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L. U. KIBLER  
CAPACITIVELY LOADED WAVEGUIDE  
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3,050,702

FIG. 1

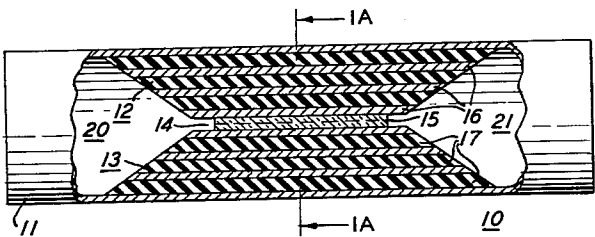


FIG. 1A

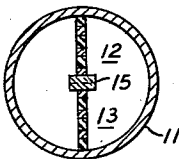


FIG. 3

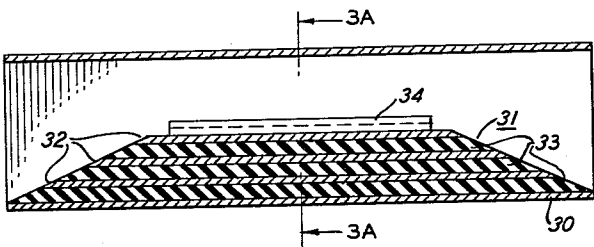


FIG. 3A

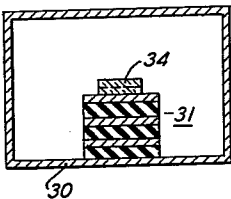


FIG. 4

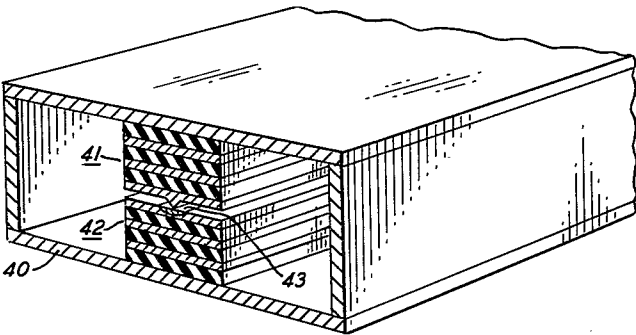


FIG. 2

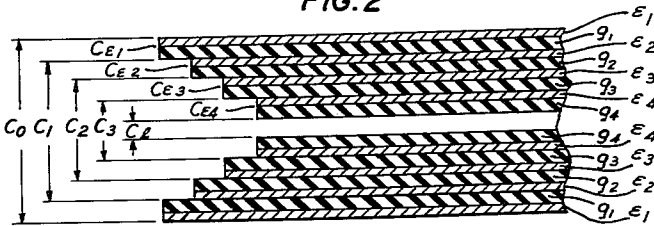
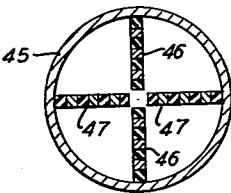


FIG. 5



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1

3,050,702

## CAPACITIVELY LOADED WAVEGUIDE

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9 Claims. (Cl. 333-98)

This invention relates to wave propagation structures and, more particularly, to those of the ridge or finline types.

As is well known in the art, a single ridge in a rectangular guide or two coplanar fins in a circular guide, for example, act as uniform, distributed capacitive loading within the guide. Such loading reduces the characteristic impedance and lowers both the phase velocity and cutoff frequency of the dominant mode of the guide. An increase in bandwidth is further augmented by the fact that when a ridged rectangular guide, for example, is properly dimensioned, not only is the cutoff frequency of the dominant  $TE_{10}$  mode lowered, but the cutoff frequencies of the  $TE_{20}$  and  $TE_{30}$  modes are increased in frequency. The presence of coplanar fins in a circular guide, hereinafter referred to as a finline guide, effects a similar increase in bandwidth over its unloaded counterpart. Such fins also make it possible to couple energy selectively from one or more modes in a multimode cylindrical guide and to propagate this energy to a region outside the original guide.

As a consequence of the wider usable bandwidth of ridge or finline guides, they advantageously can be operated at frequencies further from cutoff, where the characteristic impedance varies more slowly with frequency.

Moreover, the presence of the ridge or fins tends to maintain a fixed plane of polarization and thereby minimizes interference with many of the higher order modes which might otherwise exist.

As a result of the many aforementioned virtues of these capacitively loaded guides, it is not surprising that they have come to play an important role in the microwave art, primarily in applications as broadband, selective polarization couplers, transducer sections and even as slow wave interaction circuits when appropriate periodic discontinuities such as slots are formed therein.

One disadvantage of ridge or finline guides is the increase in attenuation that results from capacitive loading. Specifically, attenuation has been found to increase in direct relation to an increase in bandwidth as a result of increased power losses in the boundary walls caused primarily by the presence of the loading structure. Such losses, in many microwave applications heretofore, have not proven serious enough to offset the many advantages of these guides.

Recently, however, there has arisen a need for a suitable low loss, wide band waveguide either incorporating or permitting the inclusion of suitable support structure for mounting an active element of the distributed negative-resistance or reactance type. Such active elements, for example may take the form of an elongated p-n junction diode or a ferrite element in strip form utilizing various types of resonance phenomena to effect amplification of a traveling wave. It is generally desired in such forms of solid state, traveling wave devices that the active element be supported within a wave propagating structure exhibiting four basic operating characteristics. Two of these characteristics are inherently present in ridge or finline guides as described above, namely, the characteristics of a wide bandwidth free of spurious or higher order modes and a low impedance region to match the relatively low characteristic impedance of most active elements of the distributed reactance type. Advantageously, the re-

2

gion immediately adjacent the inner surface of a ridge or fin is of very low characteristic impedance and also is a region of concentrated electric field which is generally desired. The other two characteristics sought in such waveguides are extremely low attenuation and relatively simple impedance matching sections necessitating only a short longitudinal length of guide.

Unfortunately, for the reasons previously mentioned, conventional ridge or finline guides utilizing solid, conductive ridges or fins would introduce a degree of attenuation, over that realized with a hollow guide of the same dimensions, that would normally impair efficient amplification in traveling wave devices of the aforementioned types. The seriousness of any appreciable degree of attenuation in such devices resides in the fact that they invariably exhibit very low gain per unit length and low power output.

In regard to impedance matching, gradual tapering of either a ridge or fin will result in a desired impedance transformation; however, such tapering has heretofore required a relatively long and very gradual section of taper in order to minimize wave reflections and the excitation of spurious modes. Inasmuch as the aforementioned types of active elements are of very low characteristic impedance and the waveguide structure associated therewith is generally of relatively high impedance, it would be highly desirable if the impedance transformation could be effected over a longitudinal length of guide much shorter than was possible heretofore to insure a compact traveling wave tube package.

Accordingly, it is a general object of this invention to improve the wave propagating characteristics of waveguide structures.

It is a more specific object of this invention to achieve wide band, low loss characteristics in waveguides of the type particularly adapted to support active elements in devices of the solid state, traveling wave type.

It is a further object of this invention to increase the bandwidth, lower both the phase velocity and characteristic impedance of a guide and provide a mount therein for supporting active elements of the distributed reactance type without appreciably increasing the unloaded attenuation constant of the guide.

It is an additional object of this invention to achieve a desired impedance match between a capacitively loaded waveguide exhibiting a region of low characteristics impedance and a relatively high impedance waveguide connected thereto over a short, abruptly tapered longitudinal length of guide.

In accordance with one aspect of my invention in one illustrative embodiment thereof, the capacitive loading structure within a propagating guide takes the form of a pair of coplanar fins in a circular guide, each fin comprising a plurality of longitudinally extending conductive and dielectric layers interleaved in a direction transverse to the axis of the guide and having a width considerably less than that of the guide. The number, dimensions and disposition of the respective layers relative to each other and to the orientation of the electric field are such as to achieve a distribution of current and field within the conductive layers of the loading structure that is not found possible with a solid conductive loading member. As a consequence of the improved distribution of current, the otherwise experienced attenuation in capacitively loaded guides is substantially reduced.

In accordance with another aspect of this invention, a desired impedance transformation is effected over abruptly tapered end sections of the finline by progressively altering the dielectric constant of successive dielectric layers of the fins in a predetermined decreasing manner in the direction toward the axis of the finline. It

is thus seen that two coplanar fins as embodied herein are ideally adapted to support a low impedance active element or elements of the solid state type. The finline arrangement is also extended to two pairs of coplanar fins disposed at right angles to each other in another illustrative embodiment.

In accordance with other illustrative embodiments of the invention, the capacitive loading structure comprises either a single ridge or two coplanar ridges in a rectangular guide.

These and other objects and features, the nature of the present invention and its various advantages, will appear more fully upon consideration of the specific illustrative embodiments shown in the accompanying drawing and as analyzed in detail in the following explanation of the drawing.

In the drawing:

FIG. 1 is a side view, mainly in section, of a finline guide embodying the principles of this invention;

FIG. 1A is a cross-sectional view of the finline guide of FIG. 1 taken along the line 1A—1A;

FIG. 2 is an enlarged and simplified view in section of a tapered impedance matching section of a guide utilizing coplanar loading members;

FIG. 3 is a sectional view of a ridge guide in accordance with the principles of this invention;

FIG. 3A is a cross-sectional view of the ridge guide of FIG. 3 taken along the line 3A—3A;

FIG. 4 is an isometric view in section, illustrating an alternative waveguide structure embodying principles of this invention adapted for use in traveling wave devices of the solid state type; and

FIG. 5 is a cross-sectional view of a finline guide with two pairs of coplanar fins in accordance with the principles of this invention.

Referring now more particularly to FIG. 1, there is depicted, mainly in section, a finline waveguide 10 comprising a conductive, hollow, circular waveguide 11 with two diametrically disposed coplanar fins 12 and 13 extending radially inwardly toward the axis of the guide but separated from each other by a narrow gap 14. An active element 15 of the solid state type, which may comprise an elongated p-n junction diode or a ferrite element in strip form, for example, is shown mounted within the intermediate, longitudinal region of gap 14.

As this invention is primarily concerned with waveguide structures affording advantageous means for mounting such active elements rather than with a complete, operable device a detailed analysis of the amplification processes involved with the various possible types of active elements that may be utilized will not be undertaken herein. It is believed sufficient to state that it is well known that the negative resistance characteristics of a tunnel diode or the variable reactance effects induced in ferrites or a p-n junction as a result of various types of resonance phenomena may effect amplification of a traveling wave.

The only characteristics of these active elements which are of particular concern in this invention are that they generally exhibit very low gain per unit length and have a very low characteristic impedance.

The normally experienced degradation in output power attributed to waveguide losses resulting from loading and/or active element support structure positioned in prior waveguides is substantially minimized in accordance with the principles of this invention.

More specifically, in accordance with a feature of this invention, the coplanar fins 12 and 13 which are utilized to support the active element 15 in the guide 10 of FIG. 1, are each formed of a plurality of longitudinally extending conductive layers 16 and dielectric layers 17 interleaved in the direction transverse to the axis of the guide. As previously mentioned, while solid conductive fins increase the bandwidth and lower both the phase velocity and characteristic impedance of a circular guide,

their presence disadvantageously gives rise to an appreciable increase in attenuation as a result of increased power losses in the boundary walls of the guide.

In accordance with the present invention, however, the laminated coplanar fins when properly dimensioned, achieve a distribution of current and field within the conductive layers 16 which has not been found possible heretofore with conventional coplanar fins. The principles governing this type of improved current distribution were first applied to coaxial and rectangular forms of transmission lines as disclosed in A. M. Clogston Patent 2,769,148, issued October 30, 1956. The coaxial form of such a laminated line has become known as the "Clogston cable." As described in detail in that patent, an important factor in such laminated structures is the skin depth parameter  $\delta$ , more specifically referred to as "one skin thickness" or "one skin depth." This parameter measures the distance in which the penetration of current or field into a slab or layer of metal many times  $\delta$  in thickness will decrease by one neper; i.e., the distance where the magnitude of current or field will become equal to

$$\frac{1}{e} = 0.3679 \dots$$

times the magnitude thereof at the surface of the slab.

The metal layers are made as thin as possible compared with the skin depth  $\delta$ , where  $\delta$  is given by the expression

$$\delta = \sqrt{\frac{1}{\pi f \mu \sigma}}$$

where  $\delta$  is expressed in meters,  $f$  is the frequency in cycles per second,  $\mu$  is the permeability of the metal in henries per meter, and  $\sigma$  is the conductivity of the metal in mhos per meter.

One skin depth  $\delta$ , is many times, for example, 10, 100 or even 1,000 times larger than the thickness of each metal or insulating laminae. It has been found that when the composite transmission line or guide has such a laminated structure, it will propagate a wave at a certain critical velocity which is determined by the geometry of the structure and this wave will penetrate further into the composite line and, under proper conditions, will have lower attenuation than the transmission mode of a conventional transmission line of the same size. The critical velocity mentioned above is determined by the thickness of the metal and insulating laminae, the dielectric constant of the insulating laminae and the permeabilities of the conducting and insulating laminae. It is further shown in the aforementioned Clogston application that the critical velocity is achieved by equating the product of the average dielectric constant of the laminated stack and the average permeability thereof to the product of the dielectric constant and permeability of the remaining portion of the line through which the wave propagates. When these products are equal, the velocity of propagation of the waves is substantially uniform throughout the cross-sectional area of the line. For a more detailed analysis of the properties and construction of such laminated structures, reference is made to the aforementioned Clogston patent.

It is thus seen that by utilizing laminated coplanar fins constructed in accordance with the principles disclosed in the aforementioned Clogston patent, an improved distribution of current in the conductive layers of the fins and, consequently, reduced losses in the finline guide 10 of FIG. 1 will be realized. These same principles apply also to the other laminated, capacitively loaded structures described in detail hereinafter. The single most important requirement in all of the laminated structures disclosed herein with respect to effecting low attenuation is that the thickness dimension of the conductive layers 16 and of at least some of the dielectric layers 17 be small compared to the appropriate skin depth  $\delta$  of the respective layers at the highest frequency of operation.

In accordance with another feature of this invention, a desired impedance transformation between the loaded waveguide and unloaded higher impedance waveguide sections connected thereto is effected over relatively short, abruptly tapered end sections of the fins 20 and 21. This is uniquely accomplished by progressively altering the dielectric constant of successive dielectric or insulating layers in a predetermined decreasing manner in the direction toward the axis of the finline guide. Without varying the dielectric constant of successive layers in accordance with the principles of this invention, the abruptly tapered matching sections would obviously give rise to deleterious wave reflections and would present discontinuities that most likely would excite undesired modes of propagation. The novel impedance matching sections embodied herein also advantageously permit a low impedance active element to be readily matched to the loaded guide itself as well as to input and output waveguide sections of higher characteristic impedance normally associated therewith. More compact traveling wave, solid state "packages" are therefore made possible as a result of the unique transducer sections constructed in accordance with the instant invention.

As pointed out above, the dielectric constant of the insulating layers is one factor which directly affects the critical velocity of the laminated structure and, consequently, affects the degree of attenuation within the guide. However, a gradual change in the dielectric constant of successive layers of insulating material in a prescribed manner as described hereinafter, will result in the average dielectric constant of the loaded section of guide remaining close to the value of the dielectric constant of the unloaded section of guide. The attenuation in the tapered section of the guide may depart slightly from the minimum value possible if the dielectric constant of a solid state element, for example, is included as a part of the total dielectric constant of the loaded guide which is matched to that of an unloaded guide section. In any case, the attenuation in the tapered sections would be minimal and clearly offset by the substantially reflectionless transitions effected with the tapered loading structure when constructed in accordance with the invention.

In order to understand why the abruptly tapered matching sections designed in accordance with the invention do not present troublesome wave reflections as well as other forms of discontinuities to the propagating wave, the following approximate analysis will be helpful. An exact mathematical analysis is not possible due to the complex nature of the fields involved.

If we consider utilizing a tapered loading member in a rectangular or circular guide to effect a low reflection transition between the loaded guide and an unloaded guide section, we need only to consider a plane wave propagating through the tapered and loaded guide sections. The E field of a rectangular guide is given by

$$E_0 \cos \frac{2\pi x}{a}$$

where  $x$  is a variable distance measured from the axis of the guide to either side wall thereof and  $a$  is one-half the guide width. For regions near the center of the guide the E field is approximately  $E_0$ . The H field is also approximately a constant. A similar situation exists for dominant modes in cylindrical guides. It can be shown that an approximate impedance match for plane waves between two characteristic impedances can be achieved by gradually changing the equivalent L and C of the line connecting the two impedances

$$\left( Z = \sqrt{\frac{L}{C}} \right)$$

Since the reflection coefficient at any point in the taper depends on the ratio of the impedance discontinuity (presented by the loading structure) to the characteristic impedance of the unloaded guide, it would be expected that

a "good" taper would be achieved by making the relative rate of change of L and C constant. The rate of change of impedance is then constant. An exponential taper or an approximation to the exponential will yield a constant rate of change of L and C.

If we define the capacitance at any point in the taper as

$$C = C_0 e^{kz}$$

where  $C_0$  is the unloaded guide capacitance,  $z$  is a measure of axial distance along the guide and  $k$  is an arbitrary relative rate of taper constant, then the derivative of the capacitance at any point in the taper may be defined as

$$dC = \Delta C = k C_0 e^{kz}$$

and

$$\frac{\Delta C}{C_0} = k$$

It can then be shown that for  $k\lambda \ll 4\pi = 12.4$  nepers, a low reflection taper will result. If  $k = 2$  nepers, (approximately  $2\pi/3$  nepers), the above approximation is within 2 percent of a perfect reflection free taper.

We can achieve this rate of taper by either making the taper physically long as priorly done or by making the taper short physically, but in a manner which results in the equivalent capacitance and inductance of the taper changing slowly. In accordance with the principles of the invention, a slow and substantially constant rate of change in L and C is effected by an appropriate change in the dielectric constant of successive layers of the dielectric material. In order to understand more fully how a change in dielectric constant can effect a desired impedance match or transition over a much shorter length of guide than was previously possible, a tapered section of guide as embodied herein will now be examined.

As previously pointed out, each of the fins in the guide 11 of FIG. 1 comprises a series of laminations of metal and dielectric material with the thickness of the metal layers or laminations preferably being made very thin with respect to the above-defined skin depth parameter  $\delta$ . For purposes of simplifying this analysis, however, we shall consider, as depicted in FIG. 2, that the laminated loading structure comprises only four layers of dielectric material identified as having four dielectric constants  $\epsilon_1$  through  $\epsilon_4$  and four conductive layers identified as having conductivities  $g_1$  through  $g_4$ . The conductivities of the metal layers would normally be equal, the different subscripts being used herein only for the purpose of identifying more clearly the tapered segments under consideration. The three tapered guide segments in this illustration are identified as having guide capacitances  $C_1$ ,  $C_2$  and  $C_3$  with the unloaded and loaded guide capacitances being designated as  $C_0$  and  $C_l$ , respectively. As such, we can then approximate each segment of the taper, i.e., each successive pair of layers or laminations, comprising one metal layer and one dielectric layer extending in a direction transverse to the axis of the guide, by a parallel plate capacitor designated  $C_{en}$ . Such a capacitor is in series with each of the other similarly defined parallel plate capacitances and with the guide capacitances designated  $C_n$ , established by the reduced guide width in the tapered region.

It is assumed in this analysis that the axial length of each of the defined segments is less than  $\lambda$ , which in practice would invariably be the case. It should further be noted that a stepped taper has been shown in FIG. 2 only for the purpose of approximating the actual capacitive variation in a smooth or exponential taper. It is therefore to be understood that in practice, a substantially smooth taper of the type depicted in FIG. 1 would normally be employed. With the pertinent guide capacitances thus defined, the first part of the approximate analysis will be concerned with the capacitive variation in a tapered section of guide as embodied herein.

I have found that a good reflectionless impedance match over an abruptly tapered fin section of the type embodied in FIGS. 1 and 2 requires that the rate of change of  $C$  be made as small as possible. Advantageously, in accordance with the principles of this invention, even if the change occurs over a short axial length such as of the order of one wavelength, the rate of change in  $C$  would generally be small as the total capacitance of the guide is determined by both the loaded guide capacitances established by the segments and the plurality of parallel plate capacitances in series therewith established by the laminations forming the fins or ridges.

Considering FIG. 2 more specifically,  $C_1 > C_0$ , as the guide height in the region of the fins in the segment defined by  $C_1$  obviously is smaller than the unloaded guide diameter. This is clearly seen from the fact that the capacity of a parallel plate guide (the fins approximating such a guide) is given by

$$C = \frac{\epsilon b}{a}$$

where  $\epsilon$  is the dielectric constant,  $a$  is the height and  $b$  is the width of the guide, hence  $C$  increases as  $a$  decreases. Accordingly, as seen from FIG. 2, the combination of  $C_1$  in series with  $2C_{e1}$  ( $C_{e1}$  for each fin) would result in a total series capacitance across the guide only slightly less than the unloaded guide capacitance  $C_0$ . If then, for example, the first tapered matching segment is made to have a short axial length such that  $C_1 = 1.5C_0$ , it follows that the two series capacitances  $C_{e1}$  in combination with the loaded guide capacitance  $C_1$  must be adjusted such that  $C_{e1} = 8C_1$ , whereby the total or net guide capacitance at the first segment of the taper depicted in FIG. 2 would be  $1.2C_0$ . For this segment

$$\frac{\Delta C}{C} k = .2$$

If we maintain this relative value of  $k$ , the guide capacitance will vary exponentially as required for a good reflectionless taper.

The second segment identified in FIG. 2 as having a guide capacitance of  $C_2$  may be considered in the same manner. Specifically, let  $C_2 = 1.5C_1$  and retain the requirement that the total net capacitance be equal to  $1.2C_1$ . There now are two laminations to consider: the lamination containing the material of dielectric constant  $\epsilon_1$  which has already been determined, and the material of dielectric constant  $\epsilon_2$  which may be of any chosen value. With the requirement that the net capacitance of the second segment equal  $1.2C_1$ , to maintain the required effective taper rate, the added laminations of the second segment must produce a total series capacitance

$$C_{e2} = 2.75C_1$$

for the two fins. The loaded capacitance  $C_2$  will then be  $C_2 = 1.2C_1$ . It is apparent that this method of determining the dielectric constant of each successive insulative layer can be used to determine various degrees of total impedance change in a given guide. This method can also be used to determine a desired impedance match for various types of material that may load the final gap, such as the material of an active element positioned in the gap.

Thus far it has been shown that the guide capacitance in the tapered region can be made to vary slowly compared to the physical taper rate. The inductance in the tapered region can also be shown to vary slowly. The inductance of a parallel plate guide is given by

$$L = \frac{\mu a}{b}$$

where  $\mu$  is the permeability,  $a$  is the height and  $b$  is the width of the guide; hence as " $a$ " decreases  $L$  decreases. The current in the main guide wall has a given density that depends on the skin depth  $\delta$ . In the loaded section

of guide this current must divide among the various conductive layers of the laminations. Since these laminations are much less than  $\delta$  in thickness, the current density in each layer is much greater than that of the unloaded guide. The inductance of such a conductive layer is proportional to a geometrical factor and the relative distribution of current density. Since the current density is large, the inductance of each segment is larger than the inductance of the un laminated section. Thus, as the inductance of the gap defined by two coplanar fins, for example, decreases, the net inductance of the laminated finline decreases more slowly. Such variations in inductance are applicable to either a loaded rectangular or cylindrical guide.

It has thus been shown that a substantially reflectionless impedance match may be effected over an abruptly tapered transition region by varying the dielectric constant of successive dielectric or insulating layers of each fin or ridge in an appropriate, decreasing manner in the direction from the wall of the guide to the center thereof. It has also been shown that even though the taper of the matching section may be sharp or abrupt physically, the capacitive change is advantageously small resulting in a very gradual change in the characteristic impedance of the guide which, concomitantly, presents a negligible electrical discontinuity to the propagating wave. It is emphasized that the foregoing analysis is not to be construed as necessarily providing either the only or correct technical explanation of how a desired impedance match is effected over a relatively short transition region in accordance with the principles of the invention. Rather, this analysis is to be considered as only an aid in understanding how the unique impedance matching sections embodied herein function and give rise to the beneficial results described above.

FIG. 3 illustrates, mainly in section, and FIG. 3A in cross-section, a rectangular waveguide 30 capacitively loaded with a laminated ridge 31 constructed in accordance with the principles of the instant invention. As such, ridge 31 (as the coplanar fins 12 and 13 in guide 11 of FIG. 1) comprise a multiplicity of conductive layers 32 insulated from each other by a plurality of layers of a suitable dielectric material 33. Since the number, dimensions and disposition of the respective layers relative to each other and to the orientation of the electric field are ascertained in the same manner as the coplanar fins in the finline guide of FIG. 1, further discussion with respect to the design considerations thereof will not be reiterated.

An elongated active element 34, which could comprise a p-n junction diode is shown, by way of example, supported by the ridge 31. As this invention is only concerned with providing a suitable mount for such active elements, no direct-current biasing connections or signal input and output connections are shown. The ridge 31, in accordance with the principles of this invention, advantageously may effect a desired impedance match between the unloaded and loaded guide over abruptly tapered end sections by progressively decreasing the dielectric constant of successive dielectric layers in an appropriate manner as described above.

FIG. 4 depicts isometrically in section, a portion of a rectangular waveguide 40 capacitively loaded with two coplanar laminated ridges 41 and 42 constructed in accordance with the principles of the instant invention. An active solid state element 43 is shown mounted within the gap defined between the ridges. A desired impedance match may be readily effected in guide 40 over short, abruptly tapered end sections of the ridges by progressively decreasing the dielectric constant of successive dielectric layers in an appropriate manner toward the center of the guide as described above with reference to FIG. 2. Guide 40 has the advantage over guide 30 in certain applications of presenting a higher degree of capacitive loading to a guide of given size and also of providing a

more simplified way of applying bias across an active element mounted within the gap through the use of two juxtaposed conductive layers.

FIG. 5 depicts in cross-section a finline guide 45 wherein two pairs of fins 46 and 47 are mutually disposed at right angles to each other within the guide. The fins are laminated in the same manner as the finline guide 11 of FIG. 1 and, thus, their construction will not be described again at this point. One advantage of guide 45 resides in its ability to propagate more than one mode, the two pairs of fins separating two modes, for example, by either circular or elliptical polarization. In addition, guide 45 provides all the advantages inherent in loaded guides per se and, in addition, provides the important advantages made possible by the unique laminated construction of the fins as fully described hereinabove.

It should be noted that the capacitive loading members embodied herein have application in supporting a succession of active elements, such as an array of tunnel diodes as well as a single, elongated distributed reactance element in strip form. The former arrangement, for example, is embodied in a copending application of W. W. Anderson-M. E. Hines, Serial No. 6,393, filed February 3, 1960. As is well known, such traveling wave devices are generally quite susceptible to feedback as they are negative-resistance, two terminal elements. It should be noted that if the insulative layers utilized in the construction of the loading members embodied herein were replaced by ferrite layers, nonreciprocal attenuation could be effected. More specifically, if such a laminated loading member (or members) was positioned asymmetrically within the guide and suitably magnetized in a direction transverse to the direction of propagation, the ferromagnetic resonance phenomena in ferrites could effect a very low degree of attenuation (approaching an unloaded guide) in one direction of propagation and a very high degree of attenuation in the opposite direction.

It is to be understood that the specific embodiments described herein are merely illustrative of the general principles of the instant invention. Numerous other structural arrangements and modifications may be devised in the light of this disclosure by those skilled in the art without departing from the spirit and scope of this invention.

What is claimed is:

1. An electromagnetic waveguide of the capacitively loaded type comprising a plurality of longitudinally extending conductive and dielectric layers interleaved in a direction transverse to the axis of said guide forming a loading structure extending inwardly from the bounding surface of said guide to the central region thereof, and means for matching the relatively low impedance capacitively loaded section of guide at least at one end to a relatively high impedance section of guide associated therewith, said means comprising a short, abruptly tapered end section of said loading structure and including a progressively decreasing change in the dielectric constant of successive dielectric layers in the direction toward the axis of said guide.

2. An electromagnetic waveguide in accordance with

claim 1 wherein said loading structure comprises two coplanar sections diametrically disposed within said guide, the innermost layer of each loading section being of conductive material and together defining a longitudinal gap therebetween adapted to support an active element of the solid state type.

3. An electromagnetic waveguide in accordance with claim 2 wherein a second pair of coplanar sections is disposed at right angles to said first-mentioned coplanar sections in said waveguide.

4. An electromagnetic waveguide in accordance with claim 1 wherein said guide is cylindrical and said loading structure comprises two coplanar fins attached respectively to opposite sides of said cylindrical guide wall, the innermost surfaces of said fins defining a narrow longitudinal gap therebetween along at least an intermediate region.

5. An electromagnetic waveguide in accordance with claim 1 wherein said guide is rectangular and said loading structure is of rectangular cross-section forming a ridge.

6. An electromagnetic waveguide in accordance with claim 5 wherein a second ridge is diametrically disposed with respect to said first-mentioned ridge, with the innermost surfaces of said ridges defining a narrow longitudinal gap therebetween.

7. An electromagnetic waveguide adapted to support therein a low impedance, active element of the solid state type, means for supporting said active element with said guide in a low impedance region of concentrated electric field and introducing a minimal increase in the attenuation of said guide, said means comprising a plurality of longitudinally extending and interleaved conductive and dielectric layers forming at least one capacitive loading member extending inwardly from the bounding surface of said guide to the central region thereof, the thickness dimension of said conductive layers and of at least some of said dielectric layers, transverse to the axis of said guide, being small compared with the appropriate skin depth of the respective layers at the highest frequency of operation for reducing the attenuation of said guide, and means for matching the low impedance of said active element to wave propagating structure of relatively high impedance associated therewith, said means comprising at least one relatively short, abruptly tapered end section of said loading member, and including a progressively decreasing change in the dielectric constant of successive dielectric layers in the direction toward said active element.

8. An electromagnetic waveguide in accordance with claim 7 wherein a second loading member is positioned diametrically opposite said first-mentioned loading member in said guide with the innermost juxtaposed surfaces of said loading members defining a narrow longitudinal gap therebetween.

9. An electromagnetic waveguide in accordance with claim 8 wherein third and fourth loading members are positioned diametrically opposite each other within said waveguide and along a plane mutually perpendicular to the plane through said first and second loading members.

No references cited.