"ON THE DETERMINATION OF THE PHASE CENTER OF GAUSSIAN HORN ANTENNAS"

C. del Río, J. Teniente, R. Gonzalo and M. Sorolla
Electronic Engineering Department
Universidad Pública de Navarra
Campus Arrosadia s/n, 31006, Pamplona, Spain.
Phone # : +34 948 169326
Fax # : +34 948 169720
e_mail : carlos@upna.es

ABSTRACT

Gaussian horn antenna designs have experimentally demonstrated excellent performance to produce a very pure Gaussian beam mode with extremely low sidelobes and crosspolarization levels. These results make very attractive these antennas for high performance applications as satellite communications, radar and remote sensing.

The particular position of the phase center inside the horn antenna is crucial in the subsequent process to design the mirror system to be illuminated by the antenna. The Gaussian horn antennas, because the feature to excite a Gaussian beam modes, have the phase center close to the horn throat instead of the output horn aperture as usual. This feature is particular of Gaussian horn antennas, and it supposes a change in the design process using these antennas.

The mathematical determination, by correlation of the output fields with Gaussian structures, and the numerical demonstration, will be showed in this paper. Also, some considerations of the advantages or disadvantages of this property will be commented.

KEYWORDS : Gaussian, horn antennas, quasioptics, phase center.

1.- INTRODUCTION

During the last two years, we have been presented in several forums the innovation of the Gaussian horn antennas [1, 2, 3 and 4]. It was a revolutionary design process which improves the radiation features of conventional conical horn antennas being corrugated or not. The idea is really simple and consists of opening the waveguide using the Gaussian expansion formula. With this new horn profile, it has been demonstrated that a Gaussian beam mode is excited in the free space, with very low sidelobes and crosspolarization levels. These horn antennas, because the practical lack of sidelobes, reduce the noise figure of the receiver antennas in radioastronomy applications ; also can be applied to illuminate parabolic mirrors with a really high efficiency (aprox. 80%) in satellite and terrestrial communication link applications [4].

Additionally to the good features presented up to now, we want to present in this paper some considerations in relation with the phase center. The correct and precise determination of the phase center of one horn antenna is crucial for the subsequent mirror system illuminated by the horn. In the simpler case, this system consist of only one parabolic mirror. Furthermore, as the determination of his position results crucial, the variation of the phase center with the frequency is also really important, mainly in applications with broad bandwidths.

We will start with one simulated demonstration of the determination of the phase center cutting the same horn antenna to different lengths and showing how the far field radiation pattern is maintained along the Gaussian horn antenna. This experiment was presented two years ago by the authors of this paper [1], nevertheless, we consider this experiment the most clear check to probe that the excited structure has Gaussian features. But also some other conclusions can be obtained from this simulated experiment. Among others conclusions, the interesting one for this paper is to observe that the position of the phase center is always close to the throat of the Gaussian antenna.

Additionally, one sweep in frequency is done, in order to show that the fact to have the phase center close to the throat of the horn antenna instead of the final aperture gives more stability to the frequency response of the horn antenna. The test will be to introduce an ideal mixture of 85% of TE_{11} and 15% of TM_{11} modes to a pure Gaussian horn antenna profile. This test will be not so practical, because probably the main problem to directly use this configuration would be to obtain at the input the proper mixture of modes for all the frequencies. But the idea of this simulation is to show the broad bandwidth characteristics of these Gaussian antennas.

2.- SIMULATION

2.1.- Excitation of Gaussian Modes

In order to illustrate the fact to excite Gaussian structures with these such antennas, we shall present here the next experiment [1]. The idea is to work with a pure Gaussian antenna and cut the antenna at different lengths looking for the output mode mixture, beam and radiation characteristics. To excite properly the Gaussian antenna, we will need to feed the antenna with something similar to a Gaussian mode; in this particular case, in circular waveguide, the mode HE_{11}, which is known as quasi-gaussian mode because of his similarity with the fundamental Gaussian beam mode. To get this HE_{11} mode, we can take many different antenna-converters proposed in the bibliography. In this particular case, we will use the one proposed by Claricoats et. al. [5]. Also with Gaussian techniques can be designed such antenna-converter from TE_{11} to HE_{11} circular waveguide modes [3][4]. The whole component, the combination of the TE_{11}-HE_{11} mode converter and Gaussian antenna, is shown in Figure 1.

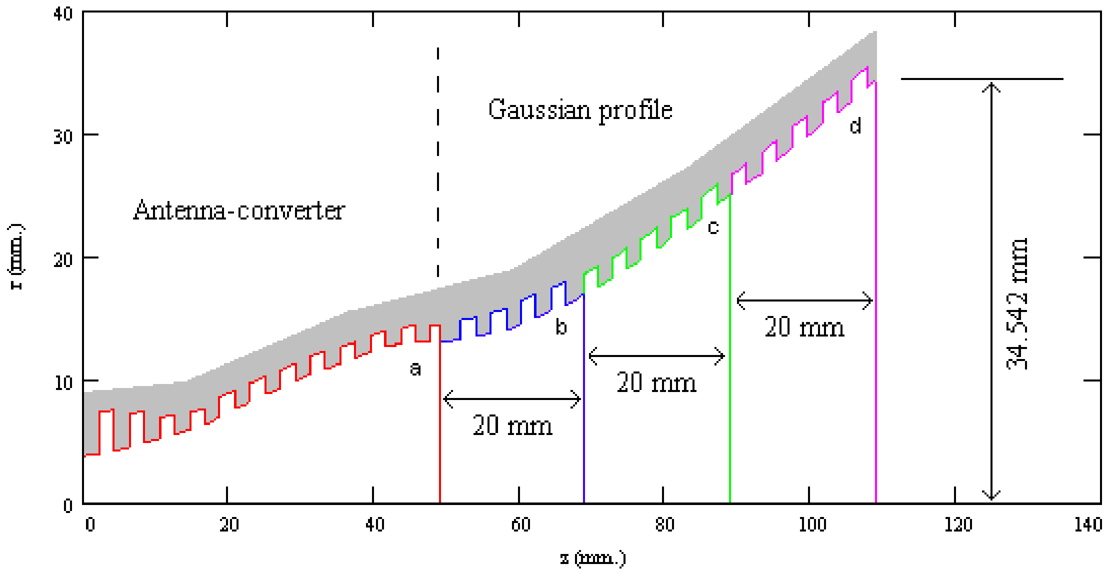

Figure 1.- Profile representation of the antenna showing the different cuts proposed.

The process will start just radiating the output of the antenna-converter proposed in [5], Figure 2.a. The simulation results are in really good agreement with the results published [5]. The output mixture at this point is something similar to 85% of TE_{11} mode and 15% of TM_{11}, which is approximately the desired mixture to shape the HE_{11} mode. For this simulation, the wavelength was selected to be λ=10 mm and the input radius is the standard one at this frequency, $R_{in}=0.39\lambda=3.9$ mm.

It is easy to show that the excited beam has the phase center just at the end of the antenna-converter, and the beam waist value is approximately 0.67 times the output radius (value very close to 0.6435, given by many authors to describe the HE_{11} mode as a Gaussian structure inside of a corrugated waveguide). Also some correlation efficiencies in E and H planes with a pure fundamental Gaussian mode with the previous parameters are shown (η_E and η_H).

For many applications this far field pattern can be good enough, but we can improve this pattern just adding 20 mm, this means, two times the wavelength, of a Gaussian antenna profile at the end, figure 2.b. Now the output radius is different, is practically 4 mm bigger, but the far field pattern is very similar to the previous one but the sidelobes levels are lower. In this case, the output mixture is more complicated, we need more modes to define properly the far field pattern, the plane efficiencies are higher than the previous case. However a clear change in the beam waist value can be observed. But the most relevant data for the study of this paper is the position of the phase center, obtained directly from the correlation integrals to obtain the efficiency (inside these integrals we have to play with the beam waist value and its position to find the maximum correlation factor). The position of the phase center is not anymore at the end of the antenna, in this case the phase center is placed 8 mm from the aperture inside the antenna. Also can be observed now how the relation between the output radius and the beam waist is 0.59, far away from the 0.6435 value.

If we increase the length of the Gaussian antenna in another 20 mm, this means, the whole component now consist in the antenna-converter proposed in [5] with a Gaussian antenna of 40 mm length connected at the end, we would obtain the next far field pattern, represented in figure 2.c. Now the obtained mode mixture is really much complicated than the previous cases, but the beam parameters are practically the same, the beam waist value is 10.4176 and its position have been changed 6 mm, and now it placed 22 mm from the aperture inside the antenna. The efficiencies are really high, corresponding with the far field pattern, practically there is no sidelobes, and the cross polarization is really low. Notice that the output radius has been increased by 8 mm, and the far field pattern is practically the same, as expected because the two excited gaussian structures in cases b and c have very similar beam parameters.

We can repeat the same experiment with an additional part of Gaussian horn antenna profile conforming a total Gaussian antenna of 60 mm, only 6 times the wavelength, with a really improved far field pattern, figure 2.d. The beam parameters in this case are practically unchanged from the previous case because every time, the beam structure is more and more far away from the antenna structure. The beam waist value and its position are the same and only a small increase in the efficient values can be observed. Observe the complication of the output mode mixture, but the simplicity by using a basis of Gaussian modes, practically we have only one significant mode, the fundamental Gaussian mode with beam waist value of 10.41768 mm and placed 18 mm from the throat of the Gaussian antenna.

Of course, also in this case, despite increase the output radius twice from the case b, the far field pattern is practically the same, loosing only the sidelobes.

2.2.- Movement of the Phase Center

The second experiment is simpler and tries to illustrate that the phase center in Gaussian antennas is practically static in frequency. To do this experiment, we will sweep in frequency one pure Gaussian antenna fed with the mode mixture of 85% TE_{11} and 15% TM_{11}, which is practically the HE_{11} mode of corrugated circular waveguide. In practical applications, it will be really difficult to keep constant the input mixture sweeping frequency, nevertheless, the objective of this experiment it is not to test the accuracy of the input mixture in frequency as to check the stability in frequency of the phase center of Gaussian antennas.

The Gaussian antenna is designed at the same frequency as the previous experiment, 30GHz (aprox. λ=10mm) and we will sweep in frequency from 20 up to 40 GHz, looking for the parameters of the excited beam. The length of the antenna is always four times the design wavelength, L=40mm. The parameters to observe will be the conversion efficiency (to measure how good is the Gaussian beam), the beam waist value and its position. In table I, are presented the obtained results.

f(GHz)	**η(%)**	**w_0(mm)**	**z(mm)**
20	76.5	8.23	15.9
22.5	93.3	12.5	1.7
25	98.7	10.16	5.5
27.5	99.8	9.65	6.6
30	99.7	9.48	5.4
32.5	99.6	9.29	4.9
35	99.5	9.25	4.6
37.5	99.5	9.07	4.2
40	99.4	9	4.2

Table I.- Sweep in frequency of Gaussian antenna fed with HE_{11} mode, showing the efficiency η in percentage, the beam waist value, w_0, and its position, z, in relation with the beginning of the antenna.

The results shows that for the frequencies below the design frequency, the obtained beams are not so good, low conversion efficiencies. However it can be observed how from 25 up to 40GHz, the conversion efficiencies are higher than 98.7 %, and the only change in this frequency range is the beam waist value, keeping practically constant its position 5mm from the throat or beginning of the horn antenna. As we go to higher frequencies, the efficiency and the beam waist value tends to decrease very slowly, and also the phase center position tends to the beginning of the horn antenna.

From this experiment we can conclude that the pure Gaussian horn antennas has the phase center close to the throat, at the beginning, and this fact gives more stability in frequency. The real problem of practical applications is to feed properly the antenna at any frequency, and the limits in the frequency response are fixed by this feeding system and not by the Gaussian antenna itself.

3.-SOME CONSIDERATIONS

The stronger conclusion to obtain of these two simulated experiments, is this change of the position of the phase center from the output aperture (big radius) to the input (smaller radius), because it suppose some important changes in the design theory. In all the horn antennas there is a relevant radius to consider far field conditions, to have some idea about the far field pattern, etc. In the conventional conical horn antennas, this relevant radius is the bigger one placed at the output of the antenna, but with the Gaussian horn antennas, this radius is placed close to the throat of the horn. Then the idea to use bigger output radius in order to get more directivity should be modified working with the Gaussian antennas (remember the first experiment, the output radius in the case d is twice the output radius in the case b, however the far field pattern, in both cases, has practically the same directivity).

To understand the Gaussian antennas, the appropriate thinking way is by using Gaussian structures. The beam waist is defined just at the position of the phase center, and the particular value for the beam waist will be related with the radius at this point of the horn antenna profile.

With the conventional conical horn antennas, we define the length, slope and output radius to obtain an appropriate mixture of modes in order to obtain something like HE_{11} mode, or something with good radiation properties. Doing this in this way, we are defining the phase center just at the aperture, and in this case the previous rule relating the size of the output radius with the radiation features is true and very well known for everyone.

However, working with Gaussian horn antennas the relevant radius is the one related with the position of the phase center. Thus the relevant parameter of this antennas is not the radius itself but beam waist value of the generated Gaussian beam. Bigger values of beam waist value means more directivity, less diffraction, and vice versa, as the beam waist value is reduced, the directivity is also reduced and increased the diffraction.

With the second presented experiment, the stability in frequency changes of the phase center in Gaussian horn antennas has been proved. This idea is consistent with the first experiment. If we try to understand this statement with the rules of conventional horn antennas, because the phase center is placed just at the output, sweep frequency the effective position of the phase center can change a lot. Nevertheless, we must keep in mind that the correct rules to understand the behavior of the Gaussian horn antennas are the rules which governs the Gaussian expansion.

If the phase center is practically static, the generated beam will start always from the same point. As we increase the frequency, the beam itself becomes more and more directive, and the electromagnetic fields are every time more far away from the metallic horn structure. In the limit, at very high frequency, the fields do not realize that there is or not horn antenna, because the diffraction is really low and practically there is no interaction with the horn walls. However, if we decrease the operating frequency, the diffraction would increase, and the interaction between the horn walls and the electromagnetic fields becomes more important.

Keeping this in mind, it is very easy to understand that the frequency response of these Gaussian antennas will be something like a high pass filter. In the presented example, the frequency range with conversion efficiencies higher than 98% starts in 25GHz, 5GHz below the design frequency, and at 40GHz the conversion efficiency to a Gaussian beam mode is still 99.4%, and probably we can achieve higher frequencies with no significant reduction of conversion efficiency.

The upper limit will be determined by the real system. For this simulation the input mode mixture was fixed, and for all frequencies the input mixture was the same. In a real systems, it will be necessary to have some mode converter, or simply, some impedance adapter between the smooth monomode circular waveguide and the corrugated circular waveguide used for this antennas. This mode converter or impedance adapter will have some particular response in frequency and it will fix the upper frequency limit of the system. There is a compromise that can be solved partially defining the Gaussian horn antenna in a frequency of the lower part of the desired working bandwidth and the mode converter or impedance adapter in a frequency placed in the middle part of the bandwidth. Taking account these design conditions, we could get wider bandwidths for the whole system.

4.- Conclusions

With the two previous experiments, we can conclude that the Gaussian antennas are something different to the traditional conical horn antennas. However, the Gaussian horn antennas and the conventional ones are compatible. Playing together one can obtain much better results ; i.e., the Gaussian horn antennas can be used to improve the far field pattern of any conventional horn antenna just cascading some part of the Gaussian profiled antenna at the end, as it was shown in the first experiment.

The second experiment shows how the phase center position is quite stable in frequency, really very important feeding quasioptical transmission systems.

5.- References

[1] Del Río, C., Gonzalo, R. and Sorolla, M., *"High purity Gaussian beam excitation by optimal horn antenna"*, Proceedings of *ISAP'96*, Chiba, Japan, pp.1133-1136.

[2] Gonzalo, R., Teniente, J., Del Río, C. and Sorolla, M., *"New approach to the design of corrugated horn antennas"*, *20th ESTEC Antenna Workshop*, Noordwijk, June 1997, pp. 155-162.

[3] Gonzalo, R., Teniente, J. and Del Río, C. *"Very short and efficient feeder design from monomode waveguide"*, Proceedings of the *AP'S Symposium 1997*, Montreal, pp.468-471.

[4] Gonzalo, R., Teniente, J. and Del Río, C., "A novel efficient corrugated feeder for reflector antennas", Proceedings of the 1997 North American Radio Science Meeting, pp. 58.

[5] Olver, A.D., Clarricoats, P.J.B., Kishk, A.A. and Shafai, L., *"Microwave Horns and Feeds"*, *IEE Electromagnetic wave series*, ISBN 0 85296 809 4, 1994.