Nov. 30, 1965 L. M. WINSLOW 3,221,278

MICROWAVE TUBE TRANSFORMER-WINDOW

Filed July 13, 1962 2 Sheets-Sheet 1

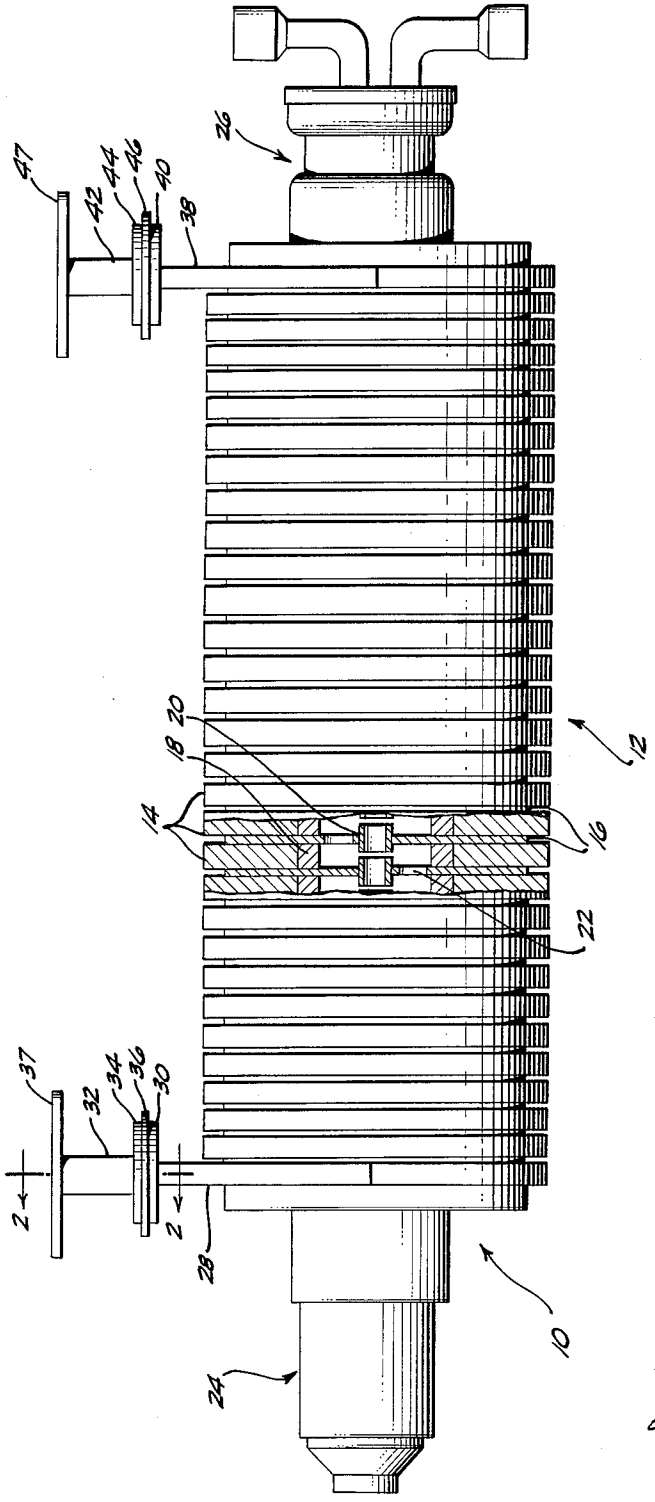



FIG. 1.

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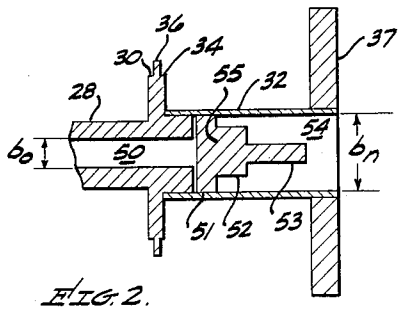



FIG. 2.

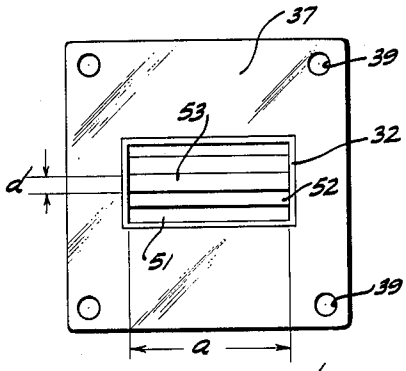



FIG. 3.

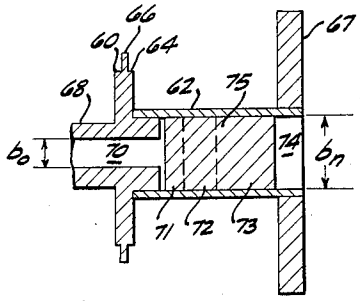



FIG. 4.

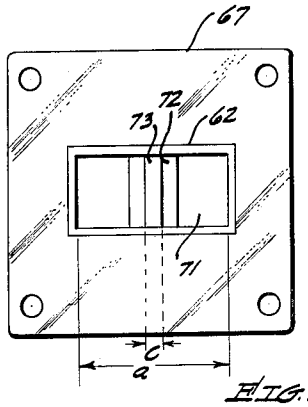



FIG. 5.

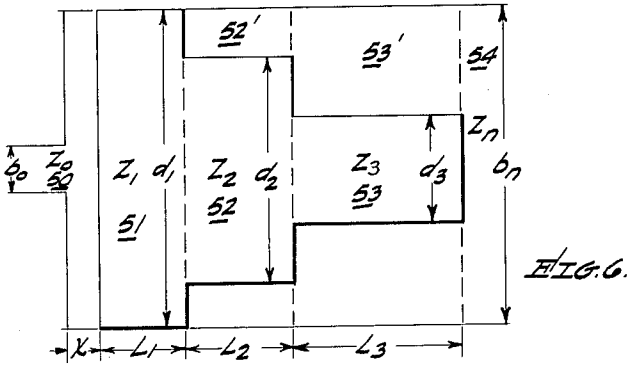



FIG. 6.

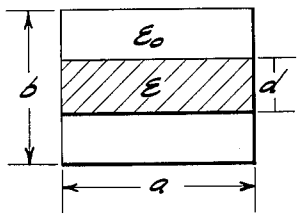



FIG. 7.

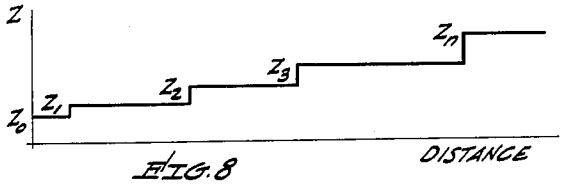



FIG. 8

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3,221,278

# MICROWAVE TUBE TRANSFORMER-WINDOW

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Filed July 13, 1962, Ser. No. 209,626
9 Claims. (Cl. 333—98)

This invention relates generally to microwave devices, and more particularly relates to a microwave tube component performing the dual function of a vacuum window and an impedance transformer.

In many microwave devices such as klystrons, magnetrons, traveling-wave tubes and the like, it is necessary to maintain the interior waveguiding portions of these devices at a reduced pressure, while allowing microwave energy to pass freely into and out of these portions. Thus, it has become the practice to insert wave-permeable gas-tight partitions, termed windows, into the input and output waveguides of the microwave device. In addition, since the characteristic impedance of the wave-propagating structure within the microwave device usually differs from that of the external waveguides feeding the device over the frequency range it is desired to transmit, it is necessary to provide an impedance transformer which matches the characteristic impedance of the internal and external waveguides. Conventionally, the desired impedance transformation is achieved by constructing the input and output waveguides of the microwave devices with transducer sections consisting of several portions of stepwise varying cross-section.

Separate vacuum window and impedance transformer arrangements of the prior art require a substantial amount of space, which becomes a particularly significant limitation in miniaturized tubes. Moreover, recent advances in the development of high power traveling-wave amplifiers having broadband operation has necessitated the extension of the bandwidth of the waveguide windows used in these tubes. Since the thickness of the window material normally limits the frequency range over which the window will be matched to the waveguide, it becomes desirable to develop new windows which do not possess such a frequency limitation.

Accordingly, it is an object of the present invention to provide a combined vacuum window and impedance transformer for the waveguiding circuitry feeding a microwave tube so as to considerably reduce the size and weight of the tube's input and output circuitry.

It is a further object of the present invention to provide a microwave tube vacuum window which is not only more compact, but which also has greater bandwidth and higher power handling capabilities than prior art windows.

It is a still further object of the present invention to provide a microwave tube waveguide impedance transformer which is more compact and shorter in length than prior art transformers.

It is still another object of the present invention to provide a compact, broadband, high power traveling-wave tube having a novel impedance-matching vacuum window arrangement at its input and output, and which arrangement possesses bandwidth and power handling capabilities at least as good as those of the remainder of the traveling-wave tube.

In accordance with the foregoing objects, a combined vacuum window and impedance transformer is provided for a microwave tube having an interior waveguiding portion of a given cross-section and a contiguous exterior waveguiding portion of a different cross-section. The window-transformer device includes an element of dielectric material disposed in the exterior waveguiding portion adjacent its end nearest the interior waveguiding portion. The dielectric element defines at least two portions of different cross-section, with one portion having a cross-section essentially equal to that of the exterior waveguiding portion and being sealed to the exterior waveguiding portion.



In one embodiment of the present invention step transitions in the cross-section of the dielectric element occur along the electric field direction, and in another embodiment step transitions occur along the magnetic field direction for electromagnetic waves traversing the window-transformer.

Other and further objects, advantages, and characteristic features of the present invention will become readily apparent from the following detailed description of preferred embodiments of the invention when taken in conjunction with the appended drawings in which:

FIG. 1 is an overall view, partly in longitudinal section, of a traveling-wave tube provided with the novel transformer-window arrangement in accordance with the present invention;

FIG. 2 is a sectional view of the window-containing portion of the input waveguide of the tube of FIG. 1 as taken along line 2—2 of FIG. 1;

FIG. 3 is an end view of the window-containing waveguide of FIG. 2;

FIG. 4 is a sectional view similar to FIG. 2 illustrating another embodiment of the present invention;

FIG. 5 is an end view of the window-containing waveguide of FIG. 4;

FIG. 6 is a side schematic diagram of the transformer-window arrangement of FIGS. 2–3 used in explaining the window design technique;

FIG. 7 is an end schematic diagram of a portion of the transformer-window of FIG. 6 also used in explaining the window design; and

FIG. 8 is a plot of impedance vs. waveguide distance for the transformer-window of FIG. 6.

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 annular permanent magnets **14**, ferromagnetic pole pieces **16**, and non-magnetic conductive spacer elements **18**. The magnets **14** and pole pieces **16** are alternately disposed along the length of the tube **10**, while each spacer element **18** is disposed radially within one of the magnets **14**. The pole pieces **16** extend radially inwardly of the magnets **14** and define drift tubes **20** in their central portions to provide a passage for an electron beam which flows longitudinally through the traveling-wave tube **10**. Each pole piece **18** further defines an off-center coupling hole **22**, with each coupling hole being staggered 180° with respect to the coupling holes on each side. Thus, the spacer elements **18** and interior portions of the pole pieces **16** constitute a coupled cavity slow-wave circuit for propagating an electromagnetic wave in a serpentine path about the axially traveling electron beam to facilitate interaction between the electrons of the beam and the traveling wave. The magnets **14** and pole pieces **16** constitute a periodic focusing device for focusing the electron beam traversing the length of the tube **10**. For further details as to the slow-wave structure and focusing arrangement **12**, reference may be made to Patent No. 2,985,792, entitled, "Periodically-Focused Traveling-Wave Tube," issued May 23, 1961, to D. J. Bates et al. and assigned to the assignee of the present invention.

An electron gun **24** 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

functions to project a stream of electrons along the axis of the tube **10** and may be of a conventional construction well known in the art. For details as to the construction of the gun **24**, reference is made to the aforesaid Patent No. 2,985,792 and the 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 **26** 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. 2,985,792 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.

Coupled to one end of the slow-wave structure **12** is a rectangular input waveguide **28** which extends externally of the arrangement **12** in a direction perpendicular to the longitudinal axis of the tube **10**, the outer end of the wave-guide **28** terminating in a circular coupling flange **30**. A rectangular waveguide **32** of larger outer cross-section than the waveguide **28** is connected to the waveguide **28**, and it is this waveguide **32** which houses the novel window-transformer arrangement of the present invention. The end of the waveguide **32** nearest the slow-wave structure **12** is provided with a circular coupling flange **34** which is secured to the coupling flange **30** of the waveguide **28** by a heliarc welding flange **36**. The end of the waveguide **32** more remote from the slow-wave structure **12** is provided with a rectangular coupling flange **37** for use in coupling to an external waveguide or other microwave transmission line (not shown). Holes **39** (see FIG. 3) may be provided in the corners of the coupling flange **37** to receive bolts or screws for attaching the flange **37** to the external waveguiding circuitry.

An output waveguiding arrangement, identical to the input waveguiding arrangement described in the foregoing paragraph, is provided at the other end of the slow-wave structure **12** and includes a rectangular output waveguide **38** coupled to the slow-wave structure **12** and provided with a circular coupling flange **40** at its end remote from the slow-wave structure. A rectangular waveguide **42** of larger outer cross-section than the waveguide **38** has a circular coupling flange **44** at one end which is secured to the coupling flange **40** by a heliarc welding flange **46**, and has a rectangular coupling flange **47** at its opposite end for coupling to external waveguiding circuitry. The input waveguides **32** and **28** serve to propagate microwave energy to be amplified from external waveguides to the input end of the slow-wave structure **12**, while the output waveguides **38** and **42** carry the amplified microwaves from the slow-wave structure to the desired external device.

As has been pointed out above, it is necessary to maintain the slow-wave structure **12** in an evacuated atmosphere, and hence a microwave-permeable window must be inserted in both the input and output waveguides. Moreover, since the characteristic impedance of the slow-wave structure is normally much lower than that of the external waveguiding circuitry, an impedance matching transformer must be inserted in both the input and output waveguides to provide a series of incremental impedance changes from the low slow-wave structure impedance to the high external waveguide impedance. The present invention provides a device, one embodiment of which is illustrated in FIGS. 2–3, which functions both as a vacuum window and as an impedance transformer. Although only the arrangement for the tube's input waveguiding circuitry is shown, it is to be understood that the output window-transformer is constructed in an identical manner.



As is shown in FIG. 2, the internal height of the waveguide **28** is of a value $b_o$, and this internal dimension extends lengthwise along the waveguide past the coupling flanges **30** and **34** and for a slight distance into the waveguide **32**. A step transition in waveguide height then occurs to a value of $b_n$, which height exists throughout most of the length of the waveguide **32**. The internal width of both of the waveguides **28** and **32** is the same and is of a value designated by the symbol $a$ (see FIG. 3). The dimension $a$ is the larger cross-sectional dimension of the waveguide and is associated with the magnetic field H of electromagnetic waves in the $TE_{10}$ mode propagating through the waveguide, while the dimension $b$ is the smaller cross-sectional dimension of the waveguide and is associated with the electric field E of the $TE_{10}$ electromagnetic waves. Thus, the waveguiding passage between the slow-wave structure **12** and the external waveguiding circuitry consists of a rectangular waveguide having a constant width $a$, and a first height $b_o$ in the portion **50** nearest the slow-wave structure and an increased height $b_n$ in the portion **54** more remote from the slow-wave structure.

An element, or slab, **55** of dielectric material is disposed in the larger height portion **54** of the waveguide **32**, with the end of the slab **55** nearest the slow-wave structure **12** being spaced from the smaller height waveguiding portion **50** by a slight distance $x$ (see FIG. 6). This spacing decreases the discontinuity susceptance caused by the height change between the waveguides **50** and **54**, and thereby provides improved bandwidth and reflection coefficient properties for the transformer. Examples of suitable dielectric materials which may be used for the slab **55** are alumina, forsterite, beryllium oxide, and steatite. The dielectric slab **55** possesses several portions, each having a different thickness in the $b$, or electric field, direction and each extending the entire width of the waveguide **54** in the $a$, or magnetic field, direction. Thus, in FIGS. 2 and 6 the dielectric slab **55** is illustrated as having three portions **51**, **52** and **53** of different respective thicknesses $d_1$, $d_2$ and $d_3$, and length $L_1$, $L_2$, and $L_3$, respectively; with the thickness of the portion **51** nearest the smaller waveguide **50** being substantially equal to the height $b_n$ of the larger waveguide **54**. It is to be understood that a three-portion dielectric slab is shown solely for illustrative purposes, and the principles of the present invention are equally applicable to an $n$-portion slab, where $n$ is any positive integer greater than one. Also, the respective portions of the slab **55** may be of different dielectric materials. The largest portion **51** of the slab **55** is sealed to the inner walls of the waveguide **54** by metallizing the edges of the slab **55** and brazing them to the waveguide. This enables the slab **55** to function as a vacuum window so that an evacuated atmosphere may be maintained within the microwave tube.

The impedance of a waveguide is a function of its dimensions and the dielectric constant of the material filling the waveguide. Since the dielectric constant of the respective portions of the waveguide **54** changes with the step transitions between the portions **51**, **52** and **53** of the dielectric slab **55**, due to different relative amounts of air and dielectric material filling these portions of the waveguide **54**, the characteristic impedance of waveguide **32** undergoes incremental, or stepwise, transitions between its value of $Z_o$ in portion **50** and $Z_n$ in the air-filled portion **54**, as will be explained in more detail below. Thus, the dielectric slab **55** in conjunction with the waveguides **50** and **54** functions as an impedance transformer which improves the impedance match between the waveguides **50** and **54**.

The embodiment of FIGS. 2 and 3 employs a stepped dielectric slab in which the step transitions occur along the smaller, or electric field, cross-sectional dimension of the waveguide. However, the step transitions may also occur along the larger, or magnetic field, cross-sectional dimension of the waveguide, and a transformer arrangement of the latter type is illustrated in FIGS. 4 and 5.

In the embodiment of FIGS. 4 and 5 a dielectric slab **75**, which may be of the same materials as those mentioned above for the dielectric slab **55** of FIG. 2, is disposed in larger height portion **74** of rectangular waveguide **62** between its outer coupling flange **67** and its inner coupling flange **64**. The flange **64** is secured to coupling flange **60** of inner rectangular waveguide **68** by a heliarc welding flange **66**. The dielectric slab **75** defines portions **71, 72** and **73** of different thickness in the *a*, or larger cross-sectional, dimension of the waveguide **74**, and extends for the entire waveguide height in the *b*, or smaller cross-sectional, waveguide dimension. The thickness of the respective slab portions in the *a*-dimension is denoted by the symbol *c* in FIG. 5. The end of slab portion **71** of greatest thickness is located a slight distance away from the end of the waveguide portion **70** of height $b_o$. The waveguide **70** is of width *a*, which is the same width as the waveguide **74**. The slab **75** is sealed to the walls of the waveguide **74** so as to provide a vacuum window. Moreover, since the characteristic impedance of the respective portions of the waveguide **74** containing the dielectric slab portions **71, 72** and **73** undergoes stepwise increases in much the same manner as in the embodiment of FIGS. 2 and 3, an impedance transformer is provided with stepwise increasing impedance values between the characteristic impedance $Z_o$ of the waveguide **70** and the characteristic impedance $Z_n$ of the waveguide **74**. However, the arrangement of FIGS. 4 and 5 possesses an advantage over that of FIGS. 2 and 3 in that it is capable of handling higher peak power.

The technique for designing the transformer-window of the present invention will now be described in detail for the window of FIGS. 2–3. The impedance of a rectangular waveguide can be written as

$$Z=A\frac{bE_b}{aH_a} \tag{1}$$

where $E_b$ is the electric field in the *b*-direction, $H_a$ is the magnetic field in the *a*-direction, *b* is the waveguide height, *a* is the waveguide width, and A is a proportionality constant. The ratio of electric to magnetic field determines the guide wavelength $\lambda_g$, and thus the impedance can be written as

$$Z=B\frac{b}{a}\lambda_g \tag{2}$$

where B is another proportionality constant.

Inspection of Equation 2 reveals that for an air-filled waveguide the impedance is determined solely by the waveguide dimensions. Thus, when it is desired to impedance match a pair of air-filled waveguides with different dimensions, the ratio of their characteristic impedances $Z_n$ and $Z_o$ is given by

$$\frac{Z_n}{Z_o}=\frac{a_o b_n}{a_n b_o} \tag{3}$$

where, with reference to FIG. 6, $Z_o$ represents the characteristic impedance of waveguide **50** having height $b_o$ and width $a_o$, and $Z_n$ represents the characteristic impedance of the air-filled portion of waveguide **54** having height $b_n$ and width $a_n$. Although Equation 3 is applicable to the general case where both waveguide cross-sectional dimensions are varied between sections, in the transformer of FIGS. 2–3 only the waveguide height *b* is varied between waveguide sections, and thus, for the example shown in FIG. 6, $a_o=a_n=a$.

For convenience in transformer design a quantity known as the impedance transformation ratio R is employed and is defined as the ratio of the characteristic impedances of the two waveguides it is desired to impedance match. Thus

$$R\equiv\frac{Z_n}{Z_o}=\left(\frac{Z_1}{Z_o}\right)\left(\frac{Z_n}{Z_1}\right) \tag{4}$$

In the transformer of the present invention, the overall impedance transformation is obtained by not only varying the height between the waveguides **50** and **54**, but also by inserting a dielectric slab of stepwise varying thickness into the larger waveguide **54**. This provides a stepwise varying effective dielectric constant for the respective regions **51, 52', 53'** and **54** of the larger waveguide **54** because the relative amounts of air and dielectric material are different in each region, thereby changing the guide wavelength $\lambda_g$. From Equation 2 it will be apparent that the characteristic waveguide impedance Z increases as the guide wavelength $\lambda_g$ increases, and since the guide wavelength increases as the dielectric constant of the waveguide material decreases, by progressively decreasing the effective dielectric constant of the material filling the waveguide, a progressive impedance increase can be obtained. Since the dielectric slab **55** is constructed in a number of stepped portions of decreasing thickness with increasing distance from the waveguide **50**, the amount of air relative to the amount of dielectric material is increased with distance into the waveguide **54**, and thus a step increase in impedance is obtained at the edge of each of the regions **51, 52', 53'** and **54**. This stepwise impedance variation is illustrated in FIG. 8.

In the actual design procedure the characteristic impedance $Z_n$ and the cross-sectional dimensions of the waveguide **54** are known, and the characteristic impedance $Z_1$ of the portion **51** of the dielectric slab **55** which extends completely across the waveguide **54** is determined by the relation

$$\frac{Z_1}{Z_n}=\frac{a_n b_1\sqrt{1-\left(\frac{\lambda_o}{2a}\right)^2}}{a_1 b_n\sqrt{\epsilon 1-\left(\frac{\lambda_o}{2a}\right)^2}} \tag{5}$$

where $\lambda_o$ is the guide wavelength of the air-filled portion of the waveguide **54** and $\epsilon_1$ is the relative dielectric constant of the material comprising the dielectric slab **55**. The thickness $d_1$ of dielectric slab portion **51** is made approximately equal to the height $b_1=b_n$ of the waveguide **54**.

Once $Z_1$ has been computed, the impedance transformation ration R may be determined from Equation 4, preferably by extrapolating between tabulated values of $Z_1$ and R (normalized with respect to $Z_o$) found in an article by Leo Young entitled, "Tables for Cascaded Homogeneous Quarter Wave Transformers," in the I.R.E. Transactions on Microwave Theory and Techniques, vol. MTT-7, pages 233–237, January 1959, and pages 243–244, March 1960.

The characteristic impedances $Z_2$ and $Z_3$ of the respective portions **52** and **53** of the dielectric slab **55** may then be determined from the following equations found in Young's aforecited article:

$$Z_2=\sqrt{R} \tag{6}$$

$$Z_3=\frac{R}{Z_1} \tag{7}$$

The length $L_1$ of the portion **51** of the dielectric slab **55** having the characteristic impedance $Z_1$ is determined by making this length one quarter wavelength for waves it is desired to propagate through the waveguide. Thus

$$L_1=\frac{\lambda_{g_1}}{4} \tag{8}$$

where $\lambda_{g_1}$ is the guide wavelength of the dielectric-filled portion **51** of the waveguide **54**.

The general equation for determining the guide wavelength $\lambda_g$ of a dielectric-containing waveguide section is

$$\lambda_g=\lambda_o\left[\epsilon e-\left(\frac{\lambda_o}{2a}\right)^2\right]^{-1/2} \tag{9}$$

where $\epsilon_e$ is the effective relative dielectric constant of the

waveguide section in question. The effective relative dielectric constant $\epsilon_e$ is determined by

$$\epsilon_e=\frac{\epsilon_o}{1-\frac{d}{b}\left(1-\frac{\epsilon_o}{\epsilon}\right)} \quad (10)$$

where $\epsilon$ is the relative dielectric constant of a dielectric slab of thickness $d$ and width $a$ centrally located in a waveguide of width $a$ and height $b$, as illustrated in FIG. 7, and $\epsilon_o$ is the relative dielectric constant of the free space. Letting $\epsilon_o$ equal unity, and solving Equation 10 for the slab thickness $d$ gives

$$d=b\left[\frac{\epsilon_e-1}{\epsilon_e}\right]\left[\frac{\epsilon}{\epsilon-1}\right] \quad (11)$$

The effective relative dielectric constant $\epsilon_e$ may be determined by making use of Equation 2 to determine the ratio of characteristic impedances of a pair of waveguides Z and Z' of respective guide wavelengths $\lambda_g$ and $\lambda_g'$ and dimensions $a$ and $b$, and $a'$ and $b'$, respectively, to give

$$\frac{Z'}{Z}=\frac{ab'\lambda_g'}{a'b\lambda_g} \quad (12)$$

Substituting Equation 9 into Equation 12 yields

$$\frac{Z'}{Z}=\frac{ab'\sqrt{\epsilon-\left(\frac{\lambda_o}{2a}\right)^2}}{a'b\sqrt{\epsilon'-\left(\frac{\lambda_o}{2a}\right)^2}} \quad (13)$$

Letting $\epsilon'=\epsilon_e$, and solving for $\epsilon_e$ gives

$$\epsilon_e=\left[\frac{Zb'a}{Z'ba'}\right]^2\left[\epsilon-\left(\frac{\lambda_o}{2a}\right)^2\right]+\left(\frac{\lambda_o}{2a}\right)^2 \quad (14)$$

Thus, in determining the dimensions for intermediate section **52** of the dielectric slab **55**, the characteristic impedance $Z_2$ of section **52** is first determined according to Equation 6. The effective dielectric constant $\epsilon_e$ of the portion **52'** of the waveguide **54** is then determined according to Equation 14 with Z equal to $Z_2$ and Z' equal to $Z_n$. The computed value of $\epsilon_{e_2}$ is then used to determine the thickness $d_2$ of portion **52** of slab **55** by means of Equation 11. The length $L_2$ of portion **52** is determined by

$$L_2=\frac{\lambda_{g_2}}{4}=L_1\left(\frac{Z_2}{Z_1}\right) \quad (15)$$

The procedure of the foregoing paragraph is repeated to determine the thickness $d_3$ and length $L_3$ of portion **53** of the slab **55**, and if transformer slabs having more than three sections are desired, the procedure is repeated as many times as necessary to determine the dimensions of all the transformer sections. The distance $x$ is determined experimentally to minimize reflections over the desired bandwidth.

The window-transformer illustrated in FIGS. 4 and 5, in which the thickness variations of the dielectric slab occur along the magnetic field, or larger, waveguide dimension may be designed by a similar procedure. Impedance relations which may be used in this design are found in a paper by P. H. Vartamian et al. entitled, "Propagation in Dielectric Slab Loaded Rectangular Waveguide," in the I.R.E. Transactions on Microwave Theory and Techniques, vol. MTT–6, pages 215–222, April 1958.

Using the design techniques described above, window-transformers have been constructed having the dimensions set forth in Table I below. In both the exemplary designs given the dielectric material used was forsterite, which has a relative dielectric constant $\epsilon$ of 6 and provides an impedance transformation ratio R of 3.5. It is to be understood that the values given are solely for illustrative purposes and are in no way intended as limitations on the scope of the present invention.



TABLE I

| | Window-Transformer of FIGS. 2-3 | Window-Transformer of FIGS. 4-5 |
|---|---|---|
| $a$ | .900″ | .900″ |
| $b_o$ | .114″ | .114″ |
| $b_n$ | .400″ | .400″ |
| $d_1$ | .395″ | ($c_1$) .895″ |
| $d_2$ | .289″ | ($c_2$) .109″ |
| $d_3$ | .085″ | ($c_3$) .027″ |
| $L_1$ | .124″ | .124″ |
| $L_2$ | .205″ | .201″ |
| $L_3$ | .346″ | .326″ |
| $x$ | .025″ | .025″ |

It is to be pointed out that the window-transformer arrangements of the present invention are not limited to employment in a traveling-wave tube, or even in any microwave tube, but rather the principles of the present invention may find application in any waveguide arrangement in which it is desired to impedance match a pair of waveguides of different characteristic impedances and wherein it is desired to maintain a pressure differential between the two waveguides. Regardless of its particular manner of employment, the present invention provides a vacuum window and impedance transformer which is more compact and which has greater bandwidth and high power handling capabilities than prior art devices of its kind. Moreover, a higher dielectric constant material may be used in the device of the present invention than in the prior art.

Although the present invention has been shown and described with reference to specific embodiments, numerous modifications or alterations which are obvious to one skilled in the art to which the invention pertains may be made therein without departing from the spirit and scope of the invention as set forth in the appended claims.

What is claimed is:

**1.** In a microwave tube having an interior waveguiding portion of a first cross-section and a contiguous exterior waveguiding portion of a second cross-section larger than said first cross-section; means for improving the impedance match between said interior and exterior waveguiding portions and for allowing a pressure differential to exist between said interior and exterior waveguiding portions while permitting the passage of microwave energy therebetween, said means including: an element of dielectric material disposed solely in said exterior waveguiding portion adjacent its end nearest said interior waveguiding portion, said element having at least two portions of different cross-section, the cross-section of one portion of said element being essentially equal to that of said exterior waveguiding portion, and said one portion of said element being sealed to said exterior waveguiding portion.

**2.** In a microwave tube having an interior waveguiding portion of a first cross-section and adapted to operate at a predetermined pressure, and a contiguous exterior waveguiding portion of a second cross-section larger than said first cross-section and adapted to operate at a pressure different from said predetermined pressure; a microwave-permeable window disposed in said exterior waveguiding portion adjacent its end nearest said interior waveguiding portion; said window comprising: an element of dielectric material having at least two portions of different cross-section, the cross-section of one portion of said element being essentially equal to that of said exterior waveguiding portion, said one portion of said element being disposed nearest said interior waveguiding portion and being sealed to said exterior waveguiding portion, and the end of said element nearest said interior waveguiding portion being spaced from said interior waveguiding portion by a preselected distance.

**3.** In a microwave tube having an interior waveguiding portion of a first characteristic impedance and adapted to operate at a predetermined pressure, and a contiguous ex-

terior waveguiding portion of a second characteristic impedance greater than said first characteristic impedance and adapted to operate at a pressure different from said predetermined pressure; a microwave-permeable window disposed solely in said exterior waveguiding portion adjacent its end nearest said interior waveguiding portion, said window comprising: an element of dielectric material, said dielectric element defining a plurality of portions of stepwise decreasing cross-section as a function of distance from said interior waveguiding portion to provide in said exterior waveguiding portion a plurality of regions of stepwise increasing characteristic impedance intermediate in value between said first characteristic impedance and said second characteristic impedance as a function of distance from said interior wave-guiding portion, the portion of said element nearest said interior waveguiding portion having a cross-section essentially equal to that of said exterior waveguiding portion, and said nearest portion of said element being sealed to said exterior waveguiding portion.

4. In a microwave tube having an interior rectangular waveguiding portion and a contiguous exterior rectangular waveguiding portion, with the larger cross-sectional dimension of said interior and exterior waveguiding portions being equal and the smaller cross-sectional dimension of said interior waveguiding portion being smaller than that of said exterior waveguiding portion; means for improving the impedance match between said interior and exterior waveguiding portions and for allowing a pressure differential to exist between said interior and exterior waveguiding portions while permitting the passage of microwave energy therebetween, said means including: an element of dielectric material disposed solely in said exterior waveguiding portion adjacent its end nearest said interior waveguiding portion, said element extending completely across said exterior waveguiding portion along said larger cross-sectional dimension throughout the length of said element, said element defining at least two portions of different extent along said smaller cross-section dimension of said exterior waveguiding portion, the extent of the portion of said element nearest said interior waveguiding portion being substantially equal to said smaller cross-sectional dimension of said exterior waveguiding portion, and said nearest portion of said element being sealed to said exterior waveguiding portion.

5. In a microwave tube having an interior rectangular waveguiding portion and a contiguous exterior rectangular waveguiding portion, with the larger cross-sectional dimension of said interior and exterior waveguiding portions being equal and the smaller cross-sectional dimension of said interior waveguiding portion being smaller than that of said exterior waveguiding portion; means for improving the impedance match between said interior and exterior waveguiding portions and for allowing a presure differential to exist between said interior and exterior waveguiding portions while permitting the passage of microwave energy therebetween, said means including: an element of dielectric material disposed solely in said exterior waveguiding portion adjacent its end nearest said interior waveguiding portion, said element extending completely across said exterior waveguiding portion along said smaller cross-sectional dimension throughout the length of said element, said element defining at least two portions of different extent along said larger cross-sectional dimension, the extent of the portion of said element nearest said interior waveguiding portion being substantially equal to said larger cross-sectional dimension of said exterior waveguiding portion, and said nearest portion of said element being sealed to said exterior waveguiding portion.

6. In a microwave tube having an interior waveguiding portion of a first cross-section and maintained at a predetermined pressure less than atmospheric pressure, and a contiguous exterior waveguiding portion of a second cross-section larger than said first cross-section and maintained at a pressure greater than that of said interior waveguiding portion; a microwave-permeable window disposed solely in said exterior waveguiding portion adjacent its end nearest said interior waveguiding portion, said window comprising: an element of dielectric material having at least two portions of different cross-section, the cross-section of one portion of said element being essentially equal to that of said exterior waveguiding portion, said one portion of said element being disposed nearest said interior waveguiding portion and being sealed to said exterior waveguiding portion.

7. In a microwave tube having a gas-containing interior waveguiding portion of a first cross-section and a contiguous gas-containing exterior waveguiding portion of a second cross-section lagrer than said first cross-section; means for improving the impedance match between said interior and said exterior waveguiding portions and for allowing a pressure differential to exist between said interior and exterior waveguiding portions while permitting the passage of microwave energy therebetween, said means including: an element of dielectric material disposed solely in said exterior waveguiding portion adjacent its end nearest said interior waveguiding portion, said element having at least two portions of different cross-section, the cross-section of one portion of said element being essentially equal to that of said exterior waveguiding portion, and said one portion of said element being sealed to said exterior waveguiding portion.

8. In a microwave tube having an interior rectangular waveguiding portion for propagating electromagnetic waves in the $TE_{10}$ mode and maintained at a pressure less than atmospheric pressure, and a contiguous exterior rectangular waveguiding portion for propagating electromagnetic waves in the $TE_{10}$ mode and maintained at a pressure greater than that of said interior waveguiding portion, with the dimensions of said interior and exterior waveguiding portions associated with the magnetic field of said electromagnetic waves being equal and the dimension of said exterior waveguiding portion associated with the electric field of said electromagnetic waves being greater than the dimension of said interior waveguiding portion associated with said electric field; a microwave-permeable window disposed solely in said exterior waveguiding portion adjacent its end nearest said interior waveguiding portion, said window comprising: an element of dielectric material disposed in said exterior waveguiding porton with its end nearest said interior waveguiding portion located a preselected distance from the end of said interior waveguiding portion, said dielectric element defining at least two portions of equal extent in the magnetic field direction and of respectively decreasing extent in the electric field direction as a function of distance from said end of said interior waveguiding portion, the extent of said dielectric element in said magnetic field direction being substantially equal to that of said exterior waveguiding portion, the extent of the portion of said element nearest said interior waveguiding portion in said electric field direction being substantially equal to the extent of said exterior waveguiding portion in said electric field direction, the extent of each portion of said dielectric element along the length of said exterior waveguiding portion being equal to one-quarter wavelength for preselected electromagnetic waves in the respective portions of said dielectric element, and said portion of said dielectric element nearest said interior waveguiding portion being sealed to said exterior waveguiding portion.

9. In a microwave tube having an interior rectangular waveguiding portion for propagating electromagnetic waves in the $TE_{10}$ mode and maintained at a pressure less than atmospheric pressure, and a contiguous exterior rectangular waveguiding portion for propagating electromagnetic waves in the $TE_{10}$ mode and maintained at a pressure greater than that of said interior waveguiding

portion, with the dimensions of said interior and exterior waveguiding portions associated with the magnetic field of said electromagnetic waves being equal and the dimension of said exterior waveguiding portion associated with the electric field of said electromagnetic waves being greater than the dimension of said interior waveguiding portion associated with said electric field; a microwave-permeable window disposed solely in said exterior waveguiding portion adjacent its end nearest said interior waveguiding portion, said window comprising: an element of dielectric material disposed in said exterior waveguiding portion with its end nearest said interior waveguiding portion located a preselected distance from the end of said interior waveguiding portion, said dielectric element defining at least two portions of equal extent in the electric field direction and of respectively decreasing extent in the magnetic field direction as a function of distance from said end of said interior waveguiding portion, the extent of said dielectric element in said electric field direction being substantially equal to that of said exterior waveguiding portion, the extent of the portion of said element nearest said interior waveguiding portion



in said magnetic field direction being substantially equal to the extent of said exterior waveguiding portion in said magnetic field direction, the extent of each portion of said dielectric element along the length of said exterior waveguiding portion being equal to one-quarter wavelength for preselected electromagnetic waves in the respective portions of said dielectric element, and said portion of said dielectric element nearest said interior waveguiding portion being sealed to said exterior waveguiding portion.

**References Cited by the Examiner**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 2,534,289 | 12/1950 | Mieher | 333—34 X |
| 2,807,784 | 9/1957 | Lerbs | 315—39 X |
| 2,886,742 | 5/1959 | Hull | 315—39 |
| 2,932,767 | 4/1960 | Van De Goor et al. | 315—39 |
| 2,956,200 | 10/1960 | Bates | 315—3.5 |
| 3,019,399 | 1/1962 | Lanciani et al. | 333—35 X |


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