

[54]	CORRUGATED WAVEGUIDE	3,527,976	9/1970	Thal, Jr.....	333/31 R X
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[21]	Appl. No.: 189,540				

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[51]	Int. Cl.....	H01q 13/02, H03h 7/38
[58]	Field of Search.....	333/95, 98, 98 M, 333/31 R, 34, 31 A, 33; 343/772-776, 786; 315/3.5, 3.6

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[57] ABSTRACT

The disclosed circular waveguide is provided on the inner wall surface with corrugated slots each having a width abruptly changed from a smaller value on that portion near to the axis of the waveguide to a larger value on the remaining portion of the slot. Also an electromagnetic horn is disclosed including such slots.

6 Claims, 7 Drawing Figures

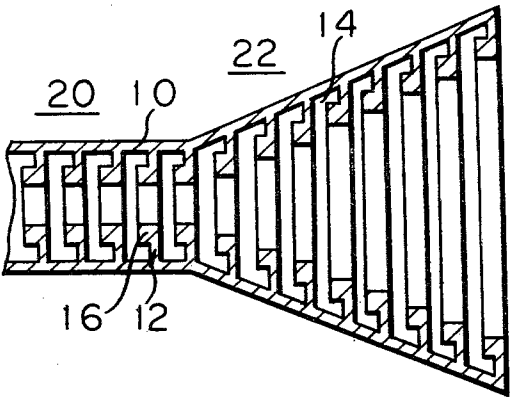


FIG. 1a PRIOR ART FIG. 1b PRIOR ART

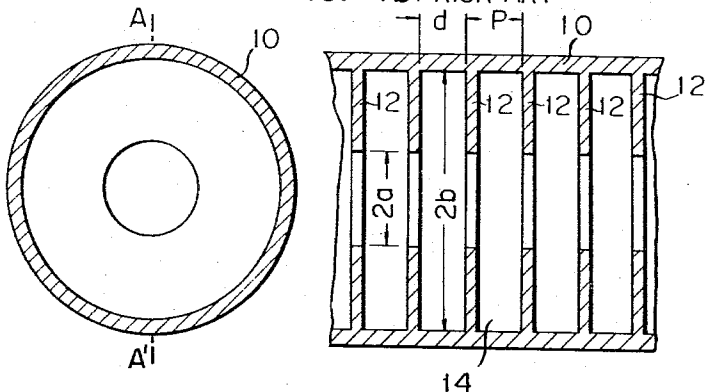


FIG. 3 PRIOR ART

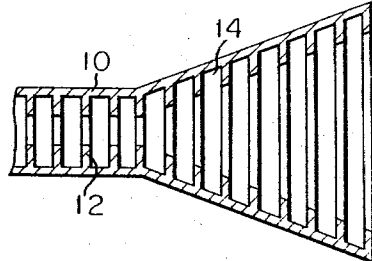


FIG. 2a

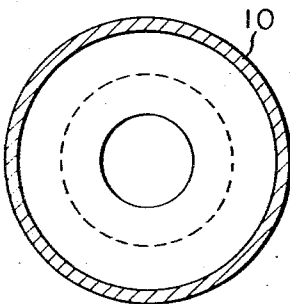


FIG. 2b

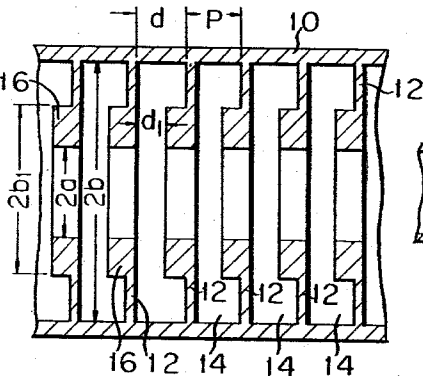


FIG. 4

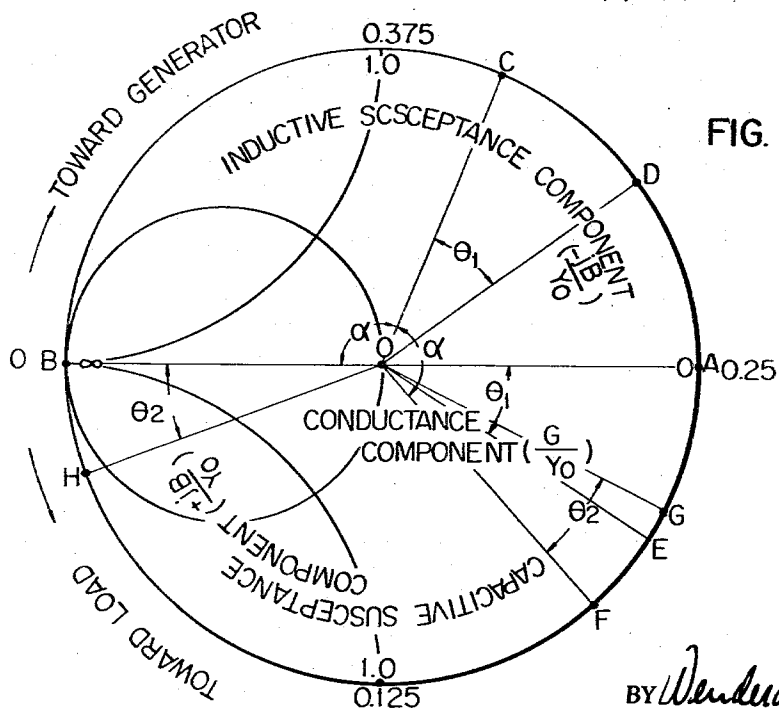
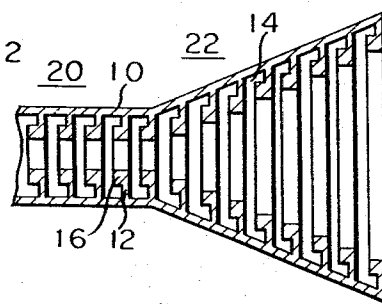


FIG. 5

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CORRUGATED WAVEGUIDE

BACKGROUND OF THE INVENTION

This invention relates to improvements in a corrugated waveguide.

The conventional type of corrugated waveguide has a plurality of annular discs or waveguide irises of the same dimension disposed at predetermined equal intervals and perpendicularly to the axis thereof to form slots between the adjacent irises while defining central openings aligned with one another. When a section of such a corrugated waveguide having a circular cross section is applied, for example, to an electromagnetic horn, the resulting directional pattern has been able to be improved only over a frequency band of about one octave.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the invention to provide an improved corrugated waveguide device having frequency characteristics maintained substantially uniform in a frequency band wider than that previously obtained.

It is another object of the invention to provide an improved electromagnetic horn of the corrugated waveguide type having directional characteristics substantially uniform over a frequency band wider than that provided by the prior art practice.

The invention accomplishes these objects by the provision of a cylindrical section of corrugated waveguide comprising a plurality of annular discs disposed at predetermined equal intervals and perpendicularly to the axis of the waveguide to form slots therebetween while defining central openings aligned with one another, wherein each of the corrugated slots has a width which varies in the direction of the depth thereof.

The width of the slot may preferably vary stepwise transversely of the direction of the waveguide.

BRIEF DESCRIPTION OF THE DRAWING

The invention will become more readily apparent from the following detailed description taken in conjunction with the accompanying drawing in which:

FIG. 1a is a cross sectional view of a section of corrugated waveguide constructed in accordance with the principles of the prior art;

FIG. 1b is a longitudinal sectional view of the section shown in FIG. 1a with the longitudinal section taken along the line A-A' of FIG. 1a;

FIGS. 2a and b are views similar to FIGS. 1a and b respectively but illustrating one form of the invention;

FIG. 3 is a longitudinal sectional view of an electromagnetic horn constructed in accordance with the principles of the prior art;

FIG. 4 is a longitudinal sectional view of an electromagnetic horn embodying the principles of the invention; and

FIG. 5 is a schematic Smith chart useful in explaining the principles of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

While the invention will be described as being applied to a cylindrical corrugated waveguide having a circular cross section it is to be understood that the same is equally applicable to cylindrical corrugated waveguides having a cross section with the shape of any

desired closed geometric figure such as a rectangular cross section. The term "cylindrical" is also used in the broadest sense. It is assumed that the corrugated waveguide of circular cross section has a hybrid mode or the HE₁₁ mode and the EH₁₁ mode propagated there-through.

Referring now to the drawing and FIGS. 1a and b in particular, it is seen that the arrangement disclosed herein comprises a length of right circular cylindrical wave guide made up of a circular metallic tube 10, and a plurality of annular metallic discs 12 of the same dimension disposed at predetermined equal intervals and substantially perpendicularly to the axis of the tube 10 to form slots 14 therebetween with bottoms of the slots constituted by the inner wall surface of the tube 10.

It is assumed that the annular discs 12 frequently called "waveguide irises" have a pitch of P, an inside diameter of 2a and an outside diameter of 2b as designated in FIG. 1b. The slots 14 shown in FIG. 1b as having a width of d have a depth equal to (b-a). It is also assumed that the waveguide illustrated has been constructed such that the pitch P is smaller than the wavelength λ in the free space. Under the assumed conditions, the inner extremity of the iris 12, that is, the slot 14 at a point spaced from the axis of tube 10 by a distance a presents an admittance $\hat{Y}_c$ in the hybrid mode expressed by the following equation:

$$\hat{Y}_c \cong j \frac{p}{d} \sqrt{\frac{\epsilon_0}{\mu_0}} \left[\frac{J'_{1(Ka)} Y_{1(Kb)} - J_{1(Kb)} Y'_{1(Ka)}}{J_1(Ka) Y_1(Kb) - J_1(Kb) Y_1(Ka)} \right] \quad (1)$$

where

j = unit of an imaginary number equal to $\sqrt{-1}$

ϵ_0 = permittivity of free space

μ_0 = permeability of free space

J_1 = first order Bessel function of a first kind

Y_1 = first order Bessel function of a second kind

J'_1 = first order differential of Bessel function J_1

Y'_1 = first order differential of Bessel function Y_1

K = phase constant in free space equal to $2\pi/\lambda$

It is noted that the corresponding conductance is negligibly small so that

$$\hat{Y}_c \cong jB_c$$

where B_c is the susceptance. For large values of K_a , the equation (1) may approximate the equation

$$\hat{Y}_c \cong jB_c = -j(p/d) \sqrt{\epsilon_0/\mu_0} \cot\{K(b-a)\}$$

If the susceptance B_c is null in the EH₁₁ mode then the electromagnetic field has a component in a plane normal to the propagation axis high in intensity of the central axis of the waveguide and decreasing to a zero value at the distance a from the central axis or on a circularly cylindrical surface formed of the inner edges of the irises 12.

In other words, when an electromagnetic horn is formed of a section of a corrugated waveguide such as above described, the same has a directional pattern in the E plane coinciding with that in the H plane. Such an electromagnetic horn is shown in FIG. 3 wherein like reference numerals designate the components cor-

responding to those illustrated in FIG. 1b. FIG. 3 will be self-explanatory.

If B_c is infinitely large (or $B_c = \infty$) in the EH_{11} mode it can be considered that the circularly cylindrical surface with the radius of a as above described is equivalently shortcircuited. This results in the coincidence of the field distribution in the EH_{11} mode with that in the TE_{11}^o mode for a circular waveguide. Therefore for electromagnetic horns utilizing the directional characteristics in the EH_{11} mode such as shown in FIG. 3, the radius a is large so that the horns are superior in direction characteristics to conical horns operated in the TE_{11}^o mode in a frequency band holding the relationship

$$0 \leq B_c \leq -\cot\{K(b-a)\} \leq \infty$$

In this case it is to be noted that the frequency band satisfying the relationship $B_c < 0$ is not used because the HE_{11} mode presented in such a frequency band is of a slow wave. Also the component of the electromagnetic field in a plane normal to the central axis becomes

higher in intensity thereon leading to the deterioration of the directional characteristics of the electromagnetic horn.

Thus electromagnetic horns to which the conventional type of corrugated waveguides are applied such as shown in FIG. 3 are disadvantageous in that a frequency band in which the directional characteristics can be expected to be improved is restricted to a frequency band of about one octave expressed by the above relationship (3).

The invention seeks to provide wide band frequency characteristics for corrugated waveguides and electromagnetic horns in the form of such waveguides.

In FIGS. 2a and b wherein like reference numerals designate the components identical or similar to those shown in FIGS. 1a and b, there is illustrated a section of corrugated waveguide of a circular cross section constructed in accordance with the principles of the invention. The arrangement illustrated is different from that shown in FIG. 1 only in that in FIG. 2, the annular discs 12 or waveguide irises 12 each are provided on one face with an annular land portion 16 radially extending from the inner edge thereof to a predetermined radius of b_1 with the land portions 16 all on the same sides of the irises 12 in the example illustrated, on the left side as viewed in FIG. 2b. Thus the resulting slot 14 has an axial dimension of a width which varies in the direction of the depth thereof. More specifically, the slot 14 has the width varied step wise from a predetermined fixed value d_1 in the region of the entrance thereof or for $a \leq \lambda \leq b_1$ to another predetermined fixed value of d greater than d_1 in the region of the bottom thereof or for $b_1 \leq \lambda \leq b$ where λ represents a radial distance from the axis of the waveguide.

FIG. 4 shows an electromagnetic horn embodying the principles of the invention. The arrangement illustrated comprises a throat portion 20 and a horn-shaped portion 22 connected thereto. A plurality of waveguide irises 14 with central land portions 16 similar to those shown in FIG. 2b are disposed in both portions in the same manner as in the arrangement of FIG. 2b

excepting that those irises 14 disposed in the horn-shaped portion 22 follow in shape the latter to progressively increase in outside and inside diameters toward the open end of the horn-shape portion 22.

The arrangement of FIG. 2 will now be discussed in terms of the admittance of the slot 14. As in the arrangement of FIG. 1 the conductance is also negligibly small and therefore it is required only to consider the susceptance. An admittance $Y(b_1)$ as viewed toward the bottom of the slot 14 at a point at a radial distance of d_1 from the axis of the waveguide is given by the equation

$$\dot{Y}(b_1) = -jY_{c1} \cot\{K(b-b_1)\} = jB_1$$

where Y_{c1} is a characteristic admittance of that portion of the slot having the width d_1 , as will readily be understood from the deduction of the equation (2). The character B_1 represents a corresponding susceptance. Similarly, the admittance $\dot{Y}(a)$ as viewed toward the bottom of the slot at a point at a radial distance of a is expressed by the equation

$$\dot{Y}(a) = -Y_{c2} \left[\frac{Y_{c1} \cot\{K(b-b_1)\} - Y_{c2} \tan\{K(b_1-a)\}}{Y_{c2} + Y_{c1} \tan\{K(b_1-a)\} - \cot\{K(b-b_1)\}} \right] = jB_2$$

where Y_{c2} represents a characteristic admittance of that portion of the slot having the width d_1 and is according to the relationship.

$$Y_{c1} < Y_{c2}$$

Also B_2 is a corresponding susceptance.

The principles of the operation of the corrugated waveguide as shown in FIG. 2 will now be described with reference to FIG. 5 wherein there is schematically illustrated a Smith chart.

Conventional corrugated waveguides have a usable frequency band as determined by the equation (3). Assuming that the frequency band is defined by frequencies f_L and f_H as the upper and lower limits respectively and that wavelengths in the free space are of λ_L and λ_H at the frequencies of f_L and f_H respectively, the normalized B_c in the equation (1) occupies a position A or B shown in FIG. 5 at the frequency f_L or f_H respectively. At any frequency f in the frequency band defined by the frequencies f_L and f_H , the normalized B_c is on a circular arc $\overset{\frown}{AEB}$.

It is now assumed that in the arrangement of FIG. 2, the slot has a total depth $(b-a)$ equal to $\lambda_L/4$ and that portion thereof having the width of d_1 has a depth $(b-b_1)$ greater than $\lambda_L/8$ and less than $\lambda_L/4$. That is the following relationships hold:

$$b-a = \lambda_L/4$$

$$\lambda_L/8 < (b-b_1) < \lambda_L/4$$

From the equation (4) and the inequality (8), it is apparent that the susceptance B_1 as viewed toward the bottom of the corrugated slot 14 at a point radially spaced away from the axis of the waveguide by a distance of b_1 fulfils the inequality

$$-1 < B_1/Y_{c1} < 0$$

This normalized susceptance B_1/Y_{c1} is on a circular arc $\widehat{ACB}$ shown in FIG. 5. Assuming that it occupies a point C on the circular arc $\widehat{ACB}$, the susceptance B_2 normalized by the characteristic inductance Y_{c2} or B_2/Y_{c2} will be moved from the point C toward the point A until it reaches a point D as will readily be apparent from the relationship (6).

This means that, with an angle COD represented by θ_1 , the normalized susceptance B_2/Y_{c2} presented by the slot 14 as viewed at a point at a radial distance of a from the axis of the waveguide is turned from the point A toward the load through the angle θ_1 until it is located at a point E shown in FIG. 5. Therefore it will be understood that at the lower limit of the frequency band or the frequency f_L , the susceptance of the corrugated slot becomes null for conventional corrugated waveguides and has a positive value for the present corrugated waveguides.

Considering the upper-limit f_H of the frequency band, it is apparent from the relationship $\lambda_H = \lambda_L/2$ that the normalized susceptance B_1/Y_{c1} of the corrugated slot as viewed toward the bottom thereof at a point at a radial distance of b_1 from the axis of the waveguide is turned from the point B through twice an angle $\alpha_1 = \angle BOC$ to a point F as shown in FIG. 5. Normalizing the susceptance B_1 by the characteristic admittance Y_{c2} of that portion of the slot having the width d_1 causes the point F to be moved toward the point A to reach a point G. Then the normalized susceptance B_2/Y_{c2} of the corrugated slot as viewed at a point at a radial distance of a from the axis of the waveguide is turned through an angle of $\theta_2 = \angle FOG$ toward the load until it is positioned at a point H shown in FIG. 5.

According to the invention, therefore, a normalized susceptance of the slot is on a circular arc EFH at any frequency in the frequency band ranging from f_L to f_H whereby the susceptances B_2 's of the slots are positive even at frequencies either lower than the f_L or higher than f_H . Thus the undesirable HE_{11} mode has an upper cut off frequency less than f_L . Also the upper limit of frequencies available for electromagnetic horns operated in the EH_{11} mode such as shown in FIG. 4 becomes higher than f_H with the result that such electromagnetic horns have a frequency band wider than the previously obtained.

By properly selecting the depth $(b - b_1)$ of that portion of the corrugated slot 14, having the width d the susceptance of the slot can be maintained substantially constant over a wider frequency band. As a result, any electromagnetic horn including such slots is enabled to provide a distribution of an electromagnetic field in the radiation mode which is substantially constant over a wide frequency band, as compared with the prior art practice.

While the invention has been illustrated and described in conjunction with the application thereof to electromagnetic horns, it is to be understood that it is

equally applicable to a variety of microwave devices other than electromagnetic horns. For example, the invention may be effectively applied to transformers for connecting a section of a circular waveguide to a section of a circular corrugated waveguide as disclosed herein. This is because the admittance presented by the slot of the invention as viewed at a point having a radial distance of a from the axis of the waveguide can be selected to have any desired value by properly changing the parameters d , d_1 , $(b - a)$ and/or $(b - b_1)$. Specifically a transformer for connecting a section of a circular waveguide to a section of a circular corrugated waveguide may be formed of a section of circular corrugated waveguide designed and constructed in accordance with principles of the invention such that corrugated slots on that end portion thereof adjacent to the end of the section of the circular waveguide have admittances as high as possible. This is because the inner wall surface of the circular waveguide has an infinitely large admittance. Then as the slot gets nearer to the other end of the section, the slot has an admittance approaching that admittance of the corrugated slot of the circular corrugated waveguide to be connected. This results in a wide band matching.

While the invention has been illustrated and described in conjunction with a few preferred embodiments thereof, it is to be understood that numerous changes and modification may be resorted to without departing from the spirit and scope of the invention. For example, the invention is equally applicable to square and rectangular waveguides.

What we claim is:

1. A section of waveguide comprising cylindrical wall means defining a section of a closed geometric figure, a plurality of annular metallic plates attached to the inner surface of said wall means at predetermined equal intervals along and perpendicularly to the axis of the waveguide to define between them a plurality of slots with the inner surface of said wall means defining the bottom of said slots, said plates having central openings aligned with one another, each of said slots having a width which varies in the direction of the depth thereof for causing said corrugated slots to have capacitive susceptances within a wide frequency band.

2. A section of waveguide as claimed in claim 1 having one end portion formed into a horn.

3. A section of waveguide as claimed in claim 1 wherein each of said slots has a width which varies stepwise transversely of the axis of the waveguide.

4. A section of waveguide as claimed in claim 3 having one end portion formed into a horn.

5. A section of waveguide as claimed in claim 1 wherein each of said slots has a width which varies stepwise from a smaller value at that portion thereof near the axis of the waveguide to a larger value at that portion thereof near the inner wall surface of the waveguide.

6. A section of waveguide as claimed in claim 5 having one end portion formed into a horn.

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