June 6, 1967 L. M. WINSLOW 3,324,338

TRAVELING-WAVE TUBE WITH OSCILLATION PREVENTING AND GAIN SHAPING MEANS INCLUDING AN ELONGATED LOSSY CERAMIC ELEMENT

Filed Feb. 24, 1964 3 Sheets-Sheet 1

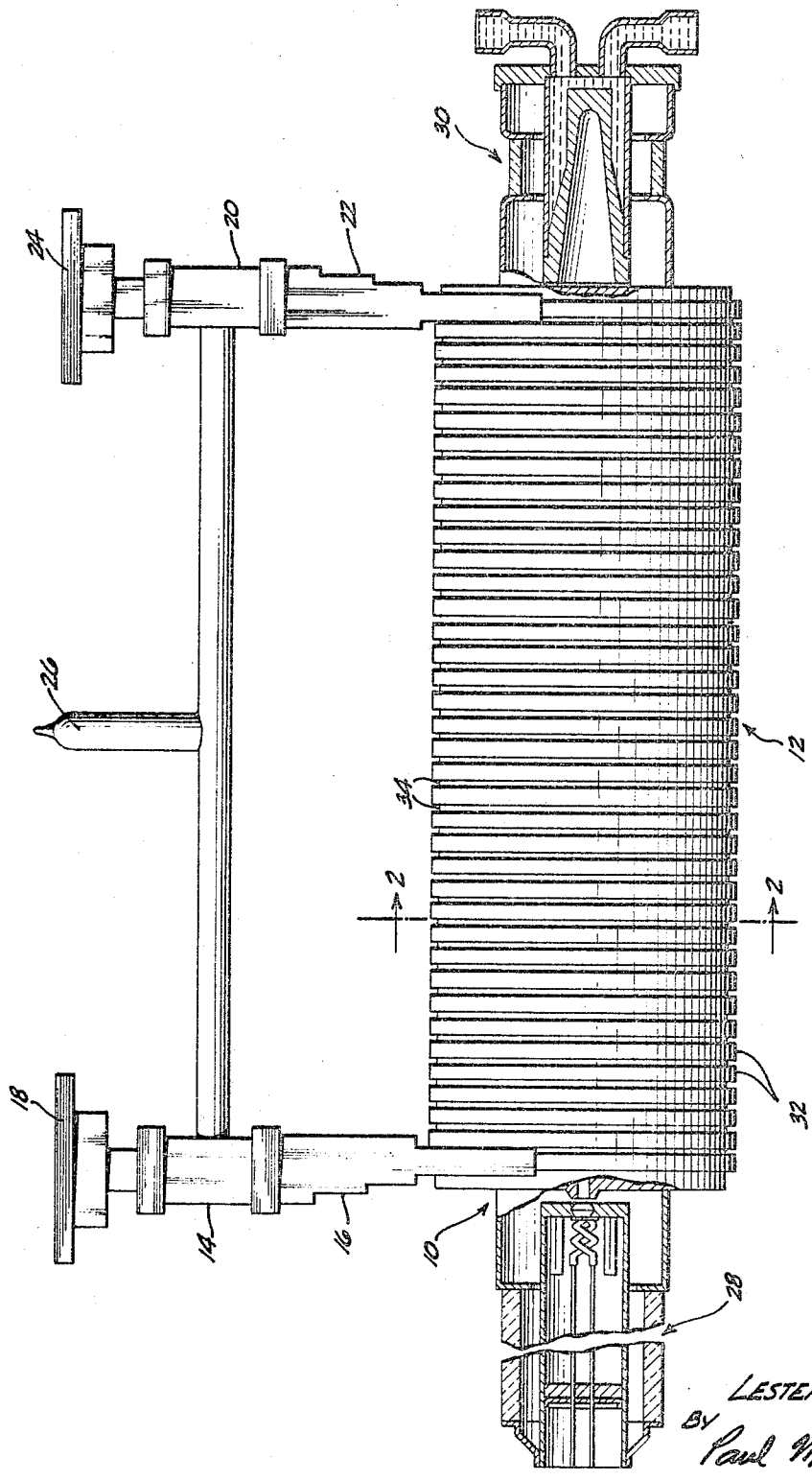


FIG. 1.

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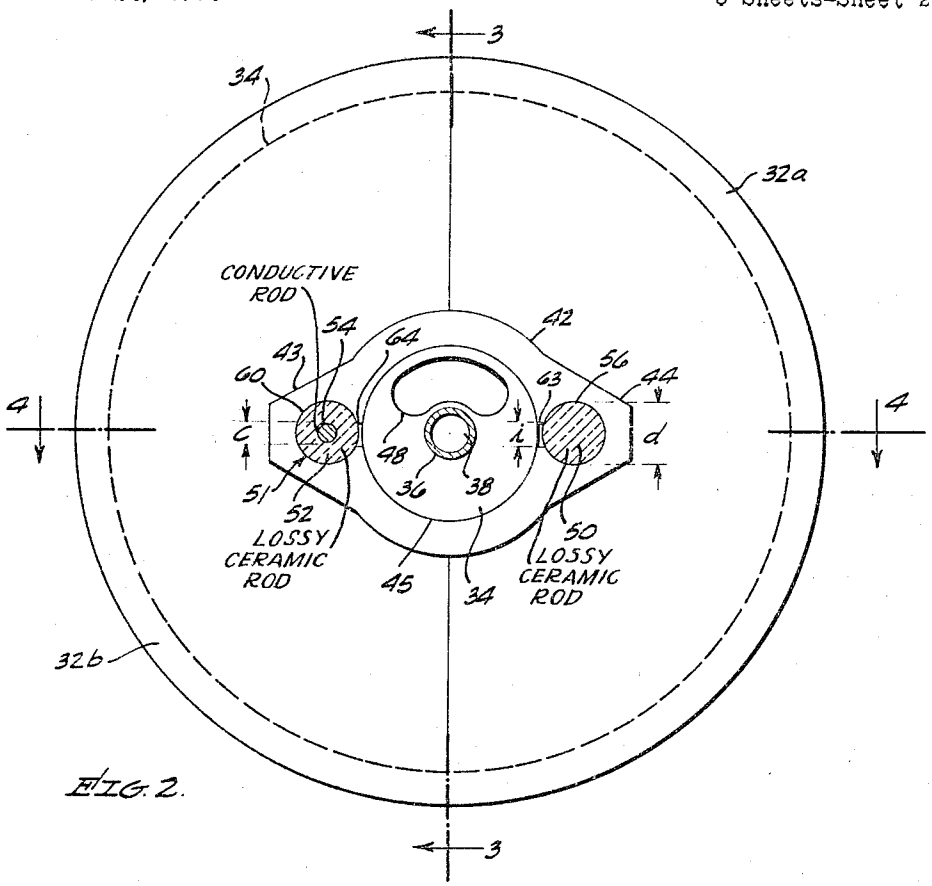


FIG. 2.

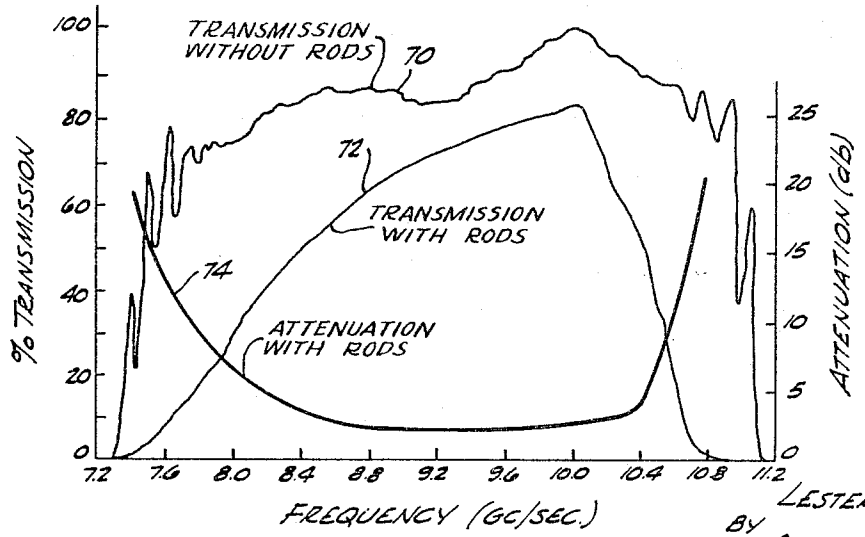


FIG. 5.

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Filed Feb. 24, 1964 3 Sheets-Sheet 3

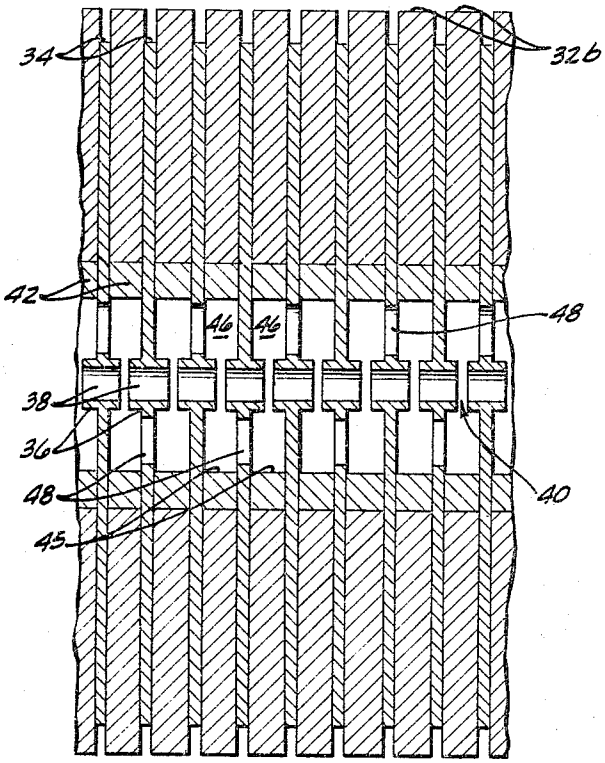


FIG. 3.

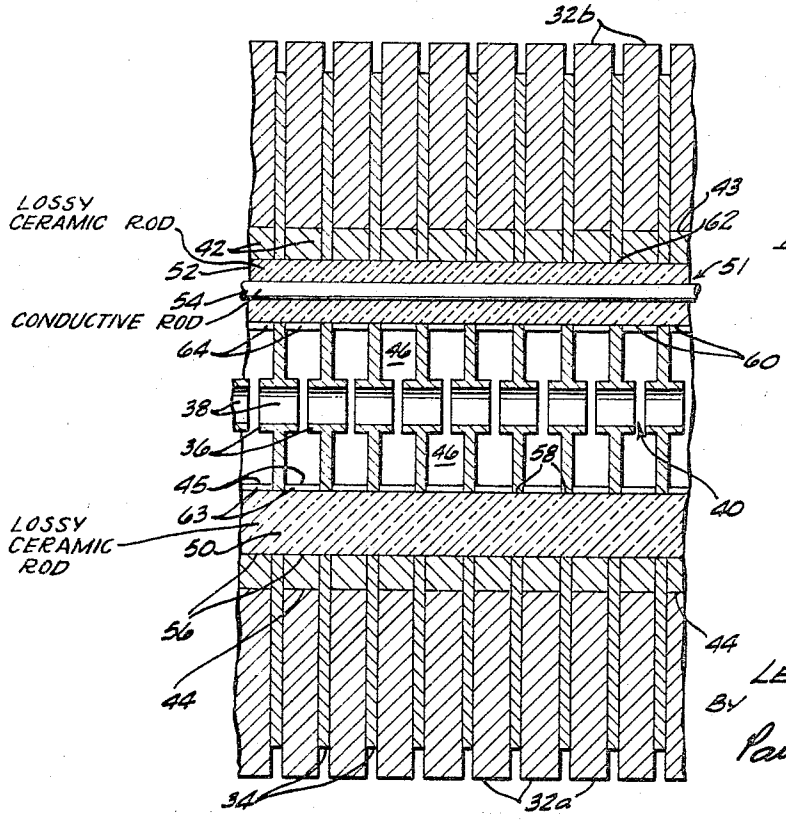


FIG. 4.

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TRAVELING-WAVE TUBE WITH OSCILLATION PREVENTING AND GAIN SHAPING MEANS INCLUDING AN ELONGATED LOSSY CERAMIC ELEMENT

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11 Claims. (Cl. 315—3.5)

ABSTRACT OF THE DISCLOSURE

A longitudinally extending attenuating transmission line is disposed proximate to and externally of a traveling-wave tube coupled cavity slow-wave structure. The transmission line may be a cylindrical lossy ceramic rod or a tubular lossy ceramic rod disposed coaxially about an electrically conductive rod. The transmission line is electromagnetically coupled to the slow-wave structure via irises in the side walls of selected slow-wave structure cavities.

This invention relates generally to microwave devices, and more particularly relates to traveling-wave tubes having means for substantially eliminating oscillations at frequencies at the edges of the frequency passband of the tube, as well as for providing a carefully shaped gain vs. frequency characteristic.

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 slowwave 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 in order to attenuate energy at the resonant frequency of the cavity. While this technique is able to attenuate energy at those frequencies where the tube is most likely to oscillate without substantially affecting energy at frequencies throughout the remainder of the tube passband, a minimum reflection coefficient is not provided. A low reflection coefficient is highly desirable in preventing large fluctuations in gain as a function of frequency at the low frequency end of the tube passband.

Accordingly, it is an object of the present invention to provide a traveling-wave tube in which any tendency for the tube to oscillate in the vicinity of the edges of the tube frequency passband is substantially eliminated, and at the same time, in which a minimum reflection coefficient is provided to minimize small signal gain variations at the low end of the frequency passband of the tube.

It is a further object of the present invention to provide a coupled cavity traveling-wave tube having a readily controllable and carefully shaped gain vs. frequency characteristic.

It is a still further object of the present invention to provide means for both suppressing oscillations and shaping the gain vs. frequency characteristic of a high power traveling-wave tube of the coupled cavity type, and which means is simpler in design and requires fewer parts than schemes heretofore employed.

In accordance with the foregoing objects, the traveling-wave tube of the present invention includes means for providing a stream of electrons along a predetermied path and a slow-wave structure having a plurality of intercoupled interaction cavities disposed sequentially along and about the electron stream path for propagating electromagnetic wave energy in such manner that it interacts with the stream of electrons. An attenuating transmission line including an elongated lossy ceramic element is disposed proximate to and externally of the slow-wave structure cavities, with the longitudinal axis of the lossy element being parallel to the electron stream path. The lossy transmission line may take the form of either a cylindrical rod of a mixture of ceramic and lossy materials, or a tubular rod of a lossy ceramic mixture disposed coaxially about an electrically conductive rod. Coupling irises in the side walls of at least certain ones of the slow-wave structure interaction cavities provide electromagnetic coupling between the slow-wave structure and the lossy transmission line.

Additional objects, advantages and characteristic features of the present invention will become readily apparent from the following detailed description of a pre-

ferred embodiment of the invention when taken 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 section view taken along line 4—4 of FIG. 2; and

FIG. 5 is a series of graphs illustrating the percent signal transmission as a function of frequency for the traveling-wave tube of FIGS. 1–4, both with and without the attenuator rods of the present invention, as well as illustrating the loss vs. frequency characteristics of the attenuator rods.

Referring now to the drawings, and more particularly to 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 end 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 project 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 Nov. 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 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 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 beam 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 non-magnetic 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 Nov. 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 maximum degree even though the electrons are decelerated toward the collector end of the tube.

As has been mentioned above, in prior art traveling-wave tubes of the type described there may be a tendency

for the tube to oscillate at frequencies near the edges of the slow-wave circuit passband and for the gain to fluctuate excessively at the low frequency end of the passband. The present invention eliminates this tendency by coupling in parallel with the slow-wave circuit at least one lossy transmission line especially designed to introduce relatively wide-band loss, and thereby shape the gain vs. frequency characteristic of the traveling-wave tube.

In one arrangement according to the present invention, best illustrated in FIGS. 2 and 4, a pair of such lossy transmission lines are utilized. The first transmission line comprises a solid cylindrical lossy ceramic rod **50** disposed on one side of the slow-wave circuit with its longitudinal axis parallel to the electron beam path. The second transmission line comprises a coaxial arrangement **51** including a tubular lossy ceramic rod **52** coaxially disposed about an electrically conductive rod **54** on the opposite side of the slow-wave structure from the rod **50**, with the common axis of the rods **52** and **54** disposed parallel to the electron beam axis. It is pointed out that it is not necessary to employ the particular arrangement shown, but rather either a single solid line such as **50**, a single coaxial line such as **51**, a pair of solid lines, or a pair of coaxial lines may alternatively be used.

In order to accommodate the solid rod **50**, cylindrical holes **56** are provided in the projecting ear portions **44** of certain successive ones of the slow-wave circuit spacer elements **42**, and which holes are axially aligned with cylindrical holes **58** of the same diameter in the pole pieces **34** lying between these spacer elements to provide a rod-receiving passageway. Similarly, the tubular rod **52** is disposed in the rod-receiving passageway defined by aligned cylindrical holes **60** and **62** in the projecting ear portions **43** of these spacer elements and in the intermediate pole pieces **34**, respectively.

The cylindrical rod **50** is of a diameter *d* which may be from essentially 0.293 inch to essentially 0.360 inch, for example. The tubular rod **52** has an outer diameter *d*, which may be of the aforementioned values, and an inner diameter *c* which may vary from essentially 0.150 inch to essentially 0.220 inch, for example. The solid rod **50** is coupled to the slow-wave circuit interaction cavities **46** by means of coupling passageways, or irises, **63** of width *i* between the rod-receiving holes **56** and the central apertures **45** of the respective spacer elements **42**. Similarly, coupling irises **64** of width *i* between the rod-receiving holes **60** and the central apertures **45** of the respective spacers **42** function to couple the coaxial line **51** to the slow-wave circuit interaction cavities. The width *i* of the irises **63** and **64** may be of a value essentially between 0.100 and 0.250 inch, for example. A material which may be used for the rods **50** and **52** is a mixture of forsterite and silicon carbide, with the percentage of silicon carbide varying from essentially 5% to essentially 60% for the solid rod **50** and from essentially 20% to essentially 60% for the tubular rod **52**. Other materials which could be used are silicon carbide and alumina, silicon carbide and talc, or other ceramic and lossy material combinations.

It should be apparent that the exact values of the dimensions *d*, *c*, and *i* and the relative amounts of ceramic and lossy materials to be used will depend upon the frequencies at which loss is to be introduced and the particular shape desired for the transmission vs. frequency characteristic of the slow-wave structure, taking into account the dielectric constant ϵ of the lossy ceramic mixture. In general, the greater the percentage of silicon carbide and the greater the diameter *d*, the greater the amount of loss that will be introduced. Increasing the inner diameter *c* of the tubular rod will generally decrease the loss, while increasing the iris width *i* will tend to increase the loss on account of increased coupling to the lossy transmission line, although care should be taken that the iris reflection coefficient is not increased excessively. Preferably, the solid transmission line **50** is designed to introduce loss around the high frequency end of the slow-wave circuit frequency passband, and the coaxial transmission line **51** provides the desired loss in the low frequency region, although with proper design either type of line can provide loss at either end of the slow-wave circuit passband.

An example of a particular oscillation suppression and gain shaping arrangement which has been constructed in accordance with the present invention will now be given. In this arrangement, which takes the particular configuration illustrated in FIGS. 2 and 4, the attenuator rods **50** and **52** both extend longitudinally along the slow-wave structure throughout eighteen of the interaction cavities **46**. For the nine cavities nearest the input (electron gun) end of the structure, the diameter *d* for both the rods **50** and **52** was 0.293 inch, with an inner diameter *c* for the tubular rod **52** of 0.160 inch; the widths *i* for the irises **63** and **64** were 0.250 and 0.205 inch, respectively; the solid rod **50** and the tubular rod **52** contained, respectively, 5% and 60% silicon carbide with the remainder forsterite. For the nine cavities nearest the output (collector) end of the structure, the widths *i* for the respective irises **63** and **64** were 0.205 and 0.235 inch; the percentage of silicon carbide in the hollow rod **52** was reduced to 20%, with the percentage of silicon carbide in the solid rod **50** and the dimensions *d* and *c* remaining the same as those given above with respect to the section nearer the input end of the tube.

The results afforded by the present invention toward eliminating oscillations and providing a carefully shaped gain vs. frequency characteristic with vastly reduced gain fluctuations may be better appreciated by making reference to FIG. 5. In this figure the curve **70** illustrates the percent transmission as a function of frequency for the traveling-wave tube shown in FIGS. 1–4 but without the inclusion of the lossy transmission lines **50** and **51**. From this curve it may be noticed that extreme fluctuations in percent transmission occur essentially between 7.3 and 7.7 gc. at the low end of the frequency passband and essentially between 10.7 and 11.1 gc. at the high end of the passband.

The transmission vs. frequency characteristics for the traveling-wave tube of FIGS. 1–4 including lossy transmission lines **50** and **51** of the particular compositions and dimensions set forth in the foregoing example is depicted by the curve **72** of FIG. 5, with the attenuation in db afforded by this arrangement being shown in the curve **74**. Starting at the lower end of the frequency passband note that as the frequency is increased, the transmission undergoes a smooth gradual increase from zero up to a maximum value at around 10.0 gc., and then smoothly decreases much more rapidly back to zero at the upper end of the passband. Although some loss is introduced throughout the entire passband (and the maximum transmission is only 85% of its value absent the lossy transmission lines), the vast fluctuations in signal transmission near both the high and low extremeties of the slow-wave circuit passband have been completely eliminated, thereby materially reducing the tendency toward oscillations in these frequency regions. In addition, the attenuator arrangement of the present invention provides a minimum reflection coefficient at the low end of the frequency passband, affording a reduction in small signal gain variations.

It is pointed out that while the curve **72** of FIG. 5 shows the general nature of the transmission vs. frequency properties of a traveling-wave tube slow-wave structure according to the present invention, variations in the shape of this transmission curve may be afforded by altering the configuration (i.e., whether solid or tubular rods) of the lossy transmission lines, as well as by changing the composition and dimensions of the rods **50** and **52** and the width of the irises **63** and **64** in the manner pointed out above. Since the gain of a traveling-wave tube is a function of its signal transmission and loss properties, a readily

controllable and carefully shaped gain vs. frequency characteristic is thus afforded.

Although the present invention has been shown and described with respect to specific embodiments, nevertheless various changes and modifications obvious to one 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 cavities disposed sequentially along and about said predetermined path for propagating electromagnetic wave energy in such manner that it interacts with said stream of electrons, an elongated lossy ceramic element disposed proximate to and externally of said slow-wave structure means with the longitudinal axis of said element parallel to said predetermined path, and said lossy ceramic element being electromagnetically coupled to a plurality of said interaction cavities.

2. A traveling-wave tube according to claim 1 wherein said lossy ceramic element comprises a mixture of silicon carbide and a material selected from the group consisting of forsterite, alumina, and talc, with the percentage of silicon carbide varying from essentially 5% to essentially 60%.

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 interaction cavities disposed sequentially along and about said predetermined path for propagating electromagnetic wave energy in such manner that it interacts with said stream of electrons, a cylindrical rod of a mixture of ceramic and lossy materials disposed proximate to and externally of said slow-wave structure means with the longitudinal axis of said rod parallel to said predetermined path, and said slow-wave structure means further defining a plurality of irises coupling selected ones of said interaction cavities to said cylindrical rod.

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 cavities disposed sequentially along and about said predetermined path for propagating electromagnetic wave energy in such manner that it interacts with said stream of electrons, a tubular rod of a mixture of ceramic and lossy materials disposed proximate to and externally of said slow-wave structure means with the longitudinal axis of said rod parallel to said predetermined path, an electrically conductive rod coaxially disposed within said tubular rod, and said slow-wave structure means further defining a plurality of irises coupling selected ones of said interaction cavities to said tubular rod.

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 cavities disposed sequentially along and about said predetermined path for propagating electromagnetic wave energy in such manner that it interacts with said stream of electrons, a cylindrical rod of a mixture of ceramic and lossy materials disposed proximate to and externally of said slow-wave structure means along one side thereof with the longitudinal axis of said cylindrical rod parallel to said predetermined path, a tubular rod of a mixture of ceramic and lossy materials disposed proximate to and externally of said slow-wave structure means along the opposite side thereof with the longitudinal axis of said tubular rod parallel to said predetermined path, an electrically conductive rod coaxially disposed within said tubular rod, and said slow-wave structure means further defining a plurality of irises coupling selected ones of said interaction cavities to said cylindrical rod and said tubular rod.

6. A slow-wave structure for promoting interaction between a stream of electrons projected along a predetermined path and an electromagnetic wave comprising: 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 cavities, said plates defining aligned apertures in their central regions to provide a passage for said electron stream and further defining coupling holes in regions readily outwardly of said central regions for interconnecting adjacent interaction cavities whereby a propagation path is provided for said 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 and plates defining aligned cylindrical apertures to provide a passageway parallel to said predetermined path, a cylindrical rod of a mixture of ceramic and lossy materials disposed within said passageway, and each of said certain ones of said spacer elements further defining a passageway between the interaction cavity and the rod-receiving aperture defined thereby.

7. A slow-wave structure for promoting interaction between a stream of electrons projected along a predetermined path and an electromagnetic wave comprising: 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 cavities, 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 cavities whereby a propagation path is provided for said 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 and plates defining aligned cylindrical apertures to provide a passageway parallel to said predetermined path, a tubular rod of a mixture of ceramic and lossy materials disposed within said passageway, an electrically conductive rod coaxially disposed within said tubular rod, and each of said certain ones of said spacer elements further defining a passageway between the interaction cavity and the rod-receiving aperture defined thereby.

8. A slow-wave structure for promoting interaction between a stream of electrons projected along a predetermined path and an electromagnetic wave comprising: 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 cavities, 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 cavities whereby a propagation path is provided for said 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 and plates defining a first and a second series of aligned cylindrical apertures on opposite sides of said interaction cavities to provide a first passageway parallel to said predetermined path on one side of said interaction cavities and a second passageway parallel to said predetermined path on the opposite side of said interaction cavities, a cylindrical rod of a mixture of ceramic and lossy materials disposed within said first passageway, a tubular rod of a mixture of ceramic and lossy materials

disposed within said second passageway, an electrically conductive rod coaxially disposed within said tubular rod, and each of said certain ones of said spacer elements further defining first and second irises between the interaction cavity and the respective first and second rod-receiving apertures defined thereby.

9. An arrangement for focussing a stream of electrons along a predetermined path and for promoting interaction between said stream of electrons and an electromagnetic wave comprising: a plurality of axially alinged 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 cavities, 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 readily outwardly of said central regions for interconnecting adjacent cavities whereby a propagation path is provided for said 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, said ear portions and each pole piece disposed between said certain ones of said spacer elements defining aligned cylindrical apertures to proivde a passageway parallel to said predetermined path, a cylindrical rod of a mixture of ceramic and lossy materials disposed within said passageway, and each of said certain ones of said spacer elements further defining a passageway between the interaction cavity and rod-receiving aperture defined thereby.

10. An arrangement for focusing a stream of electrons along a predetermined path and for promoting interaction between said stream of electrons and an electromagnetic wave comprising: 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 cavities, 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 readily outwardly of said central regions for interconnecting adjacent cavities whereby a propagation path is provided for said 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, said ear portions and each pole piece disposed between said certain ones of said spacer elements defining aligned cylindrical apertures to provide a passageway parallel to said predetermined path, a tubular rod of a mixture of ceramic and lossy materials disposed within said passageway, an electrically conductive rod coaxially disposed within said tubular rod, and each of said certain ones of said spacer elements further defining a passageway between the interaction cavity and the rod-receiving aperture defined thereby.

11. An arrangement for focusing a stream of electrons along a predetermined path and for promoting interaction between said stream of electrons and an electromagnetic wave comprising: 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 cavities, 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 readily outwardly of said central regions for interconnecting adjacent cavities whereby a propagation path is provided for said 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 first and second ear portions extending outwardly from opposite sides of said spacer element, said first ear portions and each pole piece disposed between said certain ones of said spacer elements defining a first series of aligned cylindrical apertures to provide a first passageway parallel to said predetermined path on one side of said interaction cavities, said second ear portions and each pole piece disposed between said certain ones of said spacer elements defining a second series of aligned cylindrical apertures to provide a second passageway parallel to said predetermined path on the opposite side of said interaction cavities, a cylindrical rod of a mixture of ceramic and lossy materials disposed within said first passageway, a tubular rod of a mixture of ceramic and lossy materials disposed within said second passageway, an electrically conductive rod coaxially disposed within said tubular rod, and each of said certain ones of said spacer elements further defining first and second irises between the interaction cavity and the respective first and second rod-receiving apertures defined thereby.

No references cited.

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