United States Patent

Beguin

[15] **3,680,145**

[45] **July 25, 1972**

[54] MULTIMODE HORN

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[22] Filed: **March 29, 1971**

[21] Appl. No.: **129,229**

Related U.S. Application Data

[63] Continuation of Ser. No. 743,527, July 9, 1968, abandoned.

[30] **Foreign Application Priority Data**

June 10, 1967 France 67113688

[52] **U.S. Cl.** **343/786**
[51] **Int. Cl.** **H01q 13/00**
[58] **Field of Search** 343/772, 779, 786

[56] **References Cited**

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[57] **ABSTRACT**

Multimode horn enabling to obtain a radiation pattern the phase of which is practically nil within a wide range of values of the radiation angle, characterized by the fact that the length of the paths of the modes according to the geometrical axis of the horn is such as phase differences exist between the said modes at the center of the horn aperture.

3 Claims, 5 Drawing Figures

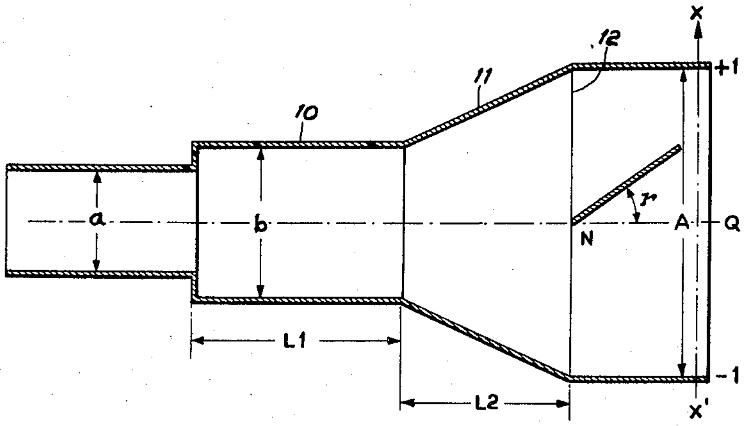

Fig. 1

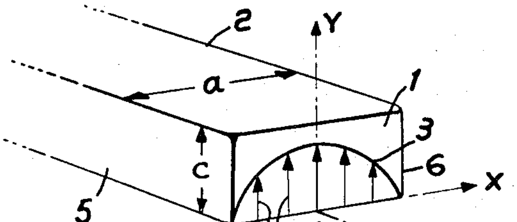

Fig. 2

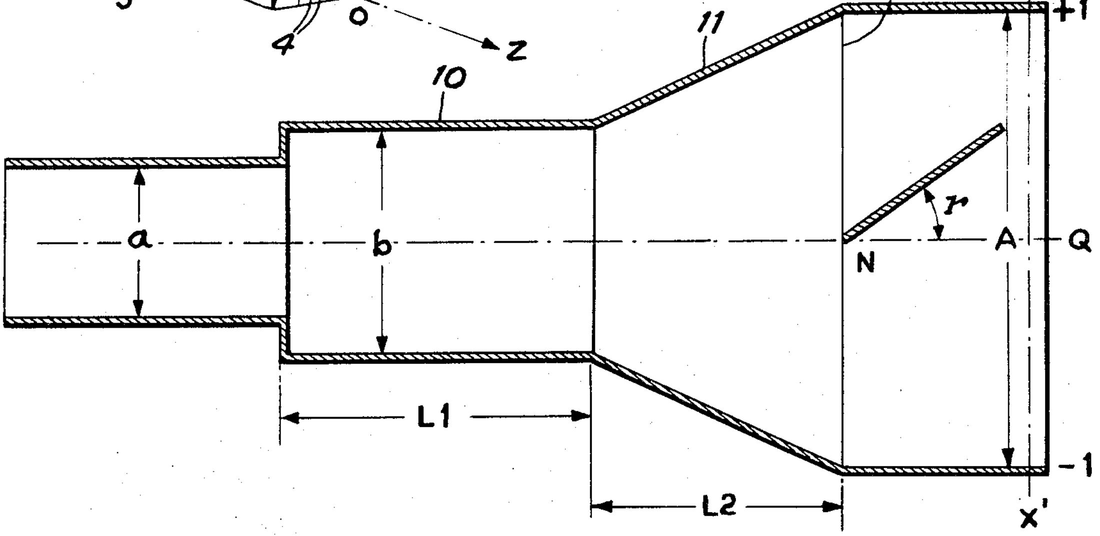

Fig. 3

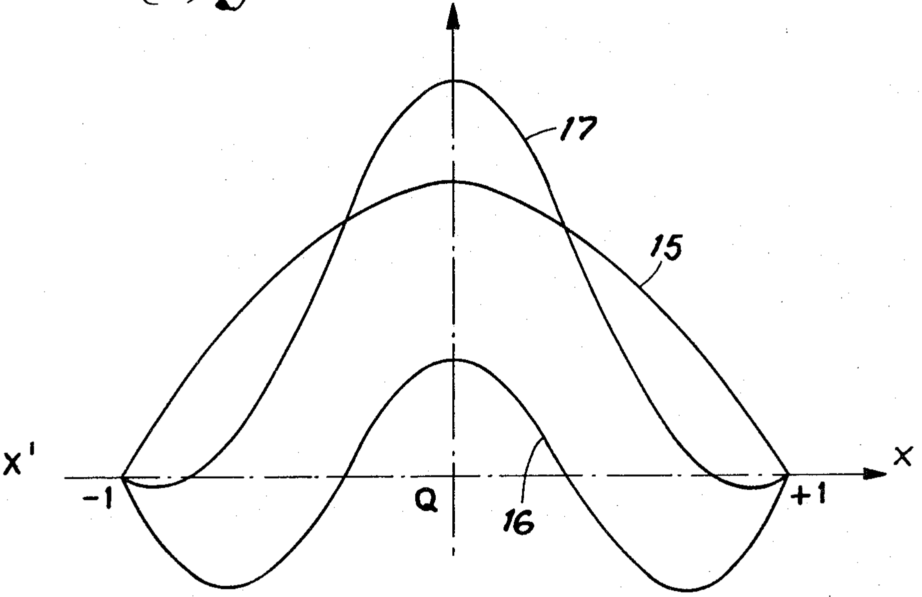

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Fig. 5

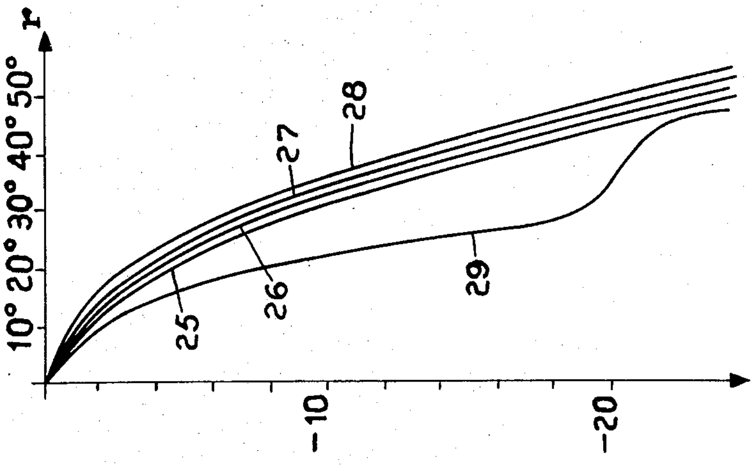
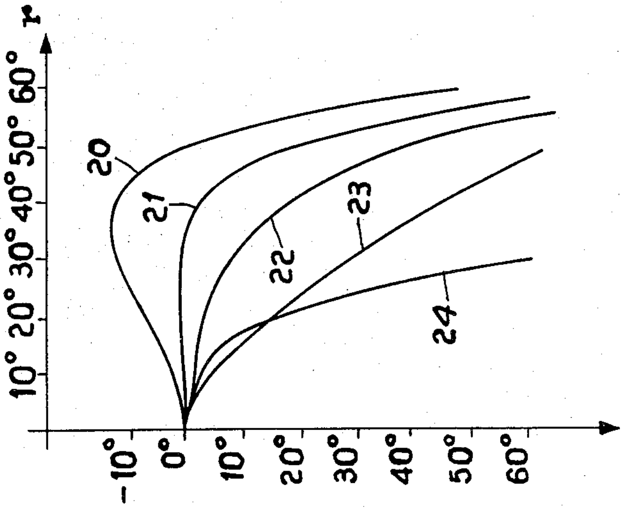


Fig. 4



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MULTIMODE HORN

This is a continuation of application Ser. No. 743,527, filed July 9, 1968.

The present invention concerns improvements to multimode horns and more particularly a process enabling to obtain, by means of such horns, a radiation pattern the phase of which is close to zero degree within a large range of values of the radiation angle.

The horn radiators or "horns" constitute the extension of the waveguides and assure the transition between the waveguides and the free space, particularly where it concerns velocities of propagation of these two media. The horns may be used either as main sources of radiation or, more generally, as sources known as primary sources associated to a reflecting surface or reflector in order to form a directive aerial system. It will be observed that several horns may be used in one same aerial system in order to obtain the required radiation pattern. It is clear that the radiation pattern of such antennae using horns depends mainly upon the distribution of the electromagnetic fields in the mouth or aperture plane of the one or several horns, this distribution being itself a function of the modes which propagate in the waveguide, the horn of which is the extension, as well as upon the shape of the horn. Thus, in the case of a rectangular waveguide, the horn may be flared, either according to one of its two dimensions in order to form a sectoral horn, or according to the two dimensions at the same time, to form a pyramidal horn. In the case of a sectoral horn, the flare is defined usually with respect to the plane of the electrical field vector E (plane E) or with respect to the magnetic field vector (plane H); the plane E is for instance the plane which contains the direction of propagation of the waves and which is parallel to the electrical field vector. Therefore, it will be said that the horn is flared in the plane E when only the sides at cross angle with this plane E have been moved. Owing to this flare, the waves located in the plane of the aperture of the horn are no longer in phase, but it is generally admitted that a phase shift of 45° between the electrical field present at the center of the aperture and that present at the ends, does not disturb noticeably the ideal radiation pattern calculated without taking into account the phase. However, in certain applications, such a phase shift is not permissible.

In order to compensate phase variations in the aperture of the horn, the use of lenses which introduce an important delay at the center and a delay nil at the ends, has been proposed. Such lenses present the drawback of increasing the losses and of dismatching the horn. Furthermore, they must, in certain applications, be made in a very homogeneous material from the point of view of its dielectric constant and must be machined with very tight tolerances.

One of the objects of the present invention is thus to achieve a multimode horn in which means implemented to compensate the phase variations in the horn aperture do not present the drawbacks quoted hereabove.

Another object of the present invention is to achieve a multimode horn which presents a radiation pattern the phase of which remains practically nil within a large range of values of the radiation angle.

According to a feature of the present invention, in a multimode horn provided for propagating two modes, the length of the path of the said modes according to the geometric axis of the horn is chosen in such a way as it exists a phase shift between these two modes at the middle of the horn aperture, the value of this phase shift depending upon the types of modes used.

According to another feature of the present invention, in a multimode horn comprising means for propagating more than two modes, means are provided for obtaining phase shifts between the different modes, the values of these phase shifts being chosen in such a way as the phase of the vectorial sum of the modes in the horn aperture, varies little within the whole useful range of values of the radiation angle.

The above mentioned and other features and objects of this invention will become apparent by reference to the following description taken in conjunction with the accompanying drawings in which:

FIG. **1** illustrates a rectangular waveguide;

FIG. **2** illustrates a cross section of a multimode horn;

FIG. **3** illustrates curves of the electrical field for two types of modes and their sum;

FIG. **4** illustrates curves of the phase of the field radiated by the multimode horn;

FIG. **5** illustrates amplitude curves of the field radiated by the multimode horn.

FIG. **1** shows the aperture **1** of a rectangular waveguide **2** of width *a* and height *c*. When the dimensions *a* and *c*, with respect to the wavelength *d* in free space, are such as $(d/2) < a < d$ and $c < (d/2)$, the only mode which propagates in the waveguide is a mode with transversal electrical field, i.e., a mode the electrical field vector of which is at cross angle with the propagation direction Oz. In the plane of the aperture, the distribution of the electrical field has the pattern of the curve **3** which constitutes the envelope of the electrical field vectors **4**. Such a mode is called mode TE_{10} or H_{10}, the indices **1** and **0** meaning that there is a maximum electrical field according to the axis Ox and no maximum at all of the said field according to the axis Oy. By keeping the same wavelength *d* in free space and by increasing the dimension *a* of the waveguide **2**, other modes may be propagated which will be called modes TE_{mo} or H_{mo}. More generally, if the dimensions *a* and *c* of the waveguide are increased, other modes appear and these modes may be with transversal electric field and are called TE_{mn} (H_{mn}), or with transversal magnetic field and are called $TM_{m\ n}$ ($E_{m\ n}$). It will be observed that in the case of the modes $E_{m\ n}$ the indices *m'* and *n'* are always different from zero.

By using this FIG. **1**, one may define an electric plane E as the one containing Oy and Oz, and a magnetic plane H as the one containing Ox and Oz, i.e., a plane at cross angle with the electrical plane E.

In order to assure the transition between the waveguide and the free space, the waveguide is flared either according to one of the two dimensions in order to form a sectoral horn, or according to the two dimensions in order to form a pyramidal horn. This flare is generally defined in relation with the electrical plane E and the magnetic plane H, and it is said that the horn is flared in the magnetic plane H when the sides at cross angle with this plane have been moved. Thus, in the case of FIG. **1**, a flare in the magnetic plane H corresponds to move one from the other the sides **5** and **6** of the waveguide.

In order to modify the radiation pattern of a horn, it is sometimes interesting to make appear simultaneously several modes in the horn aperture, each one of these modes having a determined amplitude. It is clear that in a horn, the different modes are set up as the dimensions of the aperture increase, however the amplitude of each one of these modes are not defined with accuracy. In order to obtain modes of accurate relative amplitudes, one resorts to successive widenings by steps, then when the different modes required have been obtained, the transition between the last waveguide and the free space is carried out by a horn. In the specialized literature concerning the antenna technique, a "multimode" horn designates the whole assembly constituted by the different waveguides of increasing cross sections and by the horn.

FIG. **2** gives a cross section of a multimode horn. This multimode horn has been obtained from the waveguide **2** of FIG. **1**, the dimensions *a* and *c* of this guide being such as only the mode H_{10} or fundamental mode, propagates. The larger side has been extended to a value *b* such as the mode H_{30} appears, viz. $(3d/2) < b < 2d$. The ratio *k* of the amplitude of the mode H_{30} to the amplitude of the mode H_{10} depends upon the values of *a* and *b* at a given frequency, this ratio *k* is called harmonic rate. The waveguide of side *b*, referenced **10**, is then flared in the magnetic plane H in order to form a sectoral horn **11** the width of the aperture **12** of which is *A*. FIG. **2** is thus a cross section of the multimode horn in the magnetic plane.

In the part **11** of the multimode horn, other modes different from the modes H_{10} and H_{30} appear, but these new modes are of small amplitude and it may be considered that their effect over the aperture distribution of the electromagnetic field and thus on the radiation pattern, is negligible. The aperture distribution of the electrical field is thus given by the sum of the electrical fields of the modes H_{10} and H_{30} the electrical fields being expressed with their amplitude and their phase.

FIG. **3** gives the amplitude curves in the aperture **12** of the horn, of the modes H_{10} (curve **15**), H_{30} (curve **16**) and of their sum (curve **17**) assuming that the said modes are in phase at the middle of the aperture. The axis $X'QX$ is graduated according to the values of the ratio between the abscissa measured with respect to the center of the aperture and the half-width $A/2$ of the aperture, this ratio will be called standard abscissa X.

It is possible to calculate the phase difference P between the modes H_{10} and H_{30} introduced by the path of the said modes in the multimode horn, this phase difference P is made up with a first phase shift $P1$ due to the path $L1$ in the part **10** and of a second phase shift $P2$ due to the path $L2$ in the flared part. The following is thus obtained :

$$P1 = \frac{2\pi L1}{d}\left[\sqrt{1-\left(\frac{d}{2b}\right)^2} - \sqrt{1-\left(\frac{3d}{2b}\right)^2}\right]$$

and

$$P2 = \frac{2\pi L2}{d}\left[\sqrt{1-\left(\frac{d}{A+b}\right)^2} - \sqrt{1-\left(\frac{3d}{A+b}\right)^2}\right]$$

by assimilating the flared part **11** to a rectangular guide the large side of which would have the dimension $(A+b)/2$. It will be observed that if a higher accuracy is required in the calculation of $P2$, another formula for the phase shift must be used. Thus, for instance, it may be demonstrated that the phase shift introduced by the part **11** of the horn, in the case of a mode H_{mo}, is given by :

$$\frac{2\pi L2}{A-a}\left[\sqrt{\left(\frac{A}{md}\right)^2-\frac{1}{4}} - \sqrt{\left(\frac{a}{md}\right)^2-\frac{1}{4}} + \frac{1}{2}\left(\text{arc sin}\,\frac{md}{2A} - \text{arc sin}\,\frac{md}{2a}\right)\right]$$

In the technique of multimode horns, one proceeds in such a way as the modes H_{10} and H_{30} are in phase at the middle point N of the horn aperture, i.e., that the phase shift P is equal to an integer number of times 360°. This phasing is obtained generally by varying the length L**1**, and for this reason, the part **10** is called "phasing section."

More precisely, if $G1(X)$ designates the function which defines the aperture distribution of the electrical field of the mode H_{10}, and $G3(X)$ designates the function which defines the aperture distribution of the electrical field of the mode H_{30}, one may write the general expression $G(X)$ of the electrical field in the aperture under the form:

$$G(X) = G1(X) + ke^{jPO}G3(X) \qquad (1);$$

in which formula X is the standard abscissa according to the width of the aperture and thus varies between -1 and $+1$, PO is the phase shift between the two modes at the point N, j is the complex term such as $j^2 = -1$, k is the harmonic rate defined hereabove.

On the other hand, the functions $G1(X)$ and $G3(X)$ may be written :

$$G1(X) = \cos(\pi X/2)\,e^{-jBX^2} \text{ and } G3(X) = \cos(3\pi X/2)\,e^{-jCX^2} \qquad (2),$$

B and C designating the maximum phase shifts appearing on the edges of the aperture respectively for the modes H_{10} and H_{30}. The equations (1) and (2) enable to calculate the radiated field G according to the angle r, i.e., the bearing angle, and one obtains:

$$G(r) = G1(r)\ e^{jP1(r)} + ke^{jPO}\ G3(r)\ e^{jP3(r)} = G(r)\ e^{jP(r)}.$$

FIG. **4** gives phase curves $P(r)$ for different values of PO and FIG. **5** gives amplitude curves $G(r)$ for the same values of the phase PO. These curves have been plotted by taking $k = 0,4$. In FIG. **4**, the phase curves have been referenced **20** for $PO = -20°$, **21** for $PO = -10°$, **22** for $PO = 0°$ and **23** for $PO = +20°$. The bearing r has been brought on the abscissa axis and the phase shift $P(r)$ on the ordinate axis. In FIG. **5**, the amplitude curves have been referenced **25** for $PO = -20°$, **26** for $PO = -10°$, **27** for $PO = 0°$ and **28** for $PO = +20°$; the bearing r has been plotted on the abscissa axis, and the amplitude $G(r)$ has been plotted in decibels on the ordinate axis. The different values of PO are obtained generally by varying the length $L1$ of the part **10** (FIG. **2**).

The curve **22** ($PO = 0°$) of FIG. **4** shows that the phase of the field radiated by the multimode horn varies substantially when the bearing r varies. However, it will be observed that by choosing $PO = -10°$, the curve **21** is obtained which gives a practically constant phase close to zero for r ranging between 0° and 35°. Besides, the curve **26** of FIG. **5** shows that the curve of corresponding amplitude differs very little from the curve **27** plotted for $PO = 0°$. In a general way, the amplitude curves vary very little in accordance with the phase shift PO of the modes according to the geometric axis of the horn.

By way of indication, the curves **24** and **29** of the FIGS. **4** and **5** show respectively the phase and amplitude curves of the field radiated by the mode H_{10} alone. It will thus be observed that the phase varies quickly with respect to the bearing and that the radiation pattern (FIG. **5**) is more directive.

The invention has been described assuming that the modes used were the modes H_{10} and H_{30}, however it is clear that it is applied also when other modes are used. Besides, the number of modes may be higher than two. It is also clear that it is applied to horns the radiation pattern of which is not in horizontal plane and is located in particular in the vertical plane. The characteristics of the invention may also be implemented in pyramidal horns.

While the principles of the above invention have been described in connection with specific embodiments and particular modifications thereof it is to be clearly understood that this description is made by way of example and not as a limitation of the scope of the invention.

What is claimed is:

1. A multimode horn having excited modes $TE_{10} + TE_{30}$ wherein mode TE_{30} is excited by mode TE_{10} by a broadening of the height dimension of a single guide, comprising:

at least one waveguide section having length $L1$ and large dimension b for propagating at least two modes, wherein the phase difference $P1$ between said two modes resulting from path $L1$ is defined by the equation

$$P1 = \frac{2\Pi L1}{d}\left[\sqrt{1-\frac{d}{2b}^2} - \sqrt{1-\frac{3d}{2b}^2}\right]$$

where d is the free space wave length; and

a sectoral horn coupled to said one waveguide section having length $L2$ along the common axis of said one waveguide section and said sectoral horn, said sectoral horn having aperture width A, wherein the phase difference $P2$ between said two modes resulting from path $L2$ is defined by the equation

$$P2 = \frac{2\Pi L2}{d}\left[\sqrt{1-\frac{d}{A+b}^2} - \sqrt{1-\frac{3d}{A+b}^2}\right],$$

said length L**1** and L**2** chosen to obtain a quasi-plane wave in said aperture such that the phase difference $PO = P1 + P2$ at the center of said aperture is different from zero.

2. Apparatus according to claim **1** in which said phase difference PO at the center of said aperture is less than zero degrees.

3. Apparatus according to claim **1** in which said phase difference at the center of said aperture is defined as $PO \cong -10°$.

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