Nov. 23, 1965 F. A. ZAWADA ETAL 3,219,882
SLOW WAVE PROPAGATING STRUCTURE FOR WIDE FREQUENCY
BAND ELECTRON DISCHARGE DEVICES
Filed March 29, 1961 2 Sheets-Sheet 1

FIG. 1A

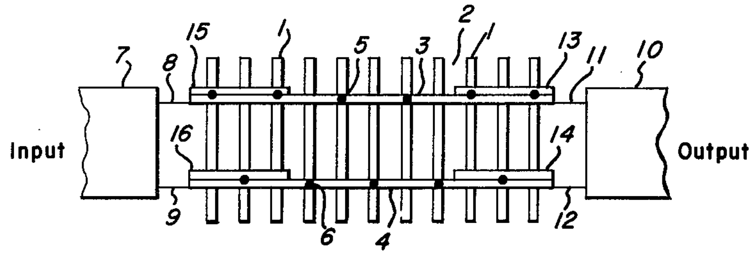

FIG. 1B

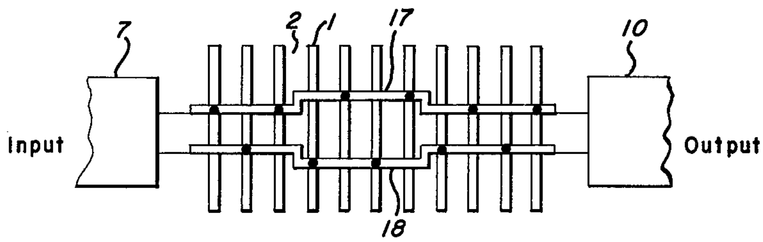

FIG. 1C

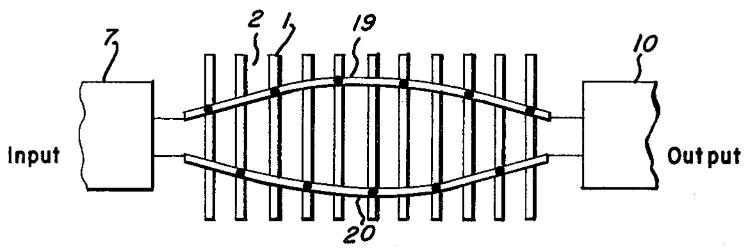

FIG. 2

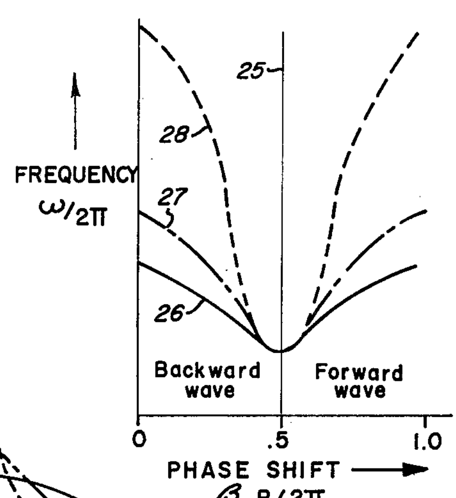

FIG. 3

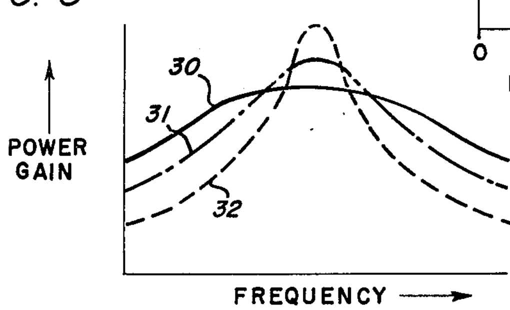

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FIG. 4

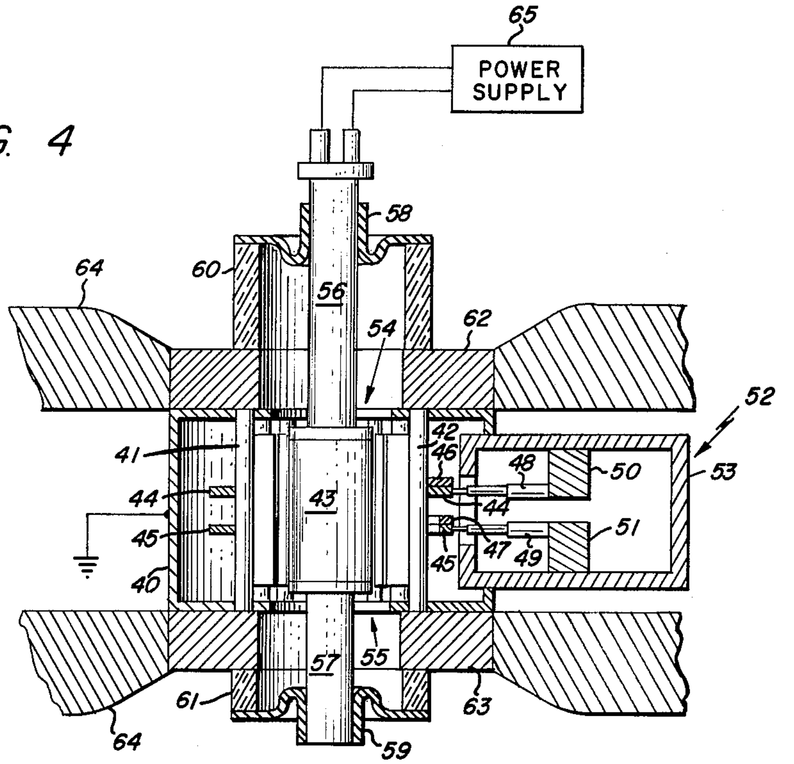
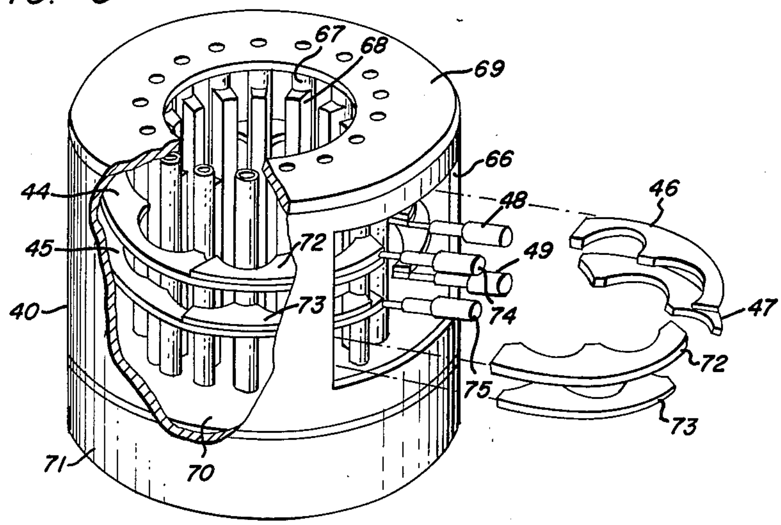


FIG. 5



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SLOW WAVE PROPAGATING STRUCTURE FOR WIDE FREQUENCY BAND ELECTRON DISCHARGE DEVICES

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This invention relates to wave propagating structures and more particularly to means of construction of a structure matched at both ends over a wide frequency band to transmission lines and suitable for use in an amplitron.

Various forms of slow wave propagating structures are employed in beam tubes for conducting radio frequency waves in energy exchanging relationship with a beam of electrons. In some of these devices the phase velocity of the wave moves in the same direction as the electron beam, and in others it moves in an opposite direction. In either case, there is interaction between the wave and the beam and energy flow from one to the other. In some applications it is desired to couple an input transmission line to one end of the slow wave structure and an output transmission line to the other end and to introduce radio frequency (RF) waves at the input which appear amplified at the output. In such applications it is generally desired to match the slow wave structure to at least one of the transmission lines to insure that waves are not reflected from the line back into the structure. Heretofore, the match between the slow wave structure and the transmission line has been achieved by, for example, employing transformer sections coupled between the end of the structure and the transmission line. These transformer sections invariably narrow the operating bandwidth and introduce losses which reduce the power gain. It is one object of the present invention to provide a slow wave propagating structure with means forming a part of the structure for providing a match with a transmission line while at the same time preserving bandwidth and power gain.

The wave propagating structure employed in stabilitron type beam tubes generally includes a plurality of conductive vanes disposed to form cavities between the vanes with conductive straps connecting alternate vanes to establish the π mode or the fundamental frequency of the cavities. In one type of stabilitron, sometimes called the amplitron, two such straps are employed, each attached to alternate groups of vanes, and input and output transmission lines are coupled to opposite ends of the straps. The cavities are arranged in a circle, and so the straps are generally circular in shape, and a cathode is disposed concentrically within the circle forming a circular interaction space between the cathode and the cavities. Electrons emitted from the cathode are compelled by crossed electric and magnetic fields to move through this interaction space exchanging energy with the waves propagating in the cavities. The general motion of these electrons may be in the same direction as the phase velocity of the waves, or it may be in an opposite direction. In either case, it is desired that the slow wave structure formed by the vanes and the straps be impedance matched at each end to input and output transmission lines so that waves will not be reflected back through the slow wave structure from the input or output. Accordingly, it is another object of the present invention to provide a slow wave structure for use in an amplitron in which active portions of the slow wave structure are constructed to have propagation characteristics necessary to match the impedance of input and output transmission lines which are coupled to the ends of the structure.

In accordance with a feature of the present invention,

a strapped vane type slow wave structure is provided in which the wave phase shift between cavities toward the ends of the structure is greater than wave phase shift between cavities along the middle of the structure.

In some embodiments of the present invention the capacitance between the ends of the straps which are coupled to the transmission lines is increased. Thus, at a given frequency, the propagation constant and wave phase shift per cavity are greater at the ends of the slow wave structure than at the middle of the structure. The present invention discloses a number of arrangements of straps and vanes whereby such a slow wave structure is formed.

Other features and objects of the invention will be more apparent in the following specific description taken in conjunction with the drawings in which:

FIGS. 1*a*, 1*b*, and 1*c* illustrate strapped vane type slow wave propagating structures in which wave phase shift between cavities toward the ends of the structure is substantially greater than phase shift between cavities along the middle of the structure;

FIGS. 2 and 3 show curves indicating the general performance of such an amplitron;

FIG. 4 illustrates a sectional view of an amplitron including a slow wave structure such as illustrated symbolically in FIG. 1*a;* and

FIG. 5 illustrates a cutaway view of the slow wave structure of the amplitron shown in FIG. 4.

Turning first to FIG. 1*a* there is shown a symbolic representation of a slow wave propagating structure such as might be employed in an amplitron including a plurality of conductive vanes **1** disposed substantially parallel to each other defining cavities such as **2** between adjacent vanes. Conductive straps **3** and **4** connect alternate groups of vanes together. The structure is shown for purposes of illustration as substantially rectilinear; however, as employed in an amplitron, it is preferred that the vanes **1** be arranged in a circle and that straps **3** and **4** be circular. Conductive strap **3** is connected to alternate vanes where indicated by junctions such as **5** and, similarly, conductive strap number **4** is connected to the other set of alternate vanes by junctions such as **6.**

An input transmission line **7** is connected to one end of straps **3** and **4** by transformer sections **8** and **9**, respectively, and an output transmission line **10** is connected to the other end of straps **3** and **4** by transformer sections **11** and **12**, respectively. In operation an RF wave is introduced via the input transmission line to one end of the structure and propagates from cavity to cavity through the structure interacting with electrons which flow longitudinally to the structure and exchanging energy with said electrons. As a result, the amplitude of the waves from cavity to cavity increases toward the output transmission line.

In accordance with a principal feature of the present invention, the ends of the slow wave structure are matched to the transformer sections **8** and **9** and **11** and **12** by increasing the capacitance between the straps at their ends. In fact, the capacitance along a substantial portion of the ends of the straps is increased so that the phase shift of the RF wave from cavity to cavity along the end portions is greater than along the middle of the straps. One method of accomplishing this, as shown in FIG. 1*a*, is to add conductive bulk to the ends of the straps by, for example, fixing additional plates of conductive material at the strap ends. Accordingly, the embodiment illustrated in FIG. 1*a* includes conductive plates **13** and **14** fixed as shown at one end of straps **3** and **4** and similar conductive plates **15** and **16** fixed to the other end of straps **3** and **4**, respectively. As a result, the phase shift of an RF wave from cavity to cavity at the ends of the slow wave structure will, by virtue of the increased capacitance across the straps, be greater than the phase shift between cavities along the middle of the structure, and this phase shift will vary with frequency.

The effect of the additional members **13** to **16** connected to the ends of straps **3** and **4** is to provide transformer sections at each end of the slow wave structure which are built into an active portion of the structure and alter the phase shift from cavity to cavity along the ends of the structure where beam and wave interaction occur and where there is a continuous transfer of energy between the electron beam and the RF wave. In other words, the portion of the slow wave structure where the transformer is located does not interrupt the energy transfer from the beam electrons to the RF wave, but merely introduces additional phase shift to the wave. This additional phase shift varies with frequency and is such that the structure is matched over a substantial frequency band to the transmission lines coupled at each end. The sections **8** to **12** between the ends of each strap and the input and output transmission lines are preferably transformer sections adding transformer action as necessary to complete the matching of the structure to the transmission lines.

FIGS. 1*b* and 1*c* illustrate other embodiments of the invention each including a plurality of conductive vanes **1** defining cavities **2** between the straps which connect alternate groups of vanes together. In FIG. 1*b* the straps **17** and **18** are spaced closer together toward the ends of the structure than toward the middle of the structure, and so the phase shift of the RF wave propagating in the structure is greater from cavity to cavity toward the end than the middle. As a result, the structure is impedance matched to the input and output transmission lines **7** and **10** which are connected to opposite ends of the straps as already described with reference to FIG. 1*a*. The increased capacitance between the straps toward the ends is obtained in FIG. 1*b* by merely shaping the straps **17** and **18** so that substantial sections toward the ends of the straps will be closer together, the spacing between the straps being uniform at the center of the structure and also uniform at the ends of the structure. In some applications it may be preferable to make the spacing between the straps at the input different from the spacing between the straps at the output. In either event, a transformer action occurs abruptly where the straps are bent and might introduce undesirable reflections or damp certain frequencies. Such reflections and damping could be avoided by employing the structure shown in FIG. 1*c*.

As shown in FIG. 1*c*, the vanes are connected by straps **19** and **20** which are shaped or disposed to converge from the center of the structure toward the input and toward the output transmission lines. As a result, the capacitance between the straps at the ends of the structure is greater than the capacitance between the straps at the middle, and there is a progressive increase in phase shift from cavity to cavity as one proceeds from the middle of the structure toward one or the other of the ends and vice versa.

In FIGS. 2 and 3 there are shown generalized performance curves to illustrate some of the advantages which can be gained by employing structures such as illustrated in FIGS. 1*a*, 1*b* and 1*c*. FIG. 2 illustrates the bandwidth characteristics of the strapped vane structure (π mode occurs at minimum frequency) and is a plot of frequency versus phase shift from cavity to cavity, sometimes called the ω,β plot. This plot illustrates the effective operating bandwidth of a wave propagating structure from a total phase shift between cavities of zero radians to one radian. The curves shown are plots of frequency versus the reactive component of the propagation constant, β, times the pitch, p, of the propagating structure. Since the units of propagation constant are usually radians per centimeter and the units of pitch are centimeters per cavity, the curves shown in FIG. 2 are plots of frequency versus cycles of phase shift per cavity.

These curves are shown to illustrate the effect of increasing phase shift per cavity at the ends of the slow wave structure.

It is established that forward wave interaction in which the phase velocity of the wave moves in the same direction as electrons will occur when the slope of the ω,β curve is positive and that backward wave interaction will occur when the slope is negative. Accordingly, the plot in FIG. 2 is divided by line **25** into two sections, one including curves of positive slope representing forward wave interaction and the other including curves of negative slope representing backward wave interaction. The solid line curve **26** illustrates the phase shift per cavity that might be expected when the capacitance between the two straps is relatively small, while curves **27** and **28** illustrate phase shift per cavity when the capacitance between straps is increasingly greater. In the present invention it is desired to increase bandwidth by increasing capacitance between straps and, thus, increasing β. Therefore, the sections of the curves which have negative slope are of primary concern. It will be noted that the backward wave portion of curve **28** covers a considerably wider frequency band than curves **26** and **27** from zero to one half cycle phase shift, and this results directly from increased capacitance between straps.

Curves in FIG. 3 represent the gain that might be obtained in an amplitron employing slow wave structures such as set forth in this invention versus frequency. The three curves **30**, **31** and **32** correspond to the curves **26**, **27** and **28**, respectively, in FIG. 2. These curves illustrate that the widest gain bandwidth is obtained when the capacitance between straps is lowest, whereas the narrowest gain bandwidth is obtained when capacitance between straps is greatest. The present invention recognizes that a wide band match to transmission lines can be achieved by increasing the phase shift per cavity to obtain a ω,β characteristic such as represented by curve **28** in FIG. 2. At the same time the invention also recognizes that this will result in a more narrow gain bandwidth such as represented by curve **32** in FIG. 3. In order to compromise and provide a structure having a reasonably wide band match as well as a wide gain bandwidth, the present invention comtemplates a structure in which the phase shift cavity is greater along the ends of the structure than along the middle. Accordingly, curve **26** and curve **30** indicate performance along the middle portion of the structure, while curves **28** and **32** represent performance along the end portions which couple to the transmission lines.

Turning next to FIG. 4 there is shown a sectional view of an amplitron incorporating features of the present invention. The structure illustrated in FIG. 4 is generally a figure of revolution except for the waveguide transmission line, straps, vanes and the magnet. As shown in FIG. 4, envelope **40** encloses a slow wave propagating structure which includes a plurality of vanes such as vanes **41** and **42** disposed about cathode **43**. One group of alternate vanes are connected together by strap **44**, and another group of alternate vanes are connected together by strap **45**. The orientation of the vanes is illustrated more clearly in FIG. 5 showing the envelope partially cut away to reveal vanes and straps. Conductive plates **46** and **47** are shown in FIGS. 4 and 5 attached to one end of straps **44** and **45**, respectively, thereby increasing the capacitance between the straps at that end. Transformer sections **48** and **49** connect the same end of the strap to opposing ridges **50** and **51** of input waveguide **52**. The output waveguide is preferably similar and might be an extension of the input waveguide separated from the input waveguide by a shorting member between the walls **53**. The wall **53** of waveguide **52** is vacuum sealed to envelope **40** and openings **54** and **55** in envelope **40** permit the insertion of cathode **43**.

Cathode **43** may be constructed as any of numerous magnetron type cathodes and may be equipped with mounting members such as **56** and **57** which are rigidly attached to the body of the magnetron, or the cathode may be supported only from one such member and cantilevered into the space enclosed by the envelope and the vanes. As shown in FIG. 4 the cathode support members **56** and **57** are each attached to similar sealing members **58** and **59** which are in turn attached and sealed to ceramic cylinders **60** and **61**, respectively. The ceramic cylinders **60** and **61** are fixed and sealed at one end to pole pieces **62** and **63**, respectively, and serve to insulate all parts of the cathode from the pole pieces, while at the same time providing rigid support for the cathode. Each of these pole pieces are preferably ring shaped permitting clearance at their centers for the cathode support members **56** and **57**. A magnet **64** in intimate contact with pole pieces **62** and **63** provides a magnetic field which is substantially parallel to the axis of the device through the interaction space between the vanes **41** and the cathode **43**. In operation it is preferred to ground the envelope **40** and to apply a negative D.C. voltage to the cathode from a power supply **65**, thus providing an electric field between the vanes **41** and the cathode **43** which is substantially transverse to the magnetic field.

Additional details of the slow wave structure including the vanes, straps, plates and connecting sections, mentioned above, are illustrated in FIG. 5. For purposes of illustration the envelope **40** is shown partly cut away in FIG. 5 permitting a view of the vane straps and the conductive plates attached to the ends of the straps. The opening **66** in the envelope accommodates two waveguide sections such as **52**, one transmitting input and the other transmitting output. Each of the vanes might, for example, be constructed of a hollow tube such as **67** with a conductive flange **68** extending the length of the tube, the tube being mounted to upper and lower walls **69** and **70** of the envelope **40**. The vanes are preferably arranged parallel to the axis of the tube in a circle which is concentric with the axis. In some applications, it may be preferred to cool the vanes, in which case the hollow tubes preferably extend through the walls **69** and **70** so that manifolds such as manifold **71** can be mounted to the walls **69** and **70** for carrying a coolant which is circulated through the tubes.

The straps **44** and **45** are attached directly to different groups of alternate vanes by connection to the tube which forms each vane. This can be accomplished in numerous ways. For example, the straps might be scallop shaped along one edge, each scallop spanning two cavities. Accordingly, the scalloped edges of straps **44** and **45** might be staggered with respect to each other as shown in FIG. 5 so that strap **44** connects to one group of alternate vanes and strap **45** connects to another group of alternate vanes. At one end of straps **44** and **45** there are attached conductive plates **46** and **47** which are shaped identical to the straps along the strap portions to which they are attached. Similarly, conductive plates **72** and **73** are attached to the other ends of straps **44** and **45** forming impedance matching sections at the output end of the device. Transformer sections **48** and **49** and **74** and **75** connect the input and output ends of the straps to the ridges of input and output waveguide transmission lines, respectively. These sections are preferably wide band and designed to perform as transformer sections perfecting the impedance match between the slow wave structure and the transmission lines.

While there are described herein numerous embodiments of the present invention disclosing various methods for increasing the bandwidth over which a slow wave propagating structure is matched to input and output transmission lines, while at the same time maintaining gain bandwidth, it should be understood that these are made only by way of example and do not limit the spirit and scope of the invention. For example, other structures attached or coupled to the vanes could be employed to alter the impedance toward the ends of the structure so as to match the transmission lines coupled to the structure, while at the same time maintaining over-all gain bandwidth of the structure. Accordingly, the spirit and scope of the invention is set forth in the accompanying claims.

What is claimed is:

1. A slow wave propagating structure comprising a plurality of conductive members spaced apart along a path to form a plurality of wave sustaining spaces along said path and at least two substantially transverse elongated conductors alternately interconnecting different groups of said members at an intermediate point along the lateral sides thereof, said elongated conductors being spaced closer toward at least one end of said structure than at the middle thereof.

2. In an amplitron having a plurality of conductive members defining a plurality of radio frequency wave sustaining cavities disposed about a cathode and potential sources coupled to said members and said cathode, means connecting input and output radio frequency wave energy transmission lines to said amplitron comprising a plurality of elongated conductors each connected to different groups of said members, the spacing between said elongated conductors varying toward said input and output transmission lines so that the impedance to said radio frequency waves in adjacent cavities varies toward said transmission lines.

3. In an amplitron having a plurality of conductive members defining a plurality of radio frequency wave sustaining cavities disposed about a cathode and potential sources coupled to said members and said cathode, means connecting input and output radio frequency wave energy transmission lines to said amplitron comprising a plurality of elongated conductors each connected to different groups of said members, the spacing between said elongated conductors diminishing toward said input and output transmission lines so that the impedance to said radio frequency waves in adjacent cavities increases toward said transmission lines.

4. An electron discharge device comprising a wave conducting structure, a cathode for producing electrons, said wave conducting structure and said cathode providing an interaction space therebetween, and means producing substantially constant fields for compelling said electrons to move through said interaction space exchanging energy with the fields of waves conducted by said structure, said structure including a plurality of conductive members spaced apart along a path to form a plurality of wave sustaining spaces along said path and at least two substantially transverse elongated conductors alternately interconnecting different groups of said members at an intermediate point along the lateral sides thereof, the capacitance between said elongated conductors being greater toward at least one end of said structure than at the middle thereof.

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