PROCEEDINGS OF ISAP '96, CHIBA, JAPAN

HIGH PURITY GAUSSIAN BEAM EXCITATION BY OPTIMAL HORN ANTENNA

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Abstract

In this paper, we present an original and optimal multimode horn design to excite free space beam modes efficiently from waveguides structures. In particular, in this paper, we focus the study in overmoded circular corrugated waveguide, but the principle presented here is absolutely general and valid also for any waveguide shape sections. As we show later, this horn improves the cross-polarization, sidelobes level and directivity of some good waveguide mode mixtures. The horn can also be used to improve the radiation features of different well known horns by simply cascading any of them with the one considered here.

An original synthesis procedure is proposed which has been successfully tested by computational simulation. The calculation method has been validated by experimental results of other authors.

1. Introduction

In multimode horns, the different properties of the modes are used to perform the radiation pattern. Basically, in order to reduce the cross-polarization, corrugated horns have become the preferred choice for antenna feeds in communication reflector antennas, radar and remote sensing, where high perfomance is required.

For many years, the main goal in horn designing was to obtain a good mixture of waveguide modes to get a good far field pattern, low sidelobes, low level of cross-polarization, a good directivity, etc. In circular corrugated waveguides, the solution was found to be a mixture of 85% of TE_{11} mode, and 15% of TM_{11} mode, with the correct phase to obtain a gaussian like radiation pattern.

In this paper, we propose an original solution to design multimode horns antennas, assuming that we have an aproximation to the good mixture at the antenna input. The aim is to improve the features of the radiation, as the sidelobe levels, cross-polarization and directivity. In other words, with these shaped-pattern horns we will increase the gaussian features of the input field distribution.

Others authors [1,2] have been built and measured non linear profile tapers. Their results are consistent with our computed results.

2. Gaussian mode beams and waveguide modes

As it is shown in [3], there are solutions of the paraxial Helmholtz equation where the field distribution has high correlation with some waveguide modes. The clearest example is the fundamental gaussian beam, Ψ_0^0 (see [3]), whose field characteristics match closely those of the circular corrugated waveguide HE_{11} mode.

Nevertheless, this is not the only possibility. We can say that there are combinations of solutions of the paraxial Helmholtz equation which produce field distributions very similar to combinations of waveguide modes. The only limitation to this matching procedure is the paraxiality of the Helmholtz solutions [3] and [4].

3. Horn antennas for gaussian mode beams

The problem to solve is to excite efficiently the gaussian structures from waveguide mode mixtures. The component sought will have a horn antenna behavior, in order to match the waveguide to the free space, as well as possible.

The main idea to design this optimal horn antenna is to taper it the same way the gaussian mode beam contours are shaped, i.e. in accordance to the profile:

$$r(z) = r_0\sqrt{1+\left(\lambda z/\pi\varpi_0^2\right)^2} \tag{1}$$

r_0 being the initial radius for the taper, λ the wavelength, and ϖ_0 the beam waist of the fundamental gaussian mode beam. In figure 1 is represented the corrugated taper profile and the gaussian mode beam contour.

This idea is based on the assumption that the beam waist is placed at the taper input and therefore the input feed has to be somewhat gaussian-like. With this taper we will improve the purity of the input gaussian distribution (correlation factor between the fields in the aperture and the gaussian mode beam in E and H planes becomes about 99%), and also decrease the sidelobe levels and cross-polarization factor.

Then, as a starting point to use this antenna, we will need to generate a good mixture with some gaussian features, to be improved by use of the non lineal horn whose contours follow equation (1) -The well-known corrugated waveguide mixture of 85% of TE_{11} and 15% of TM_{11} phased correctly, for instance, has a gaussian field distribution.

Clearly, there are other mixtures of modes with gaussian behaviour, which can also serve to feed the optimal horn antenna and by means of the design proposed here considerably improved in their gaussian structure.

Others authors have advanced different methods to obtain such mixtures from pure waveguide modes (TE_{11}, TM_{11}). They basically propose three techniques:

1.- *Changing the corrugation depth in a waveguide* from $\lambda/2$ to $\lambda/4$ ($TE_{11} \rightarrow HE_{11}$) (in an optimized way in [5]) or from smooth waveguide to $\lambda/4$ ($TM_{11} \rightarrow HE_{11}$). The input and output radius are equal.

2.- *Using some controlled step between two waveguides* with different inner radius [2]. Normally this solution is a narrowband solution, because the step can realized for one value of frequency. The output radius is bigger than the input one.

3.- *Using conical horn antennas* in order to control the coupling between two modes [6].

Olver, A.D., et alt [2] combine these techniques with a corrugated non-linear horn fed by the TE_{11} circular waveguide mode to obtain the HE_{11} circular corrugated waveguide mode. There is a change of corrugation depth from $\lambda/2$ to $\lambda/4$ (first technique) and also different slopes are defined through the horn to control the coupling between the modes generated inside the taper (third technique). The formula for the profile of this non-linear horn is:

$$r(z) = r_{in} + \left(r_{out} - r_{in}\right)\left\{(1-A)\,z/L + A\,\sin^2\left(\pi z/2L\right)\right\} \tag{2}$$

L being the lenght, r_{in} and r_{out} the input and output radius. The parameter A, for which [2] proposes a value between 0.7 and 0.9 to obtain good results, controls the amount of profile which is added to the linear taper. This same reference gives normalized values for the length, input and output radii as follows L=4.92λ, r_{in}=0.39λ, r_{out}=1.34λ. The corrugation depth starts at λ/2 and in a distance of 1.4λ goes linearly down to λ/4.

In order to show how the gaussian horn proposed in this paper improves the features of the input field distribution, we choose the horn proposed in [2] to feed the gaussian horn whose profile is given in equation 1. In our case, we work with λ=10mm. and A=0.7.

In figure 2, we present the far field pattern of the output mixture of the horn proposed in [2] (a), and the far field pattern of the mixture obtained after adding the gaussian horn at the end of the horn proposed there, with the gaussian horn length of 20, 40 and 60mm (b,c and d respectively).(These values for the horn length are absolutely arbitrary.)

The coefficient ϖ_0 used in the gaussian horn (1) is aproximately calculated from the output mixture of the horn proposed in [2] as the beam waist value for which the gaussian efficiencies in E and H planes are maximized. The r_0 value, the input radius of the gaussian horn, has to be equal to the output radius of the horn proposed in [2] r_{out}, then r_0=r_{out}=13.4λ.

It is important to notice that output radii for different horn lengths are different and their corresponding mode mixtures are different too, but nevertheless the far field pattern remains fixed for the gaussian horn. Despite the well known relations between output radius and antenna directivity, the far field pattern is unchanged. For the antennas considered here the important radius to define directivity is the input radius where is defined the beam waist of the generated gaussian beam mode.

Interpreting these results, the output mixture is automatically produced by the taper to shape properly the expansion of the gaussian structure. This was also demostrated for conical beams in [7].

In principle, the gaussian horn (1) is the best matching device between the field distribution at the output of the horn proposed in [2] and the free space. This means that for more than 40mm gaussian horn length, the gaussian structure is practically well formed, and it is not necessary any further increase of the horn length.

Also, in the figure 2, is represented the cross-polarization diagram, and we can see how the cross-polarization level decreases as the gaussian horn becomes longer. At the same time the directivity increases a little bit. Other important parameters of the created beam, as the correlation factors (gaussian efficiencies in E and H planes between the field distribution at the aperture and the gaussian structure at this point), the gain (related with directivity), the beam waist value of the generated beam (ϖ_0) and its position (z_c) (phase center), the mixture of modes at the end and the output radius value, are given too.

4. Conclusions

In this paper, an optimal and original design for a non-linear horn profile is proposed. It has to be fed with some gaussian like waveguide mode mixture, and the output is improved regarding the conversion efficiency to a gaussian structure. Also a decrease of the cross-polarization and sidelobes levels is found.

Here, we focus the study in circular corrugated waveguides, but it is also posible to apply this idea to different waveguide shapes and different feeding mixtures. These tapers are very useful to solve the problem of matching waveguides to free space.

5. References

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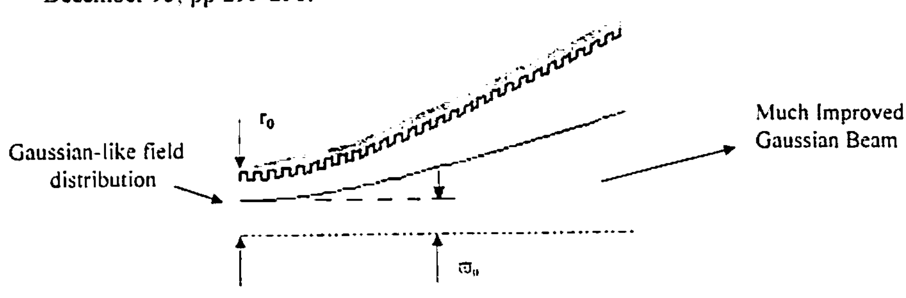
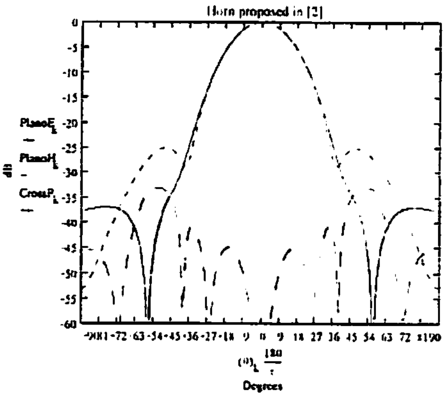
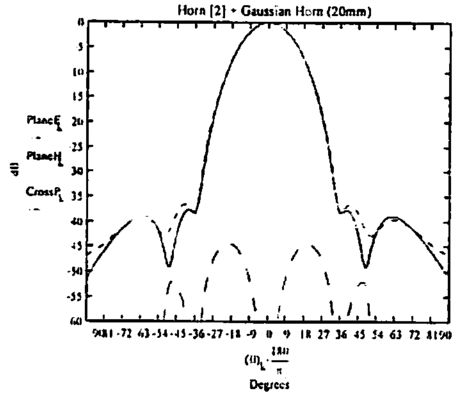


Figure 1. Optimal horn antenna

a)



b)



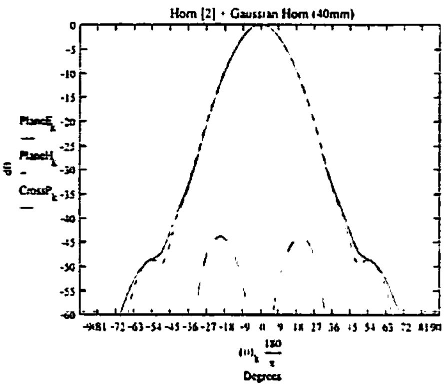
Rout=13.356mm ω_0=8.9485mm.
Gain=17.2 dBi z_c=L
η_{PlaneE}=97.2% η_{PlaneH}=97.4%

Modes	Power(%)	Phase(°)
TE_{11}	86.1188	-64.8973
TE_{12}	0.5952	-128.8639
TM_{11}	11.9079	-52.644

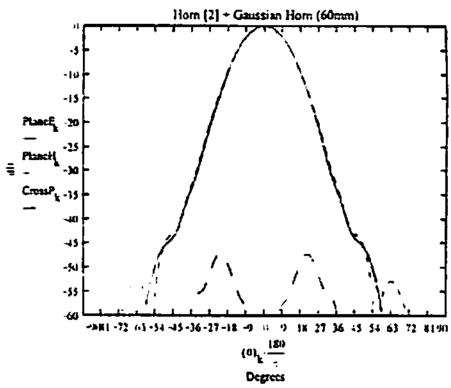
Rout=17.063mm ω_0=10.15056mm.
Gain=18.6 dBi z_c=L+12mm
η_{PlaneE}=98.9% η_{PlaneH}=98.9%

Modes	Power(%)	Phase(°)
TE_{11}	81.1053	-39.1864
TE_{12}	1.246	161.1546
TE_{13}	0.0373	-125.8252
TM_{11}	17.3833	-33.5072
TM_{12}	0.0697	-56.33
TM_{13}	0.1181	-44.3379

c)



d)



Rout=25.087mm ω_0=10.41768mm.
Gain=19.6 dBi z_c=L+18mm
η_{PlaneE}=99.9% η_{PlaneH}=99.8%

Modes	Power(%)	Phase(°)
TE_{11}	56.0597	-33.3415
TE_{12}	12.6842	-174.13
TE_{13}	0.3934	87.1243
TE_{14}	0.0064	79.0973
TM_{11}	28.4174	-17.2304
TM_{12}	2.3396	-139.6503
TM_{13}	0.0677	168.4064
TM_{14}	0.008	148.4184

Rout=34.541mm ω_0=10.41768mm.
Gain=19.5 dBi z_c=L+18mm
η_{PlaneE}=99.9% η_{PlaneH}=99.8%

Modes	Power(%)	Phase(°)
TE_{11}	33.9487	-34.5662
TE_{12}	21.7407	-171.996
TE_{13}	3.8836	80.7423
TE_{14}	0.2659	10.2575
TE_{15}	0.0159	-13.5281
TM_{11}	29.7269	-14.157
TM_{12}	9.3439	-138.6633
TM_{13}	0.9579	130.5057
TM_{14}	0.0629	85.7041
TM_{15}	0.01	62.5564

Figure 2