction between said electron stream and said electromagnetic wave, at least certain successive ones of said spacer elements defining aligned cylindrical cavities coupled to the respective interaction cells defined by the spacer elements, each of said cavities being resonant at a preselected frequency, each of said plates which is interposed between a pair of successive cylindrical cavities defining a cylindrical aperture coaxially aligned with said pair of cylindrical cavities, a cylindrical element of substantially lossless dielectric material substantialy filling each of said cavities, and a ring of lossy material disposed in each cylindrical aperture.

7. A traveling-wave tube comprising: means for providing a stream of electrons along a predetermined path, a plurality of axially aligned essentially annular electrically conductive spacer elements sequentially disposed along and encompassing said predetermined path, a plurality of electrically conductive plates each mounted between a pair of adjacent spacer elements to define in conjunction with said spacer elements a plurality of interaction cells, said plates defining aligned apertures in their central regions to provide a passage for said electron stream and further defining coupling holes in regions radially outwardly of said central regions for interconnecting adjacent interaction cells whereby a propagation path is provided for an electromagnetic wave in a manner to provide interaction between said electron stream and said electromagnetic wave, at least certain successive ones of said spacer elements defining aligned cylindrical cavities coupled to the respective interaction cells defined by the spacer elements, each of said cavities being resonant at a preselected frequency, each of said plates which is interposed between a pair of successive cylindrical cavities defining a cylindrical aperture coaxially aligned with said pair of cylindrical cavities, the diameter of said cylindrical aperture being essentially equal to the diameter of said pair of cylindrical cavities, a cylindrical element of alumina substantially filling each of said cavities, a cylindrical kanthal disk disposed in each of said cylindrical apertures and having a diameter essentially equal to that of said cylindrical aperture, and each of said disks defining a cylindrical aperture coaxially aligned with and intercoupling the adjacent pair of cylindrical cavities.

8. A traveling-wave tube comprising: means for launching a stream of electrons along a predetermined path, a plurality of axially aligned essentially annular magnets, a plurality of ferromagnetic pole pieces interposed between and abutting adjacent magnets, a hollow essentially cylindrical nonmagnetic spacer element having an outer diameter essentially equal to the inner diameter of said essentially annular magnets disposed within each of said magnets, said pole pieces projecting internally of said spacer elements to define therewith a plurality of interaction cells, said pole pieces defining aligned apertures in their central regions to provide a passage for said electron stream and further defining coupling holes in regions radially outwardly of said central regions for interconnect-

ing adjacent cells whereby a propagation path is provided for an electromagnetic wave in a manner to provide interaction between said electron stream and said electromagnetic wave, at least certain successive ones of said spacer elements each defining at least one outwardly extending ear portion, at least certain successive ones of said ear portions defining aligned cylindrical cavities coupled to the respective interaction cells defined by the spacer elements, each of said cavities being resonant at a preselected frequency, each of said plates which is interposed between a pair of successive cylindrical cavities defining a cylindrical aperture coaxially aligned with said pair of cylindrical cavities, a cylindrical element of substantially lossless dielectric material substantially filling each of said cavities, and a ring of lossy material disposed in each cylindrical aperture.

9. A traveling-wave tube comprising: means for launching a stream of electrons along a predetermined path, a plurality of axially aligned essentially annular magnets, a plurality of ferromagnetic pole pieces interposed between and abutting adjacent magnets, a hollow essentially cylindrical nonmagnetic spacer element having an outer diameter essentially equal to the inner diameter of said essentially annular magnets disposed within each of said magnets, said pole pieces projecting internally of said spacer elements to define therewith a plurality of interaction cells, said pole pieces defining aligned apertures in their central regions to provide a passage for said electron stream and further defining coupling holes in regions radially outwardly of said central regions for interconnecting adjacent cells whereby a propagation path is provided for an electromagnetic wave in a manner to provide interaction between said electron stream and said electromagnetic wave, at least certain successive ones of said spacer elements each defining at least one outwardly extending ear portion, at least certain successive ones of said ear portions defining aligned cylindrical cavities coupled to the respective interaction cells defined by the spacer elements, each of said cavities being resonant at preselected frequency, each of said plates which is interposed between a pair of successive cylindrical cavities defining a cylindrical aperture coaxially aligned with said pair of cylindrical cavities, the diameter of said cylindrical apertures being essentially equal to the diameter of said pair of cylindrical cavities, a cylindrical element of alumina substantially filling each of said cavities, a cylindrical kanthal disk disposed in each of said cylindrical apertures and having a diameter essentially equal to that of said cylindrical aperture, and each of said disks defining cylindrical aperture coaxially aligned with and intercoupling the adjacent pair of cylindrical cavities.

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